Information Stickiness and Monetary Policy on the Great Moderation*

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By utilizing a simple DSGE model with dual stickiness, this paper performs a series of empirical analysis to study the change in the effects of monetary policy shock on macroeconomic variables over the Great Moderation, and the role of information stickiness in the evolution of monetary policy implications. The parameters estimated by Bayesian estimation approach suggest that information stickiness increases, while the volatility of monetary policy shock significantly decreases during Great Moderation period. The empirical findings address that our model successfully derives the hump-shaped response of inflation and output to monetary shock, and a smaller size of the effect of shocks on macroeconomic variables during Great Moderation. Counterfactual exercises suggest that increase in both price stickiness and information stickiness and decline in volatility of monetary shock during Great Moderation period are important driving forces of this moderated effect of monetary policy shock.

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1. INTRODUCTION

This paper studies the effects of monetary policy shocks on macroeconomic variables across different economic conditions and suggests the changes in information stickiness as a possible source of state-dependent response of macroeconomic variables to exogenous shocks. By employing a simple dynamic stochastic general equilibrium (DSGE) model that economic agents are sporadically updating their information set due to the costs of collecting and processing information sets, we address a number of issues in macroeconomic policy analysis by answering that (i) how information updating behavior changed over the Great Moderation period which are represented by the low volatility of macroeconomic variables, (ii) how the effects of monetary policy shock as well as aggregate demand shock and aggregate supply shock evolve over time, (iii) what is the most important source in understanding the changes in the effects of exogenous shocks.

There are a tremendous number of literatures on analyzing monetary implications by a dynamic stochastic general equilibrium (DSGE) model. To explain the effects of monetary policy on the real economy, New Keynesian (NK) model is introduced with nominal price rigidity (Akerlof and Yellen, 1985; Blanchard and Kiyotaki, 1987; Yun, 1996; Woodford, 2003; Clarida, Gali, and Gertler, 1999; Gali, 2015). A standard NK model is successfully explain the effects of monetary policy shock on macroeconomic variables, but has a shortcoming of low level of inflation persistence (Fuhrer and Moore, 1995), and not hump-shaped response to the monetary shock (Bernanke and Gertler, 1995; Christiano, Eichenbaum, and Evans, 1999; Mankiw and Reis, 2002; Korenok and Swanson, 2007). Notwithstanding the tremendous efforts of extending the NK model

1) After then, to overcome these weaknesses, larger versions of the NK model are suggested. Some economists show that larger versions of the NK model provide a better fit to the actual data (Christiano, Eichenbaum, and Evans, 2005; Smets and Wouters, 2007; Korenok and Swanson, 2007; Coibion, 2010; Christiano, Eichenbaum, and Trabandt, 2018).
model, such as increasing model complexity and adding more frictions, the empirical performance of the NK model has been still controversial since these models basically give too much weight on forward-looking behavior. Based on this criticism, Mankiw and Reis (2002) suggests a sticky information (SI) model assuming that economic agents are only sporadically updating their information sets, rather than increase the model complexity or employing other frictions. Mankiw and Reis (2002, 2006), Coibion (2006), Reis (2009a, 2009b), Gomes (2012), Carrillo (2012), and others have suggested that the features implied by the SI model are more consistent with accepted view about the hump-shaped response of inflation and output to the monetary policy shock or at least well explain the inflation inertia than that implied by standard NK model. 2) Among these macroeconomic models documented above, which model is better to explain the output and inflation dynamics has been controversial. Whereas the staggered behavior of both price updating and information updating indeed exists together and recently Dupor, Kitamura, and Tsuruga (2010) and Kim and Kim (2019) design the model containing both sticky price and sticky information, called ‘dual’ stickiness model, and argue that dual stickiness model provide a better fit of inflation dynamics with the actual data.

We found several new empirical facts about the monetary policy shocks and the parameters of information stickiness. First, the information stickiness parameter is not constant and indeed varies with economic states. For instance, McConnell and Perez-Quiros (2000), Carroll (2003), Branch (2007), Branch, Carlson, Evans, and McGough (2008), Pfajfar and Santoro (2010), Coibion and Gorodnichenko (2015a), and others have suggested that information stickiness has rose over the Great Moderation (GM) period of post-1984. 3) This finding can be explained by

2) Sticky information model also has a shortcoming that the implication of SI model is very sensitive to the information stickiness parameters (Kiley, 2007; Mankiw and Reis, 2007; Klenow and Willis, 2007; Laforre, 2007; Coibion, 2006, 2010; Molinari, 2014).

3) By employing the logistic smooth transition autoregressive (LSTAR) model, Branch (2007) and Pfajfar and Santoro (2010) provide the evidence that sticky information model assuming time-
the Rational Inattention theory in Sims (2003) that since there is limitation of the resources such as money, time, capacity to collecting and processing the information, economic agents endogenously determine the priorities and extent of analysis among numerous economic variables. Since GM period is represented by the decline in volatility occurred broadly across US economy, economic agents’ degree of attention on economic environments falls, and therefore information rigidity becomes higher during GM periods. For the effect of monetary policy shock, inflation and output differently respond to the monetary policy shock. For instance, Barakchian and Crowe (2013), Boivin, Kiley, and Mishkin (2010), Castelnuovo and Surico (2010), and other provide the empirical evidence that the magnitude of response of output and inflation to monetary policy shock is smaller and somewhat less persistent during GM period.

As the degree of information stickiness and the effects of monetary policy shock have been changed depending on the economic condition, it is therefore imperative to discuss the effects of information stickiness on the monetary implication since one of the main objectives of the central bank is to stabilize inflation and expected inflation. Nonetheless its importance, there is little work dealing with how the monetary policy shock changed and the sources of those changes. This also motivates us to explore the evolution of monetary policy shock and their relationship with information stickiness. For this purpose, rather than sophisticating the model or adding other frictions in the model, we consider a simple DSGE model with dual stickiness which is a simplified version of the models of Dupor, Kitamura, and Tsuruga (2010) and Kim and Kim (2019) that the households has information stickiness while the firms has both information stickiness and price stickiness. Specifically, Dupor, Kitamura, and Tsuruga (2010) employ a variety of economic shocks with additional financial frictions and compare the model performance between the dual stickiness model and the hybrid

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varying information stickiness parameter deliver better fit to the survey expectations data than their static counterparts.
model in explaining the dynamics of inflation and output, while Kim and Kim (2019) investigate driving forces of inflation forecasts and forecast errors by employing several exogenous shocks. However, there are clearly different research questions in this paper. The objective of this paper is to analyze the changes in the effects of monetary policy shock on macroeconomic variables during GM period and the role of information stickiness in the evolution of monetary policy implications. Thus, we divide the sample periods into the two subsample periods, Great Inflation (GI) period and GM period, and then conduct parameter estimation and impulse response analysis by subsample periods. In addition, unlike these two papers we allow only three exogenous disturbances, the effect of monetary policy shock, risk premium shock as aggregate demand shock, and price markup shock as aggregate supply shock, and the model yields the sticky information IS equation and the Phillips curve with dual stickiness.

To study the change in the implication of monetary policy and information stickiness, we utilize the Bayesian estimation approach as in Smets and Wouters (2007) by using US quarterly data spanning from 1968Q4 through 2007Q4. Before the estimation, we consider the measurement errors in aggregate output, inflation, and average inflation forecasts of Survey of Professional Forecasters. Then, based on the prior distribution of the parameters employed as in standard in the literatures, we estimate the mode and standard deviation of the posterior distribution. To capture the changes in the parameter estimates, we divide the sample periods into the two, Great Inflation periods of 1968Q4:1979Q2 and Great Moderation period of 1984Q1:2007Q4. In general, the estimation results are quite similar to the results of previous studies Carrillo (2012), Dupor, Kitamura, and Tsuruga (2010), and Kim and Kim (2019). Interestingly, some salient features directly come from the estimation results. First, the parameter of both price stickiness and information stickiness increases during Great Moderation period which implies that economic agents update price and their information sets less frequently as the economy become less volatile. In addition, firms tend to
update their information set more frequently than households do. Second, the inflation sensitivity in monetary policy reaction function significantly increases during GM period. It represents that the policymaker has more focused on the inflation stability since Volcker’s disinflation period. Third, monetary policy shock is more persistent, while its standard deviation becomes smaller in GM period.

