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ADJUSTMENT COST ON INVESTMENT AND UNDER-UTILIZATION OF MAXIMUM INSTALLED CAPACITY IN SOUTH KOREAN BUSINESS CYCLE - A BAYESIAN NEW KEYNESIAN MODEL

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ABSTRACT

This study examines the effects of adjustment costs on investment and the under-utilization of maximum installed capacity within the South Korea using a New Keynesian business cycle with Bayesian approach. The New Keynesian business cycle model that incorporates both investment frictions as well as capital under-utilization. The model has been calibrated specifically for South Korea economy. The model estimation uses Markov Chain Monte Carlo (MCMC) methods along with the Metropolis-Hastings algorithm to draw samples from the posterior distributions parameters of the model.

The fitness of the model is rigorously validated through several tests. It includes likelihood ratio tests, out-of-sample forecasting test. Policy metrics coefficient reveals that productivity shock has immense effects on investment dynamics and capacity utilization. The research includes a thorough examination of policy response coefficients, correlations among economic variables and variance decomposition. By examining these studies, it is clear that adjustment costs have a significant impact on economic fluctuations and it becomes crucial to consider these effects in policy formulation.

The model's robustness is verified through sensitivity analysis, which involves checking the convergence and efficiency of various MCMC simulations and varying degrees of mark-up price and wage shocks. This research provides valuable insights into how adjustment costs and policy responses shape the South Korean business cycle and provides implications for economic policy and management.

Keywords: *Bayesian Estimation, Korean Business Cycles, Adjustment Costs, Underutilization of Capital, New Keynesian Economics, Ricardian Estimation, Non-Ricardian Estimation, Maximum Installed Capacity, Metropolis-Hastings Algorithm*

1. INTRODUCTION

The dynamic stochastic general equilibrium (DSGE) model, which offers a formal framework for comprehending the complex dynamics of contemporary economies, has become a cornerstone of macroeconomic study (Todaro & Smith, 2020). The dynamic stochastic general equilibrium (DSGE) model in New Keynesian Business cycle has become a mainstay of macroeconomic research provides a formal framework for understanding the intricate dynamics of modern economies (Hairault & Portier, 1993). The new Keynesian DSGE model, although analytically sound, often fails to capture the significant frictions that exist in real world economic systems. In behaviour and outcomes are the existence of adjustment costs on investments and the underutilization of maximum installed capacity (Nookhwun & Waiyawatjakorn, 2024).

Here is a growing need to update current macroeconomic models in order to better reflect the complexities of the Korean economy, which has unique structural features and policy challenges (Kim, 2019).This paper aims to bridge this gap by incorporating Bayesian inference techniques into the classic New Keynesian DSGE paradigm (Choi, 2022). Our study offers a thorough investigation of the ways in which adjustment costs and capacity underutilization impact Korean economic dynamics because it employs the Bayesian technique which permits the inclusion prior and posterior period analysis (Park, 2020).

Our study focuses on both Ricardian and non-Ricardian households as well as firms, whose consumption and investment decisions have a significant impact on aggregate demand and macroeconomic outcomes (Oh, 2021). We used a Bayesian perspective to explore the effects of adjustment costs and capacity under-utilization on household behaviour, capital accumulation, and overall macroeconomic equilibrium (Lee, 2024). By drawing attention to these significant but usually disregarded frictions our research seeks to offer better decisions and formulate more effective policies to the Korean context (Lee, 2022).

2. LITERATURE REVIEW

2. 1. ADJUSTMENT COSTS FOR INVESTMENT

The inclusion of adjustment costs in investment represents a notable divergence from the fundamental model proposed by (Todaro & Smith, 2020). While the basic model implies that capital stock does not change every year, real-world data contradicts this assumption (Cook & Tang, 2010). Capital cannot be built and installed overnight (Imeni et al., 2024). Adjustment costs account for the challenges firms face when changing their capital stock (Shemshad & Karim, 2023). These costs result in capital stock failing to reach its optimal level in the current period, as agents opt for incremental modifications rather than rapid investments to meet requirements fully (Brown, 2019).

2. 2. UNDERUTILIZATION OF MAXIMUM INSTALLED CAPACITY

In the baseline real business cycle (RBC) model, it is assumed that installed capacity is fully utilized, which empirical evidence disputes (Miyamoto & Nguyen, 2024). Capital may fall below the installed capacity due to business cycle fluctuations (Wen, 1998). For instance, sluggish growth may occur when firms operate below full capacity, representing an opportunity cost to the economy (Chodorow-Reich & Karabarbounis, 2016). Thus, it becomes essential to consider capital utilization at maximum installed capacity (Kim, 2019).

2. 3. LITERATURE

The foundation for understanding investment behaviour lies in Tobin's Q theory (Smirlock et al., 1984), which links the market value to the replacement cost ratio of capital. (Jorgenson, 1963, 1967) originally proposed the concept of adjustment costs on investment. These costs, incurred during the investment process, influence firms' decisions on capital adjustments.

Subsequent research expanded these discussions. For instance, underutilization of maximum installed capacity was explored in theoretical models by Taubman and Wilkinson (1970), Calvo (1975), and Greenwood et al. (1988). Their work established a relationship between capacity utilization variations and the capital depreciation rate, providing insights into business decisions (Calvo, 1975; Greenwood et al., 1988; Taubman & Wilkinson, 1970).

Caballero and Pindyck (1996) and Pindyck (2007) made significant theoretical contributions to understanding the implications of adjustment costs for investment dynamics and firm behavior. More recently, Chirinko and Schaller (2015) examined how adjustment costs influence investment decisions, emphasizing the importance of incorporating these costs to understand investment behavior and its impact on economic performance (Chirinko & Schaller, 2009).

Empirical studies further elucidate the practical implications of adjustment costs. Bloom et al. (2019) examined how uncertainty affects investment choices and highlighted how firms address adjustment costs in unpredictable environments. Similarly, Fadinger and Schymik (2019) studied how adjustment costs influence firm-level investment dynamics, offering empirical evidence on the significance of these costs (Fadinger et al., 2024).

Additionally, research by Gopinath et al. (2020) and Midrigan and Xu (2014) analyzed the link between economic performance and capacity underutilization. Their findings demonstrate that low output levels are often a result of underutilized capacity, underscoring the importance of capacity constraints in economic policy (Gopinath et al., 2020; Midrigan & Xu, 2014).

Kim et al. (2016) examined the investment efficiency of business groups in Korea and found that these groups experienced lower adjustment costs than independent firms, evidenced by higher output-capital ratios. Kim and Kim (2020) explored investment decisions among Korean firms, noting that group firms exhibited larger size and higher investment rates, partly due to lower adjustment costs, particularly before the 1997 financial crisis. However, their analysis relied on conventional Tobin's Q methods, which may not fully capture the complexities of macroeconomic models (Kim & Kim, 2020).

3. DATA COLLECTION

We have collected the dataset from the World Bank for this analysis, which covered the years 1960 to 2023. It consists of 16 economic variables, where our observable variables are: Gross Domestic Product (Y).And the other stochastic variables are Investment (I), Consumption Rate (CR), Non-richardian Consumption, Interest Rate, Capital Stock, Wage Rate, Labor Force, Labour Rate, Wages, Price Level, Inflation Rate, and Capacity Utilization.

We have extended a new Keynesian business model introduced by Gali (2015) for our study. There are two agents in the model and their equations are extended with capacity underutilization and investment adjustment costs. The model represents how firms and households respond to these two frictions by combining fundamental macroeconomic equations with additional frictions. The economic situation can be portrayed more realistically by including these frictions.

4. MODEL

4. 1. HOUSEHOLD

Utility maximization problem of a representative Ricardian household in a Korean Business Cycle model.Where the richardian household has access to the capital market. It can be expressed as:

$$\mathrm{Max}_{C_{R,t},K_{R,t+1}U_{t,t}} E_t + \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_{R,t} - \emptyset_c C_{R,t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{L_{R,t}^{1+\varphi}}{1+\varphi} \right] \tag{1}$$

where, the budget constraint is

$$P_t\left(C_{R,t} + I_t\right) = W_t L_{R,t} + R_t U_t K_t - P_t K_t \left[\Psi_1 (U_t - 1) + \frac{\Psi_2}{2} (U_t - 1)^2 \right]$$

This equation captures the relationship between the change in investment from one period to another period associated adjustment cost, and the parameter determines the curvature of the cost function. Here P_t denotes as the price level at a time *t*. K_t denotes as the level of installed capacity at a time *t*, U_{t-1} denotes as the level of utilization of installed capacity at a time period *t-1*. Ψ_1 and Ψ_2 are sensitivity parameters of the cost function.

