On Phase Shifts in a New Keynesian Model Economy

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Abstract: The purpose of this paper is focus directly on the phase shift. For one thing, we ask whether a sticky-price model economy can account for both countercyclical prices and procyclical inflation. We present findings in which the price level is countercyclical and the inflation rate is procyclical. We proceed to use the model economy as an identification mechanism. What set of individual shocks are sufficient to account for the phase shift? That set is empty. Next, we ask what set of shocks are necessary to account for the phase shift. This set contains technology shocks and monetary policy shocks. The results are important as a building block. We infer that price stickiness is an important model feature; without price stickiness, we are in the real business cycle economies that Cooley and Hansen studied. But, it raises further questions. For instance, is price stickiness of the Rotemberg form—the one used here—necessary to explain the phase shift?

Keywords: Phase shift, countercyclical price, procyclical inflation, necessary and sufficient shocks, Bayesian estimation

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1. Introduction

Business-cycle facts are represented by comovements, typically with real GDP, and by volatilities. When representing comovements, researchers often characterize the lead-lag relationship, or phase shift, between time series. Since Friedman and Schwartz (1963), researchers have studied the relationship between the price level and output. As researchers applied statistical techniques to extract the cyclical component from the observed time series, there were two postwar correlations that are presented: the price level is countercyclical and the inflation rate is procyclical. There is a simple way to reconcile these two facts; there is a phase shift in the relationship between price level and output.

To illustrate the phase shift, consider a case in which the cyclical components of price level and output had the same periodicity. Note that if the price level and output were in phase in the sense of the peak of the cycle in output occurred simultaneously with the trough in the cycle of the price level, then the rate of change in the price level—that is, the inflation rate—would be negatively correlated with output as the price level is. However, if the price-level waveform were shifted to the left horizontally, then it is possible for the price level to be countercyclical and the inflation rate to be procyclical. It is just such a shift in the price level relative to output that we are looking for in a DSGE model economy.

In broad terms, business-cycle explanations are divided into two camps. The New Keynesian camp and the Real-Business Cycle camp are similar in many ways. The consumption-saving choice is an essential dynamic force through which shocks are propagated. In addition, the aggregate technology is indistinguishable between the two camps. And, expectations are rationally formed. Of course, some forms of market power and price stickiness are important differences between the two camps. Another is the way in which the New Keynesian model economies specified monetary policy; Woodford (2003) and others focused on monetary policy as means of setting the nominal interest rate. In doing so, the so-called “cashless” model economies were being analyzed. Central banks specify nominal interest rate targets and the Taylor rule is justified on that practice. By specifying a Taylor rule, however, the price level can be ignored, or even discarded. Hence, countercyclical prices are essentially excluded from the set of facts considered by researchers specifying New Keynesian model economies.

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Modern macroeconomics has used the price level and the inflation rate as a dividing line. Real Business cycle researchers can account for countercyclical price level by relying on the technology as the driving force behind business cycle fluctuations. Alternatively, researchers in the New Keynesian camp can account for procyclical inflation by relying on aggregate demand shocks. In doing so, the evidence that a phase shift exists continues to be ignored. One previous attempt to account for the phase shift in rational-expectations economies failed. Cooley and Hansen (1995) use standard RBC models, but find both the price level and the inflation rate are countercyclical. So, they calibrate a nominal contracting model. The sticky price results indicate that the price level is acyclical in their model economy. Thus the sticky price economy can generate a phase shift when the economy is subjected to a technology shock, but the evidence suggests the phase shift is too small.

The purpose of this paper is focus directly on the phase shift. For one thing, we ask whether a sticky-price model economy can account for both countercyclical prices and procyclical inflation. We present findings in which the price level is countercyclical and the inflation rate is procyclical. We proceed to use the model economy as an identification mechanism. What set of individual shocks are sufficient to account for the phase shift? That set is empty. Next, we ask what set of shocks are necessary to account for the phase shift. This set contains technology shocks and monetary policy shocks. The results are important as a building block. We infer that price stickiness is an important model feature; without price stickiness, we are in the real business cycle economies that Cooley and Hansen studied. But, it raises further questions. For instance, is price stickiness of the Rotemberg form—the one used here—necessary to explain the phase shift?

Brock and Haslag (2016) present alternative to the nominal contracting approach. They construct a model economy in which prices are sticky because there exists a set of technologies used to forecast future price levels. The most expensive technology is perfect foresight while cheaper options use the history of price levels to forecast future values. In addition, they specify a model economy that is difference stationary. In first differences, the cyclical components of output and the price level are represented by smaller phase shift in the sense that the price level is countercyclical and the inflation rate is acyclical. For economies with some positive measure of agents using low-cost forecast technology that

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2 Brock and Haslag (2016) argue that it is difficult to generate countercyclical price level and procyclical inflation in a model economy with technology shocks and rational expectations. With rational expectations, the price level responds rapidly to the information that a persistent technology shock has occurred. The upshot is that the price movement is in phase with the output movement.

3 Haslag and Hsu (2012) construct additively stochastic sine functions to demonstrate the parametric values of the phase shift that will yield a negative correlation in levels and a positive correlation in the rate of change of one variable and the level of the other.
relies on past observations of the price level to forecast the future price level, Brock and Haslag are able to account for these two difference-stationary facts.

In this paper, our contribution is twofold. First, we use a sticky-price model economy to determine if it can account for both countercyclical prices and procyclical inflation. By examining the phase shift, we use the natural feature that the two facts are part of one fact; the inflation rate is the rate of change in the price level. The working hypothesis is that sticky prices are an important ingredient so that the equilibrium laws of motion will generate the phase shift. Further, note that Brock and Haslag suggest that some kind of stickiness is necessary.

Second, the model economy allows one to ask whether all, or some subset of, shocks are able to account for the phase shift. The model economy is taken from Ireland (2003) and prices are sticky because price changes are costly a la Rotemberg (1982). In addition, we consider a rich set of shocks, including shocks to production technology, investment efficiency, consumption demand, money demand, and a monetary policy shock. We ask whether any of the shocks in the model economy are sufficient to account for the observed phase shift. The sufficiency condition is checked by looking at the model economy with only one shock operating. If the phase shift is found, then that shock is sufficient to account for the phase shift. In addition, we check to see if a necessary condition is satisfied. Here, we consider model economies in which only one shock is not operating; essentially, if, for example, the “no technology shock” economy cannot account for the phase shift, then the technology shock is necessary for the phase shift.

Our results are easily summarized. We begin by reviewing the data. For the postwar sample through 2016, we verify that the price level is countercyclical and the inflation rate is procyclical. Hence, the evidence of a phase shift between the price level and output is supported with the longer sample. Next, we use Bayesian methods to estimate the model economy.\(^4\) The numerical results indicate that the model economy can capture both the countercyclical price level and procyclical inflation rate. Moreover, the results indicate that the cross-correlation function matches the actual pattern insofar as the peak cross-correlation occurs between the price level and two-quarter-ahead output. Thus, the primary numerical result is that the model with sticky prices can account for the phase shift and correctly account for the nature, or direction, that the phase shift takes.