With these estimation results, we analyze the effects of monetary policy shock, aggregate demand shock, and aggregate supply shock, and evaluate the performance of the dual stickiness model. Not surprisingly, our dual stickiness model clearly provides hump-shaped response of output and inflation to all shocks. The direction of the response of output and inflation are corresponding to the previous literatures. The size of the response of output and inflation is significantly moderated in GM period. Next, we study the main driving forces of the dynamics of output and inflation by variance decomposition analysis. Variance decomposition analysis shows that overall movement of output dynamics is primarily driven by the AD shock, while inflation dynamics is mainly driven by the AS shock. One interesting feature is that the explanatory power of AD shock in the movement of both output and inflation rise over the Great Moderation.

Finally, we explore the most important source of the reduced effects of monetary policy shock on inflation and output by counterfactual exercises. Among a variety of potential sources of the evolution of monetary policy shock, the change in dual stickiness and standard deviation of shocks are found to be a dominant factor driving the evolution of the effects of monetary policy shock on inflation and output, respectively. For the changes in the effects of AD shock and AS shock, price and information stickiness parameters and persistence of shocks are the most important driving force, respectively. Thus, we conclude that in general, employing dual stickiness, both price stickiness and information stickiness, provide a better understanding of the changes in the effects of exogenous shocks.
The remainder of the paper is organized as follows. In the next section, we introduce a simple DSGE model with dual stickiness, and derive IS equation and Phillips Curve under dual stickiness. Section 3 gives the description of the data for the variables used in the model, and presents the parameter estimates by utilizing Bayesian estimation technique. The results of impulse response analysis are provided in section 3. Section 4 investigates the changes in the effects of each shock across subsample periods, and identify the most important factor of the evolution of the transmission of each shock by counterfactual exercises. Section 5 concludes this paper with a discussion of future research directions.

2. THE DSGE MODEL WITH DUAL STICKINESS

In this section, we consider a standard DSGE model with information stickiness for both households and firms as in Dupor, Kitamura, and Tsuruga (2010) and Kim and Kim (2019). By allowing that both economic agents face informational rigidity, our framework has an advantage to compare a variety of model specifications such as a standard Real Business Cycle (RBC) model, New Keynesian (NK) model and Sticky Information (SI) model. We derive sticky information IS curve and Phillips curve (PC) with dual stickiness to investigate macroeconomic dynamics in response to monetary policy shock.

2.1 Economic Environments

The economy we assume in this paper is that there are a large number of heterogeneous economic agents, households and firms, are infrequently update their information sets as a standard sticky information model in Mankiw and Reis (2002, 2006). Particularly, our model is a simplified version of Kim and Kim (2019), as we allow only three exogenous disturbances, risk premium shocks as
aggregate demand shock, price markup shock as aggregate supply shock, and interest rate shock as monetary policy shock.

2.2 Households’ Problem

We assume that a household $j \in [0,1]$ decide infinite-horizon consumption and labor supply plan to maximize expected discounted lifetime utility based on their expected labor income and the rate of return on bond asset. An individual household $j$'s objective function is

$$\max_{(C_{j,t}, N_{j,t})} U(C_{j,t}, N_{j,t}) = \sum_{t=0}^{\infty} \beta^t \mathbb{E}_t \left[ \frac{1}{1-\sigma} C_{j,t}^{1-\sigma} - \frac{1}{1+\eta} N_{j,t}^{\eta} \right],$$

subject to the following sequence of budget constraint,

$$C_{j,t+s} + \frac{Q_{j,t+s} \cdot B_{j,t+s}}{P_{t+s}} = \frac{W_{j,t+s} \cdot N_{j,t+s}}{P_{t+s}} + \frac{B_{j,t+s-1}}{P_{t+s}} + \Pi_{t+s}, \forall s \geq 0,$$

where $\mathbb{E}_t$ indicates the expectations operator of household $j$ conditional on information at time $t$, $C_{j,t}$ is household $j$’s total real consumption expenditure, $N_{j,t}$ is hours worked, $B_{j,t}$ is the amount of maturing bonds in period $t$, $W_t$ is nominal wage rate, $P_t$ is aggregate price level, $\Pi_t$ denotes real profits received from intermediate-goods-producing firms. In addition, $\beta$, where $0 < \beta < 1$, is the utility discount factor, $\sigma$ and $\eta$ measures inter-temporal elasticity of substitution and Frisch elasticity of labor supply, respectively. In this equation, the price of bond is given by $Q_t = \frac{1}{(1+i_t) \exp(-c_t)}$, where $i_t$ is the nominal interest.
rate. We assume that the term $-c_y$ represents a risk premium shock\(^4\) that reduce current consumption when there is a positive risk premium shock. In this sense, we call this disturbance aggregate demand (AD) shock and assume that $c_y$ follows an AR(1) process, $c_y = \rho_y c_{y,t-1} + \nu_y$, with $\nu_y \sim N(0, \sigma_y^2)$ as in in Smets and Wouters (2007).

Under the limiting case of full information (i.e., no information friction), solving this maximization problem provides following the optimality condition.

$$C_{j,t} = \beta(1 + i_t) \exp(-c_y) \mathbb{E}_t \left[ C_{j,t+1} \frac{P_t}{P_{t+1}} \right]. \quad (3)$$

Under rational expectations, there is no heterogeneity in households decision making, i.e., there are a large number of identical households. Without investment, government expenditure, and net exports, the market clearing condition is $Y_t = C_t$. Therefore, by log-linearizing eq. (3) we can derive the following IS curve under full information which represents that the variation of the current output depends on the expected output, interest rate, expected inflation rate, and demand shock.\(^5\)

$$\hat{Y}_t = \mathbb{E}_t[\hat{Y}_{t+1}] - \frac{1}{\sigma} [\hat{i}_t - c_y - \mathbb{E}_t \hat{n}_{t+1}].$$

2.2.1 IS curve with sticky information

In the case of sticky information as in Reis (2006a), Mankiw and Reis (2006), and Carrillo (2012), since there exist costs of acquiring and processing information

\(^4\) The effect of this risk premium shock is quite similar to preference shock.

\(^5\) A hat (\(\hat{\cdot}\)) notation indicates a log-deviation from its steady state value.
only a fraction \(1 - \gamma_h\) of households update their information sets and re-optimize their consumption plan, while the remaining fraction \(\gamma_h\) of households is assumed to make their consumption and labor decisions based on the information sets that are the same as in the previous periods.\(^6\)

In particular, if the households updated their information in period \(t - k\), they set their optimal expected consumption plan, \(\mathbb{E}_{t-k} C_t^*\), depending on their information sets obtained in period \(t - k\). Accordingly, the aggregate consumption in period \(t\), \(C_t = \int \mathbb{E}_t^j [C_{j,t}] dj\), can be written as a weighted average of expected optimal consumption conditional on information set available at time \(t - k\),

\[
C_t = (1 - \gamma_h) \sum_{k=0}^{\infty} (\gamma_h)^k \mathbb{E}_{t-k} C_t^* .
\]  

(4)

With the market clearing conditions, \(Y_t = C_t\), this equation yields

\[
\hat{C}_t^* = \mathbb{E}_t [\hat{C}_{t+1}] - \frac{1}{\sigma} \mathbb{E}_t \left[ \hat{\nu}_t - \hat{\pi}_t - \hat{\pi}_{t+1} \right],
\]  

(5)

\[
\hat{Y}_t = (1 - \gamma_h) \sum_{k=0}^{\infty} (\gamma_h)^k \mathbb{E}_{t-k} C_t^* ,
\]  

(6)

where \(\hat{\pi}_t\) is the inflation rate between periods \(t\) and \(t-1\).

To obtain the sticky information IS curve, combining eq. (5) and (6) gives rise to the sticky information IS equation that

\(^6\) The probability of information updating in the sticky information model is calculated as in the sticky price model of Calvo (1983).
\[ \dot{Y}_t = \frac{\gamma_h}{1+\gamma_h} \dot{Y}_{t-1} + \frac{1}{1+\gamma_h} \mathbb{E}_t \dot{Y}_{t+1} - \frac{(1-\gamma_h)}{\sigma(1+\gamma_h)} \mathbb{E}_t \{ \hat{i}_t - \epsilon_t - \hat{r}_{t+1} \} \]
\[ - \frac{\gamma_h}{1+\gamma_h} \{ \mathbb{E}_t y_{t+1} - v_t \}, \]

(7)

where \( v_t \equiv (1-\gamma_h) \sum_{k=0}^{\infty} (\gamma_h)^k \mathbb{E}_{t-k} \Delta \hat{C}_t^* \). This equation directly shows that if households’ information stickiness increases, previous output will have greater impact on current output, i.e., it drives a higher persistence of output.