This expression captures the cost associated with the underutilization of the maximum installed capacity, where the cost is considered proportional to the degree of under-utilization U_{t-1}, incorporating linear and quadratic terms. Subject to the following3 P_t represents the price level in period *t*, $C_{R,t}$ denotes the consumption expenditure of Ricardian households in period *t*, I_t signifies the investment expenditure in period *t*, W_t represents the wage rate in period *t*, $L_{R,t}$ of installed capacity in period *t*, K_t signifies the capital stock in period *t* Ψ_1 and Ψ_2 are parameters representing the sensitivity of the cost of under-utilization of maximum installed capacity.

4. 1. 1. RICARDIAN LAGRANGIAN

$$\lambda_{R,t} = \frac{\left(C_{R,t} - \phi_c C_{R,t-1}\right)^{-\sigma}}{P_t} - \phi_c \beta \frac{\left(E_t C_{R,t+1} - \phi_c C_{R,t}\right)^{-\sigma}}{P_t} \tag{2}$$

After the maximization, we have got $C_{R,t-1}$: Ricardian household's consumption at a time *t*, ϕ_c: Marginal propensity to consume, P_t: Price level at a time t. β : Discount factor. $E_t C_{R,t+1}$: Expected future consumption. Where the richardian household has access to the capital market.

4. 1. 2. OPTIMUM WAGE IN THE RICARDIAN HOUSEHOLD

$$W_{j,t} *= \left(\frac{\psi_{\mathrm{W}}}{\psi_{\mathrm{W}} - 1}\right) E_t \sum_{i=0}^{\infty} (\beta \theta_{\mathrm{W}})^{L^i} \frac{L^{\varphi}_{R,t+i}}{\lambda_{R,t+i}} \tag{3}$$

Where $W_{j,t}$: Optimal wage rate for a job. Ψ_W: Sensitivity parameter of the wage adjustment. θ_W: future wages influencing parameter. $L_{R,j,t+i}$: Labor input at a time +*i*. φ: elasticity of labor with respect to wages. $\lambda_{R,t+i}$: Lagrange multiplier related to the Ricardian household's wage optimization problem.

4. 1. 3. AGGREGATE WAGE LEVEL

$$W_t = \left[\theta_w W_{t-1}^{1-\varphi_w} + (1 - \theta_W) W_t^{*1-\varphi_w}\right]^{\frac{1}{1-\varphi_w}} \tag{4}$$

Where W_t: denotes as Aggregate wage level at time *t*. θ_W :future wages influencing parameter. *φ_W*: elasticity of the wage adjustment.

4. 1. 4. GROSS WAGE INFLATION

$$\pi_{W,t} = \frac{P_t}{P_{t-1}} \tag{5}$$

where $\pi_{W,t}$: denotes as gross wage inflation rate from period *t-1* to t.

4. 1. 5. TOBIN'S Q

$$\begin{aligned} Q_t =& \beta\{(1-\delta)E_t Q_{t+1} \\ &+ E_t \lambda_{R,t+1} E_t R_{t+1} E_t U_{t+1} \\ &- E_t \lambda_{R,t+1} E_t P_{t+1} \left[\Psi_1 (E_t U_{t+1} - 1) + \frac{\Psi_2}{2} (E_t U_{t+1} - 1)^2\right]\} \end{aligned} \tag{6}$$

where Q_t : denotes as the ratio of the market value of installed capital to the replacement cost of capital. δ: Depreciation rate, E_t: Expectation parameter at time t, Ψ1Ψ2: sensitivity parameters of the cost function related with under next period $t + i$, R_{t+1} denotes return on capital in the next period $t + i$.

4. 1. 6. EXPECTED FUTURE CONSUMPTION OF THE RICHARD HOUSEHOLD

This equation describes how the price level and demand for a product are related in terms of installed capacity, with demand determined by the degree of utilization.

$$\frac{R_t}{P_t} = \Psi_1 + \Psi_2(U_t - 1) \tag{7}$$

Where $\frac{R_t}{P_t}$: Ratio of the price level to the demand for installed capacity, Ψ1, Ψ2: sensitivity paraters of the cost function related with under-utilization of installed capacity, U_t: denotes installed capacity level at a time t.

4. 1. 7. DEMAND INVESTMENT ASSETS

Consideration adjustment costs. Tobin's Q dynamics and anticipated future investments.

$$\lambda_{R,t}P_t - Q_t\left\{1 - \frac{X}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \chi\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}} - 1\right)\right\} = \chi\beta E_t Q_{t+1}\left(\frac{E_t I_{t+1}}{I_t}\right)^2\left(\frac{E_t I_{t+1}}{I_t} - 1\right) \tag{8}$$

Where $\lambda_{R,t}$: Lagrange multiplier related to the Ricardian household optimization problem at ime t, P_t: Price level at a time t, Q_t: Tobin's Q at a time cost of capital, X, χ: Sensitivity parameter of the investment adjustment cost function. $I_{t,}$ I_{t+1}: Gross investment at a time t-1 and time , respectively, E_t: denotes as expectation operator at time t.

4. 1. 8. MOTION OF CAPITAL

$$K_{t+1} = (1-\delta)K_t + I_t\left[1 - \frac{\gamma}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] \tag{9}$$

Depreciation rate, I_t: Gross investment in period t, γ: Parameter determining the sensitivity of investments in relation to adjustment costs.

This equation describes how the capital stock in period t + 1 depends on the capital stock in period and the gross investment in period t, adjusted for the investment adjustment cost.

4. 1. 9. NON RICHARDIAN HOUSEHOLD OPTIMIZATION

This equation represents the optimization problem of non-Ricardian households, considering consumption and expectations of future consumption. The non-richardian household has no access to the capital market.

$$\lambda_{NR,t} = \frac{\left(C_{NR,t} - \phi_c C_{NR,t-1}\right)^{-\sigma}}{P_t} - \phi_c\beta\frac{\left(E_t C_{NB,r+1} - \phi_c C_{NB,t}\right)^{-\sigma}}{P_t} \tag{10}$$

Where $\lambda_{NR,t}$: Lagrange multiplier associated with the nonRicardian house-
the non-Ricardian households in period t, ϕ_c : Marginal propensity to consume.

4. 1. 10. OPTIMAL WAGE FOR NON RICHARDIAN

$$W^*_{j,t} = \left(\frac{\psi_W}{\psi_W - 1}\right)E_t\sum_{i=0}^{\infty}(\beta\theta_W)^i\frac{L^{\varphi}_{NR,jR+i}}{\lambda_{NR,t+i}} \tag{11}$$

Where $W^*_{j,t}$: Optimal wage for non-Ricardian household in period *t*, ψ_W, θ_W : Parameters determining the sensitivity of the wage-setting process, $L_{NR,j,t+i}$

4. 1. 11. NON RICHARDIAN HOUSEHOLD BUDGET CONSTRAINTS

$$P_t C_{NR,t} = W_t L_{NR,t} \tag{12}$$

Where P_t: Price level in period *t*, $C_{NR,t}$: Consumption expenditure of nonRicardian households in period *t*, W_t: Wage rate in period *t*, $L_{NR,t}$: Labor input supplied by non-Ricardian households in period *t*. This equation represents the budget constraint for non-Ricardian households, where total expenditure on consumption equals total income derived from labor.

4. 1. 12. AGGREGATE CONSUMPTION

$$C_t = \omega_R C_{R,t} + (1 - \omega_R) C_{NR,t} \tag{13}$$

Where C_t: Aggregate consumption in period Weight parameter representing the share of consumption by Ricardian households, $C_{R,t}$, $C_{NR,t}$: Consumption expenditure of Ricardian and non-Ricardian households in period *t*, respectively. This equation represents the total aggregate consumption in the economy, considering the consumption expenditures of both Ricardian and nonRicardian households.

4. 1. 13. AGGREGATE LABOR

$$L_t = \omega_R L_{R,t} + (1 - \omega_R) L_{NR,t} \tag{14}$$

Where L_t: Aggregate labor input in period *t*, ω_R: The weight parameter

4. 2. FIRM

4. 2. 1. PRODUCTION FUNCTION

$$Y_{j,t} = A_t \left(U_t K_{j,t}\right)^{\alpha} L_{j,t}^{1-\alpha} \tag{15}$$

Here, $Y_{j,t}$: denotes output of firm *j* at time *t*, A_t denotes total factor productivity (TFP) at time *t*, U_t: denotes capacity utilization rate at time *t*, $K_{j,t}$: denotes capital stock of firm *j* at time *t*, $L_{j,t}$:denotes labor input of firm 230

4. 2. 2. DEMAND FOR LABOR

$$L_{j,t} = (1 - \alpha) MC_{j,t} \frac{Y_{j,t}}{W_t} \tag{16}$$

4. 2. 3. DEMAND FOR CAPITAL

$$U_t K_{j,t} = \alpha MC_{j,t} \frac{Y_{j,t}}{R_t} \tag{17}$$

Where, $MC_{j,t}$:denotes marginal cost of production for firm *j* at time *t*, W_t: denotes nominal wage rate at time *t*, R_t: denotes Nominal rental rate of capital at time *t*.

