How Much Do We Understand About Asymmetric Effects of Monetary Policy?

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Abstract

TEERAWUT SRIPINIT: How Much Do We Understand About Asymmetric Effects of Monetary Policy?.
(Under the direction of Richard Froyen.)

Whether monetary policy has symmetric effects on economy has been discussed for decades. Particularly, the evidences of the asymmetric effects are sparse and depend on the econometric technique used. Three possible causes of asymmetry have been predominant including a convex supply curve, a credit market imperfection, and a change in economic outlook. However, the proposed theories are either analyzed in a partial equilibrium framework or a linearized general equilibrium framework making the mechanism by which the asymmetric effects are created remain unclear.

This study examines the asymmetric effects of monetary policy in a new Keynesian dynamic stochastic general equilibrium model. Among the three groups of theories, this study considers a role of a convex supply curve and a credit market imperfection. The Calvo (1983) pricing mechanism and Bernanke et al. (1998)'s financial accelerator model are devised to create a convex supply curve and financial friction, respectively. The second-order perturbation method is then employed to find the solutions and to preserve the nonlinearity of the model.

Three types of asymmetric effects of monetary policy are examined: 1) expansionary versus contractionary policies; 2) moderate versus aggressive policies; and 3) policies implemented in recessions versus ones implemented in expansions.

The simulation exercise using either the first-order perturbation method or a linearization does not exhibit any asymmetric effects. When the solutions are obtained by the second-order perturbation method with a certain range of parameter values, the model shows a potential to account for asymmetric effects of monetary policy and conveys that the major source of the

asymmetric effects comes from the convex supply curve.

However, when the model parameters are calibrated to the U.S. economy, the resultant asymmetric effects are not observed in general. The only noticeable asymmetry is the difference between the effects of the policy implemented at busts and ones at booms. In addition, the degree of the asymmetry is minimal. The model is then estimated by using indirect inference estimator. Similar to those of the model using the calibrated parameters, the results show that the asymmetric effects of monetary policy are not found in general.

To Grandpa, Dad, Mom and P'Toi

Acknowledgments

"Education is what remains after one has forgotten everything he learned in school.—Albert Einstein". Writing a dissertation is a long training process. Nevertheless, the knowledge one has acquired during this process will eventually vanish. This leads me to I ask myself "What will remain? In what way have I really been educated?"

I will never forget that I had countless seemingly insurmountable and intractable challenges, and that my advisor, Richard Froyen, patiently offered me invaluable suggestions and psychological support. He became my personal definition of a good mentor.

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Chapter 1

Introduction

Monetary policy was once believed to have symmetric effects on the economy. However, there is evidence showing that the effects of the monetary policy on the economy might be asymmetric. Friedman and Schwartz (1963) argue that the 1930 Great Depression could have been just an ordinary recession if the Fed had not severely reduced money supply. However, the stringent policies aiming at preventing the speculative attack drained out liquidity from the economy and brought the economy to a deep recession. On the other hand, the efforts of expansionary policies aiming at recovering the economy from a recession seem to be futile. Milton Friedman compares the asymmetric effects of contractionary policies and expansionary policies to a string – *"Monetary policy was a string: You could pull on it to stop inflation but you could not push on it to halt recession. You could lead a horse to water but you could not make him drink."*

The asymmetry observed at business cycle peaks motivates a scientific investigation of the effects of monetary policy in general. The work of Cover (1992) provides evidences of the asymmetry. The author studies the effects of the monetary policy using money supply as a policy instrument. The effects of contractionary policies were found to have stronger effects on output than expansionary policies. Focusing on the money supply, other researchers extend the scope of the study to other aspects of the asymmetry. Ravn and Sola (1997) find the asymmetric effects in relation to the size of monetary policy shocks. Large money supply shocks were found to have less effective on the output than small money supply shocks. Thoma (1994) studies the role of the money supply over the business cycle and finds that monetary policy has different effects on the output depending on the phases of the business cycle. The author finds that tight monetary policies have stronger effects on the output during high-growth periods, while easy policies have the same effects throughout the business cycle. Other nonlinear econometric techniques are also used to find evidence of the asymmetry. Weise (1999) applies a smooth transition vector auto regression (STVAR) to test the asymmetry and find no evidence of the asymmetry between positive and negative money supply shocks. Instead, the author finds that monetary policy has more impact on the output during recessions. Garcia and Schaller (1995) use a Markov switching model to examine the effects of the policy using the interest rate as the policy instrument. The policy was found to have stronger effects on the output during recessions.

Altogether, there are at least three aspects of asymmetric effects of the monetary policy. First, there are asymmetric effects between contractionary and expansionary policies. The monetary policy is tested to see whether it has the same absolute effects to the economy. Second, there are asymmetric effects between aggressive and moderate policies. The policy is tested to see whether it has a proportionate scale in relation to the intensity of the policy. Third, there are asymmetric effects of the policy through out the phases of business cycle. The same policy is tested to see whether it has the same effects on the economy regardless of the positions in the business cycle.

Several theoretical mechanisms have been proposed to justify the existence of asymmetric responses to monetary policy shocks. Morgan (1993) has classified the theories into three groups : a convex supply curve, a financial friction, and a change in economic outlook. A convex supply curve explains the asymmetry through a mechanism of price stickiness (e.g. Rotemberg (1982), Calvo (1983) and Ball and Mankiw (1994)). The tendency that the price is sticky downward makes the supply curve a convex function. Thus, the effects of the monetary policy depend on the portion of the supply curve in which the policy is implemented.

The financial friction creates a mechanism via asymmetric information between lenders and borrowers. The lenders charge a risk premium to compensate the information risk and the default risk (e.g. Bernanke et al. (1998)). The investment risk and borrowers' net worth position determine the risk premium. A risky project has a higher default risk. Thus, a higher risk premium is charged. A higher borrowers' net worth decreases a default risk. Therefore, a lower risk premium is required. These factors determine the degree of financial accelerator and thus determine the effects of the monetary policy.

The last group of theories deals with how people react to the phases of business cycle. During recessions, people might be insecure about the economic situations making expansionary policies ineffective. On the other end, people might be confident of the economic conditions during expansions making contractionary policies ineffective. Should people be more insecure in recessions than confident of expansions, monetary policy would be less effective on the output during recessions than expansions. However, the explicit mechanism has not been developed yet. It is more a discussion in the literatures than an established micro-founded theory.

A question that has not been answered yet is how well those theories can account for the asymmetry observed from data. Even though nonlinear econometric techniques have been used to find the evidences of the asymmetric effects, those empirical works were linked to the theoretical model via a reduced-form model. The direct application of an estimated model that is supported by a reduced-form model suffers from Lucas's critique in that the estimates would experience a structural change through time due to the rational expectation hypothesis. In addition, the contribution of a particular theoretical model in explaining the existence of the asymmetry cannot be fully investigated via the reduced-form model. On the theoretical side, an analysis in a nonlinear general equilibrium framework has not been undertaken due to analytical difficulties and a high computational cost. Thus, most proposed explanations were studied in a partial equilibrium framework (for example, Ball and Mankiw (1994)). Moreover, when a model is analyzed in a general equilibrium framework, it is usually log-linearized before further analyses are done (for example Bernanke et al. (1998)). Thus, the model lost its ability in addressing the asymmetric effects of the policy.

How well can these theories explain the observed asymmetry? Do the existing theories provide enough understanding about the mechanism by which the asymmetry is created? What aspects of the theories have to be developed? To answer these questions, the performance of a particular theoretical mechanism has to be investigated. A general equilibrium framework is required to incorporate the interaction among sectors in the economy. The nonlinearity of the model has to be preserved to establish a framework to investigate the asymmetry. Then, the nonlinear general equilibrium framework could provide a channel to evaluate the performance of the model in explaining the data.

This study investigates the ability of the existing theories to explain the observed asymmetric effects of the monetary policy. Both empirical and theoretical models will be analyzed in nonlinear systems to allow the possibility of the asymmetry. The following research methodology is proposed to evaluate a theoretical model.[1]

1. Estimate the effects of the monetary policy using a nonlinear econometrics technique and measure the degree of the asymmetry.

2. Analyze the theoretical model in a DSGE model.

3. Find the solutions of the model by using a nonlinear solution method.

4. Produce a set of artificial data from the estimated DSGE model.

5. Apply the same technique in the first step to measure the asymmetry from the artificial data.

6. Compare the degree of the asymmetry measured from the actual and the artificial data produced by the model.

Completing the whole procedure will give an access to the ability of a particular model in explaining the asymmetry. The results will provide some insights into the mechanism by which the asymmetry is produced. This knowledge will be beneficial to set the direction of

[1] I would like to thank professor Lutz Hendricks for his suggestion about this procedure.

the research about the asymmetry. This research methodology can also be applied to access the performance of other alternative models along these lines.

The above procedure is implemented to investigate the asymmetric effects of the monetary policy in the U.S. economy and accomplished in three chapters.

Chapter 2 completes the first step of the procedure. The chapter empirically investigates the effects of the monetary policy. Among the choice of econometric techniques, smooth transition vector auto regressive (STVAR) is employed. It describes the economy by a mixture of two distinct VAR regimes. Each regime is weighted by a continued weighting function, a transition function, whose value depends on the value of an observable variable, a switching variable.

Chapter 3 completes the second and the third step of the procedure. It theoretically investigates two causes of asymmetric effects of the policy: convex supply curve and financial friction. The financial friction is modeled by the Bernanke et al. (1998)'s financial accelerator model and the convex supply curve is modeled by the nonlinear Phillips curve. The conventional log-linearization or linearization cannot be used. A proper solution method will be used to preserve the nonlinearity of the theoretical model. The solution of the model is obtained by the second-order perturbation method. The model's parameters are calibrated to the U.S. economy. They are taken from Bernanke et al. (1998) and Gali and Rabanal (2004). Then the asymmetric effects of the monetary policy are analyzed by using the impulse response functions.

Chapter 4 accomplishes the procedure. This chapter estimates the model discussed in chapter 3 by using indirect inference estimator, developed by Smith Jr (1993), Gourieroux et al. (1993), Gallant and Tauchen (1996), and Keane and Smith (2003). The conventional maximum likelihood procedure with the Kalman filtering is not applicable to this study. In order to use the standard maximum likelihood procedure, the likelihood function of the model has to be specified and the model has to be written in a state-space representation. However, a state-space representation can be obtained only when the solution method is the log-linearization,

linearization, or obtained by the first order perturbation method. Once the model is estimated, it can be implemented to generate a set of artificial data, which is used calculate the implied asymmetric effects and to evaluate the ability of the model.

Chapter 2

Asymmetric Monetary Policy Responses in the U.S. Economy : Smooth Transition Vector Autoregressive

2.1 Introduction and Related Literature

Monetary authority can influence output and price level by adjusting the policy variable. Responses to a policy change could vary depending on the circumstances. For example, Weise (1999) finds that the responses of output are stronger during recessions. If monetary policy has strong asymmetric effects, a standard VAR, which is a linear model, is not applicable. This paper uses smooth transition VAR (STVAR) to study asymmetric effects of monetary policy in the U.S. economy. Two forms of transition function in STVAR are considered: the first- and the second- order logistic function. The asymmetric effects of monetary policy are studied in three aspects: the effects of the policy during low versus high growth periods, the effects of expansionary versus contractionary policies, and the effects of small versus large changes in the policy.

Economic theories suggest possible asymmetric responses to monetary policy. The asymmetry responses to the policy could arise from both the aggregate demand and the aggregate supply side (see Karras (1996a)). For example, Caballero and Engel (1992) and Ball and Mankiw (1994) develop models in a sticky price context, which leads to a convex aggregate supply curve. The convex aggregate supply curve predicts that output will be more sensitive to the policy during recessions than booms, and more sensitive to big than small changes in the policy. For aggregate demand side, Bernanke and Gertler (1989), Bernanke et al. (1998) Bernanke and Blinder (1992) develop a financial accelerator model in which the firms' balance sheet conditions can amplify the effects of the policy on output. Firms borrow funds from financial institutions with a risk premium rate, which depends on firms' balance sheet position. This so-called external risk premium is higher when firms have credit constraints, for example when contractionary policy is implemented or during recessions, or both.

Recent studies in asymmetric effects of monetary policy are sparked by Cover (1992). Using U.S. data, Cover finds that output responds differently to positive and negative supply shocks. This evidence is supported by DeLong et al. (1988), Morgan (1993), Rhee and Rich (1995), Thoma (1994), Kandil (1995) and Karras (1996a). Thoma (1994) finds that only negative money supply shocks have strong effects in recessions but not in booms, while positive shocks have no asymmetric effects. However, Ravn and Sola (1997) argue that the asymmetry found in Cover (1992) arises from changing in the policy regime. After controlling for the policy regime change, the asymmetry between positive and negative supply shocks disappears. On the other hand, Ravn and Sola (1997) find evidences supporting menu cost model where large and small shocks have different effects. The above studies test the asymmetry using a threshold VAR-type model. Weise (1999) applies a smooth transition VAR to test the asymmetric responses to monetary policy and finds no evidence of asymmetric effects of positive and negative shocks. Conversely, Weise confirms that monetary policy has greater impacts on output during recessions. Garcia and Schaller (1995) use a Markov switching model to examine the effects of the policy during expansions and a recessions and find stronger effects of the policy during recessions. In summary, there are empirical evidences supporting the asymmetric effects of monetary policy. The policy has stronger effects during recessions. However, the results are mixed for the responses to the direction and the size of the shocks.

VAR[1] assumes that the relation among the variables in the system is linear and stable over time. The above findings reject the traditional VAR in favor of a nonlinear model. Alternative methods to study a nonlinear system have been developed and can be broadly classified into three categories: Markov switching model, threshold VAR model and smooth transition VAR (STVAR) model.

Hamilton (1989) and Diebold and Rudebusch (1989) develop Markov switching model to study business cycle. The model describes the economy under two regimes: for instance, expansions and recessions. The economy is allowed to switch from one to another regime. These regimes are unobservable and migrating according to a stationary migrating probability. This model is very useful when the number of regime is as small as two, but becomes computationally complicated as the number of regime increases. However, Boldin (1996) and Potter (1995) suggest that there should be at least three regimes to describe the economy. In addition, the Markov switching model assumes that the regime switches are driven by an unobservable variable, which does not provide the intuition behind the asymmetric effects of monetary policy.

Tsay (1989) develops threshold VAR model as an alternative to Markov switching model. Similar to Markov switching model, the model describes the economy under multiple regimes. At any point of time, one regime is selected with probability one. The regime is identified by an observable variable called switching variable. When the switching variable falls into a particular range of value, a corresponding regime is selected. The threshold VAR is particularly useful when there are more than two or three regimes. In the same way as Markov switching model, threshold VAR also discretely switches from one to another regime. However, it is very unlikely that the economy will jump between the regimes.

Granger and Teräsvirta (1993), Teräsvirta (1996) and Dijk et al. (2002) develop a smooth transition VAR (STVAR) to allow the regression coefficients to change smoothly from one regime to another. In addition, the transition is endogenously determined by an observable

[1]Since the seminal work Sims (1980), structural Vector Autoregressive (VAR) has become a standard tool to study the effect of monetary policy. In a VAR system, all variables are considered endogenous variables.

switching variable which provides economic intuition for the regime changes. An attribute of STVAR is that the deviations from equilibrium creates mean reversion behavior whose character depends on the transition function. The linear logistic function implies asymmetric behavior depending on whether the switching variable is above or below the equilibrium, for example the business cycle (Weise (1999), Bec (2000), Rothman et al. (2001), Lundbergh et al. (2003), Petersen (2007)). The quadratic one indicates different pattern between medium and extreme regimes, for example an exchange rate zone and an inflation targeting where authorities response more aggressively to a larger deviation from the target (Taylor et al. (2001), Martin and Milas (2004), and Sollis (2008)).

The aim of the monetary policy is to stabilize economy, which establishes nonlinear relationships and mean revision behaviors. Therefore, this paper uses STVAR model to capture the nonlinear effects of monetary policy. The rest of this paper is organized as follows. First, the economic theory predicting asymmetric response to the policy is discussed. The procedures to test nonlinearities and to set up a STVAR model are explained in the methodology section. Finally, the empirical results for the U.S. economy are presented.

2.2 Theoretical Framework

This section lays down a simple aggregate macro-model that allows for the asymmetric effects of monetary policy. The model in this section closely follows Weise (1999) and is augmented by a financial accelerator. The model starts with a simple log-linearized macro model of aggregate demand, aggregate supply and policy rule. The sources of nonlinearity are the friction in the price level and the friction in financial markets.

The simple aggregate supply is derived from a short run production function with fixed nominal wages $Y_t^s = f(\theta_t, \overline{K}, \overline{W}/P_t)$. Because of the fixed level of capital $\bar{K}$ and nominal wages $\overline{W}$, the log-linearized aggregate supply can be expresses as a function of inflation p_t, lagged endogenous variable X_{t-1} and the supply shock θ_t,

$$y_t^s = b_0 + b_1 p_t + S(L)X_{t-1} + \theta_t, \tag{2.1}$$

where $S(L)$ is a lagged polynomial and y_t is equilibrium output growth. The endogenous variable X_t depends on the choice of the policy variable, which will be discussed shortly. The output growth y_t^s deviates from the constant level b_0 by the inflation p_t and the productivity shock θ_t.

The aggregate demand is a function of market interest rate, r_t^m, inflation rate, p_t, a lagged endogenous variable, X_{t-1}, and a demand shock, ν_t,

$$y_t^d = a_0 - a_1 r_t^m - a_2 p_t + A(L)X_{t-1} + \nu_t. \tag{2.2}$$

Monetary policy is assumed to follow Taylor's rule, given in Equation 2.3.

$$r_t = r_0 + r_1 y_t + r_2 p_t + R(L)X_{t-1} + \varepsilon_t^r. \tag{2.3}$$

However, the authority can choose money supply as the policy instrument as well. Money supply growth m_t and the nominal interest rate r_t are reciprocal in this model. Equation 2.4 describes the relationship between the money growth and the interest rate. For illustration purpose, the equilibrium condition is derived by using the growth rate of money supply as the policy variable. Thus, the endogenous variables are $X_t = [y_t, p_t, m_t]'$. The monetary policy equation is rewritten as in Equation 2.6.

$$\begin{aligned}
m_t &= M_0 - \lambda r_t. && (2.4)\\
m_t &= (M_0 - \lambda r_0) - \lambda r_1 y_t - \lambda r_2 p_t - \lambda \varepsilon_t^r. && (2.5)\\
m_t &= m_0 - m_1 y_t - m_2 p_t + M(L)X_{t-1} + \varepsilon_t^m, && (2.6)
\end{aligned}$$

where $m_0 = M_0 - \lambda r_0$, $m_1 = \lambda r_1$, $m_2 = \lambda r_2$, $M(L) = -\lambda R(L)$, and $\varepsilon_t^m = -\lambda \varepsilon_t^r$.

The equilibrium interest rate r_t^m need not equal the risk free rate r_t. This will be the case only when the financial friction is not functioning. Bernanke et al. (1998) show that the asymmetric information between the borrowers and the lenders creates an external risk premium. The premium will be increased when the borrowers have weak balance sheet positions. The premium is also higher during recessions because of a higher default risk.[2] Thus, the policy will affect the economy through both liquidity and credit channels.[3] The credit channel, however, influences the economy only in an intermediate range. Under severe economic conditions, where the credit constraint strictly binds, the lenders require a very high-risk premium. All firms will face the credit constraint. The credit channel will not function, reducing the effect of the credit channel mechanism. The relationship between the equilibrium rate and the risk free rate can be summarized as follows,

$$r_t^m = b(z_t, W_t) r_t, \tag{2.7}$$

where z_t is a variable indicating the level of information asymmetry. The risk premium equals zero when there is no asymmetric information $b(\cdot) = 1$ and is a decreasing function of net worth, $\partial b(\cdot)/\partial W_t < 0$. The aggregate demand in Equation 2.2 can be rewritten as,

$$y_t^d = a_0 - a_1'(z_t, W_t) r_t - a_2 p_t + A(L) X_{t-1} + \nu_t. \tag{2.8}$$

where $a_1'(z_t, W_t) = a_1 b(z_t, W_t)$. The degree to which the asymmetric information and the net worth affect the risk premium depends on many factors, including the phase of business cycle, the degree of credit constraint faced by the firms and the investigating cost when the loans are default.

The last key variable in this system is the inflation rate p_t. The free market equilibrium is

[2] This derivation can be found in Bernanke et al. (1998).