2.3 Firm’s Problem

As in Gali (2015), we assume a continuum of firms indexed by \( i \in [0,1] \) and there are two types of firms. First, the representative final-good-producing firm makes \( Y_t \) by using intermediate goods \( Y_t \). The aggregate production is then given by

\[ Y_t = \left( \int_0^1 Y_{i,t}^{\theta_i} \, di \right)^{\frac{\theta}{\theta - 1}}, \]

(8)

where \( \theta_i \) represents the elasticity of substitution between intermediate goods. In addition, under the assumption of perfect competition (i.e., the zero-profit) in final goods market, the final-good-producing firm’s demand equation for intermediate goods is given by

\[ Y_{i,t} = \left( \frac{P_{i,t}}{P_t} \right)^{-\theta} Y_t, \]

(9)
where \( P_{i,t} \) is the price of intermediate-good-producing firm \( i \)'s goods and \( P_t \) is the aggregate price level.

Second, with identical production technology, each intermediate-good-producing firm \( i \)'s production function is

\[
Y_{i,t} = N_{i,t}^\alpha. \tag{10}
\]

Given the firm's information set, each of monopolistic competitive intermediate goods producer \( i \) maximizes its expected profits depending on their income from selling their goods \( P_{i,t} \cdot Y_{i,t} \) minus the costs of producing their goods, \( MC_{i,t} \cdot Y_{i,t} \) as

\[
\max_{P_{i,t}} \mathbb{E}_t \left[ \sum_{k=0}^{\infty} (\lambda \beta)^k \Phi_{t+k} \left( P_{i,t} - MC_{i,t+k} \right) Y_{i,t+k} \right], \tag{11}
\]

where \( MC_{i,t} \) is nominal marginal costs of producing intermediate good \( i \) in period \( t \). The Calvo parameter \( \lambda \) represents the probability that firm \( i \) does not receive a random signal of price adjustment.

Under the assumption of full information, once the firm has a chance to update their information, they are able to completely update its information. Moreover, if all firms share the same information sets, a function of each firm’s own price and aggregate market condition and its optimal price level will be identical, and therefore, \( P_{i,t} = P_t^* \). Then, the log-linearized optimal price rule under sticky prices with full information is

\[
\hat{P}_t = (1 - \lambda \beta) \sum_{k=0}^{\infty} (\lambda \beta)^k \mathbb{E}_t \left[ \hat{m}_{i,t+k} + \epsilon_t^p + \hat{P}_{t+k} \right],
\]
where the relationship between firm $i$’s real marginal costs and aggregate real marginal costs in a linear approximation, $\hat{mc}_{i_t} = \hat{mc}_i + \frac{(\alpha - 1)\theta}{\alpha} (\hat{P}_i - \check{P}_i)$. Note that $\hat{P}_i - \check{P}_i = \xi (\hat{mc}_i + \epsilon^p)$, where $\xi = (1 - (\alpha - 1)\theta)^{-1}$, and

$\epsilon^p_t = \log \left( \frac{\theta}{\theta - 1} \right) - \log \left( \frac{\theta}{\theta - 1} \right)$. In this setting, $\epsilon^p_t$ represents the price markup shocks like an AS shock, and it follows AR(1) process, $\epsilon^p_t = \rho_p \epsilon^p_{t-1} + \nu^p_t$, with $\nu^p_t \sim N(0, \sigma^2_p)$, as in Cho and Moreno (2006). With these relations, we can rewrite the optimal price setting rule as

$$\hat{P}_i = (1 - \lambda \beta) \sum_{k=0}^{\infty} (\lambda \beta)^k \mathbb{E}_t \left[ \xi (\hat{mc}_{i_{t+k}} + \epsilon^p_{i_{t+k}}) + \hat{P}_{i_{t+k}} \right]. \quad (12)$$

In recursive form, eq. (12) gives rise to the following dynamics of optimal real price,

$$\hat{P}_i^* - \hat{P}_i = \mathbb{E}_t \left[ (1 - \lambda \beta) \xi (\hat{mc}_i + \epsilon^p) + \lambda \beta \left\{ (\hat{P}_{i+1} - \check{P}_{i+1}) + \hat{\pi}_{i+1} \right\} \right]. \quad (13)$$

### 2.3.1 Phillips curve with dual stickiness

Following the mechanism of the rule of price updating in Calvo (1983), each firm receives two adjustment probabilities, in which each firm has a probability to reset its price and to update its information. Specifically, in the class of the firms that reset its price with a probability $1 - \lambda$, only a fraction $1 - \gamma_f$ of the firms resets their nominal prices by utilizing current new information, and the rest of firms with probability $\gamma_f$ resets their price with previous information. The
“dual stickiness” model endogenously leads to adding a lagged inflation, current and previous inflation expectations terms in the Phillips curve due to the interaction of the two types of stickiness. Thus, this model nests both the pure sticky price model and pure sticky information model.\(^7\)

Following Dupor, Kitamura, and Tsuruga (2010) and Kim and Kim (2019), the optimal price level under sticky information, \(\hat{P}_t\), is given by a weighted average of the predicted optimal prices, \(\mathbb{E}_{t-1}\hat{P}_t\), as

\[
\hat{P}_t = (1 - \gamma) \sum_{k=0}^{\infty} \gamma^k \mathbb{E}_{t-1}\hat{P}_t
\]

and the aggregate price level evolves in accordance with

\[
\hat{P}_t = (1 - \lambda) \hat{P}_t + \lambda \hat{P}_{t-1},
\]

where firms updated their information sets in a staggered fashion. Using eq. (15), we can calculate the inflation as

\[
\pi_t = \frac{1 - \lambda}{\lambda} (\hat{P}_t - \hat{P}_t)
\]

which represent that the inflation is proportional to newly set relative price \((\hat{P}_t - \hat{P}_t)\). In order to characterize the Phillips curve, we define the law of motion by

\[
\Xi_t = \lambda \beta \mathbb{E}_t \Xi_{t+1} + \frac{(1 - \lambda)(1 - \varphi)}{\lambda + (1 - \lambda)\gamma_f} \left[ (1 - \lambda\beta) \left\{ \xi (\hat{mc}_t + \epsilon^p_t) \right\} + \lambda\beta \mathbb{E}_t \hat{\epsilon}_{t+1} \right],
\]

\(^7\) For a detail explanation of the intuition of dual stickiness model, see Dupor, Kitamura, and Tsuruga (2010). With figures, they explain how inattentive firms set prices when a shock occurred.
This law of motion shows that the quasi-change in price inflation is determined by current and expected future price inflation, the marginal costs, the price markup shock. The expression of $\Omega_t$ indicates that a weighted average of expected value of $\Gamma_t$ based on past information sets of various vintages due to infrequent information updating, and $\Gamma_t$ represents the effects of the current and expected value of $\Psi_t$ on the price inflation. Finally, we can characterize a well-known form of the Phillips curve with dual stickiness,

$$\hat{\pi}_t = \Lambda_1 \hat{\pi}_{t+1} + \Lambda_2 \hat{\pi}_{t+1} + \Lambda_3 (\hat{\pi}_{t+1} + \pi^F_t) + \Lambda_4 (Q_t - \lambda \beta \Omega_{t+1}),$$

(17)

where

$$\Lambda_1 = \frac{\lambda \beta}{\lambda + \gamma_f (1 - \lambda + \lambda^2 \beta)},$$

$$\Lambda_2 = \frac{\lambda \gamma_f}{\lambda + \gamma_f (1 - \lambda + \lambda^2 \beta)},$$

$$\Lambda_3 = \frac{(1 - \lambda) (1 - \gamma_f) (1 - \lambda \beta)}{\lambda + \gamma_f (1 - \lambda + \lambda^2 \beta)},$$

and

$$\Lambda_4 = \frac{(1 - \gamma_f)}{\lambda + \gamma_f (1 - \lambda + \lambda^2 \beta)}.$$
According to this Phillips curve, the higher price stickiness and firms’ information stickiness are, the higher persistence of inflation is generated, which implies greater weights on backward-looking behavior. On the other hand, we know that log-linearized aggregate marginal costs associated with aggregate output is \[ \hat{mc}_t = \left( \frac{1-\alpha + \eta}{\alpha} + \sigma \right) \hat{Y}_t. \] Using this equation, our model is able to show that inflation is depending on lagged inflation, inflation expectations, aggregate output and its growth, and supply shock.\(^8\)