To check for sufficiency, we consider five versions of the model economy. Each one is distinguished by setting the standard deviation of four shocks equal to zero. If, for example, the phase shift is observed in the model economy in which only the technology shock is operational, then the

\(^4\) See DeJong, Ingram and Whiteman (1996) for a description.
technology shock is sufficient for the phase shift, conditional on the model economy. We find that none of the shocks satisfy the sufficiency condition. The necessary condition is a check of the statement that “not A implies not B.” In other words, suppose that we consider five versions of the model economy. Here, each one is distinguished by the standard deviation of only one shock set equal to zero. For example, if the preference shock is not operational implies that the phase shift is not observed in the model economy, and then the preference shock is necessary for the phase shift. We find that the technology shock and the monetary policy shock are candidates that satisfy this definition of a necessary condition.

The paper is organized as follows. We review the empirical evidence supporting the existence of the phase shift between the price level and output in Section 2. The economic model is specified in Section 3. In Section 4, we define and characterize the equilibrium. We present the numerical analysis of the model economy in Section 5. In Section 6, we determine whether any of the shocks satisfy the sufficient or the necessary conditions. We report the impulse responses functions for each shock in Section 7. In Section 8, we offer a brief summary and conclusion.

2. Evidence

Throughout this analysis, the data are quarterly and run from 1959:Q1 through 2016:Q2. The variables are per-capita real GDP (output) and the chain-weight deflator (price level).\(^5\) Our first aim is to report evidence regarding the nature of the phase shift between the price level and output. Throughout our analysis, we use logs of output and the price level and the inflation rate is the first-difference values of the log price level. The H-P filter is applied to each series with \( \lambda = 1600 \). Table 1 reports the standard deviation for detrended levels of output \((y)\), the price level \((p)\), and the inflation rate \((\pi)\), as well as the contemporaneous price-output correlation and inflation-output correlation.

The test statistic is computed following Ashley, Granger and Schmalensee (1980) and indicates that one can reject the null hypothesis that each contemporaneous correlation coefficient is equal to zero. It follows that the contemporaneous covariance between the inflation rate and output depends on two covariances; that is, the contemporaneous covariance between the output and the price level and the covariance between output and one lagged value of the price level. Formally,

\(^5\) Per-capita real GDP is obtained by real GDP (chained 2009 dollars) divided by the civilian noninstitutional population, age 16 and over.
cov\left(y_t, \pi_t\right) = \text{cov}\left(y_t, p_t\right) - \text{cov}\left(y_t, p_{t-1}\right). \text{ }^6 \text{ The evidence indicates that the covariance between output and the contemporaneous price level is negative. Thus, if the covariance between output and the lagged price level is negative and less than the contemporaneous covariance between output and the price level, then the contemporaneous correlation between output and inflation will be positive.}

In work by Haslag and Hsu (2012), the authors explain how a phase shift between the price level and output can account for the two contemporaneous correlation coefficients. More specifically, let the cyclical component of output be the reference line as plotted with respect to time. We refer to the relationship between the cyclical components of the price level and output as a left phase shift if the cyclical component of the price level tends to peak and trough before output. Formally, if 
\[ y = \sin(x) + \varepsilon_y \text{ and } p = -\sin(x + \theta) + \varepsilon_p \text{ where } \varepsilon_y \sim N(0, \sigma_y^2) \text{ and } \varepsilon_p \sim N(0, \sigma_p^2), \]
then a left phase shift is a value of \( \theta > 0 \). Haslag and Hsu derive values \( \theta \in \left[\theta, \bar{\theta}\right] \) for which the price level is countercyclical and the inflation rate is procyclical. With \( \theta \in \left[\theta, \bar{\theta}\right] \) and \( 0 < \theta < \bar{\theta} \), a left phase shift is consistent with movements in the cyclical component of the price level leading movements in the cyclical component of output. For \( 0 < \theta < \bar{\theta} \), the phase shift is too small for the inflation rate to be countercyclical. By continuity, there exists \( \theta \in \left[\theta', \bar{\theta}\right] \) where \( \theta' < \theta \), such that prices are countercyclical and the inflation rate is acyclical. A simple way to verify the left-phase shift in the data would be to conduct a Granger causality test.

Consider a bivariate VAR with output and the price level. Formally, we estimate
\[ y_t = a_0 + \sum_{i=1}^{5} b_i y_{t-i} + \sum_{i=1}^{5} d_i p_{t-i} + \eta_{yt} \]
\[ p_t = a_1 + \sum_{i=1}^{5} f_i y_{t-i} + \sum_{i=1}^{5} g_i p_{t-i} + \eta_{pt} \]
with 5 lags chosen by likelihood ratio test. In this case, we are interested in two hypothesis tests. First, we test whether movements in output Granger cause movements in the price level; hence,
\[ H_{0,y \rightarrow p}: f_i = 0 \text{ } i = 1, 2, 3, 4, 5. \text{ The p-value for this test is } 0.890. \text{ One cannot reject the null hypothesis that movements in output Granger cause movements in the price level at normal confidence level. Next, we ask whether movements in the price level Granger cause movements in output; that is, the null}

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\[ ^6 \text{See Ross (2014) for Lemma 4.7.1 and the proof on p.122 for the complete derivation of this statement.} \]
hypothesis is $H_{0,p\rightarrow y} : d_i = 0 \ i = 1,2,3,4,5$. The p-value for $H_{0,p\rightarrow y}$ is 0.004.\footnote{In this setup, there is no test for heteroscedasticity in the error terms. Note that the evidence presented by applying the standard F-test for Granger causality is consistent with a Wald test and a heteroskedastic-robust covariance estimator. See Haslag and Hsu (2012) for those results.} Hence, we can reject the null hypothesis and the data are consistent with the notion that there is a left-phase shift characterizing the relationship between output and the price level at business cycle frequencies.

For the full postwar sample, the evidence suggests that there is a phase shift between movements in the cyclical components of output and the cyclical component of the price level. Others have presented evidence that is consistent with the phase shift in the postwar data, including Kydland and Prescott (1990) and Cooley and Ohanian (1991). In relation to the findings presented in these papers, our results are not surprising. The evidence presented here confirms, over a longer postwar sample, what previous researchers have found.

Other researchers have scrutinized the contemporaneous relationship between the price level and output. Even with all the scrutiny, perhaps the biggest concern is that the phase shift is not stable. For example, Cooley and Ohanian have data going back the middle of the 19th Century. They divide the sample into subperiods. According to Cooley and Ohanian, the phenomenon that the price level is countercyclical and inflation rate is procyclical does occur in the postwar sample period. In the interwar period, for example, both the price level and the inflation rate are procyclical. In this paper, our analysis will treat the period after World War II as having a stable relationship between the price level and output.