[3] Ramey (1993) shows that the credit channel is supplementary to the liquidity or money channel. When there is a credit constraint, the credit channel will amplify the effects of the policy

the level of p_t^0 that clears aggregate demand and aggregate supply in Equation 2.8 and Equation 2.1, respectively. The interest rate in Equation 2.8 is eliminated by using Equation 2.4. The aggregate demand can be rewritten as in Equation 2.9 and the free market equilibrium inflation rate is given in Equation 2.10,

$$
\begin{aligned}
y_t^d &= \left(a_0 - \frac{a_1'(\cdot)M_0}{\lambda}\right) + \frac{a_1'(\cdot)}{\lambda}m_t - a_2 p_t + A(L)X_{t-1} + \nu_t, && (2.9)\\
P_t^0 &= \frac{1}{b_1 + a_2}\left\{\left(a_0 - b_0 - \frac{a_1'(\cdot)M_0}{\lambda}\right) + \frac{a_1'(\cdot)}{\lambda}m_t + A(L)X_{t-1} + (\nu_t - \theta_t)\right\}. && (2.10)
\end{aligned}
$$

Another friction in the model is nominal price rigidity. The price adjustment in this model follows Calvo's price setting where only a fraction, $1 - \alpha(x_t)$, of firms can adjust the prices at each time. The firms who can change their prices set the prices at the market equilibrium price and the other hold their last period prices. Equation 2.11 represents the Calvo dynamics of price, where P_t is log of aggregate price level and P_t^* is log of optimal price.

$$P_t = \alpha(x_t)P_{t-1} + (1 - \alpha(x_t))P_t^* \tag{2.11}$$

The firm chooses P_t^* to maximize expected discounted profits subject to the discount factor β and the sticky price parameter $\alpha(x_t)$. The optimial price can be expressed as:

$$P_t^* = (1 - \beta\alpha(\cdot))\sum_{i=0}^{\infty}(\beta\alpha(\cdot))^i E_t\left[P_{t+i}^0\right]. \tag{2.12}$$

Let $p_t = P_t - P_{t-1}$ denote the inflation rate at t, use Equation 2.11 and Equation 2.12 to obtain

$$p_t = \kappa(\cdot)P_t^0 + \beta E_t p_{t+1}, \tag{2.13}$$

where $\kappa(\cdot) = \frac{(1-\alpha(\cdot))(1-\beta\alpha(\cdot))}{\alpha(\cdot)}$. Then lag Equation 2.13 one period and assume that $\beta \simeq 1$ and the expectation error $E_{t-1}[p_t] - p_t$ is a function of structural shock $g(\epsilon_t)$, where $\epsilon = [\theta_t, \nu_t, \varepsilon_t^m]'$

to obtain

$$
\begin{aligned}
p_{t-1} &= \frac{(1-\alpha(\cdot))^2}{\alpha(\cdot)} P^0_{t-1} + E_{t-1}\left[p_t\right], \\
(1-L)p_t &= \frac{(1-\alpha(\cdot))^2 L}{\alpha(\cdot)} P^0_t + g(\epsilon_t), \\
p_t &= \left(\frac{(1-\alpha(\cdot))^2}{\alpha(\cdot)} \frac{L}{(1-L)}\right) P^0_t + \frac{g(\epsilon_t)}{(1-L)}.
\end{aligned}
$$

Finally, substitute definition of P^0_t from Equation 2.10 to obtain the inflation dynamic

$$
\begin{aligned}
p_t = {} & \left(\frac{(1-\alpha(\cdot))^2}{\alpha(\cdot)} \frac{L}{(1-L)}\right) \frac{1}{b_1+a_2} \left\{\left(a_0 - b_0 - \frac{a_1'(\cdot)M_0}{\lambda}\right) + \frac{a_1'(\cdot)}{\lambda} m_t + A(L)X_{t-1} + (\nu_t - \theta_t)\right\} \\
& + \frac{g(\epsilon_t)}{(1-L)}.
\end{aligned} \tag{2.14}
$$

As in a standard Calvo price model, the equilibrium price p_t will collapse to the free market equilibrium price where all firms can adjust the prices, $\alpha_t = 0$. The extension from the standard Calvo here is that the stickiness parameter $\alpha_t(x_t)$ is allowed to change depending on a switching variable x_t. Note that the price friction might come from other sources. However, those sources of stickiness can be captured by state dependent stickiness parameter $\alpha_t(x_t)$. Thus, the candidate for the switching variable can be any key economic variables, e.g. inflation rate, output growth and money supply growth. Using a menu cost model, Ball and Mankiw (1994) predict asymmetric responses to a policy in the different economic situation. During periods of high economic volatility or inflation, firms can change their prices at a relatively low cost, resulting in a small degree of stickiness. The policy will be less effective on output. On the other hand, when the economy is stable, firms face a higher menu cost yielding a higher degree of stickiness and intensifying the effect of the policy on output.

To reduce the number of variables in the system, the variables z_t, W_t and x_t, which determine the policy effectiveness $a'(z_t, W_t)$ and price stickiness $\alpha(x_t)$, are linked to a common switching variable s_t through functions $z(s_t) : s_t \to z_t$, $W(s_t) : s_t \to W_t$ and $x(s_t) : s_t \to x_t$. The policy effectiveness coefficient and the price stickiness are refined as $\tilde{a_1}(s_t) = a'(z(s_t), W(s_t))$ and $\tilde{\alpha}(s_t) = \alpha(x(s_t))$, respectively.

To transform this structural model into an econometric model, the equilibrium equations in Equation 2.9, Equation 2.14, and Equation 3.33 are written in a matrix form:

$$X_t = X_0 + B_1 X_t + B(L) X_{t-1} + C(L)\epsilon_t, \tag{2.15}$$

where,

$$X_0 = \begin{bmatrix} b_0 \\ \left(\frac{(1-\tilde{\alpha}(s_t))^2}{\tilde{\alpha}(s_t)} \frac{L}{(1-L)}\right) \frac{1}{b_1+a_2} \left(a_0 - b_0 - \frac{\tilde{a}_1(s_t)M_0}{\lambda}\right) \\ m_0 \end{bmatrix},$$

$$B_1 = \begin{bmatrix} 0 & b_1 & 0 \\ 0 & 0 & \left(\frac{(1-\tilde{\alpha}(s_t))^2}{\tilde{\alpha}(s_t)} \frac{L}{(1-L)}\right) \frac{1}{b_1+a_2} \frac{\tilde{a}_1(s_t)}{\lambda} \\ -m_1 & -m_2 & 0 \end{bmatrix}.$$

$\epsilon_t = [\theta_t, \nu_t, \varepsilon_t^m]'$ is the vector of structural shocks and $B(L)$ and $C(L)$ are lag-polynomials of endogenous variables and structural shocks, respectively. These structural equations can be transformed to an estimable reduced form by grouping X_t, then multiplying both sides by $(I - B(L))^{-1}$, assuming that $(I - B(L))$ in invertible. The reduced-form VAR is then given by,

$$X_t = D_0 + D(L) X_{t-1} + u_t, \tag{2.16}$$

where $D_0 = (I - B_0)^{-1} X_0$, $D(L) = (I - B_0)^{-1} B(L)$, and $u_t = (I - B(L))^{-1} C(L)\epsilon_t$. If the stability condition holds, this reduced-form VAR is estimable.

The structural parameters can be recovered by putting identification restrictions. The traditional Cholesky decomposition for a short-run identification scheme is applied. The output is assumed to have no contemporaneous movement to price and monetary policy. Price level can be influenced by output, but not by the policy. Lastly, the monetary authority makes the policy after observing both output and price.

2.3 Methodology

This section covers the main tools to test the asymmetric effects of monetary policy. Since STVAR is an extension of standard VAR, the procedures start from setting a standard VAR. The degree of nonlinearity is then tested. If there is evidence of nonlinearity, a transition function for STVAR is chosen. Once the STVAR is formulated, a general impulse response function is applied to study the dynamic effect of the policy.

2.3.1 STVAR

STVAR constructs infinite VAR regimes from two distinct VAR systems. The terminology "smooth transition" emphasizes how this model changes the regimes. The two VAR systems are weighted by a smooth weighting function $f(s_t)$ whose value depends on a switching variable s_t. Though there are only two distinct regimes, the resultant regime can be infinite. This feature is different from Markov switching model, which assumes that the transition between the regimes is binary. Thus, the terminology "regime" in STVAR context is not necessarily a low and high growth regime. The structure of STVAR is described in Equation 2.17a.

$$Y_t = (1 - f(s_t))\,(A_0 + A(L)Y_{t-1}) + f(s_t)\,(C_0 + C(L)Y_{t-1}) + u_t \tag{2.17a}$$

$$Y_t = A_0 + A(L)Y_{t-1} + f(s_t)(\underbrace{C_0 - A_0}_{B_0} + \underbrace{(C(L) - A(L))}_{B(L)} Y_{t-1}) + u_t \tag{2.17b}$$

$$Y_t = A_0 + A(L)Y_{t-1} + f(s_t)(B_0 + B(L)Y_{t-1}) + u_t \tag{2.17c}$$

When function $f(s_t)$ equals zero, the system follows the regime $A, Y_t = (A_0 + A(L)Y_{t-1})$ and follows the regime $B, Y_t = (B_0 + B(L)Y_{t-1})$ if $f(s_t)$ equals one. Equation 2.17a and Equation 2.17c are equivalent. However, Equation 2.17c is more convenient for estimation purposes. Equation 2.17c takes regime A as an anchor regime and takes regime B as an increment to the anchor regime.

The transition function $f(s_t)$, in theory, can be any smooth and 0-1 bounded function of

$s(t)$. However, the logistic and exponential functions are particularly useful in the business cycle context because of their simplicity and parsimony.[4] The first-order and second-order logistic transition and exponential transition functions are represented by Equation 4.2, Equation 4.3 and Equation 2.20, respectively.

$$f(s_t) = \left(1 + exp\left\{\frac{-\gamma(s_t - c)}{\sigma_{s_t}}\right\}\right)^{-1} ; \gamma > 0 \tag{2.18}$$

$$f(s_t) = \left(1 + exp\left\{\frac{-\gamma(z_t - c_1)(s_t - c_2)}{\sigma_{s_t}}\right\}\right)^{-1} ; \gamma > 0, c_1 \leq c_2 \tag{2.19}$$

$$f(s_t) = \left(1 - exp\left\{\frac{-\gamma(s_t - c)^2}{\sigma_{s_t}}\right\}\right) ; \gamma > 0 \tag{2.20}$$

In each function, the shape of the function is governed by slope γ and location c. The locater of the second-order logistic function is $\{c1, c2\}$. The transition function is scaled by the sample standard deviation of the switching variable, σ_{s_t}.

Figure 2.1 and Figure 2.2 compare logistic and exponential transition functions. Each function is evaluated at c=0 and $\gamma = 1$, 2.5 and 25. When the slope converges to zero, the function becomes linear. On the other hand, the function converges to a step function and the system becomes a threshold VAR when the slope approaches infinity. The logistic function approaches one when the value of the switching variable is greater than c and conversely approaches zero. The exponential function equals one when the switching variable deviates from the center. The second-order logistic and exponential functions have a similar form except that the logistic function has a minimum weight at 0.5. This difference will result in a different scale of the estimates in Equation 2.17c but the resultant impulse response functions are the same. The second-order logistic function has another interesting feature when c is split into $c1$ and $c2$ and when the value of the slope is high. The resultant transition function allows the zero weight area to be in a range $[c1, c2]$, instead of a single value c. In addition to the first-order logistic function, this paper applies the second-order logistic function to allow a possible intermediate range.

[4]The development of STVAR and its application in business cycle can be found in Dijk et al. (2002)

The first-order and the second-order logistic functions are useful in different circumstances. The first-order logistic function is more appropriate if the regime changes monotonically to the level of the switching variable. For example, modeling expansion and recession regimes can be done by using the output growth as a switching variable with the first-order logistic function. With a zero location parameter, the logistic function places a weight of one when the output growth is greater than zero, and a weight of zero when output growth is negative. Referring to Equation 2.17a, the recessions are described by regime A and expansions are described by regime C. Alternatively, the second-order logistic function is suitable for modeling intermediate and extreme regimes: for example, the credit constraint model. In the normal economic condition, the credit channel amplifies the monetary policy making the policy more effective. When the credit constraint binds excessively, the role of the financial accelerator is mitigated, resulting in less policy effectiveness. In this situation, the regime of STVAR is not a high and low growth regime but an intermediate-extreme regime. In addition, the policy variable itself can be a switching variable. Following Taylor's rule, a larger change in policy is expected when the output and inflation deviate too much from the target values.

2.3.2 Nonlinearity Test

A nonlinearity model would be redundant and less efficient if the true model is in fact a linear model. This section discusses how to test nonlinearity in a VAR system. If the nonlinearity is detected, the model is further investigated to choose a transition function.

Testing linearity in STVAR is equivalent to testing that parameters in two regimes are identical, assuming that the true switching variable is known. Under this null hypothesis, the standard Wald test for nonlinearity is not applicable. The linearity assumption implies that B_0 and $B(L)$ in Equation 2.17c equal to zero. In this situation, the changes in slope and location parameters do not affect the likelihood value. Teräsvirta and Anderson (1992) suggest the linearity hypothesis is also equivalent to the hypothesis that $\gamma = 0$. Thus, the system can be approximated by the first-order Taylor's expansion around the neighborhood of $\gamma = 0$, and the standard tests can be applied. Teräsvirta and Anderson (1992) then propose a three-step procedure test for nonlinearity. This procedure is also applied in Weise (1999) to test the nonlinearity in a VAR system for studying the asymmetric effects of monetary policy. The three steps are:

1. Run the standard regression to get the residual $\hat{\mathbf{u}}_t$

$$X_t = D_0 + \sum_{i=1}^{p} D_{1i} X_{t-i} + \mathbf{u_t}$$

2. Run the auxiliary regression to get the residual $\hat{\mathbf{v}}_t$

$$\hat{\mathbf{u}}_\mathbf{t} = \Gamma_0 + \sum_{i=1}^{p} \Gamma_{1i} X_{t-i} + \sum_{i=1}^{p} \Gamma_{2i} s_t \iota'(n) X_{t-1} + \mathbf{v}_t \tag{2.21}$$

3. Compute the likelihood ratio test $LR = T(log|\Omega_0| - log|\Omega_1|)$

The unit vector ι in the second step is introduced to allow the column-wise multiplication between the endogenous variable X_{t-1} and the switching variable s_t. T is the number observations and p is the number of VAR lag. $\Omega_0 = \hat{\mathbf{u}}'\hat{\mathbf{u}}/T$ and $\Omega_1 = \hat{\mathbf{v}}'\hat{\mathbf{v}}/T$ are the estimated variance-covariance of the restricted and the unrestricted model, respectively. The statistic is the nonlinearity test for the whole system. The asymptotic distribution of the test is $\chi^2(pk^2)$. The j^{th}individual equation can be tested by replacing the variance covariance by the jth diagonal element of the variance-covariance matrix. The degree of freedom is now reduced to pk. Teräsvirta and Anderson (1992) also suggest using the F version of the LM test for a small sample to correct for the small sample bias. The F statistic is computed by $[(\hat{\mathbf{u}}_i'\hat{\mathbf{u}}_i - \hat{\mathbf{v}}_i'\hat{\mathbf{v}}_i)/pk]/[\hat{\mathbf{u}}_i'\hat{\mathbf{u}}_i/(T - 2pk - 1)]$.

Luukkonen et al. (1988) argue that this procedure has a low power test when the switching variable is one of the endogenous variables or the transition function is one of the endogenous variables. The authors derive the third-order Taylor approximation around $\gamma = 0$, resulting in an augmented version of Equation 2.21:

$$\begin{aligned}\hat{\mathbf{u}}_{\mathbf{t}} &= \Gamma_0 + \sum_{i=1}^{p} \Gamma_{1i} X_{t-i} + \sum_{i=1}^{p} \Gamma_{2i} s_t \iota'(n) X_{t-1} + \mathbf{v}_t \\ &\quad + \sum_{i=1}^{p} \Gamma_{3i} s_t^2 \iota'(n) X_{t-1} + \sum_{i=1}^{p} \Gamma_{4i} s_t^3 \iota'(n) X_{t-1}\end{aligned} \tag{2.22}$$

The linearity hypothesis is $\Gamma_2 = \Gamma_3 = \Gamma_4 = 0$. This paper finds that the Luukkonen et al. (1988) adjustment obtains too strong power of the test so that the null hypothesis is always rejected at any level of significance. Due to its strength, the test is uninformative for the choice of an appropriate switching variable. Tsay (1989) and Teräsvirta (1994), on the other hand, suggest choosing the variable that gives the lowest p-value of the test. Using a wrong switching variable, the p-value of the test will increase due to the misspecification error. Moreover, the rank of the variable by p-value from these tests is very similar. Hence, this paper applies the test proposed by Teräsvirta and Anderson (1992).

2.3.3 Choosing the Transition Function

Luukkonen et al. (1988) and Teräsvirta and Anderson (1992) suggest further that the auxiliary regression in Equation 2.22 can also be used to choose between the first-order and the second-order logistic function (or exponential function). The method is based on a sequence of nested hypotheses.

1. $H_{01} : \Gamma_2 = 0 | \Gamma_3 = \Gamma_4 = 0$,
2. $H_{02} : \Gamma_3 = 0 | \Gamma_4 = 0$,
3. $H_{03} : \Gamma_4 = 0$,

The first hypothesis is essentially the linearity test. The test statistic is a traditional LR statistic, which has the asymptotic $\chi^2(pk^2)$ distribution. Conditional on rejecting the linearity hypothesis, the logistic function should be chosen if H_{03} is rejected. If H_{03} is not rejected but H_{02} is rejected, the exponential function should be chosen. If only the linearity hypothesis is rejected, the function with the lowest p-value should be chosen. This nested test is based on the misspecification error test discussed above. In addition, an exponential or a second-order logistic function has a quadratic form, while the first-order logistic function has a linear or cube function. The H_{02} hypothesis tests the significance of the squared term of the switching variable. Therefore, it validates a second-order logistic function.

Recall that all the tests above assume that the switching variable s_t is known. The switching variable can be any variable and the switching function can take any functional form. This study focuses only on variables suggested by the theory, (i.e. output growth, price level, and monetary policy). In addition, the first difference of these variables is included in the possible set of switching variables. These variables are the endogenous variables in the system. The delay of each variable is also included to allow for possible lag responses.

2.3.4 Generalized Impulse Response Function

The impulse response function represents the response of the system to shocks over time. In a linear system, the impulse response is invariant to characteristics and history of shocks. In a nonlinear system, the system responds not only to the shocks, but also to the propagation of the shocks. The impulse responses in a nonlinear system cannot be obtained analytically but only by simulation. Koop et al. (1996) develop a "generalized impulse response function" to study the responses in a nonlinear system. Their procedure is summarized as follows:

1. Set the initial state by picking a part of actual data denoted as Ω^k_{t-1}.
2. Design a hypothesized shock, e.g. the policy shock, denoted as ϵ^*_0.
3. Randomly draw a q-period shock with replacement from the estimated residual, denoted by ϵ^j_t, which have qk[5] dimension, where q is the time horizon of the impulse response function and k is the number of endogenous variables. To allow the correlation among the shocks, all k-shocks in the same period are picked.

[5] The procedure to pick up shocks is flexible. The one used in this study is similar to the procedure suggested by Koop et al. (1996).

4. Construct a benchmark path by feeding the model with a zero shock at period $t = 0$ and ϵ_t^q later on, denoted by $GI_0^{ki}(\Omega_{t-1}^k, 0, \epsilon_t^j)$.

5. Construct a hypothesized path by feeding the model with a hypothesized shock, ϵ_0^j, at period $t = 0$ and ϵ_t^q later on, denoted by $GI_1^k(\Omega_{t-1}^{ki}, \epsilon_0^*, \epsilon_t^j)$.

6. Repeat steps 2-4 B times.

7. Repeat steps 1-5 R times.

8. Compute an average impulse response function GI by $\sum_k^R \sum_j^B (GI_1^k((\Omega_{t-1}^{ki}, \epsilon_0^*, \epsilon_t^j) - GI_0^{ki}(\Omega_{t-1}^k, 0, \epsilon_t^j))/BR$, or a median impulse response function by median $((\Omega_{t-1}^{ki}, \epsilon_0^*, \epsilon_t^j) - GI_0^{ki}(\Omega_{t-1}^k, 0, \epsilon_t^j))$

The initial states in the first step are classified into two sets: low growth and high growth, distinguished by standard deviation of output growth. High growth period is defined by that the output grows at a faster rate than one standard deviation. What is left is classified as the low growth period. Alternatively, the medium growth period can be introduced by using the value of growth between the zero and the one positive standard deviation. However, the results in this period are very similar to the low growth period as a whole. Thus, the medium growth period is combined to the ones in the low growth period in the first definition.

The random draw in the third step and the repetition in the seventh step are done in the period classification. For example, when considering a high growth period, all shocks are drawn from the period where output growth is greater than one positive standard deviation. Similarly, all initial states are in the high growth period. All possible initial periods are used in repetition in the seventh step. The number of bootstrap repetitions in the sixth step is set at 100.

2.3.5 Estimation

In principle, a STVAR structure in Equation 2.17c can be estimated by maximum likelihood estimation. However, the system is very sensitive to both scale and location parameter(s), the estimation will take a long time to obtain the global maximum value. On the contrary, given particular values of the slope and location parameter(s), the system is reduced to a simple linear VAR system. Assuming that there is no serial correlation in the residual matrix, the OLS method yields the same estimates as a maximum likelihood estimator.

This paper adopts a grid search method to obtain the estimates. The procedure is:

1. Given a switching variable s_t, pick a value of slope and locators, denoted as, γ^0 and c^0.

2. Construct a weighting series $f(s(t), \gamma^0, c^0)$ and generate a column wise multiplication of endogenous variables and $f(s(t), \gamma^0, c^0)$, as in the second part of Equation 2.17c.

3. Estimate Equation 2.17c using OLS, collect the residual $\hat{u}$ and calculate $\Omega = \hat{u}'\hat{u}'/T$.

4. Use an optimization technique to minimize $log|\Omega|$.

This paper uses a grid search to find the optimal value of γ and c. The value of γ ranges from 0 to 100 with the step size equals to 0.1. The location parameter is searched over the actual value of the variable using as a switching variable. Weise (1999) also applies a similar procedure except that he fixes the location parameter to zero for output growth and inflation rate and at the mean for other variables. This assumption for both output growth and inflation rate is valid but too restrictive. It is possible that the regimes could be separated somewhere above or below zero. This paper allows the location parameter to change in a certain range. To obtain a good scale parameter, there must be enough observations in the tail area of the weighting function. For this purpose, the set of possible values is between at 20 and 80 percentile.

2.4 Empirical Results

Following Bernanke and Blinder (1992), this paper takes the federal funds rate as a policy variable. The study period covers 1960Q2 to 2007Q4. The data from 2008Q1 to 2011Q1 are used for out-of-sample predictability test. The study also examines the implications of the different policy choices in the subsample covering 1960Q2 to 1996Q4. Weise (1999) uses money supply as the money policy instrument to study the asymmetric effects of the policy covering this subsample. Thus, Weise (1999)'s results are reproduced to compare with ones of the interest rate model. Hereafter, the model using the federal funds rate and the money supply as a policy variable will be referred to as $ModelA$ and $ModelB$, respectively.

The data in this study are quarterly data of the U.S. economy. The set of endogenous variables in each model are different. $ModelA$ uses real GDP for output, GDP deflation for price and the federal funds rate for the policy variable. The commodity price is also added to the model to solve the price puzzle. $ModelB$ uses the industrial production (IP) index for output, the CPI for price level, and M1 as the policy variable.[6] All the data in this paper are obtained from the International Financial Statistic (IFS), except commodity price, which is obtained from the Global Financial Data (GFD).