### 2.4 Monetary Policy Rule

We utilize a simple Taylor rule as a monetary policy rule that Fed’s policy rate responds to the current inflation level and aggregate economic activity,

\[ \hat{i}_t^* = \hat{\pi}_t + \alpha_z (\hat{\pi}_t - \hat{\pi}_t^*) + \alpha_y \hat{Y}_t, \quad (18) \]

where \( \hat{i}_t^* \) denotes the target rate of interest rate in period \( t \), \( \alpha_z \geq 0 \) and \( \alpha_y \geq 0 \), and \( \hat{\pi}_t^* \) is Fed’s target rate of inflation.\(^9\) Following the suggestion of Clarida, Galí, and Gertler (2000) that a standard Taylor rule as eq. (18) is too restrictive to represent the actual changes of federal funds rate, we employ an interest rate smoothing tendency that Fed. does adjust the policy rate to the target rate not

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\(^8\) It is worth noting that this equation nests both the NKPC and the SIPC. Specifically, when \( \gamma_h = \gamma_f = 0 \), the model collapses into a form of NKPC as \( \hat{\pi}_t = \kappa (\hat{mc}_t + \epsilon_t^p) + \beta \delta_h, \hat{\pi}_{t-1} \), where \( \kappa = \frac{(1-\lambda)(1-2\beta)}{\lambda} \). Whereas, when \( \lambda = 0 \), the dynamics of inflation is described by a form of SIPC with supply shock, \( \hat{\pi}_t = \frac{1}{\gamma_f} \xi (\hat{mc}_t + \epsilon_t^p) + (1-\gamma_f) \sum_{k=0}^{\infty} (\gamma_f)^k \mathbb{E}_{t-1} \left[ \hat{\pi}_{t+k} + \xi \Delta (\hat{mc}_t + \epsilon_t^p) \right] . \)

\(^9\) In our model, the corresponding target rate of inflation is assumed to be zero according to Friedman rule.
immediately but gradually. As the monetary policy rule, this tendency is commonly employed as in a form that

\[ \hat{i}_t = \rho \hat{i}_{t-1} + (1 - \rho) \hat{i}_t^e + c_t^m, \]  

(19)

where \( c_t^m \sim N(0, \sigma_m^2) \) is exogenous interest rate shock and \( \rho \in [0, 1) \) measures the degree of interest rate smoothing changes. In this rule, the interest rate appears to be a weighted average of its own past level and the current target level to maintain full employment and stable inflation.

3. PARAMETER ESTIMATES AND EMPIRICAL ANALYSIS

In this section, we first describe the data used in the model estimation and present parameter estimates by using Bayesian estimation technique. To study how structural parameters are changed, we split the sample periods into Great Inflation and Great Moderation periods. Next, we analyze how various exogenous disturbances influence dynamics of inflation and output.

3.1 The Data

We utilize quarterly US time series data for the empirical analysis used in the model. As we explained previous section, the variables with the notation of a hat (\( \hat{} \)) indicates a log-deviation from its steady state value, the set of data also involves the deviation from its the steady states. Detrended real GDP is used to measure aggregate output \( \hat{Y}_t \) and inflation \( \hat{\pi}_t \) is measured by the GDP deflator and federal funds rates is employed for the nominal interest rate \( \hat{i}_t \).10) Next, for

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10) All the macroeconomic data are obtained from the FRED. To calculate the deviation from the
firm’s inflation forecasts, we employ the GDP inflation forecasts of the Survey of Professional Forecasters (SPF) which is publicly available from Federal Reserve Bank of Philadelphia. Among a variety of forecast measures, we consider 1-quarter-ahead and current quarter inflation forecasts which are denoted by $F_{t}^{SPF} \hat{\pi}_{t+1}$ and $F_{t}^{SPF} \hat{\pi}_{t}$, respectively. Following Kim and Kim (2019), we take the SPF inflation forecasts as weighted average of inflation forecasts with the weights declining exponentially at rate $\gamma_{f}$. Thus, the firm’s average $h$-period-ahead inflation forecasts are represented by $F_{t}^{\hat{\pi}_{t+h}} \equiv (1-\gamma_{f}) \sum_{k=0}^{\infty} \gamma_{f}^{k} \mathbb{E}_{t-k} \hat{\pi}_{t+h}$, where $h$ is the forecasts horizon.

On the other hand, as well documented in Bound, Brown, and Mathiowetz (2001), an issue about measurement errors is inevitable in empirical study employing survey-based data mainly due to its validation problem. Accordingly, we handle potential measurement errors in average SPF inflation forecasts as well as inflation and output. By following Kim and Kim (2019), we define the observed variable of $x$, $\hat{x}_{o,t}$, as

$$\hat{x}_{o,t} = \hat{x}_{t} + \epsilon_{o,t}^{x},$$

where the observed variables are $Y$, $\pi$, and $F_{t}^{SPF} \hat{\pi}_{t+h}$. The measurement error, $\epsilon_{o,t}^{x}$, is assumed to follow AR(1) process $\epsilon_{o,t}^{x} = \rho_{o}^{x} \epsilon_{o,t-1}^{x} + \nu_{o,t}^{x}$, where $\nu_{o,t}^{x} \sim N(0, \sigma_{x}^{2})$.

The sample periods are spanning from 1968Q4 through 2007Q4. The reason why we do not consider after 2008 global financial crisis is that federal funds rate steady states, we use the detrended RGDP by using Hodrick-Prescott filter, and demeaned inflation, federal fund rates, and the SPF inflation forecasts.

11) Conventional effects of measurement errors on estimation in the linear model is that it may produce a biased and inconsistent estimate or it may reduce an efficiency of the estimates.
has been stuck at the zero-lower bound (ZLB) and thus it has no more information about monetary policy stance. For instance, Gust, Herbst, López-Salido, and Smith (2017), Lindé, Smets, and Wouters (2016) argue that monetary policy is significantly subject to the ZLB of interest rate as it exacerbated the recession and inhibited the recovery.\footnote{Some research such as Wu and Xia (2016) employ shadow rate instead of the federal funds rate to explain the stance and effects of monetary policy at ZLB since 2009, and show that the shadow federal funds rate conveys well-known implications about monetary policy shock on inflation and output, and thus it has an important and meaningful information about monetary policy during ZLB. On the other hand, Keating, Kelly, Smith, and Valcarcel (2019) employ a broad monetary aggregate as a monetary policy instrument and show that it does not produce output and price puzzle and consistently generate the effect of monetary policy shock on output and inflation in spite of including or excluding the 2008 financial crisis.} To compare the implications of monetary policy effects across the inflation regimes, we split the sample periods into Great Inflation (1968Q4:1979Q2) and Great Moderation (1984Q1:2007Q4) as Smets and Wouters (2007). Since Great Moderation (GM) is conventionally known as a greater stability of macroeconomic variables while inflation and output are highly volatile during Great Inflation (GI) periods, we can clearly compare the implications of monetary policy across these two different economic states.

### 3.2 Time Series Properties

Table 1 presents the time series statistics. First, Panel I provide the results of persistence of major macroeconomic variables and inflation forecasts. We found that during GM periods the persistence of inflation, measured by AR(1) coefficient, is somewhat decreased by 0.9680 to 0.9553, while output becomes more persistent. This reduction in inflation persistence is consistent with the results of Cogley and Sargent (2005), Smets and Wouters (2007), Cogley and Sbordone (2008), Canova and Gambetti (2009), and Davig and Doh (2014). Not surprisingly, interest rate is more persistent during GM periods, and inflation forecasts is the most persistent, and shows higher persistence during GI period than GM period.
Next, we examine what the standard deviation of output, inflation, interest rate, and inflation forecasts would have been over the GM periods. Panel II confirms that both inflation and output are significantly less volatile in the GM period as documented in Mankiw, Reis, and Wolfers (2004), Smets and Wouters (2007),13 and Trehan (2015).