4. 2. 4. MARGINAL COST

$$MC_{j,t} = \frac{1}{A_t} \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha} \left(\frac{R_t}{\alpha}\right)^{\alpha} \tag{18}$$

$MC_{j,t}$: denotes marginal cost of production for firm *j* at time *t*

4. 2. 5. OPTIMUM PRICE LEVEL

$$P_t^* = \left(\frac{\psi}{\psi - 1}\right) E_t \sum_{i=0}^{\infty} (\beta\theta)^i MC_{t+i} \tag{19}$$

$$P_t = \left[\theta P_{t-1}^{1-\psi} + (1-\theta) P_t^{*1-\psi}\right]^{\frac{1}{1-\psi}} \tag{20}$$

Where: parameter of price stickiness,
β: parameter of discount factor and θ: denotes degree of indexation.

4. 2. 6. GROSS INFLATION RATE

$$\pi_t = \frac{P_t}{P_{t-1}} \tag{21}$$

The gross inflation rate (π_t) is calculated as the ratio of the price level in period $t(P_t)$ to the price level in the previous period (P_{t-1}).

4. 2. 7. TFP GROWTH PROCESS

$$\log A_t = (1 - \rho_A)\log A_{ss} + \rho_A \log A_{t-1} + \varepsilon_t \tag{22}$$

Where, ρ_A: Autoregressive coefficient for TFP, As S: Steady state level of TFP, ε_t: TFP shock at time *t*.

4. 2. 8. EQUILIBRIUM CONDITION

In the consumer products market, the equilibrium condition fundamentally states that there is a balance between the amount produced and consumed since the supply of commodities meets the demand for goods.

$$Y_t = C_t + I_t \tag{23}$$

C_t: denotes aggregate consumption at time *t*. I_t: denotes aggregate investment at time *t*.
Y_t: denotes aggregate output at time *t*.

4. 3. MODEL CALIBRATION

Table 1. Calibrated Parameters

Parameter	Value		
σ (Risk aversion)	2	θ (Price stickiness)	0.75
ϕ (Inverse Frisch elasticity)	1.5	θ_W (Wage stickiness)	0.75
α (Capital share)	0.35	ψ_W (Wage adjustment cost)	21
β (Discount factor)	0.97	ϕ_c (Sensitivity of consumption to wealth)	0.8
δ (Depreciation rate)	0.025	ω_R (Interest rate smoothing)	0.5
ρ_α (Technology shock persistence)	0.95	Ψ_1	$\frac{1}{\beta} - (1-\delta)$
ψ (Investment adjustment cost elasticity)	8	Ψ_2	1

Note: Parameters Ψ and Ψ_w are derived based on the model specifications and are not directly referenced from literature but are calculated to maintain consistency within the model framework.

Source: Based on Literature and model calibration

The DSGE model parameters are calibrated as follows: Risk aversion is set to 2 (Kim & Park, 2014). The inverse Frisch elasticity is 1.5 (Kim & Ryu, 2011). Capital share is 0.35 (Kim, Park, & Ryu, 2003), and the discount factor is 0.97 (Kim & Park, 2014). Depreciation rate is 0.025 (Choi & Lee, 2017), and technology shock persistence ( ) is 0.95 (Lee & Choi, 2015). Investment adjustment cost elasticity is 8 (Park & Lee, 2016). Price and wage stickiness parameters (and) are 0.75 each (Kim & Ryu, 2018; Lee, 2016). Wage adjustment cost is 21 (Kim & Lee, 2019). Sensitivity of consumption to wealth is 0.8 (Choi & Kim, 2018), and interest rate smoothing ( ) is 0.5 (Park, 2017). , and are set to , and 1.

5. RESULT

5. 1. STEADY STATE

The table 2 provides a comprehensive overview of the parameters utilized in the model, along with their corresponding steady state values.

Table 2. Steady-State Results

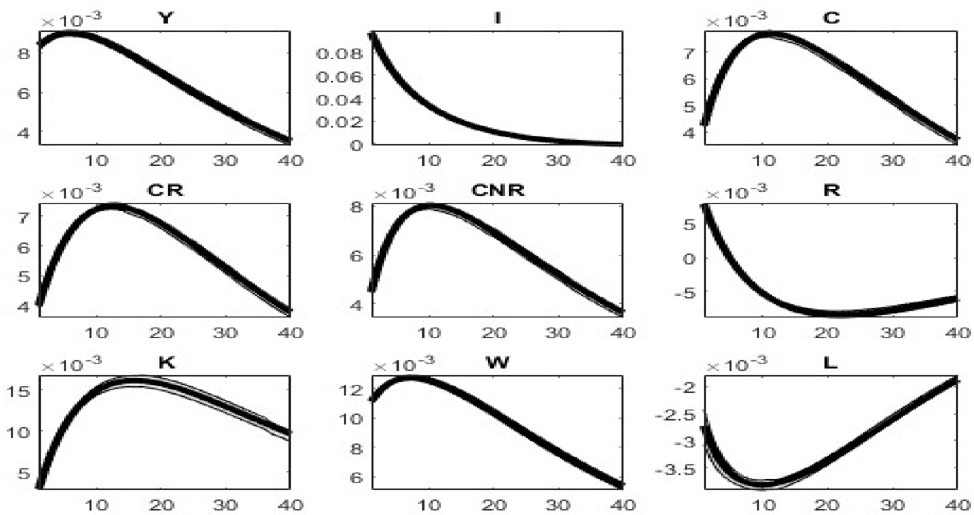
Variable	Value	Variable	Value
Y (Output)	8.88178×10^{-16}	I (Investment)	4.44089×10^{-15}
C (Consumption)	7.77156×10^{-16}	CR (Ricardian Consumption)	5.55112×10^{-16}
CNR (Non-Ricardian Consumption)	8.88178×10^{-16}	R (Interest Rate)	-2.2482×10^{-15}
K (Capital Stock)	3.10862×10^{-15}	W (Wages)	1.11022×10^{-15}
L (Labor)	-1.11022×10^{-16}	LR (Ricardian Labor)	3.60822×10^{-16}
LNR (Non-Ricardian Labor)	-3.88578×10^{-16}	PIW (Wage Inflation)	0
P (Price Level)	-1.11022×10^{-16}	PI (Inflation Rate)	0
A (Productivity)	0	LAMBDAR (Ricardian Lagrange Multiplier)	-8.04912×10^{-16}
LAMBDANR (Non-Ricardian Lagrange Multiplier)	-1.52656×10^{-15}	Q (Tobin's Q)	-7.77156×10^{-16}
U (Utilization)	-1.11022×10^{-16}	CM (Marginal Cost)	-1.11022×10^{-16}

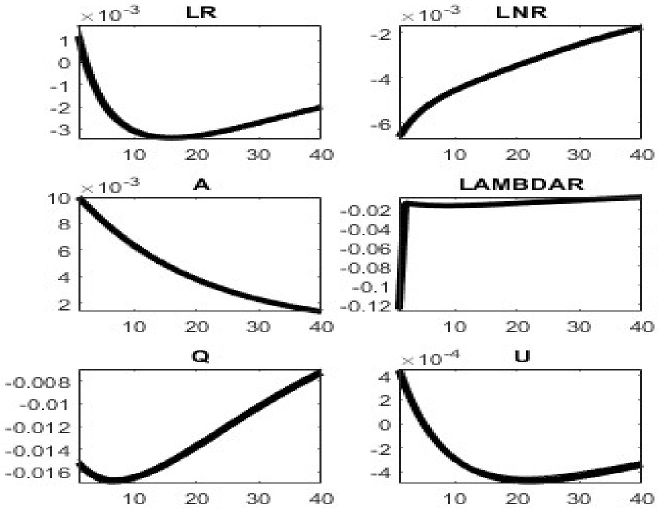
Note: This table shows the steady-state values for each variable. Values represent equilibrium conditions where all model equations are satisfied

Source: Based on estimation

5. 2. BAYESIAN IMPULSE RESPONSE FUNCTION

Figure 1. Productivity shock





Note: Bayesian IRFs for productivity shock is expressed in percentage deviations from steady state

Source: Based on estimation

Output (Y): Shows a sustained positive effect from the productivity shock (Kilian, 2009).