All data, except IP and M1 in the subsample, exhibit a unit root and need to be adjusted. To obtain stationary series, all data are transformed by log differencing, except the federal funds rate that needs only the first difference transformation. The inflation rate is multiplied by four to get an annualized rate. Moreover, the data are filtered to remove seasonal movement and possible structural breaks. Ravn and Sola (1997) show that the asymmetric effects found in Cover (1992) disappear when the structural breaks are removed. The same filtering technique is also applied in Weise (1999). Three possible structural break points are considered. The first break is the oil shock of October 1973. The second break is the shifting in policy regime of the Volcker period when the Fed abandoned the interest rate targeting and adopted a money supply targeting. The third break is the evidence of the sharp decline in output volatility in 1985.[7] The timing of the third break is about the same as of the starting period of Greenspan. To avoid too much filtering, only 1985 is selected. The data are regressed on constant, seasonal dummies, dummies for post- 72, post- 79 and post- 84 periods, a time trend and the time trend

[6] Generally, real GDP is applied to proxy output level in quarterly data. Industrial production index is used in this case to obtain a result comparable to Weise (1999).

[7] See more detail in Kahn et al. (2002), Blanchard and Simon (2001), and Stock and Watson (2002).

interacted with structure break dummies. In his study, Weise (1999) does not use the post 84 periods dummy to filter the data. Thus, to obtain a comparable result, filtering process in the first subsample omits the post 84 periods dummy.

In both sample periods, the number of lags in the VAR is set to four. Setting the maximum lag at eight, three statistical criteria suggest the optimal lag at two or three. Those tests are the lag exclusion test, Akaike's information criterion (AIC) and Schwarz Information Criterion (SIC). Increasing the number of lags in the VAR reduces the degrees of freedom but increases the explanatory power of the data. Since the data are quarterly, a four-lag VAR can better capture the cyclical movement during the year. Using the four-lag structure also avoids unnecessary nonlinearity.

2.4.1 1960Q2 to 1995:Q2

Comparing Between the First- and the Second-Order Logistic STVAR

Table 2.1 reports a linearity test of $ModelB$. The linearity test for individual equations is reported in column 2 to 4 and the whole system test is reported in column 5. The next two columns report the hypothesis test of H_{02} and H_{03}, respectively. The last column indicates a preferred transition function. The letter "L1" denotes the first-order logistic function and the letter "L2" refers to the second-order logistic function.

The first four possible candidates for a switching variable are the first lag of change in inflation rate, $ddp(-1)$, the second and the third lag of inflation, $dp(-2)$ and $dp(-3)$, and the first lag of output growth, $dy(-1)$. The linearity assumption is rejected in all four cases. As noted in Weise (1999), there is no evidence suggesting that money supply growth is a possible switching variable. However, this does not necessarily mean that there is no asymmetric effects of monetary policy. It only implies that money supply growth cannot indicate the transition between the regimes. A striking result is that the second-order logistic function is a preferred transition function in 12 out of 16 cases. This suggests that assuming only first-order logistic function, as in Weise (1999) and other authors, might be too restrictive.

The different implications of the first- and the second-order logistic are investigated in Figure 2.3. The first lag of the output growth is selected to be a case study since it is the only one case reported in Weise (1999). The slope in the first-order logistic STVAR is 67.75 and the locater is restricted to 0. While these parameters are 14.15 and (-0.97,0.47) in the second-order logistic STVAR. The top panel is a time series plot of the first lag of output growth. The parallel dash lines are the second-order logistic locator. The time series of the logistic function is plotted in the second panel. When the value of the lag output growth is greater than zero, the transition function is one, and moves to zero when the lag output growth is lower than zero. The third panel displays the time series of the second-order logistic transition function. The function gives the value one when the lag output growth deviates from zero too much on either side. When the deviation is small, however, the function gives a weight of zero. The criterion for big and small is justified by two locater variables. The last panel plots the shape of both functions for comparison. Both functions have high slope values so they migrate from one to another regime quite rapidly around the locater variables. The two functions are similar when the lag output growth is greater than zero. However, while the second-order logistic function returns to one when the lag output growth is negative, the first-order logistic function moves to another regime. The simulated impulse responses are called for examining the different results.

Figure 2.4 and Figure 2.5 are cumulative generalized impulse responses of output and price to money supply shocks, respectively. These are the impulse response functions of $ModelB$ associated with the first-order logistic STVAR. Figure 2.6 and Figure 2.7 serve the same purpose of the study for the second-order logistic STVAR.

To compare the results with Weise (1999)'s, cumulative responses are used to examine the net effects of the policy on the variables. The responses can be interpreted as total responses to a permanent change in money supply. The responses in low and high growth periods are displayed in the left and right panel, respectively. On the right panel, the initial periods are high growth. The size of the shocks is one and two standard deviation. The top panel compares the responses to positive and negative shocks. The responses to negative shocks are flipped down to be compared to responses to positive shocks. The second panel compares responses to positive shocks of size 1- and 2- standard deviation in a similar way as those of negative shocks are flipped up or down. The last panel compares responses to negative shocks of size 1- and 2- standard deviation. In every case, the impulse responses from the baseline VAR are plotted to be benchmark functions. The comparison between the responses to small and large shocks needs more clarification. The different size of the shocks definitely affects the economy in the different scales. Whether the effects are proportionate to the size of the shocks is the central question. The responses to 2-standard deviation shocks are scaled down by the factor of two. If the policy does not have asymmetric effects between the different size of the shocks, the impulse responses should lie on top of each other.

The impulse responses of the output to the policy shocks have the traditional hump-shaped curves. The output increases in the first two quarters and starts to decrease. The output level is still positive until the fourth quarter. The size of the shocks is one standard deviation, 1.56 percent. A one positive standard deviation shock results in a 0.5 percent decreases in output at 3 years later. The policy shock increases the price level throughout the horizon. The price level increases about 1.2 percent and stays at that level after 3 years elapsed.

For the first-order STVAR, hereafter L1-STVAR, there is the evidence supporting asymmetric responses of output to the policy in low growth period. The output increases for two quarters and decreases until the sixth quarter. The effect reverses for a short time at the seventh quarter and then continues decreasing again at the eight quarter. Conversely, the output responses are less sensitive when the policy shocks occur in a high growth period. The total effect on the output is about 0.2 percent after 12 quarters. The output responds symmetrically to small and large shocks. The responses to a one and two standard deviation shocks virtually lie on top of each other regardless of the shocks. The only asymmetric effect of the policy is the responses to the different direction shocks in the low growth period. The conclusion for the asymmetric responses of the price level is similar to that of the output. The only possible asymmetry is the responses to shocks during low and high growth period. The asymmetric responses to different direction of the shocks are more prominent than ones of the output responses. Comparing to the baseline VAR, all price responses in STVAR model are less sensitive.

The second-order logistic STVAR, hereafter L2-STVAR, gives the same conclusion about asymmetric responses but it produces meaningful impulse responses for output. First, the output is also more sensitive to shocks during low growth period. However, in this case, the standard VAR model is roughly an average of both periods. L2-STVAR also predicts no asymmetric responses to the different size of the shocks. Asymmetric responses to positive and negative shocks become more obvious in this case. The two different responses have an average around the baseline VAR. The responses of the price level are also similar but become more sensitive. Quantitatively, the total effects of the shocks are about a half of the baseline. Price level is less sensitive to shocks during high growth period. In addition, the asymmetric effects between difference size of the policy shocks on output are not found. Similarly, the asymmetric responses to positive and negative shocks are clearer than those of L1-STVAR.

The asymmetric responses of price level and of output are related to each other. Monetary policy has no effect on output if price is perfectly flexible. The policy will affect the output only if there is price friction. The less sensitive the price response, the more effective the policy is. Thus, if there is no asymmetric of the price responses, the output is expected to have no asymmetry as well.

In summary, both L1- and L2- STVAR show asymmetric effects of monetary policy in low versus high growth periods. The output is more sensitive to the policy when the economy is in low growth period. The price is less sensitive to the shock in high growth period. Asymmetric effects of the size of shocks are not found. There are some evidences for asymmetric responses to positive and negative shocks. However, L2-STVAR produces results that are more prominent.

STVAR: $ModelA$

This section discusses the results obtained from $ModelA$, which uses the federal funds rate as a policy variable. Table 2.2 reports the linearity tests for this model.

The first four possible candidates for a switching variable are the forth and the first lag the federal funds rate, $ff(-4)$, and $ff(-1)$, the second and the third lag of output growth, $dy(-2)$ and $dy(-3)$. Similar to the previous section, the linearity assumption is rejected in all four cases. The second-order logistic function is preferred to be a transition function in 10 out of 16 cases. There are two interesting points between these two models. First, when the federal funds rate is used, the policy variable turns to be an important switching variable. Second, the L2-STVAR is prominent if the switching variable is the federal funds rate. This suggests that STVAR regime is not a low-high growth regime, but it is an intermediate-extreme regime. However, the L1-STVAR dominates when output growth is the switching variable.

Figure 2.8 and Figure 2.9 present the impulse responses of the output and the price level from the L2-STVAR using the fourth lag of the federal funds rate as the switching variable. The estimated slope of transition function is 100, and the locater is (-0.7458,-0.7412).

The baseline responses of the output and the price level are slightly different from the ones of $ModelB$. An increase in the federal funds rate decreases output immediately. Then the effect dies down quickly up to the sixth quarter. The output is stable at about 0.7 percent lower than the initial level. The size of shocks is 0.97 percent. So the policy targeting at the interest rate policy is more effective than the one targeting at money supply. The responses of price to policy shocks have similar pattern to the one of $ModelB$ but it is less sensitive to the shocks. It increases by 1.15 percent in 3 years. The fact that the price response is less sensitive partially explains how output is more sensitive.

The same conclusions for the asymmetric effects can be drawn in this section. For the output, the only apparent asymmetry is the responses to the shocks in the low and the high growth periods. Again, the baseline VAR seems to be an average of the responses between the two periods. Asymmetric responses to the different size of shocks are not found. However, there are some evidences that the direction of the shocks has different effects. The output is less sensitive to expansionary policies than contractionary policies in both low and high growth periods. The response of the price level exhibits a price puzzle. The price level increases after an increase in the federal funds rate. The data filtering procedure might account for this observation. The seasonal variation and trends have been removed. Some important co-movements among the variables might also be removed resulting in a misleading relationship among the variables. Another difference is that the policy seems to have no effect on the price in a longer run for this case. Moreover, the responses of the price to the policy are different from the those of $ModelB$. The sensitivity of the price is in the same direction of the output. This pattern is observed in different initial growth rates and the direction of the policy shocks.

Although the linearity assumption is not rejected in the output and the price equation, the model with the first lag of the federal funds rate as a switching variable produces a similar conclusion. The same conclusions about asymmetry of the policy can also be drawn from the model with the second and third lag of the output growth. Thus, their impulse response functions are omitted.

2.4.2 1960Q2 to 2007:Q4 $ModelA$

Table 2.3 summarizes the linearity test for $ModelA$ in the full sample. The usefulness of L2-STVAR is robust in this sample. L2-STVAR is suggested in 12 out of 16 cases. Moreover, among the first five possible variables, there is only one L1-STVAR case. The federal funds rate is highly suggested to be the switching variable. Among the first five possible switching variables, four of them are lags of the federal funds rate. For the fourth lag of the federal funds rate, $ff(-4)$, the slope and locater associated with the logistic function are 100 and 7.99, respectively. The slope and locater in L2-STVAR of the first lag of the federal funds rate, $ff(-1)$, are 1 and (5.941, 8.0512), respectively. The differences of the impulse response functions from L1-STVAR with $ff(-4)$ and L2-STVAR with $ff(-1)$ are similar to ones discussed in $ModelB$. Thus, the impulse response functions of the first lag of the federal funds rate with L2-STVAR are presented in this section.

Figure 2.10 and Figure 2.11 demonstrate the resultant impulse responses from $ModelA$. The baseline impulse responses of output are very similar to ones of $ModelB$ in the subsample. However, output is less sensitive to the policy shocks in this sample set. The standard deviation of the policy shocks is 0.88 percent. The output responds to one standard deviation of shock by 0.48 percent in the twelvth quarter. The response of price level is even less sensitive to policy shocks in this sample period. The total effect on the price level is only 0.27 percent in this case. The price puzzle also appears in this sample set.

The output responds to negative shocks symmetrically during both low and high growth periods, but less sensitive to positive shocks only during low growth periods. Similarly, there is no evidence of asymmetric responses to the size of the shocks. Apparent asymmetric responses in this model are the responses to the direction of the shocks. The output is more sensitive to positive policy shocks than negative ones. The response to the positive shock is less sensitive than the baseline case up to the fifth quarter. Then the response in baseline is more sensitive up until the eleventh quarter. The response to expansionary policy is always less sensitive than the baseline. The asymmetric responses to the direction of shocks disappear in high growth periods.

The responses of price level are similar to ones of the output. The policy shocks have asymmetric effect on the price level during low and high growth periods. However, the asymmetry is not uniform. The response of the price to a positive shock is more sensitive in low growth period but the response to a negative shock is less sensitive. The responses to the different size of the shocks are proportionate scaled. The price level has asymmetric responses to positive and negative shocks and symmetric to the size of the shocks. The asymmetric responses to the direction of the shocks is very clear during the low growth period but less obvious in the high growth period. In the low growth period, the impact of positive shocks to price is stronger than one of the negative shocks and the baseline case. However, the impact on the price level of negative shocks is much stronger than in the high growth period.

Predictability Test

This section examines both in-sample and out-of-sample predictability tests of both VAR and STVAR model. The out-of-sample period covers 2008Q1 to 2011Q1. The predicting horizons are one to four quarters ahead. Mean square prediction errors (MSPEs) are employed to quantify the predictability. The extended data used for the out-of-sample test are log-differenced and annualized in the same way as the in-sample data are treated. However, the further structural break filtering is not applied.

Table 2.4 reports the MSPEs. The top and middle panels report the MPSE of VAR and of STVAR, respectively. The last panel shows the error reduction by using STVAR over VAR. For the in-sample test, STVAR improves the predictability in almost every case. The improvement ranges from 0.34 to 9.83 percent. For the out-of-sample test, STVAR greater improves the predictability on the output, the investment for three and four quarters ahead, and one quarter ahead of inflation and interest rate. However, it greatly deteriorates the predictability on inflation and interest rate beyond one quarter ahead.

2.5 Conclusion

This paper studies the responses of output and price level to the monetary policy shocks using STVAR. The study is similar to Weise (1999), and extends Weise (1999) in two directions. First, this study allows the second-order logistic function to be a transition function, known as L2-STVAR. The location parameter is allowed to change, instead of being fixed at zero for output growth and inflation. The evidence supporting L2-STVAR is very apparent. In every case, most of the possible switching variables suggest to use L2-STVAR, which implies that limiting only to L1-STVAR is too restrictive. This finding suggests that the economy behaves differently during a stable and high volatility period. This finding also supports the credit channel model. The model suggests that the financial accelerator works well during a normal to intermediate conditions and becomes less effective during excessively severe economic conditions. The impulse response functions of L1- and L2- STVAR are similar. The asymmetric responses of the output and the price level in L2-STVAR are more noticeable in L2-STVAR.

Second, the federal funds rate is used as the policy variable. The policy variable becomes a significant switching variable in STVAR. This corresponds to Bernanke and Blinder (1992) who suggest that the federal funds rate is more informative about economic conditions than the money supply. In most cases, the federal funds rate takes L2-STVAR. The economy evolves in one regime when the policy changes in a certain range. Then, the economy migrates to another regime when the policy deviates from that range. When the federal funds rate are used, the sensitivity of the output and the price to the policy move in the same way across the economic conditions. This relationship is different from the model using money supply as the policy instrument. One possible explanation to this evidence is the choice of the policy variable itself. Money supply has a direct effect on the price level. Monetary policy will not have a real effect if the price can fully respond to changes in money supply. This mechanism predicts the reverse sensitivity of the output and the price level. Conversely, the interest rate affects the output directly through the cost of capital. The change in the price level is a result of changes in both the output and the interest rate. In this way, the sensitivity of the output and of the price are not necessarily in the same direction.

The asymmetric effects of monetary policy are found in this paper. First, the output is more sensitive to policy shocks during the low growth periods. This finding is along the same line with Garcia and Schaller (1995), Ravn and Sola (1997) and Weise (1999). Second, there is some evidence supporting asymmetric responses to positive and negative shocks. This finding contradicts to Ravn and Sola (1997) and Weise (1999) and agrees with Cover (1992) and Thoma (1994). The small difference in response of output in Weise (1999) becomes clearer when L2-STVAR is used. Ravn and Sola (1997) use a Threshold VAR type of the model and Weise (1999) use L1-STVAR model. Both models explain the economy by a low-high regime, while L2-STVAR describes the economy by a stable-volatile regime. Lastly, there is no evidence for the asymmetric responses to the size of the policy shocks. This finding is consistent with both Ravn and Sola (1997) and Weise (1999).

To conclude, this study finds evidence of asymmetric effects of the monetary policy on output and price level. This finding rejects the traditional VAR in favor of STVAR. The evidence supporting L2-STVAR is very apparent suggesting that considering only L1-STVAR is too restrictive.

There are three interesting issues to be investigated further. First, the data filtering helps removing unnecessary nonlinearity but it might remove too much variation of the data, resulting in the symmetric responses to the size of the shocks. One way to handle this issue is to use a vector error correction model. The co-movement of variables can be captured by the cointegration vector in the model. Then the model has to be equipped with a smooth transition feature. This type of model is called smooth transition VECM. Second, a half standard deviation size of shocks should be studied as well. The evidence that L2-STVAR is a good model supports the financial accelerator model. This model predicts asymmetric responses to the size of shocks. A one-standard deviation shock is considered as a large shock in the model. As a result, there is no difference in the responses to one- and two- standard deviation shock. Third, similar to literatures on asymmetric effect of monetary policy, the theoretical part of this paper is abstracted from a micro-founded theory. Thus, the mechanism by which the observed asymmetry is produced is still left as a black box. Further instigation using a micro-founded theory can improve the understanding of this mechanism.

Figure 2.1: Transition Functions

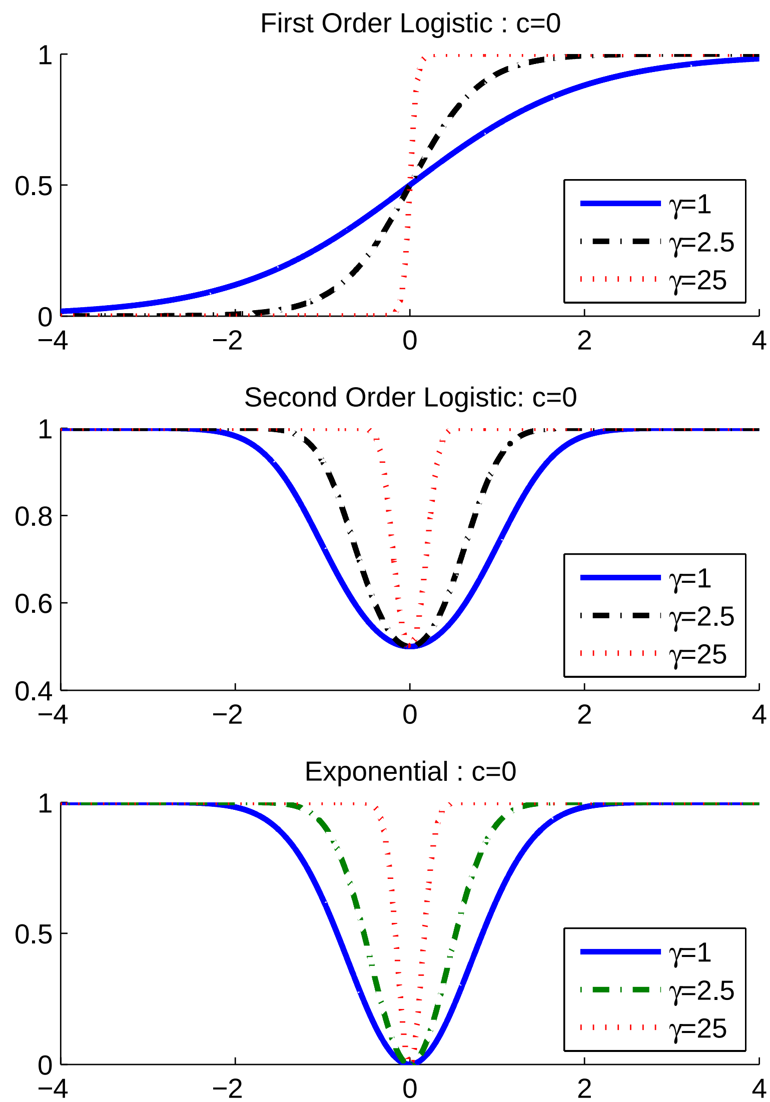

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Table 2.1: Lagrange Multiplier Tests for Linearity: Money Supply Model 1960Q2 to 1995:Q2

Switching Variable	F Statistic : Dependent Variable is dy	dp	dm	LR	H_{02}	H_{03}	Transition Function
dy(-1)	1.980	1.456	0.827	56.460	55.927	25.206	L2
	(0.032)	(0.152)	(0.623)	(0.016)	(0.018)	(0.911)	
dy(-2)	1.916	0.407	0.669	39.113	39.771	36.397	L2
	(0.039)	(0.958)	(0.778)	(0.332)	(0.306)	(0.450)	
dy(-3)	1.349	0.645	0.584	32.773	36.602	50.380	L1
	(0.201)	(0.799)	(0.851)	(0.623)	(0.441)	(0.056)	
dy(-4)	1.382	1.852	0.565	51.878	43.374	34.174	L2
	(0.185)	(0.048)	(0.866)	(0.042)	(0.186)	(0.556)	
dp(-1)	1.348	1.318	1.023	46.162	73.845	42.444	L2
	(0.202)	(0.218)	(0.433)	(0.120)	(0.000)	(0.213)	
dp(-2)	2.074	1.958	0.819	63.947	44.840	56.638	L1
	(0.024)	(0.035)	(0.631)	(0.003)	(0.148)	(0.016)	
dp(-3)	2.502	1.276	1.072	64.023	66.303	27.598	L2
	(0.006)	(0.242)	(0.390)	(0.003)	(0.002)	(0.841)	
dp(-4)	2.449	0.974	0.599	53.170	61.796	44.596	L2
	(0.007)	(0.478)	(0.839)	(0.032)	(0.005)	(0.154)	
dm(-1)	0.964	1.098	0.544	32.291	46.323	45.723	L2
	(0.487)	(0.369)	(0.882)	(0.646)	(0.116)	(0.129)	
dm(-2)	1.367	0.869	1.380	46.614	37.168	32.960	L2
	(0.192)	(0.580)	(0.186)	(0.111)	(0.415)	(0.614)	
dm(-3)	1.289	0.747	1.180	41.121	48.674	33.440	L2
	(0.235)	(0.702)	(0.306)	(0.256)	(0.077)	(0.591)	
dm(-4)	1.135	0.791	1.599	45.217	45.413	49.606	L1
	(0.339)	(0.659)	(0.102)	(0.140)	(0.135)	(0.065)	
ddp(-1)	2.436	1.335	1.218	65.997	33.978	34.247	L1
	(0.007)	(0.209)	(0.280)	(0.002)	(0.565)	(0.552)	
ddp(-2)	1.232	1.185	1.233	47.702	51.894	36.681	L2
	(0.270)	(0.302)	(0.269)	(0.092)	(0.042)	(0.437)	
ddp(-3)	1.346	0.997	0.618	36.821	51.269	42.831	L2
	(0.203)	(0.457)	(0.823)	(0.431)	(0.047)	(0.201)	
ddp(-4)	1.523	1.254	0.785	43.864	61.933	31.110	L2
	(0.126)	(0.256)	(0.664)	(0.173)	(0.005)	(0.700)	

p-value is in the parenthesis. Column 5 (LR) reports linearity test for the whole system. $H_{02} : \Gamma_3 = 0|\Gamma_4 = 0$, $H_{03} : \Gamma_4 = 0$. If the p-value of H_{02} is less than one of H_{03}, the second order logistic function is chosen, represented by "L2". Otherwise, the first order logistic is chosen, represented by "L1".