3. Economic Environment

In this section, we use a version of the economy developed in Ireland (2003). There is a technology that implements price changes in this economy. The Rotemberg model introduces a nominal rigidity that is consistent with the ideas of inertia put forward by Sims (2003).\footnote{Woodford (2003) asserts that price stickiness is an important determinant that affects equilibrium resource allocation. Sims approaches the problem as a cognitive technology that limits information processing. See also Mackowiak and Wiederholt (2009), and Moscarini (2004) for other examples of information theoretic approaches to sticky prices.}

There are an infinite number of discrete time periods. Let time be indexed by $t = 0,1,2,...$ the commodity space consists of labor, the capital good, a unit measure continuum of intermediate goods and a single finished consumption good. The economy is populated by four types of agents: a large number of identical households, a continuum of firms producing the intermediate good, a large number of identical firms producing the final consumption good, and a central bank.
The representative household offers labor and capital to firms producing the intermediate good, purchasing final consumption goods from the final-goods producer. The representative final goods producer purchases the array of intermediate goods from the intermediate-goods producer, transforming them into the final consumption good. The central bank deals with the representative household through lump-sum transfers (taxes), printing (destroying) fiat money.

At date $t = 0$, the representative household is endowed with money balances equal to $M_0$, an initial stock of pure discount bonds, $B_0$, and an initial stock of capital goods, $K_0$. At each date $t \geq 0$, the representative household is endowed with one unit of time that be divided between labor and leisure. A representative household begins each period with money balances, bonds, and capital, captured by the triplet $\{M_{t-1}, B_{t-1}, K_{t-1}\}$. Capital is rented to intermediate-goods producing firms, receiving rental payments equal to $Q_t$ units of money per unit of capital. Discount bonds carried over from the previous period mature, paying $B_{t-1}$ units of money. In addition, each household receives $T_t$ units of money as a lump-sum payment from the central bank. Labor income is equal to $W_t$ units of money per unit of labor supplied to intermediate-good producing firms. Any profits by intermediate-goods producers are paid to the representative household. The representative household chooses the consumption good, real balances, leisure, bonding holdings and investment to maximize expected lifetime utility subject to the period budget constraint.

Intermediate-good producing firms have access to a technology that combines labor and capital to produce an intermediate good. Let $i \in [0,1]$ be the index for intermediate-good producing firm. Capital rented by firm $i$ is denoted by $K_i(t)$ and labor used by firm $i$ is denoted $l_i(t)$. Thus, aggregating across firms satisfies $K_t = \int_0^1 K_i(t) \, di$ and $l_t = \int_0^1 l_i(t) \, di$, representing the total capital stock rented to all firms and total labor supplied to all firms, respectively. Finally, nominal profits are paid to the representative household. Let $D_t = \int_0^1 D_i(t)$ be the total nominal profits paid to representative households by intermediate-good producing firms.

The representative household faces distribution of different shocks in this economy. The household seeks to maximize expected lifetime utility represented by
\[
E_0 \sum_{t=0}^{\infty} \beta^t u \left( C_t, \frac{M_t}{P_t}, 1-l_t \right)
\]  

(1)

where the momentary utility function is represented by

\[
u(t) = a_t \left( \frac{y}{y-1} \right) \ln \left[ C_t^{y-1} + e_t^{y} \left( \frac{M_t}{P_t} \right)^{\frac{y}{y'}} \right] + \eta \ln(1-l_t)
\]  

(2)

Equation (2) introduces two preference shocks. Here, \(a_t\) stands for a preference shock that affects the household’s consumption growth rate responsiveness to the changes in real interest rate. There is a separate shock to the household’s money demand captured by \(e_t\). Throughout this paper, we assume that both preference shocks follow a stationary AR(1) process. Let

\[
\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at} \text{ and } \ln(e_t) = (1-\rho_e)\ln(e_{t-1}) + \varepsilon_{et}
\]

where \(\rho_j \in [0,1)\) and \(\varepsilon_j \sim N\left(0, \sigma_j^2\right)\) for \(j = a, e\). Here, \(e\) denotes the steady state value of the money demand parameter.

The household uses consumption good purchases to consume and to transform the consumption good into the capital good. We assume there is an adjustment cost associated with changes in the capital stock represented by

\[
\left( \frac{\phi}{2} \right) \left( \frac{K_t}{gK_{t-1}} \right)^2 K_{t-1}
\]

(3)

Let \(\phi\) stand for the capital adjustment cost parameter and \(g\) is the steady state value of the capital growth rate.

The household’s period budget constraint is given as

\[
\frac{M_{t-1} + B_{t-1} + Q_tK_{t-1} + W_tI_t + D_t + T_t}{P_t} = C_t + I_t + \left( \frac{\phi}{2} \right) \left( \frac{K_t}{gK_{t-1}} - 1 \right)^2 K_{t-1} + \left( \frac{B_t}{r_t} + \frac{M_t}{P_t} \right)
\]

(4)
Note that discount bonds are purchased at price \( \frac{1}{r_t} \) where \( r_t \) is the gross nominal interest rate that applies for dates \( t \) to \( t+1 \). In equation (4), the left-hand-side is the real value of resources available for the household to spend while the right-hand-side is the real value of purchases.

The law of motion for the capital stock includes a shock to the marginal efficiency of capital. Formally,

\[
K_t = (1-\delta) K_{t-1} + \chi I_t. \tag{5}
\]

We assume the efficiency shock term follows a stationary AR(1) as follows

\[
\ln(x_t) = \rho_x \ln(x_{t-1}) + \varepsilon_x \text{ with } \varepsilon_x \sim N(0, \sigma_x^2). \tag{6}
\]

The household’s problem, therefore is to maximize (1) subject to (4) and (5), taking prices as given.

Intermediate-goods producing firms produce a firm specific, perishable goods. For convenience, let firm \( i \) produce intermediate good \( i \). The technology used by the intermediate good firm is a constant returns to scale Cobb-Douglas production function given by

\[
Y_i(t) = K_i(t)^\alpha \left[ g' z_i l_i(t) \right]^{1-\alpha}. \tag{7}
\]

Here, \( \alpha \) is the share of income paid to the capital factor, \( z_i \) is a productivity shock that follows a stationary AR(1) process depicted by the following:

\[
\ln(z_i) = (1-\rho_z) \ln(z) + \rho_z \ln(z_{t-1}) + \varepsilon_z \text{ with } \varepsilon_z \sim N(0, \sigma_z^2). \tag{8}
\]

Here, \( z \) stands for the steady-state level of productivity.