Table 1  Time Series Properties

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th>Great Inflation</th>
<th>Great Moderation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel I: AR(1) Coefficient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Y_t$</td>
<td>0.9245</td>
<td>0.9026</td>
<td>0.9535</td>
</tr>
<tr>
<td>$\pi_t$</td>
<td>0.9729</td>
<td>0.9680</td>
<td>0.9553</td>
</tr>
<tr>
<td>$i_t$</td>
<td>0.9351</td>
<td>0.9541</td>
<td>0.9649</td>
</tr>
<tr>
<td>$F_t\pi_t$</td>
<td>0.9827</td>
<td>0.9808</td>
<td>0.9740</td>
</tr>
<tr>
<td>Panel II: Theoretical Moment (Standard Deviation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\hat{Y}_t$</td>
<td>1.6620</td>
<td>2.2383</td>
<td>1.2264</td>
</tr>
<tr>
<td>$\hat{\pi}_t$</td>
<td>0.5118</td>
<td>0.7695</td>
<td>0.2430</td>
</tr>
<tr>
<td>$\hat{i}_t$</td>
<td>0.6780</td>
<td>0.9365</td>
<td>0.5731</td>
</tr>
<tr>
<td>$\hat{F}_t\pi_t$</td>
<td>0.4754</td>
<td>0.6748</td>
<td>0.1996</td>
</tr>
<tr>
<td>Panel III: Correlation Coefficient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{Corr}(\hat{Y}_t, i_t)$</td>
<td>0.1798</td>
<td>-0.0474</td>
<td>0.3087</td>
</tr>
<tr>
<td>$\text{Corr}(\hat{\pi}_t, i_t)$</td>
<td>0.5958</td>
<td>0.6906</td>
<td>0.6263</td>
</tr>
<tr>
<td>$\text{Corr}(\hat{\pi}_t, \hat{F}_t\hat{\pi}_t)$</td>
<td>0.9906</td>
<td>0.9829</td>
<td>0.9757</td>
</tr>
</tbody>
</table>

13) Smets and Wouters (2007) document that recent changes in the inflation volatility is mainly due to the volatility of the temporary components with little changes in the volatility of the permanent component.
In addition, interest rate and inflation forecast are also less volatile in GM period. In particular, inflation forecasts are less volatile than inflation and these results are consistent with the conventional feature of actual inflation and inflation expectations. With the statistics from Panel I, we can summarize that economic agent’s inflation forecasts is more persistent and less volatile than actual inflation rate. This finding imply that agents may form their inflation forecasts heavily depending on their past forecasting experiences, that is, economic agents may use backward-looking rule when predicting future inflation.

Finally, to measure the extent of co-movements, we calculate the correlation between the variables as presented in Panel III. Interestingly, the output appears not to be related to the interest rate in GI period, but after then its correlation becomes weakly positive (0.3087). On the other hand, the correlation between inflation and interest rate does somewhat decreases as the correlation coefficient is changed from 0.6906 in GI period to 0.6263 in GM period. That is, inflation and interest rate are moving in the same direction. In addition, in spite of a small reduction of correlation in the GM period, we found that inflation moves very closely with current inflation forecasts since the correlation coefficient is about 0.98 in the GM period.

These descriptive results show well known features of Great Moderation, low inflation persistence and less volatile macroeconomic variables. However, we should be cautious in the interpretation of this result since it does not imply a source of the evolution of response of inflation and output to monetary policy shocks. We therefore, investigate what factors lead to the evolution of the effects of monetary policy in section 4.4.

3.3 Bayesian Estimation

Table 2 reports the descriptions of the parameters we estimate and the information
Table 2  Bayesian Estimation Results: Prior Distribution

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Distribution</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma )</td>
<td>Normal (1.00, 0.50)</td>
<td>Elasticity of intertemporal substitution</td>
</tr>
<tr>
<td>( \gamma_h )</td>
<td>Beta (0.50, 0.15)</td>
<td>Household's information stickiness</td>
</tr>
<tr>
<td>( \gamma_f )</td>
<td>Beta (0.50, 0.15)</td>
<td>Firm’s information stickiness</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Beta (0.50, 0.15)</td>
<td>Price stickiness</td>
</tr>
<tr>
<td>( \alpha_z )</td>
<td>Normal (0.60, 0.25)</td>
<td>Inflation sensitivity in Taylor rule</td>
</tr>
<tr>
<td>( \alpha_y )</td>
<td>Normal (0.25, 0.05)</td>
<td>Output sensitivity in Taylor rule</td>
</tr>
<tr>
<td>( \rho )</td>
<td>Beta (0.80, 0.05)</td>
<td>Persistence of interest rate (interest rate smoothing)</td>
</tr>
<tr>
<td>( \rho_m )</td>
<td>Beta (0.50, 0.25)</td>
<td>Persistence of monetary policy shock</td>
</tr>
<tr>
<td>( \rho_p )</td>
<td>Beta (0.50, 0.25)</td>
<td>Persistence of price markup shock (AS shock)</td>
</tr>
<tr>
<td>( \rho_y )</td>
<td>Beta (0.50, 0.25)</td>
<td>Persistence of risk premium shock (AD shock)</td>
</tr>
<tr>
<td>( \rho_o )</td>
<td>Beta (0.50, 0.25)</td>
<td>Persistence of measurement errors of output</td>
</tr>
<tr>
<td>( \rho_o^{\text{1spf}} )</td>
<td>Beta (0.30, 0.15)</td>
<td>Persistence of m. e. of 1q-ahead SPF forecast</td>
</tr>
<tr>
<td>( \rho_o^{\text{0spf}} )</td>
<td>Beta (0.30, 0.15)</td>
<td>Persistence of m. e. of current SPF forecast</td>
</tr>
<tr>
<td>( \nu_i )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of risk premium shock</td>
</tr>
<tr>
<td>( \nu_p )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of price markup shock</td>
</tr>
<tr>
<td>( \nu_m )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of monetary policy shock</td>
</tr>
<tr>
<td>( \nu_y )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of measurement errors of output</td>
</tr>
<tr>
<td>( \nu_o )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of m. e. of inflation</td>
</tr>
<tr>
<td>( \nu_o^{\text{1spf}} )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of m. e. of 1Q-ahead SPF forecast</td>
</tr>
<tr>
<td>( \nu_o^{\text{0spf}} )</td>
<td>Inv. G. (1.00, ( \infty ))</td>
<td>Std. dev. of m. e. of current SPF forecast</td>
</tr>
</tbody>
</table>

Note: The number in parenthesis indicates mean and standard deviations for prior distribution.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma )</td>
<td>1.4211 (0.4137)</td>
<td>1.1286 (0.4079)</td>
<td>1.4750 (0.4117)</td>
</tr>
<tr>
<td>( \gamma_h )</td>
<td>0.8488 (0.0589)</td>
<td>0.6470 (0.1249)</td>
<td>0.8085 (0.0851)</td>
</tr>
<tr>
<td>( \gamma_f )</td>
<td>0.5375 (0.0731)</td>
<td>0.6270 (0.0683)</td>
<td>0.6531 (0.0675)</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>0.9289 (0.0403)</td>
<td>0.8289 (0.0632)</td>
<td>0.8884 (0.0415)</td>
</tr>
<tr>
<td>( \alpha_e )</td>
<td>0.1246 (0.1643)</td>
<td>0.2350 (0.2490)</td>
<td>0.7493 (0.2224)</td>
</tr>
<tr>
<td>( \alpha_y )</td>
<td>0.3090 (0.0436)</td>
<td>0.2846 (0.0477)</td>
<td>0.2836 (0.0475)</td>
</tr>
<tr>
<td>( \rho_i )</td>
<td>0.8102 (0.0270)</td>
<td>0.7949 (0.0461)</td>
<td>0.7309 (0.0564)</td>
</tr>
<tr>
<td>( \rho_m )</td>
<td>0.1709 (0.0895)</td>
<td>0.4001 (0.1919)</td>
<td>0.6507 (0.1264)</td>
</tr>
<tr>
<td>( \rho_p )</td>
<td>0.9206 (0.0232)</td>
<td>0.9060 (0.0286)</td>
<td>0.8458 (0.0333)</td>
</tr>
<tr>
<td>( \rho_y )</td>
<td>0.7875 (0.0508)</td>
<td>0.8495 (0.0646)</td>
<td>0.8766 (0.0366)</td>
</tr>
<tr>
<td>( \rho_o )</td>
<td>0.2179 (0.1512)</td>
<td>0.2223 (0.1603)</td>
<td>0.3058 (0.1791)</td>
</tr>
<tr>
<td>( \rho_o^{*} )</td>
<td>0.3800 (0.1110)</td>
<td>0.2577 (0.1305)</td>
<td>0.3944 (0.1363)</td>
</tr>
<tr>
<td>( \rho_o^{**} )</td>
<td>0.3698 (0.1101)</td>
<td>0.3712 (0.1637)</td>
<td>0.5319 (0.1534)</td>
</tr>
<tr>
<td>( \rho_o^{***} )</td>
<td>0.1696 (0.0891)</td>
<td>0.2182 (0.1320)</td>
<td>0.3837 (0.1522)</td>
</tr>
<tr>
<td>( \nu_y )</td>
<td>1.3985 (0.5397)</td>
<td>0.6465 (0.2372)</td>
<td>0.4724 (0.1461)</td>
</tr>
<tr>
<td>( \nu_p )</td>
<td>0.2971 (0.0743)</td>
<td>0.3576 (0.0944)</td>
<td>0.3014 (0.0717)</td>
</tr>
<tr>
<td>( \nu_m )</td>
<td>0.2199 (0.0126)</td>
<td>0.2536 (0.0293)</td>
<td>0.1219 (0.0090)</td>
</tr>
<tr>
<td>( \nu_o^{*} )</td>
<td>0.3446 (0.0563)</td>
<td>0.4136 (0.1114)</td>
<td>0.2635 (0.0392)</td>
</tr>
<tr>
<td>( \nu_o^{**} )</td>
<td>0.2293 (0.0140)</td>
<td>0.3256 (0.0382)</td>
<td>0.1852 (0.0150)</td>
</tr>
<tr>
<td>( \nu_o^{***} )</td>
<td>0.1165 (0.0075)</td>
<td>0.1716 (0.0194)</td>
<td>0.1076 (0.0082)</td>
</tr>
<tr>
<td>( \nu_o^{**} )</td>
<td>0.1274 (0.0087)</td>
<td>0.1921 (0.0220)</td>
<td>0.1147 (0.0090)</td>
</tr>
<tr>
<td>(-\log\text{likelihood})</td>
<td>4.334</td>
<td>55.702</td>
<td>171.781</td>
</tr>
<tr>
<td>(\log\text{density} )</td>
<td>-50.218</td>
<td>-91.251</td>
<td>128.574</td>
</tr>
</tbody>
</table>
Note: The numbers indicate the estimated parameters, modes and standard deviations in parenthesis for posterior distribution. The large extent of the information about the prior distribution of the parameters are corresponding to a standard Bayesian DSGE approach of Smets and Wouters (2007) and Kim and Kim (2019).