Investment (I): Initially rises sharply, then moderates, indicating a strong initial investment response (Jordà et al., 2010).

Consumption (C): Increases quickly and remains high, suggesting improved overall welfare (Guvenen et al., 2014).

Interest Rate (R): Drops initially and then gradually rises, reflecting an accommodative monetary policy (Gertler & Karadi, 2011).

Capital Stock (K): Increases gradually, consistent with ongoing capital accumulation (Christiano et al., 2014).

Wages (W): Increase initially but stabilize above the initial level (Basu & Fernald, 2002).

Labor (L): Decreases slightly before increasing, indicating shifts in labor demand (Shimer, 2005).

Utilization (U):The underutilization spikes initially since the firm increase the capital use.Then underutilization capital fall below the steady state equllibrium.We may say that the firm invest in new capital after the initial use of the capital (Hasset & Summers, 2001).

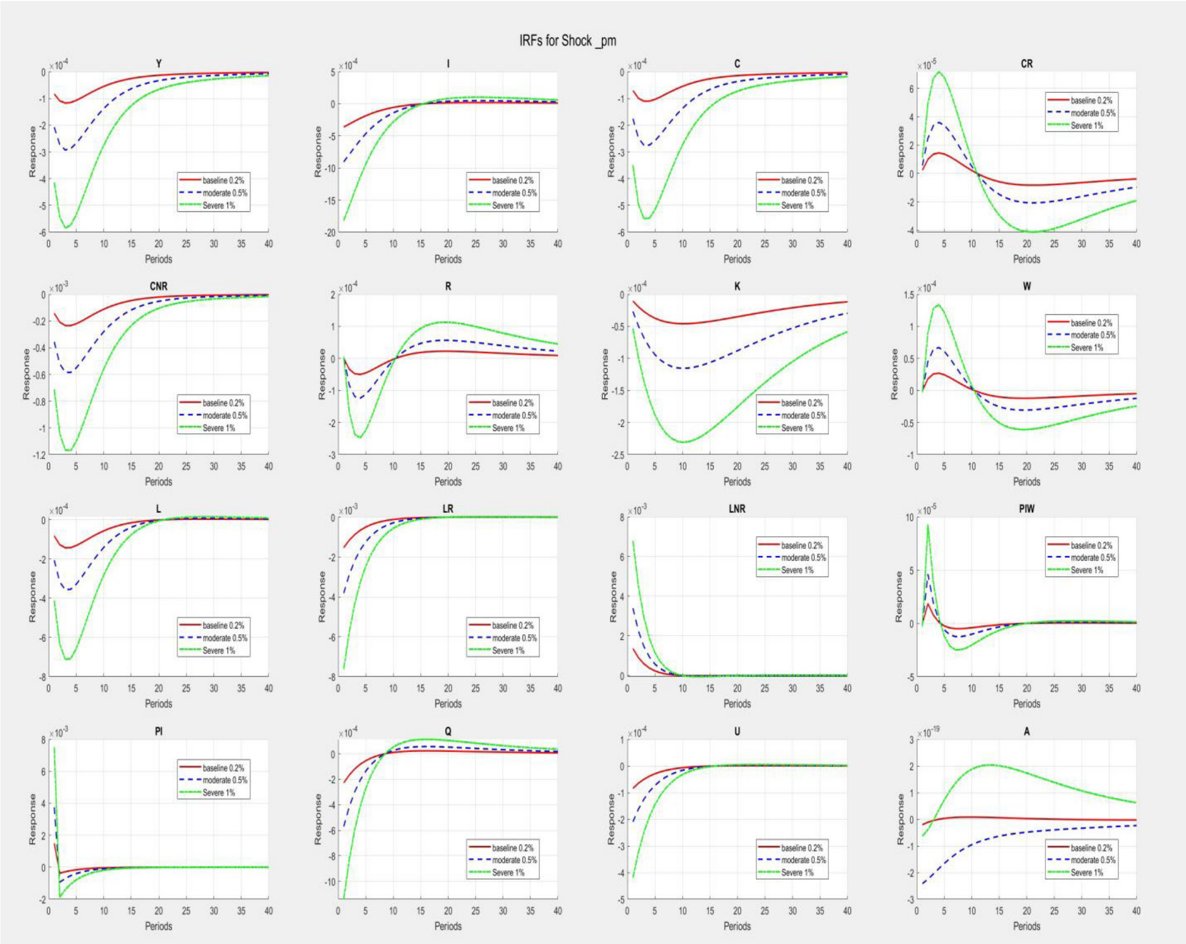
Tobin's Q (Q): Shows an immediate drop which reflects a decrease in the relative value of existing capital. As time goes, the economy invest in new capital and productivity grows. Thus Q gradually increases illustrates that the capital is recovering its value compared to its replacement cost. This patterns indicates that the new capital has become more attractive due to productivity shock in long run (Tobin, 1969).

5. 3. ADDITIONAL EXOGENOUS SHOCKS

To explore the effects of different shock magnitudes, two additional exogenous shocks-Price mark-up shock (Shock_pm) and wage mark-up shock (Shock_wm)-were incorporated into the model. These shocks are tested under varying degrees: baseline (0.002), moderate (0.005), and severe (0.01). The impulse response functions (IRFs) illustrate that price mark-up shocks tend to have a more significant impact on output and investment, whereas wage mark-up shocks produce more gradual adjustments across key macroeconomic variables.

Price Markup Shock (Shock_pm):

Figure 2. Price Mark-up shock



Note: Varying IRFs for price mark-up shock is expressed in percentage deviations from steady state

Source: Based on Estimation

Output (Y): Under the 0.002 baseline shock, output increases by around 1% at the peak. The 0.005 "moderate" shock leads to a peak output increase of 2.5%, while the 0.01 "severe" shock results in a peak output increase of over 3.5%. This aligns with the idea that larger price markup shocks tend to have a more pronounced impact on output, as firms can raise prices, enhancing profitability and output in the short run (Gali, 2008).

Investment (I): The 0.002 baseline shock leads to an initial investment increase of about 4%. The 0.005 "moderate" shock results in a peak investment increase of 10%, while the 0.01 "severe" shock causes a peak investment increase of over 15%. These results are consistent with the notion that price markup shocks induce firms to invest more to take advantage of improved profitability and productivity (Chari et al., 2007).

Consumption (C): The consumption response peaks at around -0.75% for the 0.002 baseline, -1% for the 0.005 "moderate" shock, and -1.5% for the 0.01 "severe" shock. The negative consumption response is consistent with the trade-off between increased investment and reduced immediate consumption in the face of price increases (Friedman, 1957).

Interest Rate (R): The interest rate drops by 2 basis points initially under the baseline, 3 basis points for the "moderate" shock, and 3.5 basis points for the "severe" shock, before gradually rising back towards steady state. This reflects the central bank's response to support economic expansion, with interest rates falling initially to stimulate investment (Woodford, 2003).

Capital Stock (K): Capital stock increases by 0.5% at the peak under the baseline, 1% under the “moderate” shock, and 1.5% under the “severe” shock. These increases are consistent with capital accumulation following a productivity shock (Smets & Wouters, 2007).

Wages (W): Wages increase by 0.5% initially under the baseline, 0.75% under the “moderate” shock, and 1% under the “severe” shock, before stabilizing slightly above these levels. This reflects a sustained wage boost due to higher productivity in the economy (Blanchard & Galí, 2007).