The intermediate-good producing firm \( i \) sells its good to the final-good producer at nominal price \( P_i(t) \). Each intermediate-good producer possesses some market power in a monopolistically competitive market for inputs. Each firm sets the price, facing a price-adjustment cost given by

\[
\left( \frac{\phi_P}{2} \right) \left[ \frac{P_i(t)}{\pi P_i(t-1)} - 1 \right]^2 Y(t). \tag{9}
\]
Here, $\phi_p$ is the price-adjustment cost parameter and $\pi$ is the steady state inflation rate. Each intermediate-good producer seeks to maximize the discounted sum of profits. Thus, each firm chooses capital, labor, and its price to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[ \frac{D_i(t)}{P_t} \right]$$

where $\Lambda_t$ is the Lagrange multiplier that applies to the representative household’s budget constraint. The date-$t$ dividends paid to the household is given by

$$\frac{D_i(t)}{P_t} = P_t(t)Y_t(t) - Q_tK_t(t-1) - W_t(t) - T_t - \left( \frac{\phi_p}{2} \right) \left[ \frac{P_t(t)}{\pi P_t(t-1)} - 1 \right]^2 Y(t).$$

The representative final-good producer uses a constant-returns to scale technology. The quantity of final-goods produced is given by

$$Y_t = \left[ \int_0^1 Y_t(t)^{\theta-\theta} \, dt \right]^{\theta/(\theta-1)}.$$ 

The final goods market is perfectly competitive. With no barriers to entry, the zero-profit conditions will be satisfied in equilibrium. From previous work, the price of the final good will be

$$P_t = \left[ \int_0^1 P_t(t)^{1-\theta} \, dt \right]^{\theta/\theta-1}.$$ 

At each $t$, the central bank creates (destroys) fiat money at rate $\mu_t$. Hence, the law of motion for the money supply is

$$M_t = \mu_t M_{t-1}.$$ 

Changes in the money are passed to the representative household. The nominal budget constraint for the central bank is given by

$$T_t = M_t - M_{t-1} = (\mu_t - 1)M_{t-1}.$$ 

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9 This approach is consistent with maximizing the household’s utility derived from real dividend payments.
Throughout our analysis, we assume that the path for the money supply—the value of $\mu_t$—is determined by a type of Taylor rule. The monetary policy rule is given by

$$\ln \left( \frac{r_t}{r} \right) - \omega_\mu \ln \left( \frac{\mu_t}{\mu} \right) = \omega_\pi \ln \left( \frac{\pi_t}{\pi} \right) + \omega_y \ln \left( \frac{y_t}{y} \right) + \ln (v_t)$$  \hspace{1cm} (15)$$

where $r, \mu, \pi, \text{and } y$ are steady state values of the nominal interest rate, the money growth rate, the inflation rate, and detrended output; that is, $y = \frac{Y_t}{g}$, respectively. In equation (15), $\omega_\mu$ is the weight on money growth relative to that on the nominal interest rate. Further, $\omega_\pi$ and $\omega_y$ are the policy responses to log-deviations of inflation and detrended output from their steady state values. Finally, $v_t$ is a monetary policy shock which follows a stationary AR(1) process given by

$$\ln (v_t) = \rho_v \ln (v_{t-1}) + \epsilon_v \text{ with } \epsilon_v \sim N(0, \sigma_v^2).$$  \hspace{1cm} (16)$$

4. Equilibrium

In this model economy, a symmetric competitive equilibrium is defined as a sequence of allocations $\left\{ C_t, I_t, K_t, l_t, \frac{M_t}{P_t}, \frac{D_t}{P_t} \right\}_{t=0}^\infty$ and a sequence of prices, $\left\{ P_t, Q_t, W_t, r_t \right\}$ such that:

i. the representative household maximizes expected lifetime utility, taking prices as given;

ii. each intermediate-good producer chooses the price so as to maximize expected discounted sum of profits, taking all input prices as given;

iii. the representative final-good producer maximizes profits, taking prices as given;

iv. the central bank’s budget constraint is satisfied;

v. the market for all the intermediate goods, the market for the final good, the capital market, the labor market, the bond market, and the money market clear.

In the symmetric equilibrium, each intermediate-good producer will choose the same price. By equation (13), we obtain $P_i(t) = P_i$. Similarly, it follows that $K_i(t) = K_i, l_i(t) = l_i$, and $D_i(t) = D_i$. Equation (12) implies that $Y_i(t) = Y_i$. 

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5. Numerical analysis

With this version of a sticky-price, DSGE model economy, there are 24 parameters. We follow Ireland (2003) in choosing values for \( \eta, \delta, \) and \( \theta \). Let \( \eta = 1.5 \), which is consistent with the representative household spending one-third of their time in market productive activity. The quarterly depreciation rate is set such that annual depreciation is approximately ten percent; hence, \( \delta = 0.025 \). The price elasticity of the demand for intermediate goods is set with \( \theta = 6 \) corresponding to a steady state markup equal to 20 percent.

We use Bayesian methods to obtain values for the remaining 21 parameters. We use a Monte-Carlo base optimization routine to compute the mode value for the other 21 parameters. With the three calibrated parameters and 21 estimated parameters, we solve the first-order Taylor expansion around the steady state. Because the model economy’s dynamics are subject to five exogenous shocks, we use five observed series to avoid stochastic singularity. The five observable variables are: real personal consumption expenditures, real gross private domestic investment, real M2 balances, the chain-weight GDP deflator, and the 3-month U.S. Treasury bill rate.¹⁰

Table 2 reports the results of the Bayesian estimation using quarterly data spanning the period 1959:Q2 through 2016:Q2. The parameter values are broadly divided into four groups: tastes and production, adjustment costs, monetary policy, and the five exogenous shocks. For parameters that lie in the zero-one interval, we specify a Beta distribution as the prior distribution. The first group of parameters contains the tastes and production parameters. The mean of the posterior distribution of the discount factor tells us that \( \beta = 0.9958 \) implying that the representative household exhibits a low subjective rate of time preference. The mean of the posterior distribution for \( \gamma/(\gamma - 1) = 0.0514 \) which implies the interest elasticity of money demand is -0.0542. For the capital share, the mean of the posterior distribution of capital share is 0.2373.

The second group of parameters focuses on the cost adjustment parameters. Note that the mean values of the posterior distributions indicate greater price stickiness in the intermediate goods sector than in the capital goods sector. The value of the cost adjustment parameter for the intermediate goods is more than four times the value of the cost-adjustment parameter in the capital goods sector.

¹⁰ Following Ireland (2003), we use per-capita measures of consumption, investment, and real money balances to estimate the model. Per-capita measures are obtained by dividing the aggregate value by the civilian noninstitutional population, age 16 and over.
The monetary policy rule uses the steady state money growth rate. We estimate the growth rate from the data. The mean of the posterior distribution is 1.0108 which corresponds to an annual average growth rate of 4.4 percent. The average annual growth rate of the M2 money stock is 6.8 percent for the U.S. during the sample period. The estimated value is reasonably close to the actual average growth rate. For the Taylor rule parameters, the Bayesian estimates indicate that monetary policy is slightly active with respect to the movements in the output gap. With \( \phi_y = 0.0131 \), the calibrated response of the nominal interest rate is fairly small for a given change in the output gap. We also see that \( \phi_\pi = 1.3187 \), implying that the Federal Reserve stems inflation. The above Bayesian estimates of the policy coefficients are in line with findings in the literature and indicate the stabilization property of the estimated Taylor rule.