Table 2.2: Lagrange Multiplier Tests for Linearity: Interest Rate Model 1960Q2 to 1995:Q2

Switching	F Statistic : Dependent Variable is							Transition
Variable	dy	dp	dpc	ff	LR	H_{03}	H_{04}	Function
dy(-1)	0.776	0.906	0.967	1.526	78.298	89.321	104.756	L1
	(0.709)	(0.564)	(0.497)	(0.104)	(0.108)	(0.020)	(0.001)	
dy(-2)	1.228	0.917	0.902	2.769	104.930	75.403	90.363	L1
	(0.259)	(0.552)	(0.569)	(0.001)	(0.001)	(0.156)	(0.017)	
dy(-3)	1.773	0.536	0.942	1.570	100.912	86.117	107.906	L1
	(0.045)	(0.922)	(0.525)	(0.090)	(0.002)	(0.034)	(0.000)	
dy(-4)	0.660	1.385	1.031	1.348	71.595	70.499	87.441	L1
	(0.827)	(0.164)	(0.431)	(0.183)	(0.240)	(0.269)	(0.027)	
dp(-1)	0.490	1.845	1.195	1.821	95.641	112.981	104.602	L2
	(0.947)	(0.035)	(0.285)	(0.038)	(0.006)	(0.000)	(0.001)	
dp(-2)	1.615	1.234	1.202	1.634	98.522	104.006	107.750	L1
	(0.077)	(0.255)	(0.279)	(0.073)	(0.004)	(0.001)	(0.001)	
dp(-3)	1.354	1.302	1.725	1.334	100.264	94.672	85.214	L2
	(0.180)	(0.210)	(0.053)	(0.191)	(0.003)	(0.008)	(0.039)	
dp(-4)	0.799	1.034	1.121	1.033	77.589	80.417	61.725	L2
	(0.683)	(0.428)	(0.346)	(0.430)	(0.118)	(0.081)	(0.557)	
ff(-1)	1.306	0.925	1.128	2.829	116.000	98.637	86.650	L2
	(0.207)	(0.544)	(0.340)	(0.001)	(0.000)	(0.004)	(0.031)	
ff(-2)	1.543	0.916	0.961	1.664	87.401	89.188	83.588	L2
	(0.099)	(0.553)	(0.504)	(0.066)	(0.028)	(0.020)	(0.051)	
ff(-3)	1.531	1.560	0.758	1.224	97.003	114.586	94.498	L2
	(0.103)	(0.093)	(0.728)	(0.262)	(0.005)	(0.000)	(0.008)	
ff(-4)	1.900	1.839	1.291	2.421	142.776	99.005	65.751	L2
	(0.028)	(0.035)	(0.217)	(0.004)	(0.000)	(0.003)	(0.416)	
ddp(-1)	1.011	1.789	0.622	1.167	88.860	109.038	73.322	L2
	(0.451)	(0.042)	(0.860)	(0.307)	(0.022)	(0.000)	(0.199)	
ddp(-2)	1.245	0.717	0.980	1.726	91.585	92.720	85.223	L2
	(0.248)	(0.772)	(0.484)	(0.053)	(0.013)	(0.011)	(0.039)	
ddp(-3)	0.861	1.009	0.788	1.181	73.179	78.496	113.185	L1
	(0.614)	(0.454)	(0.696)	(0.295)	(0.202)	(0.105)	(0.000)	
ddp(-4)	0.575	1.150	1.314	1.330	65.868	111.534	69.905	L2
	(0.896)	(0.321)	(0.203)	(0.193)	(0.412)	(0.000)	(0.286)	

p-value is in the parenthesis. Column 5 (LR) reports linearity test for the whole system. $H_{02} : \Gamma_3 = 0|\Gamma_4 = 0$, $H_{03} : \Gamma_4 = 0$. If the p-value of H_{02} is less than one of H_{03}, the second order logistic function is chosen, represented by "L2". Otherwise, the first order logistic is chosen, represented by "L1".

Table 2.3: Lagrange Multiplier Tests for Linearity: Interest Rate Model 1960Q2 to 2007:Q4

Switching Variable	F Statistic : Dependent Variable is dy	dp	dpc	ff	LR	H_{03}	H_{04}	Transition Function
dy(-1)	0.679	0.861	1.454	2.104	85.750	92.446	100.506	L1
	(0.811)	(0.615)	(0.124)	(0.011)	(0.036)	(0.012)	(0.002)	
dy(-2)	1.672	0.526	0.524	3.142	105.194	105.700	76.245	L2
	(0.058)	(0.930)	(0.931)	(0.000)	(0.001)	(0.001)	(0.140)	
dy(-3)	1.682	0.459	1.273	2.340	117.766	130.456	90.766	L2
	(0.055)	(0.963)	(0.221)	(0.004)	(0.000)	(0.000)	(0.016)	
dy(-4)	1.096	1.219	1.155	2.846	109.746	83.636	108.935	L1
	(0.363)	(0.259)	(0.310)	(0.000)	(0.000)	(0.050)	(0.000)	
dp(-1)	0.964	1.191	1.018	1.143	78.625	109.440	53.748	L2
	(0.499)	(0.281)	(0.441)	(0.321)	(0.103)	(0.000)	(0.816)	
dp(-2)	1.609	0.870	1.028	1.833	89.735	131.789	89.986	L2
	(0.072)	(0.604)	(0.431)	(0.031)	(0.019)	(0.000)	(0.018)	
dp(-3)	1.959	1.095	0.859	1.824	102.917	108.542	107.485	L2
	(0.019)	(0.364)	(0.617)	(0.032)	(0.001)	(0.000)	(0.001)	
dp(-4)	0.795	0.849	1.497	1.517	94.172	68.848	72.545	L1
	(0.690)	(0.628)	(0.107)	(0.100)	(0.008)	(0.317)	(0.217)	
ff(-1)	1.600	0.881	0.600	4.212	141.411	147.594	81.040	L2
	(0.075)	(0.592)	(0.881)	(0.000)	(0.000)	(0.000)	(0.074)	
ff(-2)	1.821	0.727	0.804	3.334	125.271	112.227	95.786	L2
	(0.033)	(0.764)	(0.679)	(0.000)	(0.000)	(0.000)	(0.006)	
ff(-3)	2.039	1.037	0.595	1.979	114.466	97.574	83.867	L2
	(0.014)	(0.422)	(0.884)	(0.018)	(0.000)	(0.004)	(0.049)	
ff(-4)	2.381	1.695	1.103	3.685	169.001	87.356	100.324	L1
	(0.003)	(0.053)	(0.357)	(0.000)	(0.000)	(0.028)	(0.003)	
ddp(-1)	1.001	2.126	0.742	1.829	102.902	122.855	63.225	L2
	(0.459)	(0.010)	(0.748)	(0.032)	(0.001)	(0.000)	(0.504)	
ddp(-2)	1.430	0.609	0.936	1.727	87.990	129.333	101.617	L2
	(0.134)	(0.873)	(0.530)	(0.047)	(0.025)	(0.000)	(0.002)	
ddp(-3)	1.310	1.516	1.168	2.365	111.887	129.499	100.658	L2
	(0.197)	(0.100)	(0.300)	(0.004)	(0.000)	(0.000)	(0.002)	
ddp(-4)	0.870	1.400	1.348	2.044	89.728	128.790	87.650	L2
	(0.605)	(0.148)	(0.175)	(0.014)	(0.019)	(0.000)	(0.027)	

p-value is in the parenthesis. Column 5 (LR) reports linearity test for the whole system. $H_{02} : \Gamma_3 = 0|\Gamma_4 = 0$, $H_{03} : \Gamma_4 = 0$. If the p-value of H_{02} is less than one of H_{03}, the second order logistic function is chosen, represented by "L2". Otherwise, the first order logistic is chosen, represented by "L1".

Table 2.4: Mean Squared Prediction Errors

VAR

	In-Sample Test				Out-of-Sample Test			
Horizon(Q)	Y	Inv	π	rn	Y	Inv	π	rn
1	8.130	47.188	1.201	1.081	13.702	155.066	3.601	2.238
2	8.479	53.893	1.622	2.274	9.901	222.072	3.872	3.355
3	9.436	59.529	1.818	3.122	10.440	251.897	4.400	3.646
4	9.800	61.808	1.987	3.779	11.342	269.139	3.705	3.073

STVAR

	In-Sample Test				Out-of-Sample Test			
Horizon(Q)	Y	Inv	π	rn	Y	Inv	π	rn
1	7.504	42.551	1.129	1.056	15.233	173.490	2.802	0.853
2	7.913	52.042	1.545	2.228	8.794	222.049	3.912	3.747
3	9.477	60.467	1.808	3.156	8.183	236.315	4.956	4.052
4	9.717	63.494	1.949	3.766	10.040	249.557	3.825	3.441

Error Reduction (%)

	In-Sample Test				Out-of-Sample Test			
Horizon(Q)	Y	Inv	π	rn	Y	Inv	π	rn
1	-7.698	-9.827	-6.018	-2.338	11.170	11.882	-22.190	-61.882
2	-6.674	-3.434	-4.755	-2.007	-11.175	-0.010	1.035	11.662
3	0.432	1.575	-0.517	1.086	-21.616	-6.186	12.630	11.158
4	-0.851	2.728	-1.924	-0.349	-11.477	-7.276	3.238	11.968

The full sample period is quarterly data covering 1965Q2 to 2011Q1. The out-of-sample test begins in 2008Q1. The predicting horizons are ranging from one to 4 quarters ahead. The Last panel computes the error reduction in percentage number. The negative numbers indicates the improvement in predictability.

Figure 2.2: Comparison of the Second Order Logistic and Exponential Function

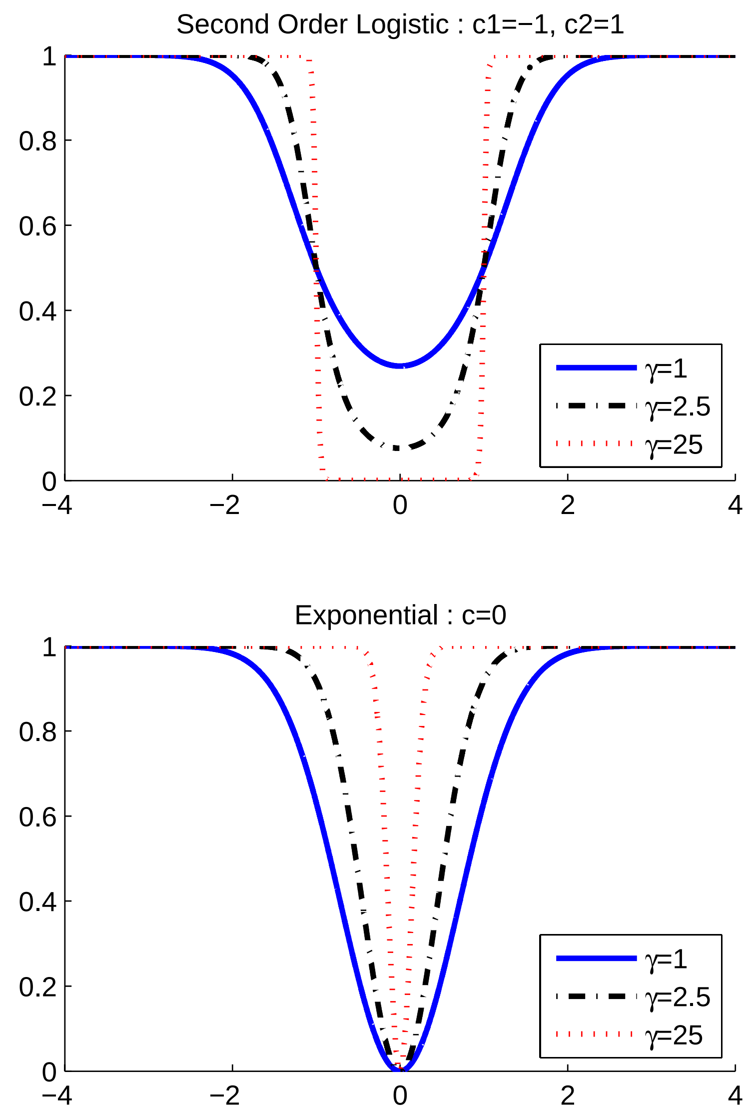

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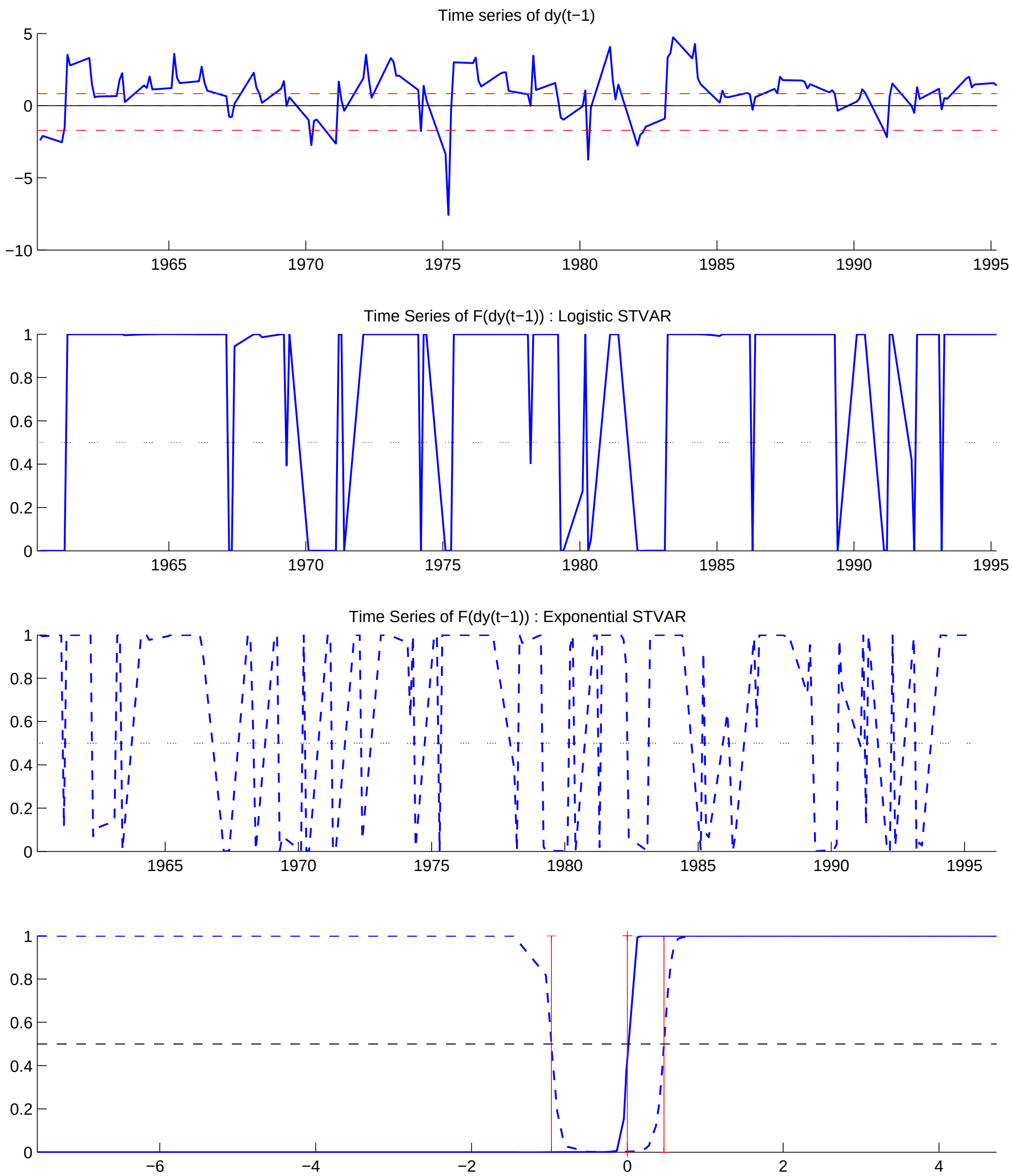
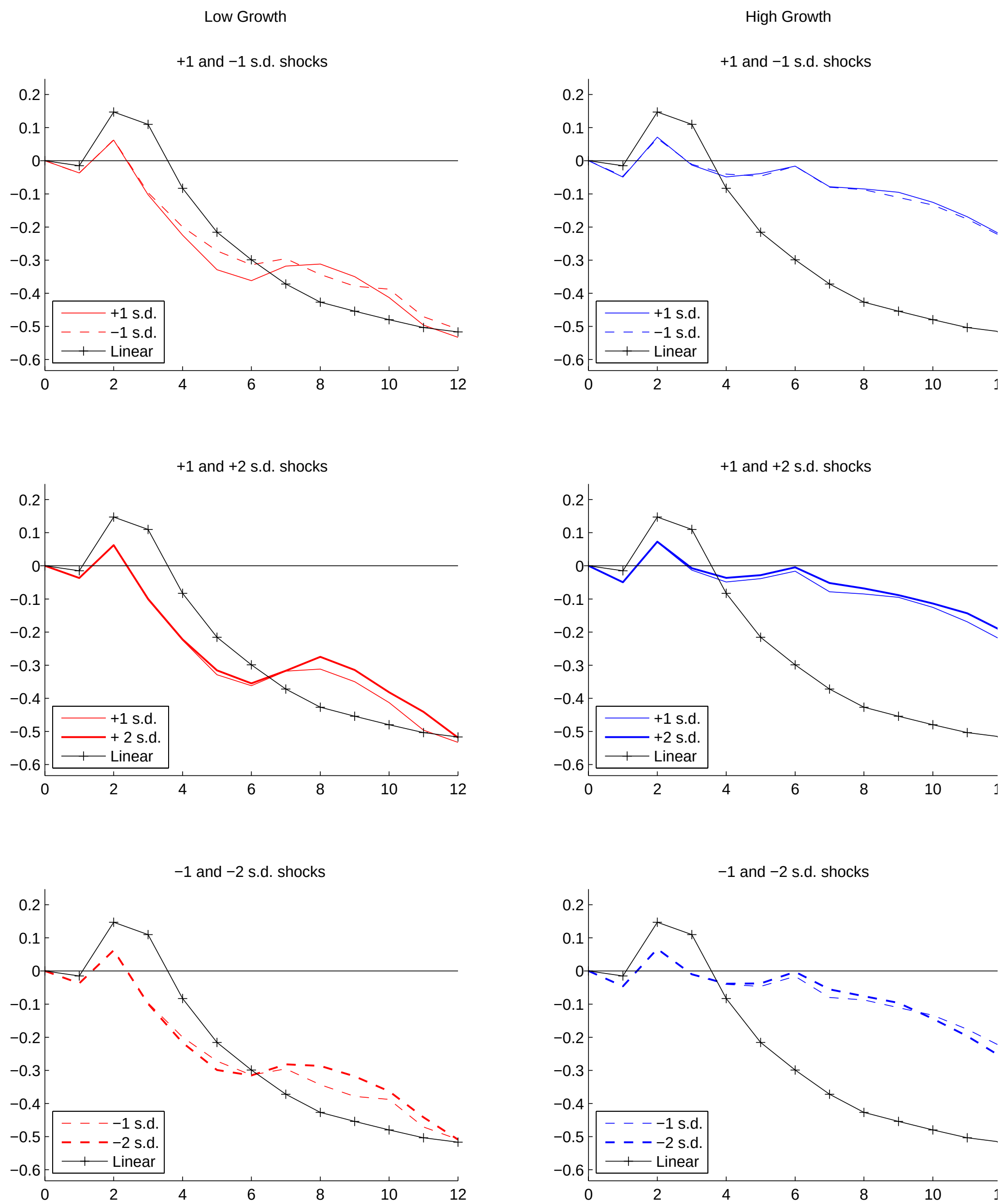
Figure 2.3: Transition functions of STVAR : $ModelB$ 1960Q2 to 1995Q2