As presented in table 2, for the elasticity of intertemporal substitution, $\sigma$, and responsiveness to inflation and output, $\alpha_{\pi}$ and $\alpha_{y}$, we use Normal distribution. While information stickiness parameters for households ($\gamma_h$) and firms ($\gamma_f$), price stickiness ($\lambda$), the persistence of interest rate, $\rho_i$, and the persistence of monetary policy, aggregate supply shock, and aggregate demand shock, $\rho_m$, $\rho_p$, and $\rho_o$ follow Beta distribution, respectively. In addition, since we assume a stationary AR process of the measurement errors (m. e.), $\rho_{\psi}^y$, $\rho_{\psi}^\pi$, $\rho_{\psi}^{spf1}$, and $\rho_{\psi}^{spf0}$ corresponds to the Beta distribution. Finally, the inverse gamma distribution is utilized for the standard deviation of the shocks, $\psi_y$, $\psi_{\pi}$, $\psi_m$ and the standard deviation of measurement errors, $\psi_{\psi}^y$, $\psi_{\psi}^\pi$, $\psi_{\psi}^{spf1}$, and $\psi_{\psi}^{spf0}$.

The posterior distribution of the estimated parameters is displayed in table 3. The modes and their standard deviations for full sample periods are qualitatively similar to previous research. First, information stickiness parameters for households and firms are $\gamma_h = 0.8488$ and $\gamma_f = 0.5375$, respectively. These results are consistent with previous findings of Carroll (2003), Mankiw, Reis, and Wolfers (2004), Mankiw and Reis (2007), Pfajfar and Santoro (2013), Carrillo (2012), and Knotek (2010) that the household updates their information sets on average every year, while the firm updates information sets more frequently than households. These estimates clearly show that inattentiveness for economic agents is substantial. In addition, the price stickiness is also substantially high as $\lambda = 0.9289$. On the other hand, the persistence parameters for interest rates

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14) We set the rest of parameters that are not estimated as following: the utility discount factor, $\beta = 0.99$, Frisch elasticity of labor supply, $\eta = 2.0$, labor share, $\alpha = 0.66$, and the elasticity of substitution between intermediate goods, $\theta = 6$.

15) It is worth noting that there are two types of information rigidity, information stickiness and noisy
\[ \rho = 0.8102 \] and the monetary policymaker’s responsiveness to inflation and output are, \[ \alpha_x = 0.1246 \quad \text{and} \quad \alpha_y = 0.3090 \], respectively. The parameters measuring the persistence of monetary policy, AD, and AS shocks are \[ \rho_m = 0.1709 \], \[ \rho_p = 0.9206 \], and \[ \rho_y = 0.7875 \], and their standard deviations are estimated as \[ \nu_m = 0.2199 \], \[ \nu_p = 0.2971 \], and \[ \nu_y = 1.3985 \], respectively. The estimated AR(1) coefficients for measurement errors are consistently less than those for AD shock and AS shock as estimated in Kim and Kim (2019).

The parameter estimates are substantially different across the subsample periods. There are three main differences between the subsample periods, Great Inflation and Great Moderation periods. First, information stickiness for both households and firms and price stickiness are higher during GM periods than those in GI periods as household’s information rigidity increase from \[ \gamma_h = 0.6470 \] to \[ \gamma_h = 0.8085 \], while firm’s information rigidity is changed from \[ \gamma_f = 0.6270 \] to \[ \gamma_f = 0.6531 \]. These results are in line with the theory of Rational Inattention\(^\text{16}\) and a variety of studies show an high information stickiness during GM periods (McConnell and Perez-Quiros, 2000; Carroll, 2003, 2006; Branch, 2007; Branch, Carlson, Evans, and McGough, 2008; Gorodnichenko, 2008; Pfajfar and Santoto, 2010; Maćkowoak and Wiederholt, 2012; Coibion, 2010; Coibion and Gorodnichenko, 2015a).\(^\text{17}\) In addition, the change in the household’s information stickiness is greater than the firms, which may imply that information updating behavior for households is more sensitive to the economic states than the firms do.

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\(^{16}\) Under the rational inattention, which is proposed by Sims (2003), economic agents adjust their resources to collect and process the information in response to economic conditions due to the limitation of the resources.

\(^{17}\) By employing the logistic smooth transition autoregressive (LSTAR) model, Branch (2007) and Pfajfar and Santoro (2010) provide the evidence that state-dependent sticky information model delivers better fit to the actual survey expectations data than their static counterparts. On the other hand, Molinari (2014) suggests that due to more news information and development of information technology, and more accurate professional’s forecasts, information stickiness is lower during GM.
For the price rigidity, firm’s price stickiness is higher during GM periods since its parameter increases from $\lambda = 0.8289$ to $\lambda = 0.8884$.

Finally, for GM periods, the sensitivity parameter of policy rate to inflation deviation is significantly increased from $\alpha_\pi = 0.2350$ to $\alpha_\pi = 0.7493$. This result confirms the innovation of the monetary policy, i.e., the higher inflation sensitivity of monetary policy during GM periods, as shown in Smets and Wouters (2007), Boivin, Kiley, and Mishkin (2010), and Pancrazi and Vukotić (2019).

Lastly, consistent with Smets and Wouters (2007), the standard deviations of exogenous shocks, $v_m$, $v_y$, and $v_p$ have significantly fallen from $(v_m, v_y, v_p) = (0.2536, 0.6465, 0.3576)$ in GI periods to $(v_m, v_y, v_p) = (0.1219, 0.4724, 0.3014)$ in GM periods. The persistence of those shock processes has increased except for the price markup shock.

### 3.4 Impulse Response Analysis

Using the Bayesian estimation results in table 3, we analyze how macroeconomic variables respond to three exogenous shocks. Figure 1 presents the impulse response to monetary policy shock (M shock), aggregate demand (AD) shock, and aggregate supply (AS) shock, respectively. Panel (a) to (b) show the impulse response to monetary policy shock, Panel (c) to (d) show the impulse response to AS shock, and Panel (e) to (f) show the impulse response to AS shock, respectively. Not surprisingly, both output and inflation show a hump-shaped response to all shocks and this result is consistent with the conventional wisdom that sticky information model can generate the hump-shaped response to monetary shocks.