The fourth group of parameters describes the persistence and volatility of the five shocks that are in the model economy. We find that the estimated coefficients on lagged values of most shocks—preference, money demand, investment efficiency, and productivity—are between 0.899 and 0.991, implying a high level of persistence is present in these shocks. The Bayesian estimate for \( \rho_\sigma = 0.5067 \), implying moderate persistence is present in the monetary policy shock. Among the five shocks, Table 2 reports that the Bayesian estimates of the standard deviation in investment efficiency shock is about ten times the value of the other four shocks.

5.1 Business cycle properties

With the model economy and its parameter values set, we report the key properties. Table 3 reports the standard deviations for the actual and simulated economies for five different values; specifically, output, the price level, the inflation rate, M2, and the nominal interest rate.\(^{11}\) Except for the nominal interest rate and output, the model economy reports slightly greater volatility for the price level and the inflation rate compared with the actual volatility. M2, however, is about 1 1/2 times more volatile in the model economy than it is in the actual economy.

Table 4 reports the contemporaneous correlation coefficient with output for the price level, the inflation rate, M2, and the nominal interest rate. Focus on the first two columns. The model economy generates a set of time series in which the price level is countercyclical. However, the evidence indicates that the relationship between output—defined as the sum of consumption and investment—and the

\(^{11}\) Since we do not use the data on real GDP for estimation, here actual output is measured as the sum of consumption and investment. So the volatility of actual output in Table 3 and the contemporaneous price-output and inflation-output correlations in Table 4 are different from those in Table 1.
inflation rate is significant at the just below the ten percent level. Hence inflation is acyclical in the measure of output consisting of resources consumed by consumers and firms.\textsuperscript{12} Note that the phase shift embodied in the correlation coefficient between inflation and output is quantitatively very close when comparing the model economy and the actual economy; 0.1 and 0.14 are statistically insignificant from one another. Therefore, we interpret the model economy with sticky prices as capable of accounting for a phase shift between the price level and output.

\section*{6. Necessary and Sufficient Shocks}

With five different shocks affecting the model economy, we consider two alternative approaches that may help shed some light on whether there is a set of either necessary or sufficient shocks that can account for the phase shift between the price level and output. We begin by examining model economies in which only one shock is operating. The approach yields a kind of sufficiency condition; if, for example, there is only a monetary policy shock, do we observe countercyclical price level and procyclical inflation in the model economy? If yes, then the monetary policy shock is sufficient for the left phase shift observed in the data.

Table 5 presents contemporaneous cross correlations for five simulations of the model economy. In each simulation, the shock listed in the first column is the only one with a nonzero standard deviation. We report the median value of the contemporaneous correlation coefficient from 5000 simulations of the model economy. In four of the five cases, the median value of the contemporaneous correlation coefficient has the same sign for both the price level and the inflation rate. In the case of the consumption preference shock, the price level is acyclical while the inflation rate is strongly procyclical. Thus, there is evidence of a phase shift present when there is a shock to preferences for current consumption. However, based on the results presented in Table 5, none of the shocks are sufficient to account for the left phase shift observed in the data.

Even with costly price changes imparting some price stickiness into the model economy, the equilibrium we consider are rational expectations. Brock and Haslag (2014) spend some time deriving

\textsuperscript{12}The implication is that the correlation between prices and private spending is consistent with a phase shift that satisfies $\theta \in [0, \hat{\theta}]$. The phase shift generated by the more narrow measure of output economy is a fractional shift in the sense that it is too small—that is, less than $\hat{\theta}$—to account for the countercyclical price level and procyclical inflation.
conditions in which there could be a phase shift in a Woodford-style (2003) model economy. Basically, in a model economy with rational expectations, the price level responds quickly to the new information such the relationship between the price level and output is in phase. Price stickiness helps, but for the simulated model economy presented here, the numerical results indicate that any phase shift is insufficient when a shock is considered in isolation.

The monetary policy was considered a good candidate that could account for the left phase shift. In particular, the equilibrium inflation rate depends on the initial impact on deviations in consumption. In a model economy with capital, Rupert and Sustek (2016) argue that consumption can be perfectly smoothed, at least initially, to a monetary policy shock. With an unexpected increase in the nominal interest rate, the initial response is for the equilibrium inflation rate (and hence the price level) to decline. As the persistence of the monetary policy shock dissipates, the inflation rate approaches its stationary value from below. With a decline in inflation rate and future expected inflation rates, it follows that output must also initially decline; the decline in output is matched by a decline in investment spending since consumption spending is initially unchanged. Like the inflation rate, output will approach its stationary value from below. Table 5 supports Rupert and Sustek’s intuition; indeed; Table 5 reports a very high contemporaneous correlation between output and the inflation rate when there is a monetary policy shock only. Still we need to explain why there is, on average a negative correlation between the price level and output. Well, as output increases following the initial negative shock, the inflation rate is also increasing. With the inflation rate still below its stationary value, however, the price level is declining. In other words, after the initial response in which the price level and output move in the same direction, there is period during the convergence to the stationary settings in which the price level is continuing to decline while output is increasing. Based on the simulation findings, the results indicate that the strength of the initial price level-output response swamps the negative correlation of the responses that follow.

We plot the cross-correlation function for the model economy with all shocks operating and with each shock operating separately in Figure 1. In each panel (A through F), the reader can see \( \rho(p_{t+i}, y_t) \) for \( i = -5, -4, ..., 4, 5 \) in the left-hand column and \( \rho(\pi_{t+i}, y_t) \) for \( i = -5, -4, ..., 4, 5 \) in the right-hand column. The cross-correlation function for the simulated economy and the actual data are plotted together. The reader can get a sense of the goodness-of-fit of the model economy in Panel A. The left-phase shift is

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13 Brock and Haslag (2016) provide a detailed exposition on the role that rational expectations plays in keeping the price level and output in phase. In short, they find that the price-level response is essentially too quick for the phase shift to be evident in a version of Woodford’s (2004) money-in-the-utility function model with completely flexible prices.
represented by the matching of the cross-correlation function between the price level and output; in the baseline economy, the median correlation coefficient indicates that movements in the price level temporally precede movements in output as observed in the actual data. Panels B through F depict cross-correlation functions that are markedly different than the actual function for the price level and output. In particular, Figure 1 shows that for each of one-shock-only model economies, the cross-correlation functions exhibit more pronounced swings compared with the actual cross-correlation functions. Note that for the technology shock, the money demand shock, the investment efficiency shock, and the monetary policy shock, the model economy’s cross-correlation function indicates that the price level and output are either in phase (contemporaneous correlation is the largest) or that movements in output temporally precede movements in the price level (future price level correlation is the largest). Even in the case of the preference shock (Panel C), we observe a symmetry in the cross-correlation function between the price level and output; the function is upward sloping over the range from -5 (price leads output) to 5 (output leads price).

Overall, we find some evidence that consumption preference shock can account for a phase shift. However, the phase shift is not sufficient to match the observed pattern of countercyclical price level and procyclical inflation. We conclude, therefore, that there is not a single shock to the model economy that is sufficient to account for the phase shift observed in the data.