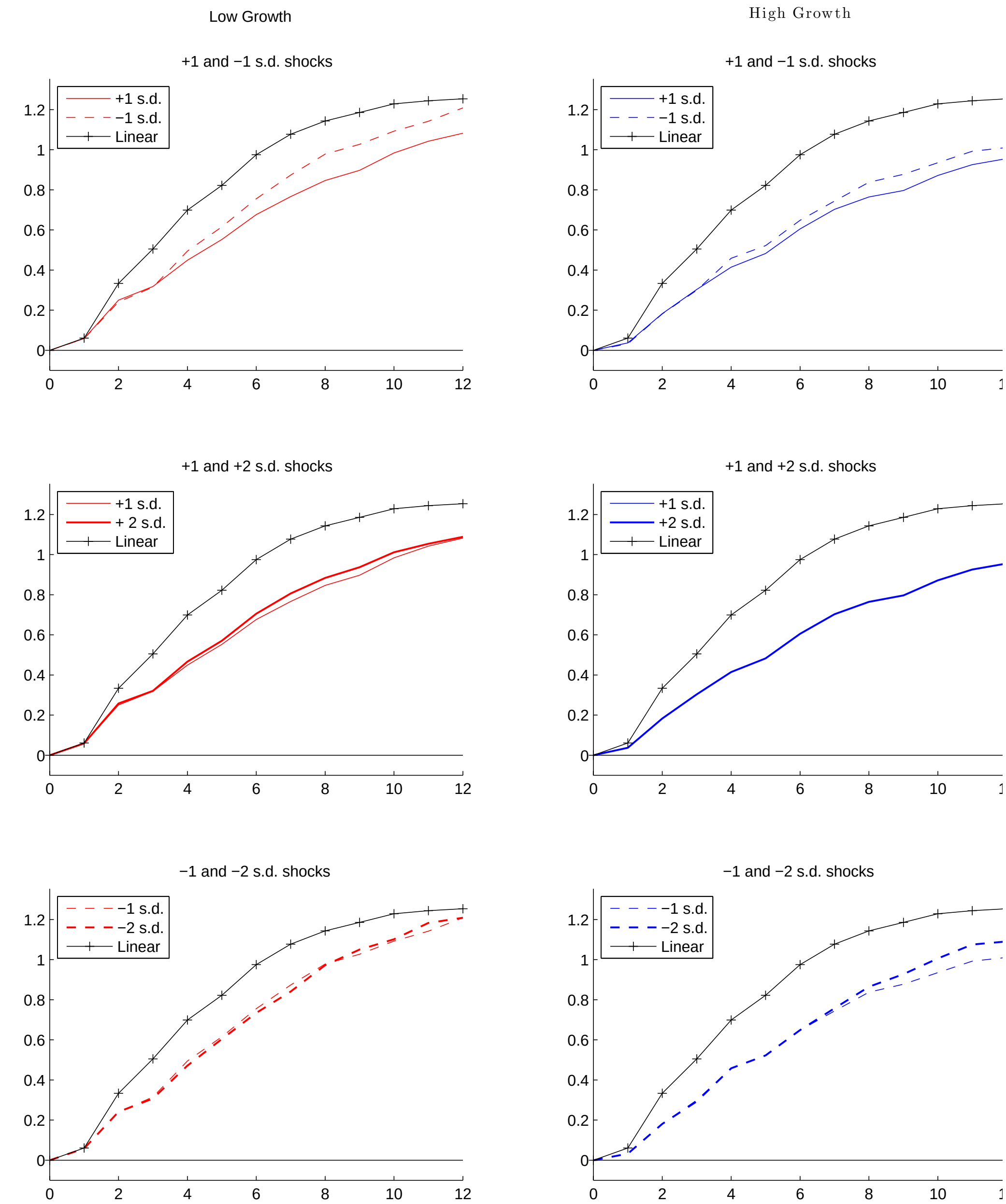
The VAR system is $[dy, dp, dm]'$. The first order logistic function has slope=67.75, locater = 0. The second order logistic or exponential function has slope = 14.15, locaters = -0.97 and 0.47.

Figure 2.4: Cumulative Responses of dy to dm : First Order Logistic STVAR



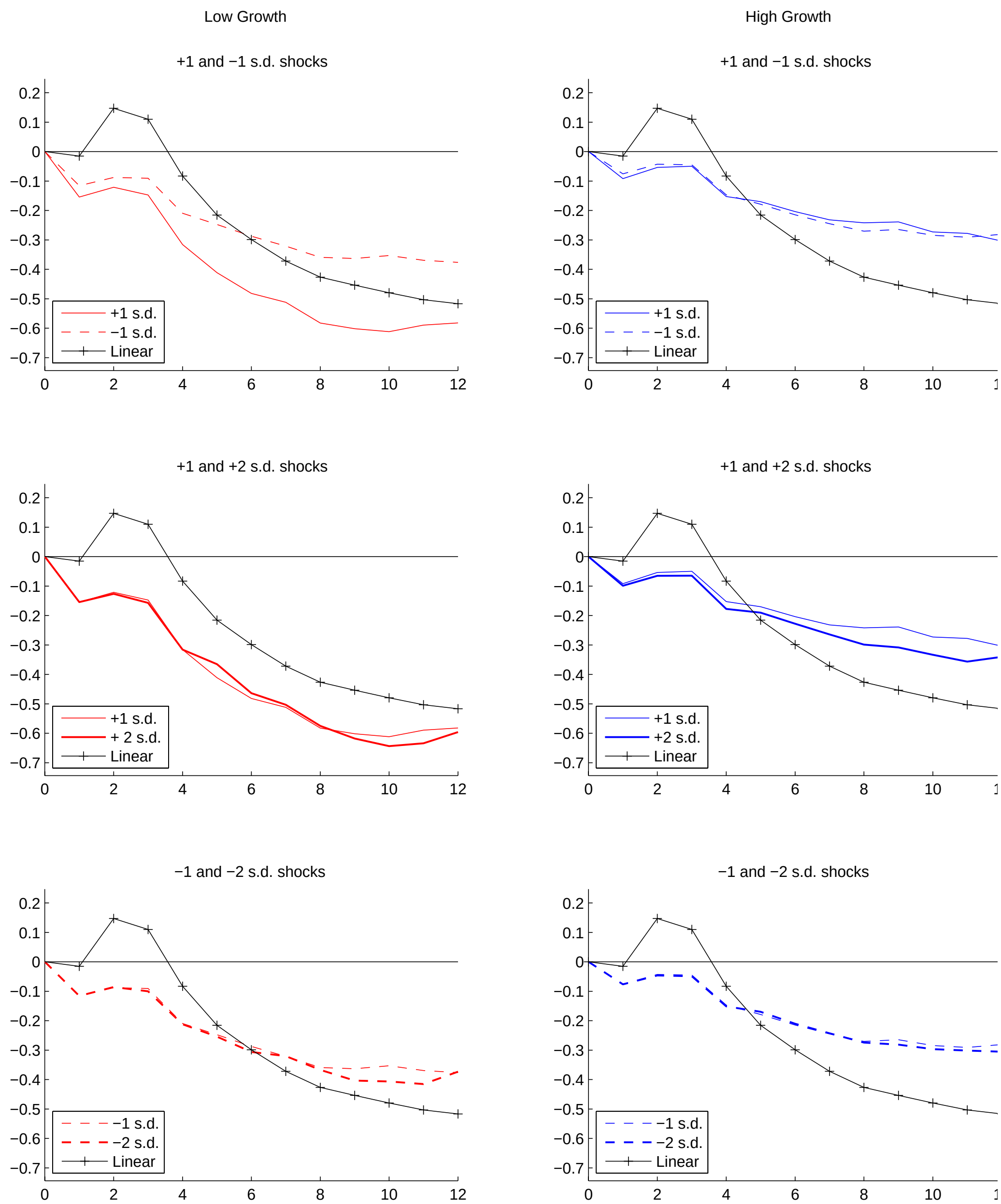
The VAR system is $[dy, dp, dm]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972 and 1979, time trend and the interaction between time trend and structural break dummies. dy output growth from industrial production index, dp CPI inflation rate, and dm M1 Money supply growth. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 1.75 which is one standard deviation of output growth.

Figure 2.5: Cumulative Responses of dp to dm : First Order Logistic STVAR



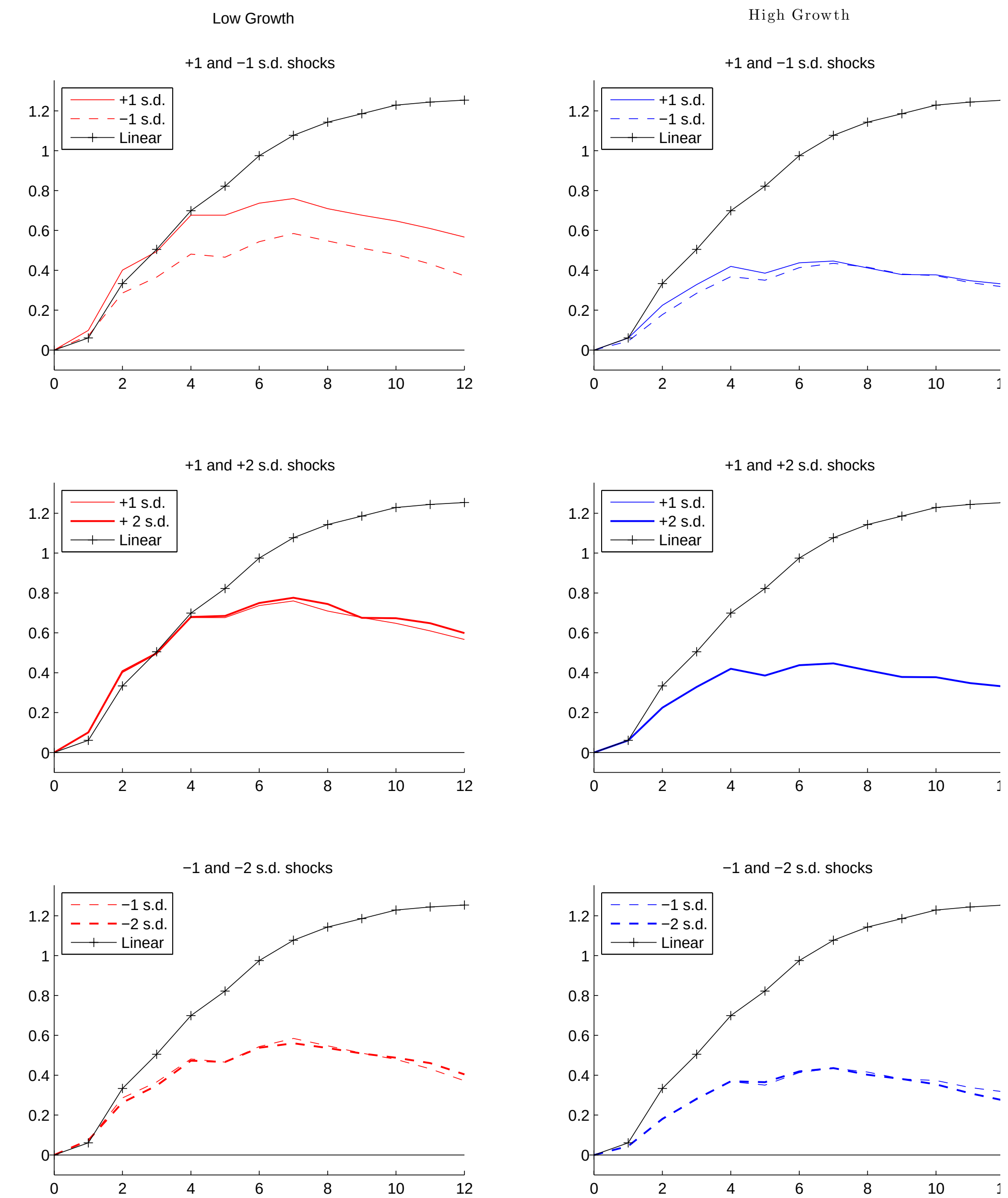
The VAR system is $[dy, dp, dm]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972 and 1979, time trend and the interaction between time trend and structural break dummies. dy output growth from industrial production index, dp CPI inflation rate, and dm M1 Money supply growth. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 1.75 which is one standard deviation of output growth.

Figure 2.6: Cumulative Responses of dy to dm : Second Order Logistic STVAR



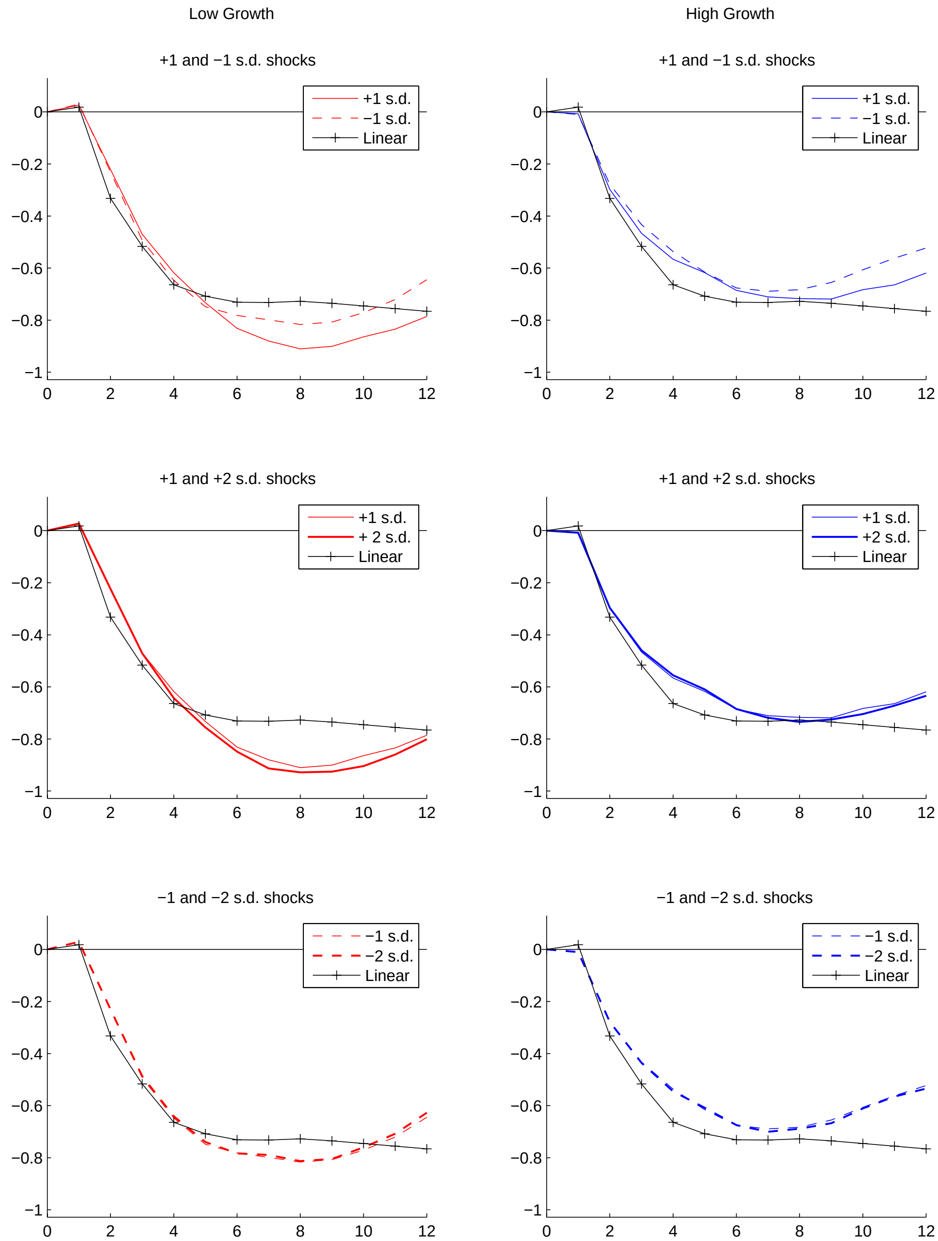
The VAR system is $[dy, dp, dm]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972 and 1979, time trend and the interaction between time trend and structural break dummies. dy output growth from industrial production index, dp CPI inflation rate, and dm M1 Money supply growth. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 1.75 which is one standard deviation of output growth.

Figure 2.7: Cumulative Responses of dp to dm : First Order Logistic STVAR



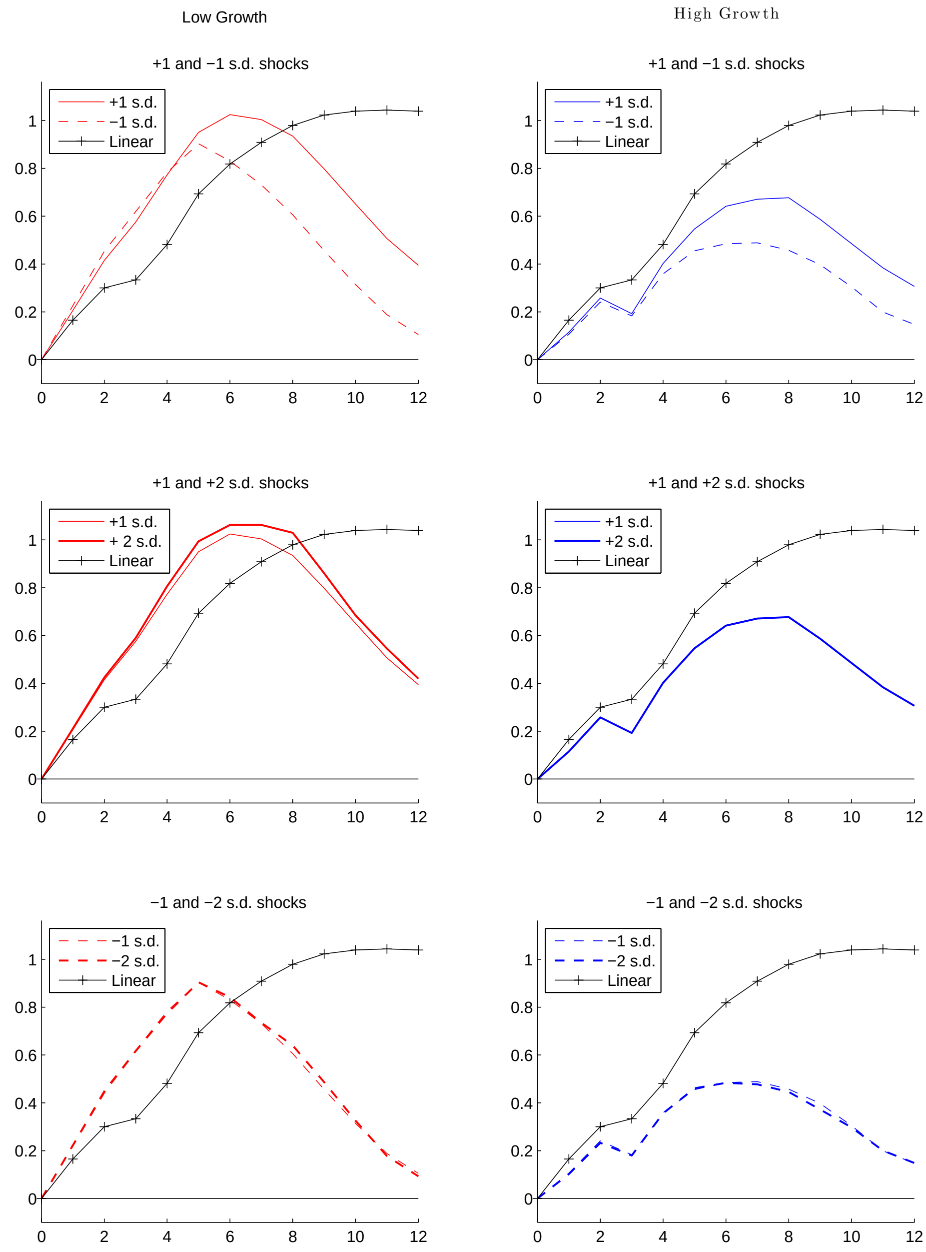
The VAR system is $[dy, dp, dm]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972 and 1979, time trend and the interaction between time trend and structural break dummies. dy output growth from industrial production index, dp CPI inflation rate, and dm M1 Money supply growth. Inflation is annualized rate of one quarter difference of log. Low or high growth refer to the level of output growth when a shock is feed. The cutting point is 1.75 which is one standard deviation of output growth.

Figure 2.8: Cumulative Responses of dy to ff : Second Order Logistic STVAR



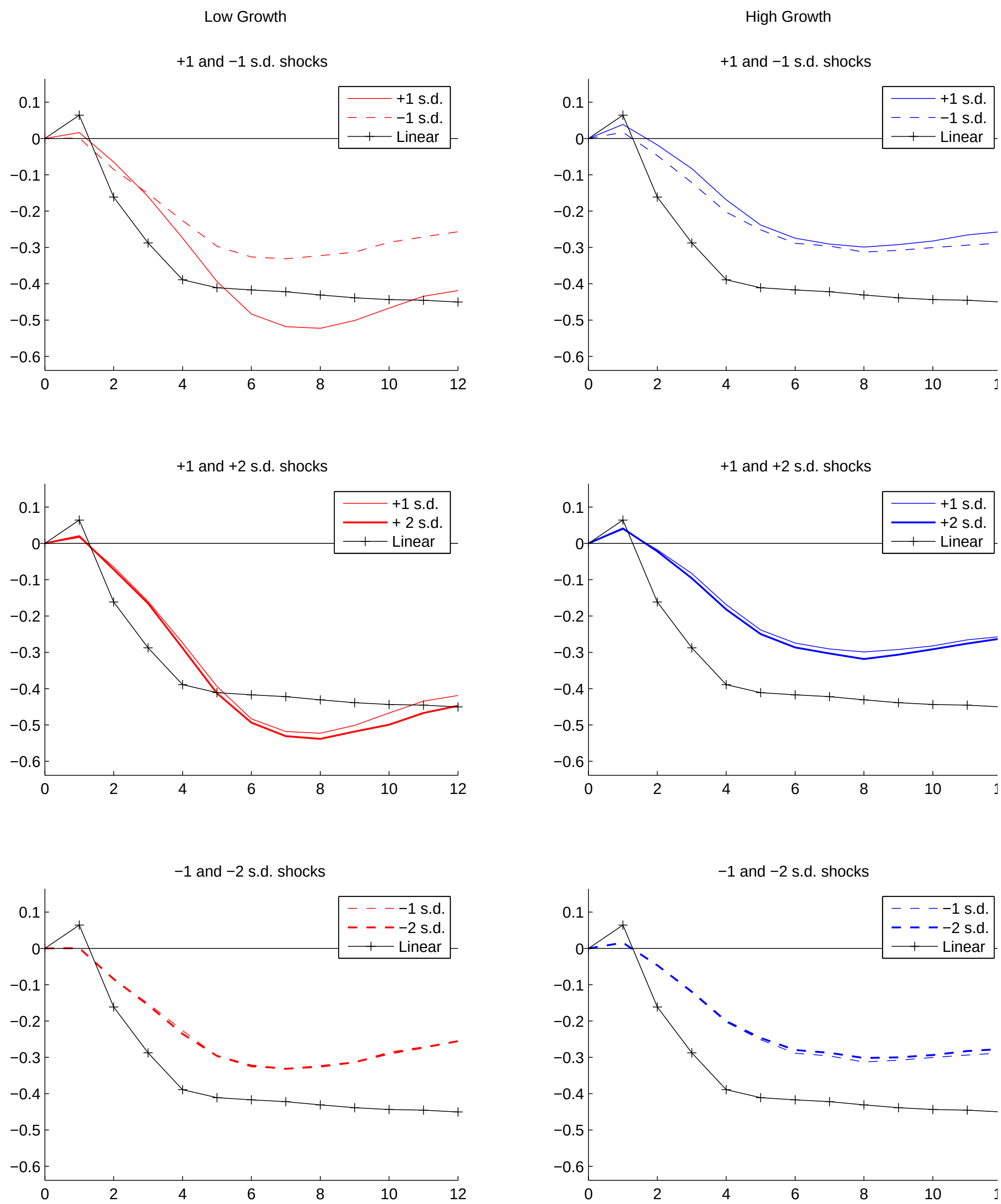
The VAR system is $[dy, dp, dpc, ff]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972,1979 and 1984, time trend and the interaction between time trend and structural break dummies. dy is output growth from real GDP, dp is GDP deflater based inflation rate, dpc is first difference of commodity price, and dff fed funds rate. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 0.91 which is one standard deviation of output growth.