In addition, Panel (a) to (b) display a contractionary monetary policy shock decrease both output and inflation. The maximum response of output and inflation to M shock is $-0.1675$ after 3 quarter and $-0.0051$ after 3 quarter, respectively. Like a number of previous studies, we find that AD shock has a
Figure 1  Impulse Response of Output and Inflation

(a) Output to Monetary Shock
(b) Inflation to Monetary Shock

(c) Output to AD Shock
(d) Inflation to AD Shock

(e) Output to AS Shock
(f) Inflation to AS Shock
positive effect on output and inflation with the maximum response at 0.7365 after 3 quarter and 0.0199 after 2 quarter, respectively. Whereas, AS shock influences dynamics of inflation and output with different direction. Specifically, as shown in Panel (e) and (f), AS shock has a positive impact on inflation, while output respond to AS shock negatively. Its maximum responses of output and inflation are occurred at −0.1730 after 10 quarter and 0.1643 after 4 quarter, respectively.

4. HOW HAVE THE EFFECTS OF EXOGENEOUS SHOCKS CHANGED?

This section first investigates how the effect of monetary policy shock as well as AD shock and AS shock on inflation and output are changed during Great Moderation period, and identify the main shock driving the dynamics of output and inflation. After then, among several possible sources of the change on the effects of three shocks, we investigate the most important driving force of the reduced effects of each shock on inflation and output by counterfactual exercises.

4.1 Changes in the Effects of Exogenous Shocks

Now, we study how the macroeconomic dynamics driven by exogenous shocks are different by the subsample analysis. As we noted earlier, we split the sample periods into Great Inflation (GI, 1968Q4:1979Q2) and Great Moderation (GM, 1884Q1:2007Q4) as Smets and Wouters (2007). Some important features directly come from figure 2. First, with recent data of GM period, despite a little difference in the persistence of the propagation of monetary policy shock, the magnitude of response of output and inflation to monetary policy shocks is remarkably smaller than those results in GI period. These findings are consistent
with the findings of Galí and Gambetti (2009), Barakchian and Crowe (2013), Boivin, Kiley, and Mishkin (2010), Castelnuovo and Surico (2010).  

Specifically, as apparent in Panel (a) and (b) in figure 2, the maximum response of output and inflation during GI periods occurred at $-0.5141$ after 2 quarter and $-0.0423$ after 2 quarter, while during GM period output and inflation react to monetary policy shock with a maximum point at $-0.1949$ after 3 quarter and $-0.0109$ after 3 quarter, respectively. Similarly, Panel (c) to (f) display AD shock and AS shock have smaller effects on output and inflation during GM period compared to GI periods. Boivin, Kiley, and Mishkin (2010) suggests a possible explanation of moderated response to AD shock during GM period. Their explanation is that after 1980s there is a significant structural change in the US credit markets, and it results in wider access to credits, i.e., enormous expansion of the “shadow banking system” meaning lending via securities markets. The wide access to credits contributes to an increase in risk-taking behaviors, and thus the sensitivity to transitory income shock and the responsiveness of spending to monetary policy shock decreased indirectly.

Interestingly, inflation and inflation expectations react to monetary policy shock with the same direction, but inflation expectations respond very little to the shock as in figure 3. This difference can be explained by stylized facts that inflation expectations is less volatile than actual inflation rate and is more persistent than actual inflation. As a possible explanation, Boivin, Kiley, and Mishkin (2010) mentions that this considerable reduction in the response of inflation expectations to monetary policy shock may be due to a better anchoring of inflation expectations in the periods following Volcker’s disinflation.

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183 Our replication results of Christiano, Eichenbaum, and Evans (1999) also present a smaller response of inflation and output to monetary policy shock.

199 Gali, López-Salido, and Vallés (2003), Boivin and Giannoni (2006), Gali and Gambetti (2009) and Boivin, Kiley, and Mishkin (2010) show that the effects of demand-type shocks on output and inflation have reduced since GM periods.
Figure 2  Impulse Response of Output and Inflation on Great Moderation

(a) Output to Monetary Shock

(b) Inflation to Monetary Shock

(c) Output to AD Shock

(d) Inflation to AD Shock

(e) Output to AS Shock

(f) Inflation to AS Shock
Figure 3  Inflation and Inflation Expectations to Monetary Policy Shock

4.2 Main Driving Forces of Movements of Output and Inflation

Figure 4 gives variance decomposition of output and inflation based on the mode of our model’s posterior distribution across the sample periods. Panel (a) displays that the overall movement of output is primarily driven by the AD shock, i.e., the risk premium shock which affects both the consumption and bond assets in the Euler equation. To be specific, they account for 89.05% of output variation for full sample, 65.66% for GI period, and 78.31% for GM period. This result can be explained by the highest level of mode of AD shock process among three exogenous shocks for all sample periods. On the other hand, AS shock and monetary shock, contribute a smaller fraction of output dynamics. For instance, monetary policy shock drives 17.77% and 11.36% of the movement of output during GI and GM periods, respectively.
Whereas, it is clear that the most dominant force of inflation is AS shock, i.e., price markup shock. As shown in Panel (b), more than 90% of inflation movements are explained by AS shock during GI period. After GI period, the role of AD shock is greatly strengthened since its explanatory power is about three times strengthened from 7.13% to 20.08%, and thus 79.02% of inflation movements are driven by AS shock. The increase in the role of AD shock on inflation dynamics can be explained by the relative increase in the persistence of AD shock during GM period. In the case of monetary policy shock, its impact on inflation varies little for all subsample periods.

### 4.3 Possible Sources of the Evolution of Exogenous Shocks

A number of studies has tried to explain why the effects of monetary policy shock on inflation and output is shrunk in Great Moderation. As we noted in section 3, Great Moderation period is represented as low inflation persistence, less volatile macroeconomic variables, high information and price stickiness, higher
sensitivity of policy rate to inflation stabilization, and low standard deviation of exogenous shock process. Consistent with these findings, Smets and Wouters (2007), Boivin, Kiley, and Mishkin (2010), and Pancrazi and Vukotić (2019) suggest the innovation of monetary policy may lead inflation and output to respond less to monetary policy shock. In this regard, some economists examine the hypothesis of anchored inflation expectations (Bernanke, 2010; Ball and Mazumder, 2011). Specifically, Ball and Mazumder (2011) show that inflation expectations are substantially shock-anchored since the 1980s and it can reduce the extent of responsiveness of inflation to monetary shock.\(^{20}\) However, Coibion and Gorodnichenko (2015b) argue that this channel is not effective to explain smaller response of inflation to monetary shock. Second, as documented in ample empirical studies, the slope of PC has been declined over time due to structural changes in the US economy, and this fact can be a driver of this evolution of monetary policy transmission (Carlstrom, Fuerst, and Paustian, 2009; IMF, 2013; Coibion, Gorodnichenko, and Kousta, 2013; Coibion and Gorodnichenko, 2015b).

Third, Smets and Wouters (2007), Christiano, Eichenbaum, and Trabandt (2015, 2018), Del Negro, Giannoni, and Schorfheide (2015), and others, suggest that NK model with financial frictions can successfully predict a relatively modest response of inflation. For instance, they additionally consider a variety of frictions such as higher credit spreads, habit persistence, and investment adjustment costs, and etc in their NK models and show not much decline in inflation after GM period. Fourth, Smets and Wouters (2007) mention that since standard deviations of exogenous shocks are sharply decreased and its persistence increases during GM period, inflation and output become less volatile and this can lead to the moderated effects of exogenous shocks. Otherwise, as a source of modest response of inflation and output to exogenous shocks, the development of

\(^{20}\) A better-anchored inflation expectation can be related to higher credibility of the central banks, but this is out of scope here.
labor market (Llaudes, 2005; Daly, Hobijn, Lucking et al., 2012) and survey measures of inflation expectations for firms (Coibion and Gorodnichenko, 2015b) are suggested in related literatures.

Lastly, information stickiness subsequently rises over the course of the Great Moderation and it can be a source of modest response of macroeconomic variables to exogenous shocks. This idea is supported by our findings of higher information stickiness and modest response of output and inflation to shocks during GM period, and most of all, it is consistent with the stylized facts in the previous studies.

4.4. **Counterfactual Exercises**

Notwithstanding a variety of potential sources of the evolution of monetary policy transmission being suggested, there is little work dealing with what factor is indeed the most important driving force of the reduced effects of monetary policy shocks on inflation and output. Now, for given all parameters estimated in the Great Inflation period in table 3, we examine four counterfactual cases that would have occurred in Great Moderation period if the standard deviation of shocks, the persistence of shocks, the monetary policy reaction function, and the information and price stickiness have the same as the ones estimated in the Great Moderation period.