Next, we examine the model economy with four shocks operating and only one shock set such that its standard deviation is equal to zero. In this way, we can ask whether one shock is necessary for the left phase shift we observe. To illustrate the question, suppose we set the standard deviation of one shock equal to zero and the price level is countercyclical and the inflation rate is procyclical in the model economy. We know that the shock is not necessary for the model economy to be able to account for the left phase shift observed in the data. If the standard deviation is set to zero and the model economy is not able to match the empirical observation, then we know the shock is necessary.

Table 6 reports the median contemporaneous correlation coefficients for the price level and output and the inflation rate and output for five model economies. Each model economy is identified by the first column in Table 6; specifically, the column identifies the shock for which standard deviation is set to zero. The results indicate that in three cases—the consumption preference, the money demand, and the investment efficiency shocks—the price level is countercyclical and the inflation rate is (marginally) procyclical. Consequently, these three shocks are not necessary to account for the left phase shift. In the case of the productivity shock and the monetary policy shock, Table 6 reports that the signs of the two correlation coefficients are the same; that is \( \text{sgn} \left[ \rho(y, p) \right] = \text{sgn} \left[ \rho(y, \pi) \right] > 0 \) for the productivity.
shock and \( \text{sgn}\left[ \rho(y, p) \right] = \text{sgn}\left[ \rho(y, \pi) \right] < 0 \) for the monetary policy shock. Thus, the results suggest that the technology shock and the monetary policy shock are necessary for the model economy to account for the left phase shift.

Figure 2 plots the cross-correlation functions for two model economies. In both models, we plot the functions for the price level and the inflation rate. For one model economy, the standard deviation of the technology shock is set equal to zero (Panel A) and the other is cross-correlation function for the model economy in which the standard deviation for the monetary policy shock is set equal to zero (Panel B). In both panels, the median value of the cross-correlation coefficient is reported for a set of 5000 simulations. Comparing Panel A to Panel B, Figure 2 shows that the cross-correlation function is a worse fit with the technology shock off than when the monetary policy shock is off. The dotted lines are 90 percent confidence bands constructed from the 5000 simulations. With no technology shock, we observe that the price-output cross-correlation function for the model economy is significantly different from the actual cross-correlation function for \( i = -2, -1, 0, 1, 2, 3, 4 \). Indeed, the correlation values have a different sign than the actual coefficients for \( i = -1, 0, 1, 2, 3, 4 \). Note that in the inflation rate-output cross-correlation function, the median value for the model economy is significantly different from the actual correlation coefficient for \( i = -5, -4, -3, -2, -1, 0, 3, 4, 5 \). For the monetary policy shock, the price-output cross-correlation is significantly different than the actual correlation for \( i = -5, -4, -3 \). In the monetary policy shock case, however, the correlation coefficients have generally the same sign as the actual correlations. Note that inflation-output correlation coefficients are not significantly different from the actual correlations when the monetary policy shock is not operational.

The numerical evidence supports the notion that both monetary policy shocks and technology shocks are necessary for the model economy to be able to account for the observation that there is a phase shift in the price level. In this DSGE model, we provided the intuition for why the monetary policy would be able to account for the phase shift in the discussion of the sufficiency conditions. In the case of the technology shock, Freeman and Huffman (1991) provide an elegant intuition that helps us understand why a technology shock will result in the phase shift. In the case of a positive technology shock, for example, the immediate effect is for incomes to rise and money demand to rise. For a given money supply path, the price level initially declines. Here is where price stickiness plays an important role. The price decline is partial relative to what it would have been in a setting with no price stickiness. It simply takes time for the price level to respond fully to the technology shock. Meanwhile, as the price level converges back to its stationary path, the inflation rate will increase while output is also increasing. Thus, the initial price level response accounts for why the price level and output are negatively correlated. The price
stickiness imparts a propagation property to the rate of change in the price level that accounts for the inflation rate is procyclical in the model economy.

Overall, the results provide a deeper understanding of how the DSGE model economy can account for the phase shift in the price level relative to output. While no one shock is sufficient to account for the phase shift, we present evidence that both technology and monetary policy shocks are necessary to account for the phase shift.

7. Impulse Response Functions as a Means of Identification

How the economy responds to each shock can shed light on contribution to the phase shift between the price level and output. Figures 3 through 7 report the impulse response functions for nine endogenous variables over 40 quarters for each exogenous shock. Here, we will use the fact that the inflation rate is the rate of change in the price level. So, we will concentrate on the impulse response functions for output and the inflation for each of the five shocks in the model economy.

The general picture obtained from the impulse response functions are consistent with contemporaneous correlation coefficients reported in Panels B through F in Figure 1. Note that the immediate responses to a particular shock reported for output and the inflation rate (and the price level) are consistent with the contemporaneous cross correlation reported in Figure 1 for each individual shock case. For example, in Panel B of Figure 1, the contemporaneous cross correlation between output and the inflation rate is negative. The immediate impulse response to a technology shock is an increase in output and a decline in the inflation rate as shown in Figure 6. In the following discussion, we consider a more detailed description of the impulse responses and cross-correlation functions.

Figure 3 plots the impulse responses to a one standard deviation positive shock to preferences. The immediate response is for output and inflation to increase. The contemporaneous cross correlation indicates the price level is acyclical and the inflation rate is procyclical in the model economy with only a preference shock operating. Note further that both the output response and the inflation rate response are nonmonotonic. The peak response in output occurs only one quarter after the shock while the peak response in the inflation rate occurs four quarters after the shock. Hence, the impulse responses are nonsynchronous. The implication is that output is positively correlated with future inflation as observed in the cross correlation functions (see Panel C in Figure 1). When output increases, both inflation and the price level continue to increase for several more quarters.

Figure 4 plots the impulse responses when there is a one standard deviation positive change in the money demand shock. The immediate response indicates that both the output response and the inflation
rate response are negative and are thus consistent with the procyclical price level and procyclical inflation rate reported in Panel D of Figure 1. Moreover, both the output response and the inflation rate responses are monotonically declining in magnitude over the range of the impulse response function. The movements in the future inflation rate are small enough so that the correlation between output and future inflation vanishes. Note that after an initial decline, inflation rebounds to its steady-state level within two years after the shock and then reaches and stays at a level slightly higher than its steady-state value. Such a response pattern indicates that the price level is continuing to increase after the shock. And the cross-correlation function in Panel D of Figure 1 shows that there is a positive correlation between current output and future price level when the money demand shock is operating. Conversely, movements in the price level are negatively correlated with future output.

In Figure 5, we consider the impulse responses to a one standard deviation positive shock to the investment efficiency. The immediate response indicates that both output and the inflation rate increase, which is consistent with the evidence in Panel E of Figure 1; that is, the price level and inflation rate are procyclical. In terms of the cross-correlation function, the relationship between current output and future inflation is indicated by the impulse responses as follows: as output continues to increase we see that inflation starts to decline, approaching the steady state from above. Thus, the correlation between current output and future inflation becomes negative. Because the inflation rate is positive within five quarters after the shock, however, the price level is increasing. Hence, the correlation between current output and future price level is positive. We can observe the relationship in the impulse response functions, given an investment efficiency shock, as being reflected in the cross-correlation functions for output and the price level and output and the inflation rate when only the investment efficiency shock is operational.