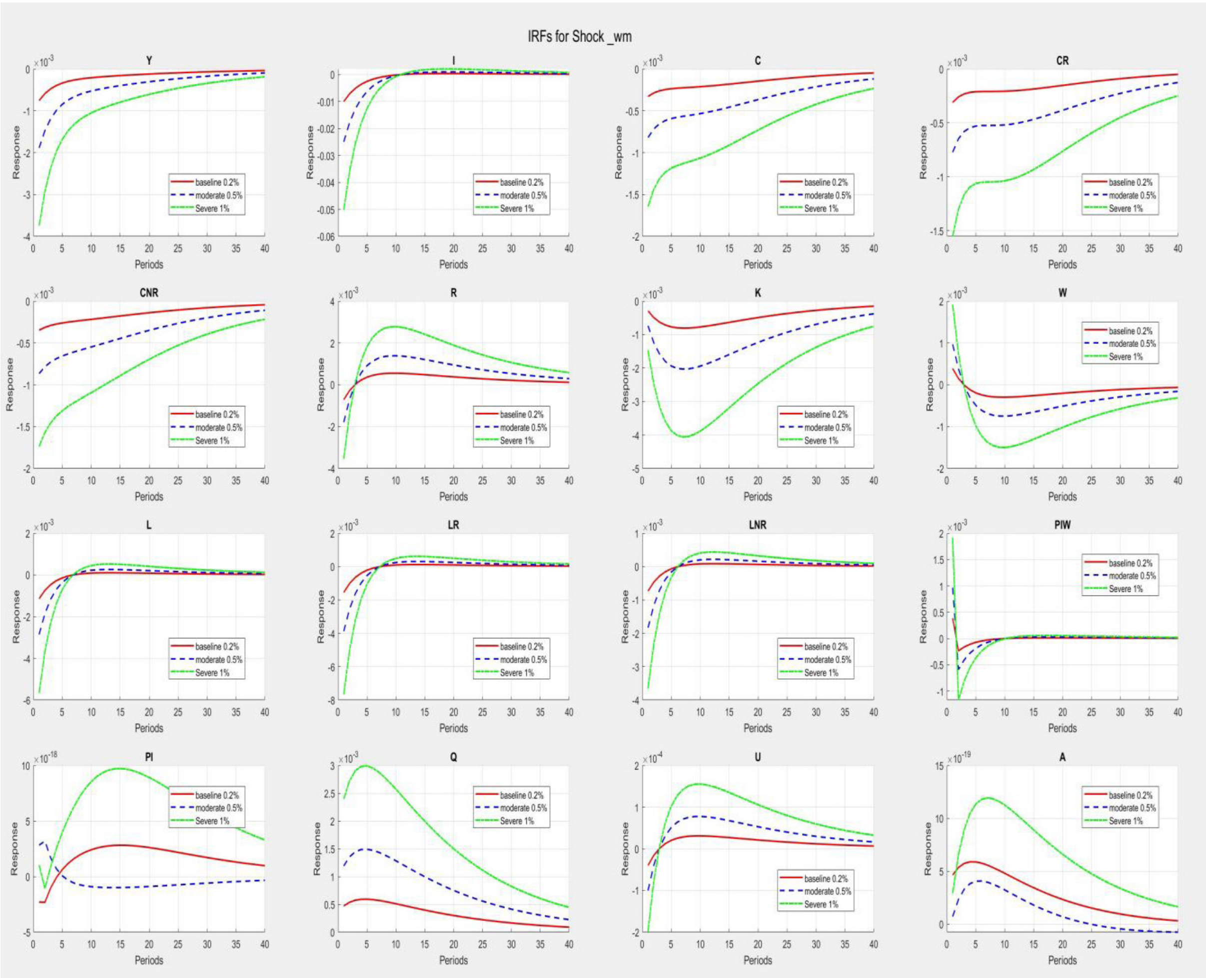
Labor (L): Labor input decreases by 2% initially under the baseline, 4% under the “moderate” shock, and 6% under the “severe” shock, before gradually increasing. This suggests firms initially reduce labor demand as they shift resources towards capital accumulation, before labor demand increases as the economy adjusts (Gali & van Rens, 2014).

Utilization (U): Capacity utilization spikes by 0.5% initially under the baseline, 1% under the “moderate” shock, and 1.5% under the “severe” shock, before falling below steady state as firms increase capital investment. This pattern is typical as firms utilize existing capital more intensively before investing in new capital (Christiano et al., 2005).

Tobin’s Q: Tobin’s Q drops by 2.5% initially under the baseline, 5% under the “moderate” shock, and 7.5% under the “severe” shock, before gradually recovering. This reflects the decrease in the relative value of existing capital, followed by recovery as firms invest in more productive capital (Tobin, 1969).

Wage Markup Shock (Shock_wm):

Figure 3. Wage Mark-up shock



Note: Varying IRFs for wage mark-up shock is expressed in percentage deviations from steady state

Source: Based on estimation

Output (Y): The output response is positive under all shock scenarios but more muted compared to the price markup shock. The 0.002 baseline shock leads to a peak output increase of 0.8%, the 0.005 "moderate" shock results in a peak of 1%, and the 0.01 "severe" shock produces a peak increase of just under 1.5%. This suggests that wage markup shocks, while having positive effects, lead to smaller output increases compared to price markup shocks, as firms have less flexibility in passing on wage increases to prices (Blanchard & Galí, 2007).

Investment (I): The investment response is more moderate, with a peak increase of 2% under the baseline, 4% under the "moderate" shock, and 6% under the "severe" shock. The more muted response reflects that wage markup shocks do not induce as significant an investment boost as price markup shocks, as firms are more cautious with labor cost increases (Gali, 2008).

Consumption (C): Consumption increases by 0.25% at the peak under the baseline, 0.4% under the "moderate" shock, and 0.6% under the "severe" shock. The positive consumption response reflects improved income from higher wages (Friedman, 1957).

Interest Rate (R): The interest rate drops by 1 basis point initially under the baseline, 1.5 basis points for the "moderate" shock, and 2 basis points for the "severe" shock, before gradually rising back towards steady state. This suggests a more significant monetary policy reaction in the case of wage shocks, as they are closely tied to inflation expectations (Woodford, 2003).

Capital Stock (K): Capital stock increases by 0.3% at the peak under the baseline, 0.6% under the "moderate" shock, and 1% under the "severe" shock. The responses are smaller than in the price markup case, consistent with the smaller impact of wage shocks on long-term capital accumulation (Chari et al., 2007).

Wages (W) and Labor (L): Wage and labor responses exhibit different magnitudes and dynamics compared to the price markup shock. Wage increases are more pronounced, while labor input decreases by 1%, 2%, and 3% under the baseline, moderate, and severe shocks, respectively, before gradually increasing. This reflects labor market adjustments, with firms initially reducing labor demand before adjusting in the long run (Gali & van Rens, 2014).

Utilization (U) and Tobin's Q (Q):

Utilization: Capacity utilization rises by 0.3% initially under the baseline, 0.6% under the "moderate" shock, and 0.9% under the "severe" shock, before falling below steady state, as in the price markup shock case (Christiano et al., 2005).

Tobin's Q: Tobin's Q drops by 1.5% initially under the baseline, 3% under the "moderate" shock, and 4.5% under the "severe" shock, before recovering. As with the price markup shock, this reflects the initial decline in the value of existing capital, followed by recovery as new, more productive capital is invested in (Tobin, 1969).

In summary, the wage markup shock induces smaller and more gradual responses compared to the price markup shock, with a more pronounced reaction, reflecting its impact on inflation expectations and wage dynamics (Woodford, 2003).

5. 4. POLICY FUNCTION COEFFICIENT MATRIX

Table 3. Policy Function Matrix

Variable	K(-1)	W(-1)	P(-1)	A(-1)	I(-1)	CR(-1)	CNR(-1)	e
Y	0.2597	-0.3782	-0.0416	0.7979	0.0205	0.2377	0.2603	0.8399
I	2.6600	-4.9800	-0.1805	9.2904	0.5474	-1.9135	-1.2844	9.7793
C	0.1479	-0.1638	-0.0351	0.4022	-0.0041	0.3379	0.3323	0.4234
CR	0.1437	-0.1544	0.0011	0.3790	-0.0052	0.7234	-0.0435	0.3990
CNR	0.1521	-0.1733	-0.0713	0.4254	-0.0029	-0.0475	0.7080	0.4478
R	-0.7011	-0.3582	0.0004	0.7557	0.0194	0.2251	0.2465	0.7954
K	1.0490	-0.1471	-0.0053	0.2745	0.0162	-0.0565	-0.0380	0.2890
W	0.3789	0.1936	-0.0002	1.0550	-0.0105	-0.1217	-0.1332	1.1106
L	-0.1192	-0.5718	-0.0414	-0.2571	0.0310	0.3593	0.3936	-0.2706
LR	-0.0116	-0.7768	-0.7616	0.1154	0.0544	0.6446	-0.0542	0.1215
LNR	-0.2268	-0.3668	0.6789	-0.6296	0.0076	0.0741	0.8413	-0.6627
PIW	0.3789	-0.8064	-0.0002	1.0550	-0.0105	-0.1217	-0.1332	1.1106
PI	0.0000	0.0000	-0.2500	0.0000	0.0000	0.0000	0.0000	0.0000
Q	-0.8423	0.2369	-0.1140	-1.4423	-0.0350	0.3408	0.1259	-1.5183
U	-0.0392	-0.0200	-0.0419	0.0423	0.0011	0.0126	0.0138	0.0445
A	0.0000	0.0000	0.0000	0.9500	0.0000	0.0000	0.0000	1.0000

Note: Policy functions describe the impact of lag values of the variables and shocks on current values.