Figure 5 presents the results of counterfactual exercises. The dark blue dashed line and red solid line are not the result of counterfactual exercises, but actual model-implied response of output and inflation to each shock during GI period and GM period, respectively. The others are represented by the counterfactual (i) standard deviation of shocks, (ii) persistence of shocks, (iii) monetary policy reaction function, and (iv) information and price stickiness that are estimated in the GM period for given all the rest of parameters based on GI period. We found that the changes in the structural parameters and the standard deviation of shocks
have contributed to some changes in the response of output and inflation to all shocks. Surprisingly, this result clearly shows that the increase in information and price stickiness and decline in volatility of monetary shock are important drivers of the smaller effect of monetary policy shock on output and inflation during GM period. For the output response, the decline in standard deviation of monetary policy shock leads the closest response of output to monetary shock during GM periods, and the dual stickiness is the second most important source for that moderated response of output. An interesting thing in this result is that the change in the monetary policy reaction function does not significantly affect the effect of monetary shock, and furthermore the counterfactual exercise with the increased persistence of monetary policy shock presents not smaller output response, but rather dramatically greater response of output and inflation to monetary shock. For inflation response, similar conclusion comes from Panel (b) in figure 5. The increase in dual stickiness parameters estimated in the GM period is the most important factor for reducing the response of inflation to monetary shock.

Panel (c) and (d) present the counterfactual exercise results for AD shock. Similar to the case of monetary policy shock, the change in standard deviation of AD shock and dual stickiness parameter over GM period are very important drivers in reducing the modest response of output to the shock than other sources. Especially, when we assume the dual stickiness parameters are estimated over the GM period, it produces almost same response of inflation to AD shock in GM period. Whereas, unlike monetary shock and AD shock, Panel (e) and (f) show that the evolution of the effect of AS shock on output and inflation over GM period is found to be significantly explained by the decrease in the persistence of AS shock in GM period, while the change in monetary policy reaction function substantially increase the size of the effect of AS shock on output.

To explore how the explanatory power of each shock explaining the dynamics of output and inflation is changed by the counterfactual examples, we calculate the
Figure 5  Counterfactual Exercises I: Change in Parameters and Shock Volatility

(a) Output to Monetary Shock
(b) Inflation to Monetary Shock
(c) Output to AD Shock
(d) Inflation to AD Shock
(e) Output to AS Shock
(f) Inflation to AS Shock
variance decomposition. As presented in Panel (a) in figure 6, if we assume GM period’s shock persistence, monetary policy shock would explain the movement of output the most, about 37.31%, while if we assume GM period’s shock volatility, only 8.06% of variation in output is explained by monetary shock. These results indicate that increase in the persistence of monetary shock generates higher explanatory power of monetary policy shocks, while decreases in the shock volatility make smaller part of output movement be explained by monetary policy shock. Panel (b) in figure 6 suggests that GM period’s volatility of shocks and stickiness parameters lead the closest variance decomposition results for inflation as in figure 4. Accordingly, the result of variance decomposition by counterfactual exercises suggests that employing GM period’s dual stickiness parameter provides the most similar result of general variance decomposition for both output and inflation that are calculated during GM period as in figure 4.

**Figure 6  Variance Decomposition (in percent): Counterfactual Exercise I**

To sum up, the increase in dual stickiness parameters and the decline in the volatility of shocks are main driving force of the reduced reaction of output and
inflation to monetary shock and AD shock as in GM period, with the only exception of the response to AS shock. Moreover, the variance decomposition result in GM period is similarly obtained by considering the change in stickiness parameters the most, followed by the change in shock volatility.

Now, we examine what type of stickiness is a main driving factor of the evolution of shock effects over GM period. In the same way as the previous counterfactual exercises in figure 5 and 6, based on all parameters estimated in GI period we examine three counterfactual cases that would have occurred in GM period if information stickiness of households or firms, and firms’ price stickiness parameters are assumed to be changed individually as estimated in GM period. Figure 7 presents the results of counterfactual exercises with actual model-implied response of output and inflation to each shock, in which gray dotted line with (+) sign indicates the results when all stickiness parameters are changed as in GM period. We found that a large increase in households (HH)’ information stickiness is the most significant driver of the change in output response to monetary shock and AD shock over GM period, while there is no significant effect of little increase in firm’s information stickiness on those responses. On the other hand, most of moderation of inflation response to all shocks appear to be mainly due to the increase in price stickiness since inflation responses to all shocks are not sensitively changed by the increase in information stickiness of households and firms.21)

Meanwhile, despite these remarkable differences in the shock effects across different specifications of price and information stickiness parameters, the empirical results from variance decomposition in figure 8 are quite similar across four counterfactual exercises for both output and inflation. As in previous results,

21) Since there is little increase in information stickiness parameter for the firms while other stickiness parameters increase with larger volume, an insignificant change in the response of output and inflation to shocks does not imply that firm’s information stickiness is not an important source of the evolution of effects of each shock. Therefore, we should be cautious in the interpretation of the results in figure 7.
Figure 7  Counterfactual Exercises II: Role of Price and Information Stickiness

(a) Output to Monetary Shock  
(b) Inflation to Monetary Shock  
(c) Output to AD Shock  
(d) Inflation to AD Shock  
(e) Output to AS Shock  
(f) Inflation to AS Shock
most of movements of output is mainly attributed to AD shocks and there is no clear difference among four counterfactual cases. If we assume that only household’s information stickiness estimated in GM period is utilized, it would reflect more explanatory power of AS shocks on output compared to those results assuming increase in other stickiness parameters.

**Figure 8  Variance Decomposition (in percent): Counterfactual Exercise II**

![Variance Decomposition Graph]

**CONCLUDING REMARKS**

This paper explores the evolution of the effects of monetary policy shock and their relationship with information stickiness. For this purpose, rather than sophisticating the model or adding other frictions in the model, we consider a simple DSGE model with both price stickiness and information stickiness. By employing the effect of monetary policy shock along with risk premium shock as aggregate demand shock, and price markup shock as aggregate supply shock, this framework allows us to analyze the changes in the effects of monetary policy...
shock on macroeconomic variables during Great Moderation period and the role of information stickiness in the evolution of monetary policy implications.

We address a number of important implications from several stages of empirical analysis. First, during Great Moderation period, both information and price stickiness have risen from Great Inflation period, while the persistence of monetary policy shock greatly increases but its volatility falls significantly which is consistent with empirical evidence in previous studies. Second, with the parameters estimated by Bayesian approach, our model successfully derives the hump-shaped response of inflation and output to monetary shock, aggregate demand shock, and aggregate supply shock. The variance decomposition analysis reveals that aggregate demand shock and aggregate supply shock are the main driving force of the movement of inflation and output, respectively. In addition, the role of aggregate demand shocks in explaining macroeconomic dynamics has increased over the Great Moderation.

Third, the model also well captures smaller magnitudes of the effects of shocks on macroeconomic variables over the Great Moderation. We suggest that our model incorporating both price stickiness and information stickiness is useful to understand this change in the effects of exogenous shocks. Specifically, the counterfactual exercises clearly show that the moderated responses of inflation and output to monetary policy shock and aggregate demand shock are significantly attributed to the change in dual stickiness parameters or standard deviation of shocks that are estimated in Great Moderation period. Whereas, a smaller reaction of output and inflation to aggregate supply shock is dominantly explained by the decrease in persistence of aggregate supply shock over the Great Moderation. Therefore, in that our empirical findings provide an evidence on the significant relationship between information stickiness and monetary policy shock, macroeconomic analysis taking into account for both price stickiness and information stickiness may help policymakers design effective policy actions that stabilize inflation and enhance economic growth.
For a deeper understanding of relationship between state-dependent information stickiness and monetary policy, further research must be needed. For instance, since the parameter estimates of information stickiness as well as macroeconomic dynamics in response to an economic shock are found to vary depending on economic condition, it is imperative to employ endogenously state-dependent information stickiness in the model. It should prove fruitful to improve model fit to actual macroeconomic dynamics, and to emphasize the importance of the role of information rigidity in monetary policy analysis.

REFERENCES


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Carroll, C. D., “The Epidemiology of Macroeconomic Expectations,” in L. Blume, and S. N. Durlauf eds., *The Economy as an Evolving Complex*


Knotek, E. S., “A Tale of Two Rigidities: Sticky Prices in a Sticky-Information Environment,” Journal of Money, Credit and Banking, 42(8), 2010, 1543-1564.


Pfajfar, D. and E. Santoro, “News on Inflation and the Epidemiology of Inflation
Expectations,” *Journal of Money, Credit and Banking*, 45(6), 2013, 1045-1067.