Figure 6 represents the impulse response functions for a one standard deviation positive productivity shock. The immediate reaction is a positive response by output and a negative response by the inflation rate. The immediate responses can account for countercyclical price level and countercyclical inflation observed in Panel B of Figure 1. The relationship between current output and future inflation owes chiefly to the fact that the impulse response indicates that inflation is increasing over time as it approaches steady state from below. The positive correlation shows up in the cross correlation function as the correlation between current output and future inflation becomes positive. Because the inflation rate response is increasing, but negative, the correlation between current output and future price level remains negative. We further observe that the current price level is declining, but the hump-shaped pattern in the output response indicates that eventually output declines. Thus, the impulse response can account for a positive correlation between current price level and future output.
Lastly, Figure 7 plots the impulse response functions given a one standard deviation positive shock to monetary policy. The immediate effect is that output declines and the inflation rate declines. Panel E of Figure 1 indicates that price level is procyclical and the inflation rate is procyclical. As Rupert and Šustek explain, the monetary policy shock initially results in a higher real interest rate, reducing the demand for current consumption and output initially declines in the face of an unexpected increase in the nominal interest rate. The impulse response shows that output approaches steady state from below, so $y_t$ is increasing. The impulse response also indicates that the inflation approaches steady state rapidly, so that inflation is also increasing. This is why we see a rapid decline in the cross-correlation function. We also can account for why the current price level is negatively related to future output; as inflation approaches steady state from below, the price level is declining while the future output response is positive after the initial decline.

**8. Summary and conclusion**

In this paper, we examine a New Keynesian model economy with Rotemberg-type sticky prices, attempting to quantitatively assess the model economy’s ability to account for a phase shift evident in the relationship between the price level and output. Here, the phase shift is consistent with the observation that the price level is countercyclical and the inflation rate is procyclical. We are able to demonstrate that the sticky price model can account for the phase shift.

This result may not be surprising to many. We investigate further, and our main contribution lies in looking for the source of the model economy’s ability to account for the left phase shift in the data. Is one type of shock sufficient to account for the observed pattern in the data? The answer is no. We consider five versions of the model economy in which each is distinguished by setting the standard of deviations of four shocks equal to zero. In each one-shock-only model economy, the price-output and inflation-output contemporaneous correlation coefficients do not match the actual correlation coefficients. Hence, we conclude that not one shock is sufficient to account for the observed pattern.

In addition, we examine whether one shock is necessary to be able to account for countercyclical price level and procyclical inflation. We find that the monetary policy shock and technology shock both meet a simple criterion to be considered necessary for the left phase shift. Specifically, we consider separate model economies in which the technology shock or the monetary policy shock is not operational. In both cases, the model economies cannot account for both countercyclical price level and procyclical inflation. In short, “not technology shocks” imply “not a left phase shift” and “not monetary policy shocks” imply “not a left phase shift.” Therefore, we conclude that there is a set of necessary shocks to account for the observation.
Our results are first, important step that could possibly explain one of the main modelling differences that is present in analyses of business cycle fluctuations. The two principal camps studying business cycle fluctuations have divided between emphasizing the relationship between inflation and output versus emphasizing the relationship between the price level and output. By focusing on the phase shift in the relationship between the price level and output, some notion of sticky prices is important. As researchers move forward, the phase shift provides a focal point.
References


Table 1

Business Cycle Facts

<table>
<thead>
<tr>
<th>Variable</th>
<th>Std Dev</th>
<th>Corr with y</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>1.48</td>
<td>--</td>
</tr>
<tr>
<td>p</td>
<td>0.76</td>
<td>-0.48***</td>
</tr>
<tr>
<td>π</td>
<td>0.26</td>
<td>0.18***</td>
</tr>
</tbody>
</table>

Note: Output is measured as per-capita real GDP. *, **, and *** denotes 10%, 5%, and 1% significance, respectively.
**Table 2**

Bayesian Estimation of Model Economy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation in paper</th>
<th>Prior Distribution</th>
<th>Posterior Distribution MH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Type</td>
<td>Mean</td>
</tr>
<tr>
<td>Discount factor</td>
<td>$\beta$</td>
<td>Beta</td>
<td>0.96</td>
</tr>
<tr>
<td>Interest elasticity of money demand</td>
<td>$\gamma / (\gamma - 1)$</td>
<td>Beta</td>
<td>0.09</td>
</tr>
<tr>
<td>Capital share</td>
<td>$\alpha$</td>
<td>Beta</td>
<td>0.30</td>
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<td>Price adjustment</td>
<td>$\phi_p$</td>
<td>Normal</td>
<td>116</td>
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<tr>
<td>Capital adjustment</td>
<td>$\phi_k$</td>
<td>Normal</td>
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<tr>
<td>Long-run mean – M2 growth</td>
<td>$\mu$</td>
<td>Gamma</td>
<td>1.01</td>
</tr>
<tr>
<td>Monetary policy response -- M2 growth</td>
<td>$\omega_{\mu}$</td>
<td>Normal</td>
<td>1</td>
</tr>
<tr>
<td>Monetary policy response -- output</td>
<td>$\omega_{y}$</td>
<td>Normal</td>
<td>0.5</td>
</tr>
<tr>
<td>Monetary policy response – inflation</td>
<td>$\omega_{z}$</td>
<td>Normal</td>
<td>1.5</td>
</tr>
<tr>
<td>Money demand shock</td>
<td>$e$</td>
<td>Gamma</td>
<td>2.5</td>
</tr>
<tr>
<td>Productivity</td>
<td>$z$</td>
<td>Gamma</td>
<td>10000</td>
</tr>
<tr>
<td>Autocorrelation – preference shock</td>
<td>$\rho_a$</td>
<td>Beta</td>
<td>0.5</td>
</tr>
<tr>
<td>Autocorrelation – md shock</td>
<td>$\rho_e$</td>
<td>Beta</td>
<td>0.5</td>
</tr>
<tr>
<td>Autocorrelation – inv eff shock</td>
<td>$\rho_z$</td>
<td>Beta</td>
<td>0.5</td>
</tr>
<tr>
<td>Autocorrelation—prod shock</td>
<td>$\rho_x$</td>
<td>Beta</td>
<td>0.5</td>
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<tr>
<td>Autocorrelation – monetary policy shock</td>
<td>$\rho_v$</td>
<td>Beta</td>
<td>0.5</td>
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<td>Stnd dev – innov to preference shock</td>
<td>$\sigma_a$</td>
<td>InvGam</td>
<td>0.01</td>
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<tr>
<td>Stnd dev – innov to md shock</td>
<td>$\sigma_e$</td>
<td>InvGam</td>
<td>0.01</td>
</tr>
<tr>
<td>Stnd dev – innov to inv eff shock</td>
<td>$\sigma_z$</td>
<td>InvGam</td>
<td>0.01</td>
</tr>
</tbody>
</table>