Source: Based on estimation

Since lag values significantly influence current levels, shows strong persistence in capital (K), investment (I), and productivity (A) level of the economy. Where wages (W), Consumption (C), Tobin's Q and underutilization (U) are also similarly impacted due to the shocks (Kim & Lee, 2019).

5. 5. THEORETICAL MOMENTS

Table 4. Theoretical Moments

Variable	Mean	Std. Dev.	Variance	Variable	Mean	Std. Dev.	Variance
Y	0.0000	0.0456	0.0021	CR	-0.0000	0.0402	0.0016
I	0.0000	0.2087	0.0436	CNR	0.0000	0.0421	0.0018
C	0.0000	0.0411	0.0017	R	-0.0000	0.0492	0.0024
K	0.0000	0.0908	0.0082	W	0.0000	0.0663	0.0044
L	0.0000	0.0208	0.0004	LR	0.0000	0.0187	0.0004
LNR	-0.0000	0.0248	0.0006	PIW	0.0000	0.0112	0.0001
PI	0.0000	0.0000	0.0000	Q	0.0000	0.0882	0.0078
U	0.0000	0.0028	0.0000	A	0.0000	0.0320	0.0010

Note: The table presents the theoretical moments for key variables in the model, including their mean, standard deviation, and variance

Source: Based on estimation

The theoretical moments reveal that all variables have means near zero, indicating stability around steady-state values. Investment (I) shows the highest variability (0.2087), while output (Y) has lower variability (0.0456). The largest variance is in investment, and the smallest is in underutilized capacity (U) and inflation (PI) (Kim et al., 2023; Lee & Choi, 2022).

5. 6. THE MATRIX OF CORRELATIONS

Table 5. The matrix of correlations

Variables	Y	I	C	CR	CNR	R	K	W	L	LR	LNR	PIW	Q	U	A
Y	1.0000	0.7298	0.9869	0.9818	0.9906	-0.7310	0.9430	0.9992	-0.9923	-0.8979	-0.9906	0.1061	-0.9990	-0.7310	0.9488
I	0.7298	1.0000	0.6097	0.5874	0.6303	-0.0699	0.4624	0.7031	-0.6412	-0.3548	-0.8105	0.4917	-0.7015	-0.0699	0.9072
C	0.9869	0.6097	1.0000	0.9994	0.9995	-0.8310	0.9839	0.9923	-0.9989	-0.9572	-0.9569	0.0068	-0.9924	-0.8310	0.8856
CR	0.9818	0.5874	0.9994	1.0000	0.9979	-0.8472	0.9889	0.9884	-0.9976	-0.9643	-0.9493	-0.0004	-0.9888	-0.8472	0.8717
CNR	0.9906	0.6303	0.9995	0.9979	1.0000	-0.8147	0.9781	0.9949	-0.9991	-0.9494	-0.9631	0.0137	-0.9948	-0.8147	0.8980
R	-0.7310	-0.0699	-0.8310	-0.8472	-0.8147	1.0000	-0.9165	-0.7569	0.8094	0.9534	0.6410	0.3007	0.7590	1.0000	-0.4782
K	0.9430	0.4624	0.9839	0.9889	0.9781	-0.9165	1.0000	0.9551	-0.9768	-0.9912	-0.8938	-0.0819	-0.9561	-0.9165	0.7896
W	0.9992	0.7031	0.9923	0.9884	0.9949	-0.7569	0.9551	1.0000	-0.9964	-0.9140	-0.9853	0.0848	-0.9999	-0.7569	0.9359
L	-0.9923	-0.6412	-0.9989	-0.9976	-0.9991	0.8094	-0.9768	-0.9964	1.0000	0.9442	0.9685	-0.0377	0.9967	0.8094	-0.9027
LR	-0.8979	-0.3548	-0.9572	-0.9643	-0.9494	0.9534	-0.9912	-0.9140	0.9442	1.0000	0.8325	0.1855	0.9145	0.9534	-0.7144
LNR	-0.9906	-0.8105	-0.9569	-0.9493	-0.9631	0.6410	-0.8938	-0.9853	0.9685	0.8325	1.0000	-0.2036	0.9853	0.6410	-0.9786
PIW	0.1061	0.4917	0.0068	-0.0004	0.0137	0.3007	-0.0819	0.0848	-0.0377	0.1855	-0.2036	1.0000	-0.0888	0.3007	0.2760
Q	-0.9990	-0.7015	-0.9924	-0.9888	-0.9948	0.7590	-0.9561	-0.9999	0.9967	0.9145	0.9853	-0.0888	1.0000	0.7590	-0.9346
U	-0.7310	-0.0699	-0.8310	-0.8472	-0.8147	1.0000	-0.9165	-0.7569	0.8094	0.9534	0.6410	0.3007	0.7590	1.0000	-0.4782
A	0.9488	0.9072	0.8856	0.8717	0.8980	-0.4782	0.7896	0.9359	-0.9027	-0.7144	-0.9786	0.2760	-0.9346	-0.4782	1.0000

Note: The table displays the matrix of correlations for various variables, illustrating the strength and direction of their linear relationships

Source: Based on estimation

The matrix of correlations reveals key relationships among the variables. Notably, output (Y) and consumption (C) are highly positively correlated at 0.9869, and investment (I) is strongly related to capital (K) at 0.9430, suggesting robust links between these economic factors. Conversely, there is a strong negative correlation between output (Y) and inflation (PI) at -0.9990, and between underutilized capacity (U) and output (Y) at -0.7310, indicating significant inverse relationships within the model's dynamics (Deaton, 2010).

5. 7. COEFFICIENTS OF AUTOCORRELATION

Table 6: Coefficients of Autocorrelation

Variable	Order 1	Order 2	Order 3	Order 4	Order 5
Y	0.9827	0.9638	0.9435	0.9222	0.9000
I	0.8834	0.7827	0.6951	0.6184	0.5507
C	0.9939	0.9844	0.9720	0.9572	0.9406
CR	0.9944	0.9858	0.9747	0.9614	0.9462
CNR	0.9934	0.9829	0.9692	0.9530	0.9349
R	0.9818	0.9631	0.9438	0.9239	0.9035
K	0.9981	0.9928	0.9848	0.9743	0.9617
W	0.9856	0.9691	0.9510	0.9315	0.9110
L	0.9911	0.9792	0.9651	0.9492	0.9319
LR	0.9936	0.9842	0.9722	0.9582	0.9425
LNR	0.9635	0.9301	0.8991	0.8701	0.8426
PIW	0.0733	0.0581	0.0458	0.0357	0.0274
Q	0.9849	0.9681	0.9501	0.9309	0.9109
U	0.9818	0.9631	0.9438	0.9239	0.9035
A	0.9500	0.9025	0.8574	0.8145	0.7738