Figure 2.9: Cumulative Responses of dp to ff : Second Order Logistic STVAR



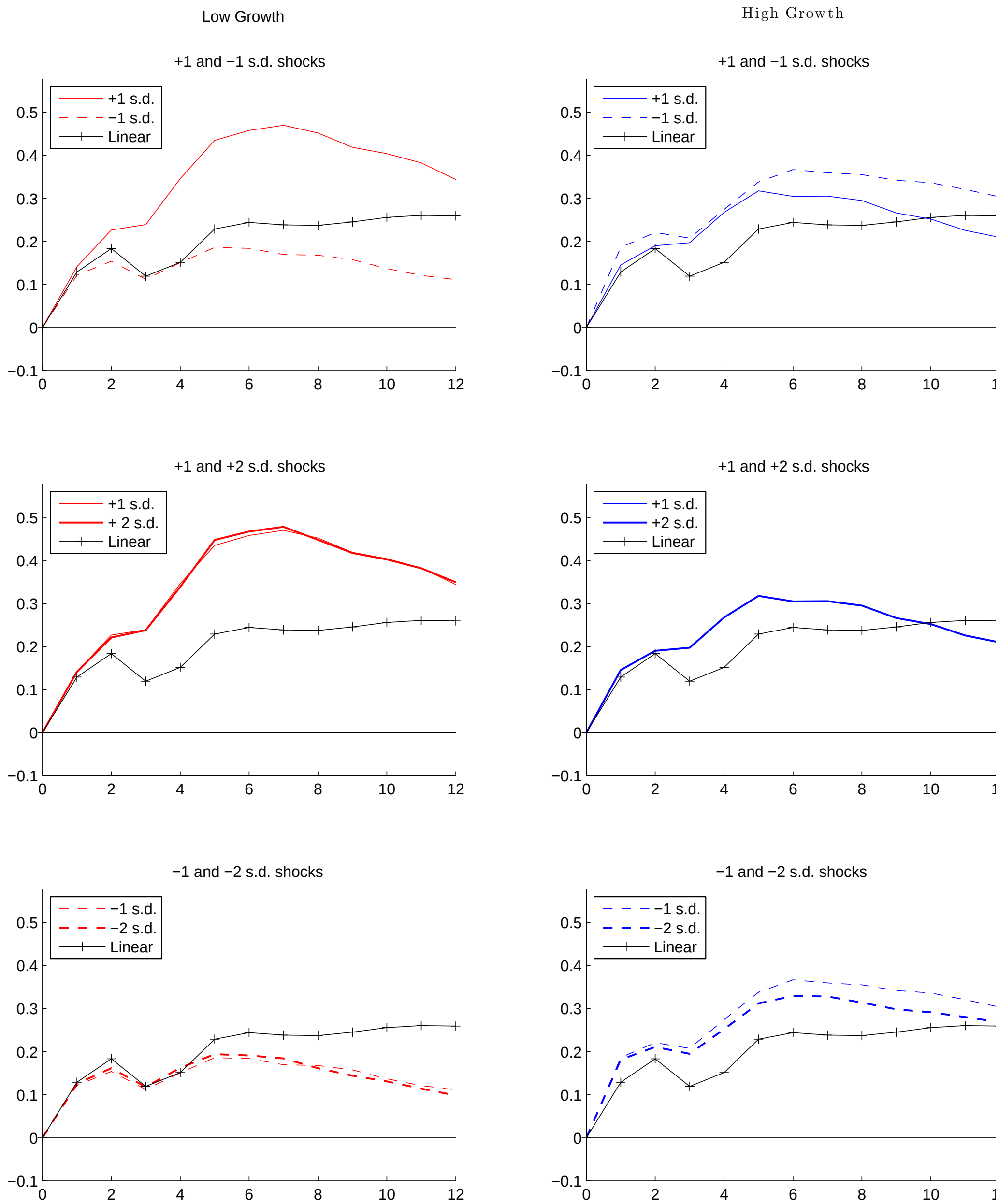
The VAR system is $[dy, dp, dpc, ff]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972,1979 and 1984, time trend and the interaction between time trend and structural break dummies. dy is output growth from real GDP, dp is GDP deflater based inflation rate, dpc is first difference of commodity price, and dff fed funds rate. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 0.91 which is one standard deviation of output growth.

Figure 2.10: Cumulative Responses of dy to ff : Second Order Logistic STVAR



The VAR system is $[dy, dp, dpc, ff]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972,1979 and 1984, time trend and the interaction between time trend and structural break dummies. dy is output growth from real GDP, dp is GDP deflater based inflation rate, dpc is first difference of commodity price, and dff fed funds rate. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 0.79 which is one standard deviation of output growth.

Figure 2.11: Cumulative Responses of dp to ff : Second Order Logistic STVAR



The VAR system is $[dy, dp, dpc, ff]'$. All variables are the percentage number of difference of log. All variables are filtered by seasonal dummies, structural break dummies after 1972,1979 and 1984, time trend and the interaction between time trend and structural break dummies. dy is output growth from real GDP, dp is GDP deflater based inflation rate, dpc is first difference of commodity price, and dff fed funds rate. Inflation is annualized rate of one quarter difference of log. Low or high growth refers to the level of output growth when a shock is feed. The cutting point is 0.79 which is one standard deviation of output growth.

Chapter 3

Asymmetric Effects of Monetary Policy in a DSGE Model

3.1 Introduction

"Regarding the Great Depression: You're right, we did it. We're very sorry. But thanks to you[Milton Friedman and Anna Schwartz], we won't do it again." ...*Ben Bernanke 2002.*

During the mid 2006 when there were speculative investments in the real estate sector in the U.S. economy, instead of using strong contractionary policies, Bernanke continued providing money supply. His policies were contrast with public belief in the time of speculative attack when contractionary policies were expected. However, Bernankes philosophy of handling the 2007 financial crisis was vividly conveyed on his remark about Friedman and Schwartz (1963) in 2002. According to Friedman and Schwartz (1963), the 1930 Great Depression could have been just an ordinary recession if the Fed had not severely reduced money supply. The stringent policy aiming at preventing the speculative attack drained out the liquidity from the economy. After the bubble had burst, the inadequate money supply precluded private sector from investing and turned the recession into the Great Depression. Having this notion in mind, Bernanke provided enough money supply and prevented the economy from leading to another great depression. Even though the economy was saved from such incident, it was still drifting in a deep recession. A series of expansionary policies were implemented to recover the economy. The Fed decreased the federal funds rate until it hit a record low near zero in December 2008. However, the policies seemed to be ineffective to restore the economy.

The contrast between strong effects of contractionary policies and the ineffectiveness of expansionary policies casts doubt on the symmetric effects of monetary policy. While contractionary policies could lead the economy to a deep recession, expansionary policies failed to restore it. The evidences of asymmetric effects of monetary policy can be widely observed. For example, in the U.S., the collapse of the Bretton Woods system in 1972 and the oil shocks of 1973 instigated high inflation in the U.S.. The Fed, by Paul Volcker, implemented restricted policies using Friedman's k-percent rule. The lower inflation rate was observed to correspond to the implementing of contractionary policies. However, the policies also led to a higher unemployment rate. In the U.K., stringent monetary policies were engaged to end a hyperinflation episode. Similarly, the inflation was tamed with a higher unemployment rate. On the other end of the spectrum, the long-lasting recession in Japan is an example of an ineffective monetary policy. Japan fell into a long-lasting recession after the financial bubble in 1991. The interest rate dropped to 0.5 percent during 1995. With deflation, the interest rate approached zero-bound, leaving no room for further reduction. Irrefutably, there are numerous factors driving the recession. Thus, the monetary policy cannot be dismissed as a complete failure. However, it shows that monetary policy is less effective to restore the economy than to cool it down.

The notion of asymmetric effects of monetary policy has been discussed for decades. In 1967, Milton Friedman compared the monetary policy to a *"Monetary policy was a string: You could pull on it to stop inflation but you could not push on it to halt recession. You could lead a horse to water but you could not make him drink".* Attempts to scientifically capture the asymmetric effects of monetary policy were sparked by the seminal work by Cover (1992). Later on, the evidences of various types of the asymmetry were documented in both the U.S. and other countries. Both theoretical and empirical works have been developed to explain and measure the asymmetry. Empirically, many nonlinear econometric techniques have been applied to preserve possible nonlinearity in parameters, making it possible to detect asymmetric effects of monetary policy from the data. In the meantime, many theoretical explanations have been proposed to account for the asymmetry.

However, shortcomings are found in both current empirical and theoretical works. For the empirical studies, even though a nonlinear methodology is applied, and the study is supported by a sound theory, the estimable model is linked to the theory via a reduced-form model, leaving the mechanism to which the key factors contribute as a black box (for example, Weise (1999)).Therefore, exactly how much a supporting theory explains the asymmetry remains unclear. On the theoretical side, most models are constructed in a partial equilibrium framework (for instance, Ball and Mankiw (1994)). Partial equilibrium does an excellent job in delivering a comprehensible mechanism of the economy. However, the established conclusions from a partial equilibrium framework might fail when extended to a general equilibrium framework where all relevant factors and their interactions are considered.

The new Keynesian stochastic dynamic general equilibrium (DSGE) model has been developed in response to the above criticism and become a workhorse of contemporary research in monetary policy. The model takes into account the interactions among relevant factors and the expectation of the uncertain future state of the economy. The model provides a framework to explain the mechanism in which the asymmetry is produced. Due to a highly nonlinear system, the exact solutions of a DSGE model are practically unobtainable. Traditionally, the model will be linearized or log-linearized before further analysis is implemented. However, by wiping out the nonlinearity, the model has lost its potential to explain the asymmetry.

This paper reexamines the asymmetric effects of monetary policy in a new Keynesian DSGE model. The nonlinearity of the model is preserved by using the second order perturbation method. Literatures have been discussing about three possible causes of asymmetry, which are a convex supply curve, a credit market imperfection and a change in economic outlook. Among these three explanations, this paper considers the role of a convex supply curve and a credit market imperfection. The Calvo (1983)'s pricing mechanism and Bernanke et al.

(1998)'s financial accelerator model are devised to create a convex supply curve and a financial friction, respectively. The model is then applied to verify three types of asymmetric effects of the policy that have been discussed in the literatures: asymmetry between 1) expansionary and contractionary policies, 2) moderate and aggressive policies, and 3) policies implemented in recessions and in expansions.

3.2 Literature Review

3.2.1 Empirical Evidence

The evidence that expansionary policies seem to be less effective on output than contractionary policies draws attention to a scientific analysis of asymmetric effects of monetary policy. The seminal work by Cover (1992) spurs empirical examinations of the asymmetry. The author uses a two-stage regression to examine the effect of money supply shocks on the output. Expansionary policy is found less effective to the output than contractionary policy. Morgan (1993) applies an approach similar to that of Cover (1992) to verify whether the results are limited only to when money supply is considered as the policy instrument. The author uses an alternative measurement of monetary policy: the federal funds rate and the narrative approach by Romer and Romer (1989). Similar results confirmed that tight policies are generally found to have stronger effects on the output than easy policies. Karras (1996a) and Karras (1996b) extend the study to other countries and document the asymmetric effects of monetary policy in other countries including European countries.

Provided with some evidences of asymmetric effects of monetary policy, researchers pay more attention to the methodology and extend the scope to other aspects of the asymmetry. Ravn and Sola (1997) cast a doubt on Cover (1992)'s results. After controlling policy regime changes, the asymmetry between positive and negative policy shocks is not found. However, another type of the asymmetry is found. The authors find the asymmetric effect between small and large policy shocks: only a small shock affects the output. Ball and Mankiw (1994) propose that a convex supply curve, which is a result of a menu cost, could lead to the asymmetric effects of the policy. Within a convex supply curve framework, the downward price stickiness increases (reduces) the efficiency of tight monetary policies on the output (price), especially when there is a positive trend of inflation. Subsequently, whether the convex supply curve contributing to policy asymmetry or not is explored. Senda (2001) further argues that the degree of the asymmetry varies depending on the inflation rate. Rhee and Rich (1995) use the Markov switching model to tackle the asymmetric effects of the policy and support that the degrees of the asymmetry and the inflation rate have positive relationships. Donayre (2009) remarks that large sizes of the policy shocks might be found more effective if the threshold that separates "big and small" is not appropriately defined. Karras and Stokes (1999) generalize Cover (1992)'s method to control the endogeneity and the structural break problem, making it possible to detect the source of the asymmetry whether it comes from a convex supply curve or from a pushing a string,[1] or both. The authors conclude that both a convex supply curve and a pushing string are working together.[2]

The previous studies are not conditioned on a particular part of a business cycle. Generally, an easy policy is implemented at recessions, while a tight policy is applied at expansions. An immediate comparison between easy and tight policies would essentially compare policies implemented at recessions with ones implemented at expansions, instead of comparing the effects of easy versus tight policies. The states of the economy in different phases of the business cycle might contribute to the efficiency of monetary policy as well. Toward this end, Thoma (1994) examines the role of a monetary policy over a business cycle and finds that tight monetary policies have a stronger effect on the output during high-growth periods, while easy policies have the same effects over the business cycle. Weise (1999) uses a smooth transition VAR to test three possible aspects of the asymmetry: positive and negative policy shocks, big and small policy shocks and policy shocks over a business cycle. The author finds that money supply has a stronger effect on the output with a small effect on prices when the output growth

[1]Note that thought pushing a string is considered, it has not yet supported by a sound theory as the convex supply has. Pushing a string is the notion to describe the observed evidences.

[2]While a convex supply curve predicts that easy policies will have less effect on output but large effect on prices, pushing a string projects the little effect on both output and prices.

is low. Garcia and Schaller (1995) use Markov switching model and monthly data focusing on the effectiveness of monetary policy over business cycle. In addition to previous findings that tight monetary policies are more effective in general, the same monetary policies are found more effective during busts than booms. Lo and Piger (2005) and Hoppner et al. (2008) also find supporting conclusions by using a switching coefficients model.

In summary, there are evidences of asymmetric effects of monetary policy in many countries, including the U.S.. Generally, tight monetary policies are found more effective on the output than easy policies. Moreover, the asymmetry is not only limited to the direction of the policies. The asymmetry between small and large shocks is also documented, even though the results are empirically mixed. Lastly, conditioning on phases of business cycle, it is empirically suggested that monetary policy is less effective in fighting recessions than in controlling heated economic situations.

3.2.2 Theories for Asymmetric Effects of Monetary Policy

The theories suggesting the causes of the asymmetric of monetary policy can be classified into three groups[3]: 1) prices being less flexible downward 2) credit constraints and 3) changing economic outlook.

Prices Less Flexible Downward

Price stickiness allows the room for monetary policy to influence the real economy. Time-varying degree of stickiness changes policy effectiveness. Theoretical research suggests that prices tend to be sticky downward. Positive trend inflation and a costly price adjustment process lead to the asymmetry of price adjustment. The downward price stickiness leads to a convex aggregate supply curve where tight (easy) policies have a larger (smaller) effect on output and a smaller (large) effect on prices.

[3]See Morgan (1993) for the survey

The mechanism by which price stickiness is created is motivated by a costly price adjustment or that only a fraction of firms can change their prices. Rotemberg (1982) and Ball and Mankiw (1994) assume that changing prices is costly. Rotemberg (1982) focuses on the implicit cost that is caused by customers' responses. This cost depends on the price level and customers' preferences. The author assumes that customers prefer an often-small price change to an occasional large one, leading to a quadratic adjustment cost function. Ball and Mankiw (1994) focus on the administrative (menu) cost, which is explicit and fixed. If the expected profit from changing prices is less than this menu cost, the firms will stick to the current prices. While Rotemberg (1982) predicts that the firms will gradually change their prices, Ball and Mankiw (1994) predict an occasionally big change. On the other hand, Calvo (1983) assumes that the firms can change their prices costlessly. However, only a fraction of firms can change their prices at a given period. Mispricing strategies incur an opportunity cost to the firms. With the positive trend inflation, it is more costly for the firms to drop or even to freeze their prices. They tend to increase rather than to drop the prices. Granted the positive trend inflation, the firms will be reluctant to cut the prices even when the demand drops as a result of a tight policy.

Credit Constraints

Financial market plays an important role in the modern economy. It allows the firms to reach funds and to pursue a fruitful project that they cannot self-finance. Balancing the expected return and managing the risk, financial intermediators have a role to "create" money and to amplify the effects of monetary policy. This accelerating role depends on the friction in the credit market caused by both entry barrier and asymmetric information. Banks will charge a higher premium to the firms that have limited access to the credit market due to their lack of information, which raises the default risk. In addition, when the market is tight, i.e. higher demand and less supply of funds, higher premium will be charged, reflecting a higher opportunity cost of funds.

The central idea of financial friction is rooted in the asymmetric information between lenders and borrowers. Townsend (1979) argues that realized returns are lenders' private information. Thus, it is costly for lenders to acquire information about the realized returns. An optimal loan contract is then designed to make borrowers truthfully report the realized returns and to give lenders maximum profit. Bernanke and Blinder (1988) and Bernanke and Gertler (1995) extend the idea of a costly state verification (CSV) to explain the credit channel of monetary policy through two channels: lending channel and balance sheet channel. Lending channel particularly refers to how banks allocate loans. When the monetary authority changes the interest rate, banks act accordingly by changing their loan portfolios to maximize their expected profits. For instance, if the monetary authority increases the interest rate, the borrowers have a higher burden to pay back the loans and a higher default risk. Banks consider this additional risk and relocate funds to safer projects. Moreover, banks may supply fewer funds if portfolio risk is too high making the effects of tightening policies more effective. The balance sheet channel explains how banks charge premium to a particular borrower. Given the same size of loan, borrowers with a higher equity have a smaller default risk and a lower loan rate.

Bernanke and Gertler (1989), Carlstrom and Fuerst (1997) and Bernanke et al. (1998) incorporate Tobin's Q to emphasize the role of balance sheet channel. Allowing capital prices to adjust, borrowers' assets become more sensitive to the market condition. Expansionary policies push up an aggregate demand and prices. Moreover, they increase borrowers' net worth. A higher value of borrowers' net worth improves their credit constraints allowing them to continue investing. On the other hand, tight policies lower an aggregate demand and decrease the prices. Consequently, they devalue borrowers' net worth, tightening their credit constraints and contracting the investment projects. The mechanism in which variation in asset prices amplifies the effect of monetary policy is called "financial accelerator." Financial accelerator will be more operative when the credit market is tight, generally at booms, making the monetary policy more effective.

The credit constraints hypothesis helps explain the asymmetric effects of monetary policy over the business cycle in two ways: i) throughout the business cycle, and ii) at a certain point of the business cycle. The first implication arises from the credit market condition and the financial accelerator theory. Kocherlakota (2000) and Florio (2006)[4] show that tight credit market conditions reinforce the effectiveness of monetary policy. They show that with an initial credit constraints not binding, the firms can absorb shocks with their own assets. The shocks will have minimal effects on the economy. However, if the credit constraint is binding at the beginning, the shocks will have a larger effect on the real output. Normally, the credit market is tight during booms making monetary policy more effective during those periods. However, increases in borrowers' net worth during booms help relaxing the credit constraints and mitigating the financial accelerator. Thus, the effectiveness of monetary policy over the business cycle depends on the total effect of the credit market condition and on the borrowers' net worth position. The second implication deals with the relationship between borrowers' net worth and default risk. If the relationship is nonlinear with a low curvature (or is linear), equi-proportionate changes in the risk premium are expected in both directions. Thus, monetary policy will have symmetric effects. Otherwise, the risk premium will respond differently to expansionary and contractionary policies, resulting in the asymmetric effects of the monetary policy. Bernanke and Gertler (1990) show that the risk premium is a convex function of the borrowers' net worth. As a result, tight policies are expected to be more effective on than expansionary ones.

Changing Economic Outlook

In addition to the monetary transmission mechanism, economic outlook also contributes to the effectiveness of the policy. Pessimism deteriorates the effectiveness of expansionary policies. It defers the firms from investing regardless of how low the investment cost might be. Households would increase precautionary savings even though the saving rate is high. Stimulus policies would fail to boost the economy. At the opposite end, optimism keeps the economy growing even when tight policies are implemented. At booms, firms perceive a number of investment

[4] Florio (2006) extends Dell'Ariccia et al. (1998) to explain the role of credit market tightness in explaining the effectiveness of monetary policy. The model applies matching function in job market, developed by Mortensen and Pissarides (1994)

opportunities. They expect their projects to yield high profits even though the investment cost is high. Households would expect a higher stream of income and consume more. Altogether, the effectiveness of tight policies is reduced.