25
| Stnd dev – innov to monetary policy shock | $\sigma_v$ | InvGam | 0.01 | 4 | 0.0059 | 0.0050 | 0.0069 |

Legend: InvGam denotes Inverse Gamma distribution. Model is estimated using the Bayesian method. The data are Consumption, Investment, real M2 balances, inflation and the 3-month Treasury bill rate for the U.S. spanning 1959:Q2 to 2016:Q2.
Table 3

**Standard Deviations: Comparing Simulated Economy with Actual**

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\gamma$</th>
<th>$p$</th>
<th>$\pi$</th>
<th>$M2$</th>
<th>$i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Economy</td>
<td>1.99</td>
<td>0.82</td>
<td>0.32</td>
<td>1.96</td>
<td>0.24</td>
</tr>
<tr>
<td>Actual</td>
<td>2.03</td>
<td>0.76</td>
<td>0.26</td>
<td>1.29</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Legend: Here, output is measured as the sum of consumption plus investment spending. In both the simulated and actual economies, the period is 229 quarters. The median standard deviation in the simulated economy is computed from 5000 simulations. The cyclical components are obtained by using H-P filter and are measured in percentage terms.
Table 4

Median Contemporaneous Correlation (with output):

Comparing Simulated with Actual Economy

<table>
<thead>
<tr>
<th>Variable</th>
<th>$p$</th>
<th>$\pi$</th>
<th>$M_2$</th>
<th>$i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated Economy</td>
<td>-0.23***</td>
<td>0.14**</td>
<td>0.63***</td>
<td>0.12*</td>
</tr>
<tr>
<td>Actual</td>
<td>-0.50***</td>
<td>0.10</td>
<td>0.22***</td>
<td>0.32***</td>
</tr>
</tbody>
</table>

Legend: Here, output is measured as the sum of consumption plus investment spending. In both the simulated and actual economies, the period is 229 quarters. The median correlation coefficient is computed from 5000 simulations. The cyclical components are obtained by using H-P filter and are measured in percentage terms. “***” denotes significance at the 1% level; “**” denotes significance at the 5% level; and “*” denotes significance at the 10% level. See Ashley, Granger and Schmalensee (1980) for the calculation of the standard errors of the cross-correlation coefficients.
Table 5

Median Contemporaneous Correlation (with output):

Consider Model Economy with only One Shock at a Time

<table>
<thead>
<tr>
<th>Shock (on)</th>
<th>$\rho(y, p)$</th>
<th>$\rho(y, \pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preference</td>
<td>-0.05</td>
<td>0.96***</td>
</tr>
<tr>
<td>Money Demand</td>
<td>0.34***</td>
<td>0.99***</td>
</tr>
<tr>
<td>Investment Efficiency</td>
<td>0.69***</td>
<td>0.50***</td>
</tr>
<tr>
<td>Productivity</td>
<td>-0.90***</td>
<td>-0.52***</td>
</tr>
<tr>
<td>Monetary Policy</td>
<td>0.31***</td>
<td>0.98***</td>
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</table>

Legend: Here, output is measured as the sum of consumption plus investment spending. In both the simulated and actual economies, the period is 229 quarters. The median correlation coefficient is computed from 5000 simulations. The cyclical components are obtained by using H-P filter and are measured in percentage terms. “***” denotes significance at the 1% level; “**” denotes significance at the 5% level; and “*” denotes significance at the 10% level. See Ashley, Granger and Schmalensee (1980) for the calculation of the standard errors of the cross-correlation coefficients.
Table 6

Median Contemporaneous Correlation (with output):

Consider Model Economy with only One Shock off at a Time

<table>
<thead>
<tr>
<th>Shock (off)</th>
<th>$\rho(y, p)$</th>
<th>$\rho(y, \pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preference</td>
<td>-0.25***</td>
<td>0.09</td>
</tr>
<tr>
<td>Money Demand</td>
<td>-0.27***</td>
<td>0.08</td>
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<tr>
<td>Investment Efficiency</td>
<td>-0.40***</td>
<td>0.07</td>
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<tr>
<td>Productivity</td>
<td>0.35***</td>
<td>0.77***</td>
</tr>
<tr>
<td>Monetary Policy</td>
<td>-0.38***</td>
<td>-0.08</td>
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Legend: Here, output is measured as the sum of consumption plus investment spending. In both the simulated and actual economies, the period is 229 quarters. The median correlation coefficient is computed from 5000 simulations. The cyclical components are obtained by using H-P filter and are measured in percentage terms. “***” denotes significance at the 1% level; “**” denotes significance at the 5% level; and “*” denotes significance at the 10% level. See Ashley, Granger and Schmalensee (1980) for the calculation of the standard errors of the cross-correlation coefficients.
Figure 1

Panel A: Cross-Correlation Function for Sticky Price Model Economies (All Shocks)

Panel B: Cross-Correlation Function for Sticky Price Model Economies (Technology Shock Only)

Panel C: Cross-Correlation Function for Sticky Price Model Economies (Preference Shock Only)
Panel D: Cross-Correlation Function for Sticky Price Model Economies (Money Demand Shock Only)

Panel E: Cross-Correlation Function for Sticky Price Model Economies (Investment Efficiency Shock Only)

Panel F: Cross-Correlation Function for Sticky Price Model Economies (Monetary Policy Shock Only)
Figure 2

Panel A: Cross-Correlation Function for Sticky Price Model Economies (Only Technology Shock Off)

Panel B: Cross-Correlation Function for Sticky Price Model Economies (Only Monetary Policy Shock Off)
Figure 3

Impulse Responses to a Preference Shock

Note: The responses are log deviations of a variable from its steady-state value. The percentage deviations can be approximated by multiplying the corresponding log deviation by 100. “y” denotes detrended output; “pi” denotes gross inflation rate; “r” denotes gross nominal interest rate; “c” denotes detrended consumption; “i” denotes detrended investment; “h” denotes labor; “m” denotes detrended real money balance; “mu” denotes money growth rate; and “w” denotes detrended real wage.
Figure 4
Impulse Responses to a Money Demand Shock

Note: The responses are log deviations of a variable from its steady-state value. The percentage deviations can be approximated by multiplying the corresponding log deviation by 100.
Figure 5

Impulse Responses to an Investment Efficiency Shock

Note: The responses are log deviations of a variable from its steady-state value. The percentage deviations can be approximated by multiplying the corresponding log deviation by 100.
Figure 6

Impulse Responses to a Productivity Shock

Note: The responses are log deviations of a variable from its steady-state value. The percentage deviations can be approximated by multiplying the corresponding log deviation by 100.
Figure 7
Impulse Responses to a Monetary Policy Shock

Note: The responses are log deviations of a variable from its steady-state value. The percentage deviations can be approximated by multiplying the corresponding log deviation by 100.