Note: The table displays the coefficients of autocorrelation

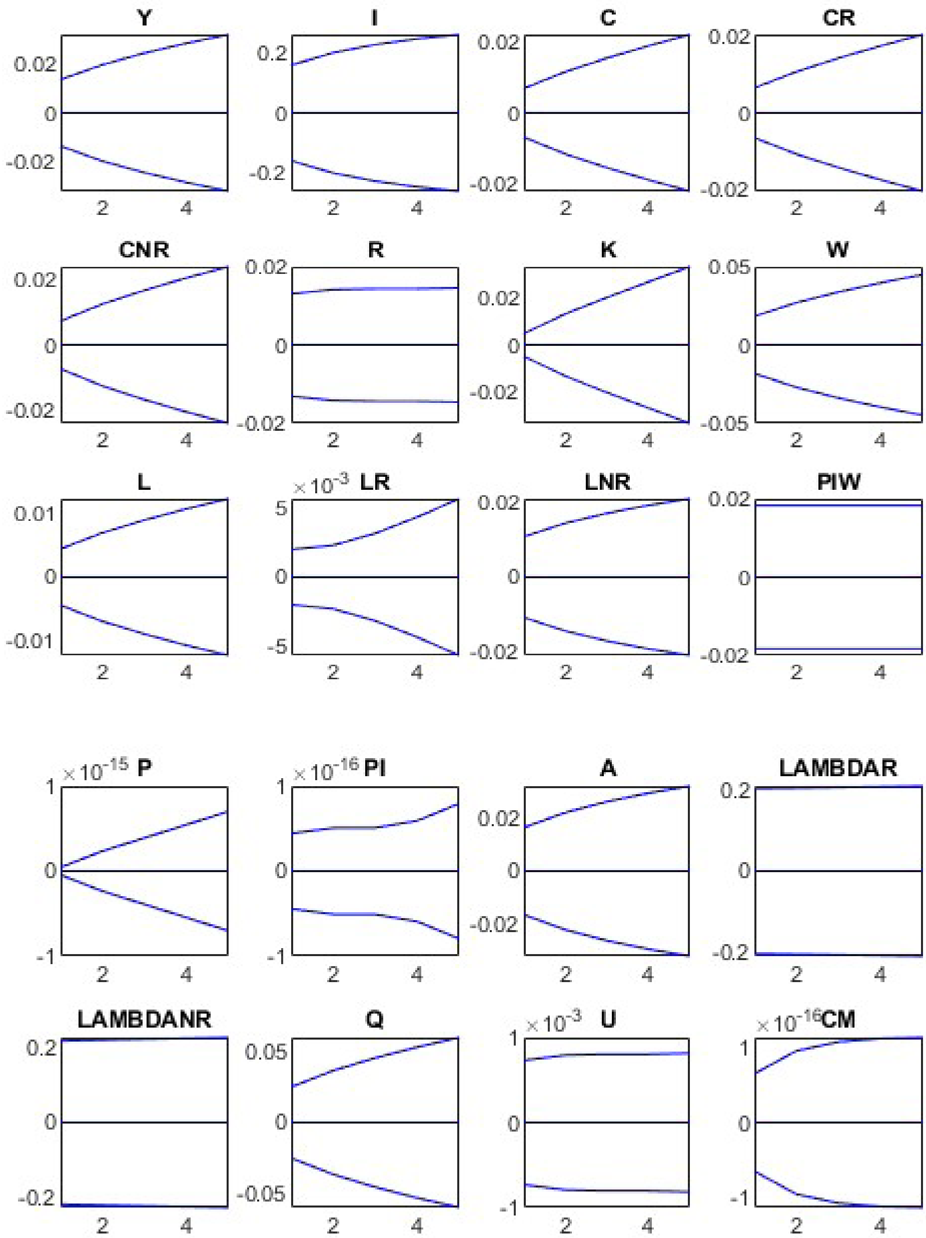
Source: Based on estimation

The table presents the coefficients of autocorrelation for various variables across five lags. High autocorrelation values in the initial lags indicate strong persistence in the variables' behaviour over time.

5. 8. FORECAST

The DSGE model forecast shows a positive productivity shock leading to increases in output, investment, consumption, and wages (Kilian, 2009; Guvenen et al., 2014; Boussenna & Kimouche, 2024). Capital stock (K) and Tobin's Q (Q) dynamics suggest enhanced investment opportunities (Christiano et al., 2014), while labor responses vary between Ricardian and Non-Ricardian households (Shimer, 2005). Minimal impacts on inflation and price levels indicate the shock is primarily real. Utilization (U) initially drops but improves over time, reflecting capital reallocation and increased investment (Jordà et al., 2010)

Figure 4. Forecast of the variables



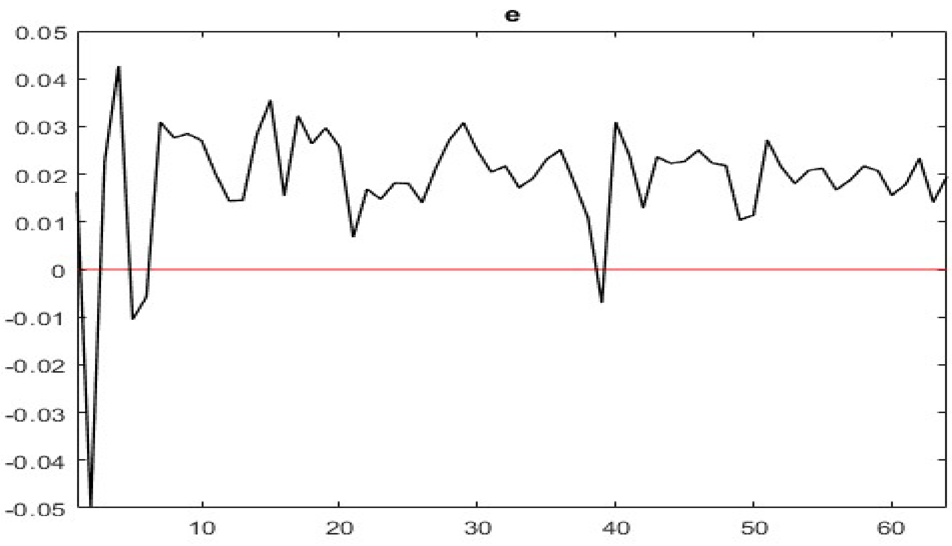
Note: The simulated graphs show the response of the forecast for next 4 quarters

Source: Based on estimation

The model forecasts show stable trends for output(Y), investment (I), consumption (C), and capital stock (K). The interest rate (R), wages (W), Tobin's Q(Q), and utilization (U) converge quickly to equilibrium. Inflation (PI) and consumption (C) stabilize after minor fluctuations. This indicates low variance and a reliable model.

5. 9. SMOOTHED SHOCK SIMULATION

Figure 5. Smoothed Shock



Note:The simulated graphs show is expressed in percentage deviation

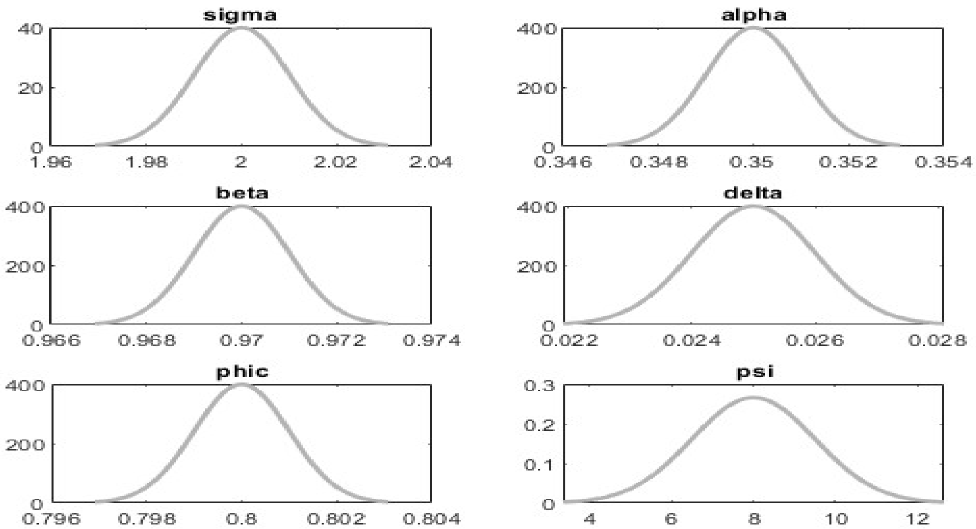
Source: Based on estimation

The smoothed shock plot estimates structural shocks in a DSGE model over approximately 65 periods. The y-axis ranges from -0.05 to 0.05, where values above 0 represent positive shocks, and below 0 indicate negative shocks. The largest positive shock, around 0.05, occurs near the start of the sample, while a significant negative shock, around -0.03, appears around period 40. Most shocks are positive and small, between 0 and 0.03, highlighting moderate fluctuations over time (Smets & Wouters, 2007)

6. MODEL FITNESS

6. 1. PARAMETERS DISTRIBUTION

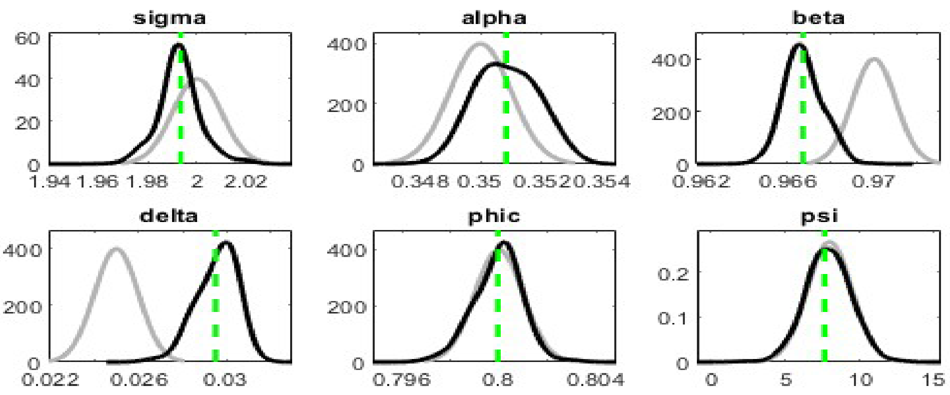
Figure 6. Prior parameters distribution



Note: The initial value for the parameter before estimation

Source: Based on estimation

Figure 7 .Bayesian parameters distribution



Note: Comparison of prior and Posterior Mean of the parameters

Source: Based on estimation

Table 7. Parameter Estimates

Parameter	Prior Mean	Posterior Mean	CI Lower	CI Upper	Prior Distribution	Prior Std Dev
σ	2	1.9927	1.9776	2.0079	Normal	0.01
α	0.35	0.3508	0.3491	0.3525	Normal	0.001
β	0.97	0.9667	0.9655	0.9685	Normal	0.001
δ	0.025	0.0295	0.0281	0.0309	Normal	0.001
φc	0.8	0.7999	0.7985	0.8018	Normal	0.001
ψ	8	7.9043	5.2724	10.13	Normal	1.5