Morgan (1993) argues that the discussion above is not sufficient to explain the asymmetric effects of the policy as It only addresses why the effects of the policy are diminished. To observe the asymmetric effects of the policy, the effects of optimism and pessimism have to be made different. Knowing that monetary policy is less effective in fighting recessions, pessimism should have stronger effects than optimism.

However, the theoretical works on how economic outlook has an influence on the effectiveness of monetary policy are still scattered. They have been more discussions of the possibility of this mechanic, rather than a micro-founded theory. The most related work is done by Van-nieuwerburgh and Veldkamp (2006). The authors suggest that people do not exactly know about the economic conditions. They make an expectation based on what they have been observing and believe. The more information people have, the less uncertain they become about the world they live in. During the booms, more economic activities can be observed, and thus providing more information to people. Therefore, they will be more sensitive to any shocks. With less information from fewer activities during recessions, people will be more careful and respond to shocks more slowly.

3.3 Model

The model is a new Keynesian DSGE model augmented by a financial sector, based on Bernanke et al. (1998)'s financial accelerator model. Two possible sources that lead to the asymmetric effects of the monetary policy are considered. First, the role of convex supply curve is captured by a nonlinear Phillips curve. Price stickiness is motivated by a Calvo (1983)'s pricing. Second, the role of financial friction is explained by a financial accelerator model, which is motivated by the asymmetric information between borrowers and a lender.

The model is composed of households, entrepreneurs, retailers, a bank and a government.

The bank and entrepreneurs are introduced into the model to establish a financial accelerator. The rest of the model is a standard new Keynesian model. Households live infinitely. They supply their labor hours to entrepreneurs to receive wages. They obtain other sources of income from the interest payment from their deposit and the dividend from retailers. Households then allocate their incomes into consumption spending, money balance maintenance and interest-earning deposit holding.

Entrepreneurs compete in a perfect competition market. They produce intermediate goods by combining capital and labor service and then sell them to retailers. Such group plays an important role in a credit market. They are the borrowers in the model. To make entrepreneurs being borrowers, their life expectancy is assumed shorter than the households'. At each period, a fraction $1 - \gamma$ of entrepreneurs will pass away and be born, making the number of entrepreneurs constant over time. Since their expected lifetime is shorter than that of the households', entrepreneurs are more impatient and inclined to borrow. This assumption also prevents entrepreneurs from having the sufficient funds enabling them to self-finance. Thus, in this model, entrepreneurs borrow funds from the bank to produce intermediate goods and sell them to retailers. The intermediate goods are sold in a monopolistic competition market.

Retailers produce differentiated products from intermediate goods and sell them to consumers in a monopolistic competition market. The bank lends money to the entrepreneurs whose investment projects are risky, and offers households a risk-free deposit. The government is responsible for both fiscal and monetary policies to stabilize the economy.

The key element of the model is the optimal contract between the entrepreneurs and the bank. There are two components of the investment risk in this model: an aggregate risk and an idiosyncratic risk. While the aggregate risk is public information, the idiosyncratic risk is entrepreneurs' private information. Since the optimal contract is essential to the model, it will be discussed first.

3.3.1 Optimal Contract

The bank and entrepreneurs are risk neutral. The bank raises funds by issuing a risk-free deposit to households. The entrepreneurs borrow funds from the bank to finance their investment projects. The value of investment project of each entrepreneur j is $Q_t K_{t+1}^j$, which is the nominal value of next period capital, K_{t+1}, at current period capital price, Q_t. The entrepreneurs' gross return, $\omega_{t+1}^j R_{t+1}^k \left(Q_t K_{t+1}^j\right)$, is composed of the aggregate return on capital and the individual specific return or idiosyncratic risk. The aggregate return on capital, R_{t+1}^k, is public information and common to all entrepreneurs. The specific return, ω_{t+1}^j, is each entrepreneur's private information and i.i.d. across the entrepreneurs and periods with distribution $F(\omega_{t+1}^j)$ and $E_t(\omega_{t+1}^j) = 1$ for all j.

The bank has to pay a fraction μ of the realized returns[5] to verify the actual returns and to liquidate the projects. Then the bank can keep the remainders, $(1-\mu)(\omega_{t+1}^j R_{t+1}^k Q_t K_{t+1}^j)$. This costly state verification causes an agency cost problem. The entrepreneurs will have an incentive to misreport their realized returns. Thus, the optimal financial contract between the bank and the entrepreneurs is designed to make the entrepreneurs always report truthfully.

In this paper, the contract is assumed to be a one period contract. Even though a multi-period contract is more realistic, it is complicated to be derived in a context of general equilibrium and does not change the role of net worth on borrowing conditions (this assumption of the contract is similar to Bernanke and Gertler (1990) and Carlstrom and Fuerst (1997)).

The entrepreneurial sector is composed of a continuum of entrepreneurs in a unitary mass. At the end of period t, each entrepreneur j decides how much to invest by purchasing capital for the next period, K_{t+1}^j at price Q_t. Because the value of the investment exceeds the entrepreneur's net worth, N_{t+1}^j, the entrepreneur will have to make a loan, $B_{t+1}^j = Q_t K_{t+1}^j - N_{t+1}^j$, to finance the investment project. The bank and the entrepreneur will agree on a gross loan rate, Z_{t+1}.

[5]Carlstrom and Fuerst (1997) assume that the verifying cost is a proportion of investment value.

The entrepreneur j will be able to pay back the loan if the project's return is greater than the obligation, i.e. $\omega^j_{t+1}R^k_{t+1}Q_tK^j_{t+1} \geqslant Z^j_{t+1}B^j_{t+1}$. Given a common aggregate return on capital, each entrepreneur's solvency condition will depend only on a specific return ω^j_{t+1}. The break-even specific return, ϖ_{t+1}, can be defined by:

$$\varpi^j_{t+1}R^k_{t+1}Q_tK^j_{t+1} = Z^j_{t+1}B^j_{t+1} \tag{3.1}$$

If the project is solvent, the entrepreneur pays back the obligation and keeps the surplus, otherwise the entrepreneur gets nothing. Assuming for a moment that the specific return is observable, the entrepreneur will not have any benefit from declaring bankruptcy if the project is solvent. Thus the entrepreneur's expected return is,

$$\int_{\varpi^j_{t+1}}^{\infty}(\omega^j_{t+1}R^k_{t+1}Q_tK^j_{t+1} - Z^j_{t+1}B_{t+1})dF(\omega^j_{t+1}).$$

Using definition of ϖ^j_{t+1} in Equation 3.1 to eliminate Z^j_{t+1} leads to the entrepreneur's expected profit as a function of ϖ^j_{t+1},

$$\begin{aligned}
&\int_{\varpi^j_{t+1}}^{\infty}(\omega^j_{t+1}R^k_{t+1}Q_tK^j_{t+1} - \varpi^j_{t+1}R^k_{t+1}Q_tK^j_{t+1})dF(\omega^j_{t+1}),\\
R^k_{t+1}Q_tK^j_{t+1}&\left\{\int_{\varpi^j_{t+1}}^{\infty}\omega^j_{t+1}dF(\omega^j_{t+1}) - \int_{\varpi^j_{t+1}}^{\infty}\varpi^j_{t+1}dF(\omega^j_{t+1})\right\},\\
&R^k_{t+1}Q_tK^j_{t+1}f_{t+1},
\end{aligned} \tag{3.2}$$

where $f_{t+1} = \int_{\varpi^j_{t+1}}^{\infty}\omega^j_{t+1}dF(\omega^j_{t+1}) - \int_{\varpi^j_{t+1}}^{\infty}\varpi^j_{t+1}dF(\omega^j_{t+1})$.

However, when the specific return is unobservable, the entrepreneur will have an incentive to declare bankruptcy if the profit obtained from the project is too low. To verify the entrepreneur's realized return, the bank has to pay a verifying cost proportional to the realized return, $\mu(\omega^j_{t+1}R^k_{t+1}Q_tK^j_{t+1})$. The net asset that the bank can obtain after verifying the realized return is $(1-\mu)(\omega^j_{t+1}R^k_{t+1}Q_tK^j_{t+1})$. Thus, the bank's expected income also depends on $\bar{\omega}$ and can be written as:

$$
\begin{aligned}
&\int_{\overline{\omega}_{t+1}^{j}}^{\infty} Z_{t+1}^{j} B_{t+1} dF(\omega_{t+1}^{j}) + \int_{0}^{\overline{\omega}_{t+1}^{j}} (1-\mu)(\omega_{t+1}^{j} R_{t+1}^{k} Q_t K_{t+1}^{j}) dF(\omega_{t+1}^{j}),\\
&R_{t+1}^{k} Q_t K_{t+1}^{j} \left\{ \int_{\overline{\omega}_{t+1}^{j}}^{\infty} \overline{\omega}_{t+1}^{j} dF(\omega_{t+1}^{j}) + \int_{0}^{\overline{\omega}_{t+1}^{j}} (1-\mu)(\omega_{t+1}^{j}) dF(\omega_{t+1}^{j}) \right\},\\
&R_{t+1}^{k} Q_t K_{t+1}^{j} \left\{ (1-F(\overline{\omega}_{t+1}^{j}))\overline{\omega}_{t+1}^{j} + \int_{0}^{\overline{\omega}_{t+1}^{j}} (1-\mu)(\omega_{t+1}^{j}) dF(\omega_{t+1}^{j}) \right\},\\
&R_{t+1}^{k} Q_t K_{t+1}^{j} g_{t+1},
\end{aligned}
\tag{3.3}
$$

where $g_{t+1} = (1-F(\overline{\omega}_{t+1}^{j}))\overline{\omega}_{t+1}^{j} + \int_0^{\overline{\omega}_{t+1}^{j}} \omega_{t+1}^{j} dF(\omega_{t+1}^{j}) - \mu \int_0^{\overline{\omega}_{t+1}^{j}} \omega_{t+1}^{j} dF(\omega_{t+1}^{j})$.

Even though the specific return is unobservable to the bank, this idiosyncratic risk is perfectly averaged out by the large number of entrepreneurs. Thus, the only risk that the bank has to bear is the aggregate one. Assuming there are no other operating costs, the only cost of funds that the bank has is the opportunity cost of funds acquired from the deposit. Thus the bank's expected profit is reduced to a function of the aggregate capital, K_{t+1}

$$
R_{t+1}^{k} Q_t K_{t+1} g_{t+1}. \tag{3.4}
$$

Note that $f(\overline{\omega}_{t+1}^{j}) + g(\overline{\omega}_{t+1}^{j}) = 1 - \int_0^{\overline{\omega}_{t+1}^{j}} \mu(\omega_{t+1}^{j}) dF(\omega_{t+1}^{j})$. The second term appears because of the verifying cost μ. The total amount of the verifying cost depends on the level of $\overline{\omega}_{t+1}^{j}$, which depends on the loan rate, Z_{t+1}^{j}. The loan rate, Z_{t+1}^{j}, affects the bank's expected income in two opposite ways. If the entrepreneur can meet the loan obligation, a higher loan rate will increase the bank's income. However, a higher loan rate also increases the default risk. It will make the entrepreneur declares bankruptcy more often incurring a higher verifying cost to the bank.

The optimal contract is designed in the way that all entrepreneurs obtain a maximized profit and the bank still participates in the contact. If the expected discounted return to capital is defined as $S_t \equiv E_t[\frac{R_{t+1}^{k}}{R_t}]$, S_t can also be interpreted as the external finance premium

(EFP). The optimal contract implies that:

$$S_t = \psi(\frac{Q_t K_{t+1}}{N_{t+1}}), \;\; with \;\; \psi(1) = 1, \;\; \psi'(\cdot) > 0. \tag{3.5}$$

Equation 3.5 is the key relationship of the model. The EFP is an increasing function of entrepreneur's leverage. Higher leverage level increases the default risk, escalating the cut off level, $\overline{\omega}^j_{t+1}$. Thus, the bank will charge a higher risk premium to compensate the risk.

3.3.2 The General Equilibrium

Entrepreneurs

The infinite numbers of entrepreneurs use identical constant return technology to produce wholesale goods and sell them to the retailers. Besides the investment decision described in the previous section, the entrepreneurs also supply labor service and consume consumption goods. The production function is a standard Cobb-Douglas production function:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}, \tag{3.6}$$

$$L_t = H_t^{\Omega} (H_t^e)^{1-\Omega}. \tag{3.7}$$

The aggregate wholesale goods, Y_t, is a function of aggregate capital, K_t, aggregate labor service, L_t, and a stochastic productivity, A_t. The aggregate labor service is a combination of the household labor supply, H_t and the aggregate entrepreneurs labor supply, H_t^e. By supplying labor service, entrepreneurs will have positive incomes even if the projects are default. To make the model comparable to a standard model, the labor income share of the entrepreneurial sector , $(1-\Omega)(1-\alpha)$, is assumed small. Furthermore, the entrepreneurial labor supply is assumed to be inelastic and normalized to one. Lastly, the productivity is an exogenous stochastic process following an AR(1) process,

$$ln(A_{t+1}) = \rho_a ln(A_t/\bar{A}) + \varepsilon^a_{t+1}, \tag{3.8}$$

where ε_t^a is an i.i.d. productivity shock and ρ^a is the AR coefficient.

The aggregate capital stock depends on the aggregate investment level, I_t and can be written as:

$$
\begin{aligned}
K_{t+1} &= \Phi\left(\frac{I_t}{K_t}\right) + (1-\delta)K_t, && (3.9)\\
\Phi\left(\frac{I_t}{K_t}\right) &= \left(\frac{I_t}{K_t} - \frac{\Psi}{2}(\frac{I_t}{K_t} - \delta)^2\right) K_t, && (3.10)
\end{aligned}
$$

where δ is the depreciation rate. A convex investment adjustment cost, $\Phi\left(\frac{I_t}{K_t}\right)$, is introduced to allow the asset price movement. As pointed out by Kiyotaki and Moore (1997), the variability of the capital contributes to the entrepreneurs' net worth volatility and enhances the fluctuation in business cycle. The adjustment cost is an increasing and concave function and equals to zero at the steady state. The capital price in terms of consumption good, Q_t, will be:

$$
Q_t = \left[\Phi'\left(\frac{I_t}{K_t}\right)\right]^{-1}. \tag{3.11}
$$

The wholesale goods is sold to the retailers who will repackage and resell the products in a monopolistic competition at a higher price with a gross markup price X_t. Because the price of the consumption goods is normalized to one, the markup price is just the inverse of the nominal marginal cost, $X_t = \frac{1}{MC_t}$. The first order conditions and the Cobb-Douglas production function imply the following gross input returns:

$$
\begin{aligned}
R_t^k &= \frac{\alpha \frac{Y_t}{K_t} MC_t + Q_t(1-\delta)}{Q_{t-1}}, && (3.12)\\
W_t &= (1-\alpha)\Omega \frac{Y_t}{H_t} MC_t, && (3.13)\\
W_t^e &= (1-\alpha)(1-\Omega)\frac{Y_t}{H_t^e} MC_t, && (3.14)
\end{aligned}
$$

where R_t^k is the aggregate capital return and W_t and W_t^e are the wage payment for labor service from households and entrepreneurs, respectively.

Let V_t be the entrepreneur's realized return in period t. From Equation 3.2, the entrepreneurs' realized return is $V_t = R_t^k Q_{t-1} K_t^j f_t(\overline{\omega}_t^j)$. At the end of each period, there is a fraction, $1-\gamma$, of entrepreneurs who pass away and were born. The surviving entrepreneurs carry the project returns and their wages to the next period. The dying entrepreneurs spend all incomes on consumption. The dynamics of aggregate entrepreneurial net worth and aggregate entrepreneurial consumption are given by:

$$N_{t+1} = \gamma V_t + W_t^e, \tag{3.15}$$

$$C_t^e = (1-\gamma) V_t. \tag{3.16}$$

Households

Households live infinitely. In each period, they consume C_t, hold money balance $\frac{M_t}{P_t}$, and supply labor service H_t. Their incomes come from wage payment W_t, the benefits from deposits $R_t D_t$ and the dividends from the retailers F_t. Households also have to pay a lump-sum tax T_t every period. Households' optimization problem can be written as:

$$\max \; E_t \, \Sigma_{k=0}^{\infty} \beta^k U(C_{t+k}, \frac{M_{t+k}}{P_{t+k}}, H_{t+k}),$$

subject to

$$C_t = W_t H_t - T_t + F_t + R_t D_t - D_{t+1} + \frac{(M_{t-1} - M_t)}{P_t}.$$

The first order conditions implie that,

$$U_{C_t} = E_t(\beta U'_{C_{t+1}}) R_{t+1}, \tag{3.17}$$

$$-\frac{U_{H_t}}{U_{C_t}} = W_t, \tag{3.18}$$

$$\frac{U_{M_t/P_t}}{U_{C_t}} = \left(\frac{R_{t+1}^n - 1}{R_{t+1}^n} \right)^{-1}, \tag{3.19}$$

where

$$U(\cdot) = \frac{(C_t - \psi\bar{C})^{1-\sigma_C}}{1-\sigma_C} + \rho\frac{(1-H_t)^{1-\sigma_n}}{1-\sigma_n} + \xi \ln(\frac{M_t}{P_t}), \tag{3.20}$$

$$R^n_{t+1} = R_t \frac{P_{t+1}}{P_t}. \tag{3.21}$$

Retailers

The infinite number of retailers in a unit interval competes in a monopolistic competitive market. They purchase wholesale goods from entrepreneurs, repackage and resell them to the households at a higher price. The market friction makes room for monetary authority to influence the real economy. Let $Y(z)$ and $P(z)$ be the output and the price sold by the retailer z, respectively.

On the demand side, the final consumption goods, Y_t^f is a Dixit-Stiglitz composite of differentiated products. The final goods and its price index, P_t, are:

$$Y_t^f = \left[\int_0^1 Y_t(z)^{(\varepsilon-1)/\varepsilon} dz\right]^{\varepsilon/(\varepsilon-1)}, \tag{3.22}$$

$$P_t = \left[\int_0^1 P_t(z)^{(1-\varepsilon)} dz\right]^{1/(1-\varepsilon)}, \tag{3.23}$$

where $\varepsilon > 1$ and $\frac{1}{\varepsilon}$ is the elasticity of substitution. At the equilibrium $\eta = \frac{\varepsilon}{\varepsilon-1}$ defines the gross mark-up pricing. The demand curve facing each retailer is:

$$Y_t(z) = \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} Y_t^f. \tag{3.24}$$

Additionally, the price dynamics follows the Calvo type setting. At any period, a random fraction $1-\theta$ of the retailers have a chance to change their prices. The aggregate price index is a composite of a new optimal price, P_t^*, set by the fraction of retailers who can change their prices and the last period price, P_{t-1}, of which the fraction of retailers cannot change. The price index according to Calvo pricing evolves:

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}. \tag{3.25}$$

Retailer z who can change the price chooses P_t^* to maximize the expected real profit,

$$E_t \sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} \left[\frac{P_t^* Y_{t+k}(z)}{P_{t+k}} - \frac{TC(Y_{t+k}(z))}{P_{t+k}}\right], \tag{3.26}$$

where $\Lambda_{t,t+k} = \beta^k \frac{U'(C_{t+k})}{U'(C_t)}$ is the discount factor taken from the households sector and $TC(Y_{t+k}(z))$ is the total cost of producing $Y_{t+k}(z)$. Let MC_{t+k} be the marginal cost of producing an additional unit of $Y_{t+k}(z)$ and $\Pi_{t,t+k} \equiv \frac{P_{t+k}}{P_t}$ be the cumulative inflation from period t to $t+k$. The first order condition implies:

$$\frac{P_t^*(z)}{P_t} = \frac{\eta E_t\left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} MC_{t+k} \Pi_{t,t+k}^{\varepsilon-1} Y_{t+k}^f\right]}{E_t\left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} \Pi_{t,t+k}^{\varepsilon} Y_{t+k}^f\right]} = \frac{N_t}{D_t}. \tag{3.27}$$

Equation 3.25 and Equation 3.27 are the key equations of the Phillips curve. However, both equations are not particularly useful for computation purpose. Equation 3.25 can be rewritten as a function of inflation rate at period t, $\Pi_t = \frac{P_t}{P_{t-1}}$ by raising both sides by $1-\varepsilon$ and dividing by P_t,

$$\theta \Pi_t^{\varepsilon-1} = 1 - (1-\theta)\left(\frac{N_t}{D_t}\right)^{1-\varepsilon}.$$

The numerator N_t and de-numerator D_t in Equation 3.27 can be rewritten in a recursive structure which denotes each variable as a function of its next period variable.

$$\begin{aligned} N_t &= \eta E_t \left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} MC_{t+k} \Pi_{t,t+k}^{\varepsilon-1} Y_{t+k}^f\right], \\ &= \eta U_{C_t} MC_t Y_t^f + \theta\beta E_t\left[\Pi_{t+1}^{\varepsilon} N_{t+1}\right], \end{aligned}$$

and

$$
\begin{aligned}
D_t &= E_t \left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} \Pi_{t,t+k}^{\varepsilon} Y_{t+k}^f \right], \\
&= U_{C_t} Y_t^f + \theta \beta E_t \left[\Pi_{t+1}^{\varepsilon-1} D_{t+1} \right].
\end{aligned}
$$

The Calvo price dynamics in Equation 3.25 and the optimal pricing in Equation 3.27 are now rewritten as:

$$
\begin{aligned}
\theta \Pi_t^{\varepsilon-1} &= 1 - (1-\theta) \left(\frac{N_t}{D_t} \right)^{1-\varepsilon}, && (3.28) \\
N_t &= \eta U_{C_t} MC_t Y_t^f + \theta \beta E_t \left[\Pi_{t+1}^{\varepsilon} N_{t+1} \right], && (3.29) \\
D_t &= U_{C_t} Y_t^f + \theta \beta E_t \left[\Pi_{t+1}^{\varepsilon-1} D_{t+1} \right]. && (3.30)
\end{aligned}
$$

Government

The government conducts both fiscal and monetary policies to stabilize the economy. The government expenditure G_t is financed by money creation and lump-sum tax,

$$
G_t = \frac{M_t - M_{t-1}}{P_t} + T_t. \tag{3.31}
$$

The government expenditure is governed by a stochastic process,

$$
ln(G_{t+1}) = \rho_a ln(G_t/\bar{G}) + \varepsilon_{t+1}^g, \tag{3.32}
$$

where g_t is a stochastic process, ε_t^t is the government expenditure shock and ρ_g is an AR coefficient. Monetary authority uses interest as a policy instrument. The nominal interest rate R_t^n follows Taylor rule. It is set to respond to the deviation of output and inflation.

$$
R_t^n = \overline{R} \left(\frac{R_{t-1}^n}{\overline{R}} \right)^{\rho_r} \left(\left(\frac{\Pi_t}{\overline{\Pi}} \right)^{\rho_\pi} \left(\frac{Y_t}{\overline{Y}} \right)^{\rho_y} \right)^{1-\rho_r} mp_t, \tag{3.33}
$$

where the variables with a bar are steady state values and , $\rho_r > 0$, $\rho_{pi} > 0$ and $\rho_y > 0$ are the policy coefficients of the policy rule. The monetary policy shock is governed by an exogenous process:

$$ln(mp_{t+1}) = \rho_{mp} ln(\frac{mp_t}{\bar{mp}}) + \varepsilon_{t+1}^{mp}. \tag{3.34}$$

Since the nominal interest rate is the policy instrument, the money stock M_t in Equation 3.31 is determined endogenously by money demand in Equation 3.19. Thus, the lump-sum tax T_t in Equation 3.31 is endogenously adjusted to balance the government budget.