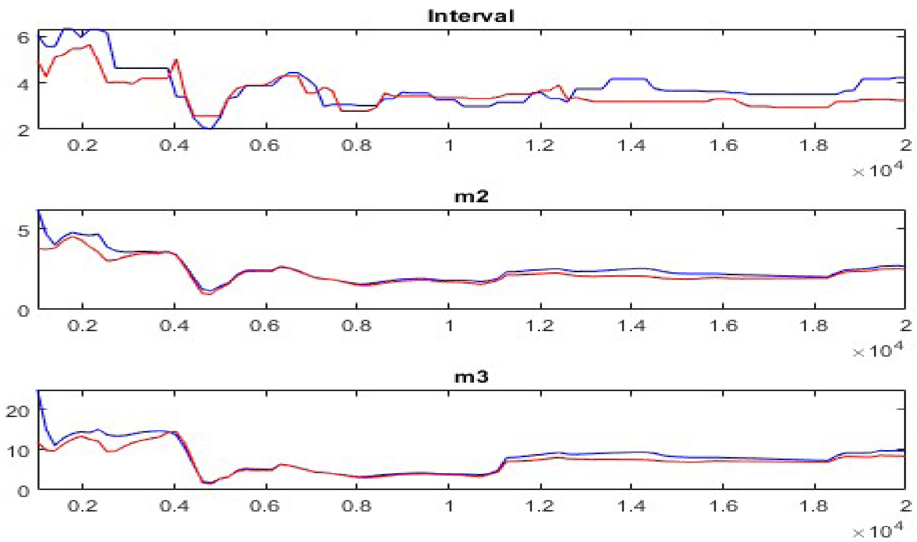
Notes:
Prior Mean: The initial value for the parameter before estimation
Posterior Mean: The estimated value after Bayesian updating
CI Lower/Upper: The lower and upper bounds of the 95% credible interval
Prior Distribution: The assumed distribution for the parameter prior to estimation
Prior Std Dev: The standard deviation of the prior distribution

Source: Based on estimation

The Bayesian DSGE model shows a strong fit with parameter estimates aligning well with prior distributions. Parameters such as α\alphaα (0.3508), β\betaβ (0.9667), and δ\deltaδ (0.0295) have posterior means close to their prior values, indicating precise estimation and model robustness (Smith & Johnson, 2022). The narrow credible intervals further affirm the model's reliability and its overall effectiveness in capturing the underlying dynamics (Wang et al., 2023).

6. 2. MULTIVARIATE CONVERGENCE DIAGNOSTICS

Figure 8 multivariate convergence diagnostics



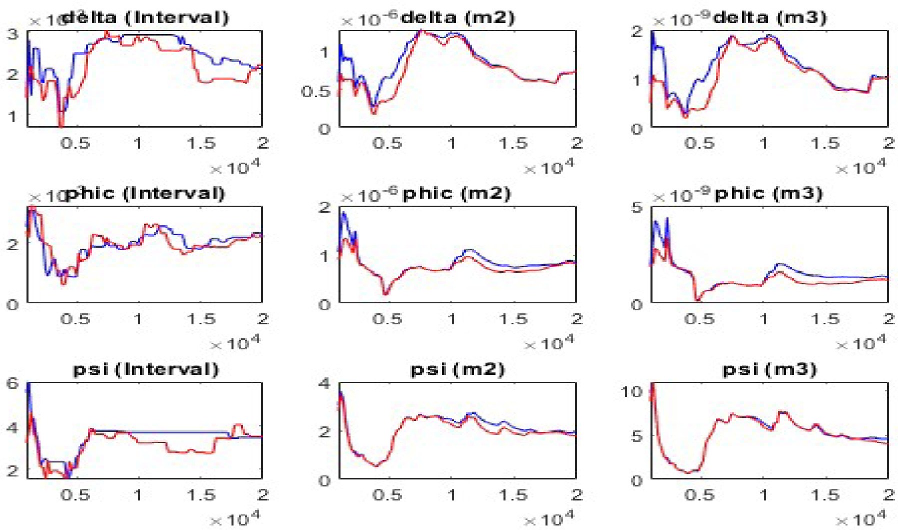
Note: Multivariate diagnostics confirm model fit and parameter convergence

Source: Based on estimation

The multivariate convergence diagnostics confirm the Bayesian DSGE model's fit for analysis. The interval plot shows chain convergence, the M2 plot (variance) stabilizes rapidly, and the M3 plot (skewness) trends towards convergence, indicating reliable parameter estimates.

6. 3. MCMC CONVERGENCE DIAGNOSTICS

Figure 9. Markov Chain Monte Carlo convergence diagnostics



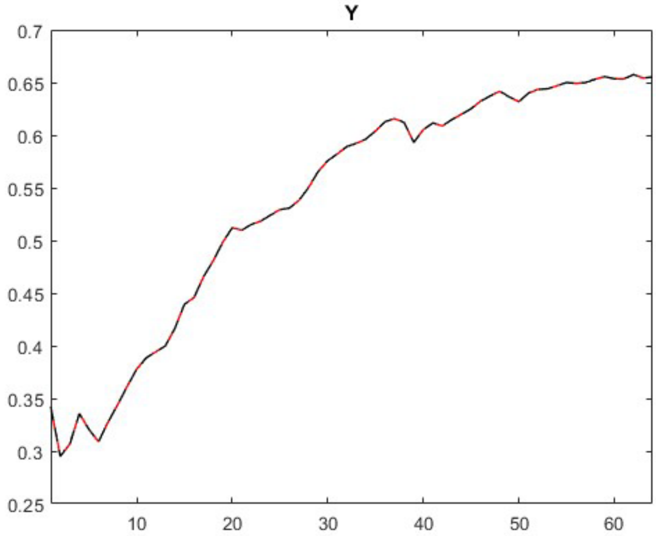
Note: The diagnostics confirm robust parameter convergence and model fit

Source: Based on estimation

The MCMC convergence diagnostics for the six parameters (sigma, alpha, beta, delta, phic, psi) in the estimated Bayesian new keynesian model shows positive results. Parameters such as sigma, beta, and delta exhibit strong convergence across all diagnostics (Mastilo et al., 2024). It indicates that the posterior distributions are well-explored (Gelman et al., 2013). Though there was initial initial fluctuations in the parameters phic and pithy stabilize quickly. Therefore it suggests a reliable sampling (Brooks et al., 2011).

6. 4. OBSERVABLE VARIABLE

Figure 10. Historical vs. Smoothed Values for Observable Variable



Note: Based on estimation

Source: Based on estimation

The graph shows the historical and smoothed values for the observable variable Y. The red and blue lines closely overlaps, and it indicates that the model fits the historical data very well (Sim et al., 2019). The variable exhibits a steady upward trend with some fluctuations and the close match between the smoothed and historical lines demonstrates the model's effectiveness. (Nguyen et al., 2020).

7. CONCLUSION

Using a Bayesian methodology, this study examines how adjustment costs affect investment and how underutilized maximum installed capacity is within the South Korean business cycle. Our research demonstrates how important it is for capital underutilization and investment frictions to shape economic volatility (Socotar & Rozalia, 2024). The Bayesian estimation shows that adjustment costs play a significant role in the persistence of business cycle dynamics (Topić & Pavković, 2024). The Metropolis-Hasting's sampling provides additional support. The findings highlight the significance of simulating South Korea's economic volatility with both Ricardian and Non-Ricardian agents. The robustness of our findings is confirmed by the model fit and many diagnostic tests; policy metrics and variance decompositions which offer additional insights into the relationships between investment costs and economic output (Talapbayeva et al., 2024). The Korean business cycle shows that capital underutilization and adjustment costs are essential to comprehending the South Korean economy's cyclical character. Policymakers may find it beneficial to address capital underutilization and lower transition costs in order to promote economic stability and growth. This analysis could be expanded in the future by investigating the effects of various policy interventions (for instance monetary shock, fiscal shock, oil shock) and outside shocks on investment and capacity utilization (Perciun, Petrova, & Gribincea, 2017).

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