Equilibrium Conditions

Final goods are distributed to private consumption, investment and government consumption. The aggregate verifying cost is represented in the last term in the following equation:

$$Y_t^f = C_t + C_t^e + G_t + I_t + \int_0^{\overline{\omega}_t^j} \mu(\omega_t^j) dF(\omega_t^j). \tag{3.35}$$

Intermediate goods market clearing condition:

$$Y_t = \int_0^1 Y_t(z)dz = Y_t^f \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} dz = Y_t^f \Delta_t, \tag{3.36}$$

where $\Delta_t \equiv \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} dz$ is the price dispersion. Using Calvo pricing dynamics, the dynamics of the price dispersion is,

$$\Delta_t = \theta \Delta_{t-1} \Pi_t^{\varepsilon} + (1-\theta) \left(\frac{N_t}{D_t}\right)^{-\varepsilon}. \tag{3.37}$$

Financial market clears the aggregate borrowing from entrepreneurs and deposit from the households:

$$B_t = D_t. \tag{3.38}$$

3.4 Solution Method

Most dynamic models do not have known analytical (closed-form) solutions. Traditionally, the models are linearized or log-linearized around the steady state to obtain a system of linear policy rules (Kydland and Prescott (1982) and King et al. (1988)). This procedure greatly reduces the computational burden and is suitable for many questions in the neighborhood of steady state. However, it is not suitable when the curvature of the models is important: for instance the questions involving welfare comparison and policy asymmetry. Alternatively, the behavior of dynamic models can be obtained by using the computational methods. The most direct approach is to apply the value function iteration to the social planner's problem. However, this approach is extremely inefficient due to computational burdens and a strong curse of dimensionality. The other alternative solution methods can be classified into two broad classes: perturbation and projection methods.

The perturbation method involves a local approximation using Taylor's expansion. The agents' policy functions are approximated around the steady state and a perturbation parameter. Hall (1971) and Magill (1977) demonstrate the usefulness of using the first-order perturbation method to find the solutions. The first-order method gives linear decision rules. Thus, the dynamic of the model is governed by linear rules. Judd and Guu (1993) extend the methodology to higher orders. The first- and second-order perturbation methods are extensively studied by Schmitt-Grohé and Uribe (2004).

The projection method builds approximated decision rules from basis functions (see Judd (1992) and Miranda and Helmberger (1988)). Basis functions with the optimal parameters are combined to minimize a residual function. There are two common types of basis functions used in the projection method: finite elements (neural network) and spectral (Chebychev orthogonal). While the former's basis functions are non-zero only locally, the latter's are non-zero globally. Thus, the projection method with spectral functions is more accurate in general. However, the procedure becomes increasingly complicated as the number of state variables rise.

Aruoba et al. (2006) examine the performances of the perturbation and the projection methods. Both methods have good convergence properties as well as computing time. The perturbation method gains more accuracy when a higher order is used. The only cost of increasing the order of approximation is to take a number of derivatives. However, the accuracy of the perturbation method is limited only to the neighborhood of the steady state since it is a local approximation. The projection method is a global approximation and generally provides more accurate solutions. For the choice of basis function, the finite element method is more robust and gives more accurate solutions along the range of parameters, while the Chebsyshev method shares most preferred features of finite elements if the system is not very highly nonlinear.

This paper uses the second-order perturbation method. The main objective of the paper is to explain asymmetric effects of monetary policy in a DSGE framework. Market frictions that are incorporated in the model will add up the curvature of the model. As a result, the curvature of the model would create the asymmetric responses. Thus, the solution method must be able to capture the nonlinearity of the model. Moreover, since most analysis will be done at the steady state, with the exception of the perturbation method which might not give an accurate result as the projection method, it would be able to capture the effects of nonlinearity if the model has enough curvature.

3.4.1 Solving the Model Using Perturbation Method

The perturbation method applies Taylor approximation around the steady state level (see Schmitt-Grohé and Uribe (2004) and Fernández-Villaverde and Rubio-Ramirez (2006)). The equilibrium conditions for most dynamic models can be written as:

$$E_t f(\mathbf{y}_{t+1}, \mathbf{y}_t, \mathbf{x}_{t+1}, \mathbf{x}_t), \tag{3.39}$$

where $\mathbf{y}_t$ is a vector of endogenous variables and $\mathbf{x}_t$ is a vector of state variables. State variables can be both endogenous and exogenous (shock process).

For example, a particular endogenous variable consumption C_t is taken in to consideration. The policy function for consumption, $c(\mathbf{x}_t, \sigma)$, is a function of state variables $\mathbf{x}_t$ and perturbation parameter σ. Further assumption can be made that there is only one endogenous state variable, capital k_t, and only one exogenous variable, technology A_t. Thus, the vector of state variables is $\mathbf{x}_t = \{k_t, A_t\}$. If the optimal consumption is smooth at the steady state level of state variables, $(k_0, A_0, \sigma = 0)$, then the approximated function can be written as:

$$c(k_t, A_t, \sigma) \simeq \sum_{i,j,m} \frac{1}{(i+j+m)!} \frac{\partial^{i+j+m} c(k_t, A_t, \sigma)}{\partial k_t^i \partial A_t^j \partial \sigma^m}\Big|_{k_0, A_0, 0} (k_t - k^0)^i (A_t - A^0)^j \sigma^m. \tag{3.40}$$

The above equation is essentially a standard Taylor series expansion. The policy functions for other variables would have the same representations. The extension to the system with many endogenous-state and exogenous-state variables is very straightforward. The only cost for the extension is just taking a number of derivatives.

The objective of the method is to obtain the unknown parameters $\frac{\partial^{i+j+m} c(k_t, A_t, \sigma)}{\partial k_t^i \partial A_t^j \partial \sigma^m}\Big|_{k^0, A^0, 0}$. The recursive algorithm is applied for this purpose. The first step is acquiring parameter values for the first-order approximation. The solutions of only the first-order approximation at the steady state are equivalent to those of a linear deterministic model. Once a linear system is obtained, the model is solved by a forward-looking rational expectation procedure. Among other procedures[6], Blanchard and Kahn (1980) and King et al. (1988) use the eigenvalue decomposition. The procedure decouples the solutions to forward-looking and backward-looking parts. Then each part can be separately solved and combined to get the solutions. Next, the second-order approximation is applied around the steady state. With the parameters obtained from the first-order approximation, the second-order approximation can be uniquely solved by using the same procedure. Ultimately, the solutions of the higher order approximation can be solved by iterating this procedure.

[6]The other solution procedures are (see Fernández-Villaverde and Rubio-Ramirez (2006)); linear quadratic approximation(Kydland and Prescott (1982)), generalized Schur(QZ) decomposition (Klein (2000) and Sims (2002)). These solution methods deliver the same linear policy functions.

3.5 Model Simulation

How much the model can explain the asymmetric effects of monetary policy depends on both structure of the model and its parameters. This paper examines the ability of the model to explain the asymmetric effects of the monetary policy for the U.S. economy. The parameters of this paper are calibrated to the U.S. economy. All parameters in the model are standard except the financial contract part are taken from Bernanke et al. (1998) and Gali and Rabanal (2004).

The subjective discount factor $\beta = 0.99$ implies a 4 percent annualized discount rate. The consumption habit, ψ, is set to 0.40 of the steady state consumption level, $\bar{C}_t$. The inverse intertemporal elasticity of substitution, σ_c, and the inverse labor supply elasticity, σ_n, are set to 2. The capital income share α is 0.35. Capital depreciates is 2.5 percent ($\delta = 0.025$) and the investment adjustment cost parameter (Ψ) is 10.48. The retailers compete in a monopolistic competitive market whose the elasticity of substitution of goods equals 7, implying that the gross mark-up price equals 1.1667. The share of the government expenditure ,$\bar{G}$ is 0.2. The exogenous government and monetary policy shocks follow random processes ($\rho_g = \rho_{mp} = 0$) with the standard deviations equal to 0.009 and 0.003, respectively. The monetary policy follows a standard Taylor's policy that puts weight on the deviation of inflation (ρ_π) and the output (ρ_y) equal to 1.5 and 0.5, respectively. In addition, the monetary policy adopts a smoothing policy by putting a weight ($\rho_r = 0.9$) on the previous period nominal interest rate.

The entrepreneur sector and the contract parameters are not standard to the new Keynesian DSGE model. All parameters are calibrated to the U.S. economy and set along with BGG's to make the models comparable. The first parameter is the entrepreneur labor income share. The positive labor income for entrepreneur, $(1-\alpha)(1-\Omega)$, is necessary to preclude the possibility of zero income when the project fails. Since the entrepreneur sector does not exist in a standard new Keynesian model, this parameter is set as close as possible to zero to make the model comparable to a standard new Keynesian model. In this paper, it is set at 0.01.

The optimal financial contract is linked to the distribution of idiosyncratic risk, $F(\omega)$ which is described by mean, μ_ω, and standard deviation σ_ω. These two parameters determine the risk spread, $E_t(R^k_{t+1} - R_t)$, and the business failure rate, $F(\bar{\omega})$. They are calibrated to the U.S. historical average. The risk spread is calibrated to the average spread between the prime lending rate and the six-month treasury bill, which is 2 percent annualized. The annualized business failure is calibrated to 3 percent. To match these two variables, the mean and the standard deviation of the idiosyncratic risk are set at 0.12 and 0.271, respectively. Another nonstandard parameter is the entrepreneur surviving rate, γ. Given other things being equal, this parameter determines the leverage ratio $\frac{N}{K}$ which equals to 0.5 in the data. Thus, γ is set at 0.979. The values of all parameters are summarized in Table 3.1.

Table 3.1: Model Parameters

Consumption Habit	ψ	0.400
Discount Factor	β	0.990
Inv. Inter temporal Elasticity of Substitution	σ_c	2.000
Inv. Labor Supply Elasticity	σ_n	2.000
Slope Labor Disutility	ρ	1.000
Slope Real Money Bal. Utility	ξ	1.000
Price Stickiness	θ	0.500
Elasticity of Substitution	ε	7.000
Capital Share	α	0.350
Entrepreneur Labor Inc. Share	$(1-\alpha)(1-\Omega)$	0.010
Depreciation Rate	δ	0.025
Inv. Adj. Cost	Ψ	10.480
Taylor Rule : Interest Rate Smoothing	ρ_{rn}	0.900
Taylor Rule : Inflation Coefficient	ρ_π	1.500
Taylor Rule : GDP Coefficient	ρ_y	0.500
Autocorr. Monetary Shock	$\rho_{\varepsilon^{mp}}$	0.000
Autocorr. Technology Shock	ρ_a	0.000
Autocorr. Government Shock	ρ_g	0.000
Std.Dev. Monetary Shock	σ_{mp}	0.003
Std.Dev. Technology Shock	σ_a	0.009
Std.Dev. Government Shock	σ_g	0.009
Verifying Cost	μ	0.120
Std.Dev. Market Risk	σ_ω	0.271
Entrepreneur Surviving Rate	γ	0.979

Two sources of the asymmetry considered in this paper are financial friction and nonlinear Phillips curve. The paper analyzes three types of asymmetric effects. First, moderate and aggressive monetary policy shocks are tested whether their effects are proportionately scaled. Second, contractionary and expansionary policies are tested if they have perfectly opposite effects. Third, the effects of policies implemented at different phases of business cycle are analyzed.

The first two types of the asymmetry are studied and analyzed at the steady state . For the third type, only the effects of moderate monetary policy shocks are considered at expansions and recessions. Both recessions and expansions are defined by a 5 percent deviation of the output from the steady state in either direction. Deviations from the steady state could result from demand or supply shocks. These two types of shocks might drive the economy in different directions. Thus, both demand and supply shocks are considered. Either demand or the supply shocks will be pre-imposed to deviate the system from the steady state. The demand shocks will be represented by government expenditure shocks while the supply shocks will be represented by technology shocks. As the system responds to shocks nonlinearly, the demand or the supply shocks will be normalized. It will be set to have a net 5 percent deviation of the output from the steady state in either expansions or recessions.

To examine the role of the financial friction and the nonlinear Phillips curve, the model will be analyzed in four settings. It starts from turning both channels off. Then one channel is turned on at a time. Finally, both channels are turned on to combine both mechanisms. $Model1$ considers the potential of a standard model when the nonlinearity is preserved. The external financial premium (EFP) is fixed at the steady state level and the Phillips curve block is log-linearized. $Model2$ tests only the role of the financial friction. The EFP is allowed to change (nonlinearly) while the Phillips curve is still log-linearized. $Model3$ studies only the role of the nonlinear Phillips curve. In this case, the Phillips curve block is approximated by second-order approximation, while the risk premium is fixed at the steady state. $Model4$ combines both financial friction and nonlinear Phillips curve.

Monetary policy shocks are classified by their signs and sizes. On the one hand, the sign of the policy shocks determine the type of monetary policy. Contractionary policies are defined by positive monetary policy shocks, which increase the nominal interest rate while expansionary polices are defined by negative monetary policy shocks, which lower the nominal interest rate. On the other hand, the size of the shocks determines the policy intensity. One standard deviation size of the shocks, which is a conventional size of shocks, represents moderate policies. Two standard deviation sizes of the shocks represents aggressive policies. Thus, hypothetical aggressive contractionary policies will be represented by two negative standard deviation size of monetary policy shocks.

Impulse response functions are plotted to analyze the asymmetric effects of monetary policy. Since various size of the shocks are taken into account, the impulse response functions must be scaled to match the reference functions for comparison purpose. This paper uses moderate contractionary policies as the references. Thus, the impulse response functions will be scaled down by half for aggressive policies. In addition, the responses will be flipped over the horizontal axis by multiplying by -1, for the responses to expansionary policies. Should the monetary policy be symmetric, the impulse response functions will lie on top of each other.

3.5.1 Results

For each model, a series of three figures of the impulse response functions are plotted. The first figure of the series shows the responses to the shocks at the steady state. The second shows the responses to the shocks during expansions and recessions when demand shocks are pre-imposed. Similarly, the third figure shows the responses to the shocks during expansions and recessions when supply shocks are pre-imposed.

$Model1$ represents a standard New Keynesian DSGE model. The purpose of this model setting is to assess the ability of the standard model to explain the asymmetric effects. In this setting, only curvature of the standard model is preserved. The financial accelerator is turned off and the Philips curve is log-linearized. The impulse responses from this model are shown in Figure 3.1, Figure 3.2, and Figure 3.3.

Figure 3.1 considers the effects of the monetary policy shocks at the steady state. The combinations of expansionary or contractionary policies and moderate or aggressive policies are fed into the model. The impulse responses are normalized to ones of the base shocks for comparison purpose as mentioned earlier. The percent deviations from the steady state (annualized) of each variable are plotted in a quarterly time interval. It is clear that there are no asymmetric responses in this model. The responses to monetary policy shocks lie on top of one another in all cases, except the leverage ratio ($\frac{Q_t K_{t+1}}{N_{t+1}} \equiv qkn$), which shows slightly asymmetric responses. This suggests that even though the curvature of the model is preserved by the second-order perturbation method, the curvature of the standard model is not enough to produce the asymmetric effects of the monetary policy. In other words, the standard model does not contain a mechanism that can explain the asymmetric effects of the monetary policy. Besides the asymmetry, the impulse responses exhibit the standard pattern. Increases in the nominal interest rate put pressure on the investment cost and drive the output growth and inflation to drop. The external financial premium, s_t, does not respond to the shocks because the financial accelerator is turned off.

Turning to the effects of the policy throughout the phases of business cycle, Figure 3.2 and Figure 3.3 show the effects of moderate contractionary policies during expansions and recessions, driven by demand and supply shocks, respectively. Responses during expansions and recessions are represented by bold and dash lines, respectively. The responses to contractionary policies during expansions and recessions virtually lie on top of each other for both demand and supply shocks. Moreover, the magnitudes of the responses to the different shocks are the same. Similar to the previous exercises, this indicates that the effects of nonlinearity of the standard model are not strong enough to produce asymmetric effects of monetary policy.

In $Model2$, only the financial accelerator is turned on. The Phillips curve is still log-linearized. Figure 3.4, Figure 3.5 and Figure 3.6 demonstrate the role of the financial accelerator. The key difference from the standard model is that the external financial premium, s_t, is now an increasing function of leverage ratio, $\frac{Q_t K_{t+1}}{N_{t+1}}$, instead of being fixed at the steady state value. The wedge between the borrowing and the lending rate amplifies the effects of the monetary policy as pointed out in BGG.

Figure 3.4 shows the responses to various monetary policy shocks at the steady state. The investment cost increases according to the nominal interest rate. Higher investment cost escalates the default probability. To compensate for a higher expected loss, the bank increases the risk premium s_t. As a consequence, the entrepreneurs' balance sheet positions are worsen due to the higher cost of funds. In return, the bank charges an extra premium in accounting for deteriorating entrepreneur balance sheet positions. Thus, the effects of the initial increase in the nominal interest rate are amplified by this feedback, or the so-called financial accelerator. As a result, the output is more responsive to the changes in the nominal interest rate as suggested by BGG.

The financial friction model predicts that the effects of the monetary on the output would be greater when there is a higher pressure on the interest rate, implying that the responses to aggressive contractionary policies should have unproportionately higher magnitudes than ones to aggressive expansionary policies. However, this conjecture is not found in this study. There are two possible explanations for this finding. As previously mentioned, in order for a model to account for the asymmetric responses, the model itself must have enough curvature and the solution method has to be able to preserve the nonlinearity of the model. Thus, the proposed mechanism might not introduce enough curvature or the solution method might fail to preserve it, or combinations of these two. Modeling wise, even though BGG's model is constructed in a general equilibrium framework, the projection of the asymmetric effects of monetary policy is made in a partial equilibrium. It is possible that when considering everything, the interactions among the variables might offset the effects of changes in the risk premium s_t. Thus, the potential asymmetric effects might be mitigated. Moreover, even though there are no offsetting movements in any variables, the convexity of the risk premium might be too low to generate the asymmetric responses. Secondly, the second-order perturbation method might not preserve enough nonlinearity of the model. The method works well in a neighborhood of the steady state and gives a good approximation for a low to medium nonlinear system. Even with a highly nonlinear system, the second-order perturbation can still provide a set of nonlinear solutions but they may be inaccurate. Moreover, even though the second-order approximation preserves the nonlinearity, it cannot account for the time varying volatility. A higher order of approximation might be beneficial to investigate the possible role of the time varying volatility.

Figure 3.5 and Figure 3.6 show the responses to moderate contractionary policies at expansions and recessions driven by demand and supply shocks, respectively. Only the risk premium s_t has noticeable asymmetry. Even though the differences between the responses at expansions and recessions are small, they exhibit the importance of the risk premium function or the financial friction in generating the asymmetric responses. The direction of the asymmetry, however, depends on the type of the shocks that deviates the economy from the steady state. At expansions, the risk premium will be more sensitive to policy shocks if demand shocks drive the business cycle. While positive demand shocks increase the prices in general, supply shocks deflate the prices level. When demand shocks hit the economy, the investment projects become more expensive, leading to a higher leverage ratio as well as higher default risk. Thus, the bank charges an extra premium to compensate for the increasing risk. On the other hand, supply shocks put less pressure on the prices, making the investment projects relatively cheaper. Thus, a smaller risk premium is required for the same investment projects.

$Model3$ considers only the role of the nonlinear Phillips curve. The model is approximated by the second-order perturbation method. The risk premium is fixed at the steady state value. The impulse responses from this model are shown in Figure 3.7, Figure 3.8, and Figure 3.9.

Figure 3.7 shows the responses to various monetary policy shocks. Some evidences of asymmetric effects of monetary policy are found in this model. While the output responds more to contractionary policy shocks than expansionary ones, the inflation responds less to contractionary ones. In addition, the output responds more to aggressive contractionary policies than to aggressive expansionary ones. In other words, contractionary policies are more effective in influencing the output and less effective in controlling the prices as found in Weise (1999). These asymmetric responses reflect the role of the nonlinear Phillips curve by which the increasing degree of inflation-output trade-off is created. Another noticeable asymmetric responses are ones of the leverage ratio. The effects of the nonlinear Phillips curve to the leverage ratio are similar to the prices. As a result, the value of investment projects responds more to expansionary policies than contractionary policies as shown in the bottom right panel of Figure 3.7.

The nonlinear Phillips curve and the convex supply curve can be further explored by considering the responses in different phases of business cycle. It is shown in Figure 3.8 that the output is more sensitive to monetary policy shocks during recessions than expansions, while the price is more sensitive to policy shocks during expansions. The opposite direction of the asymmetry between the output and the prices can be considered a result of a convex supply curve. By feeding the model with demand shocks, new equilibriums are a result of a moving along the aggregate supply curve. Thus, the price (output) is more (less) sensitive to policy shocks during expansions than recessions. In Figure 3.9, the business cycle is driven by supply shocks. The direction of asymmetry is opposite from the ones from the demand shocks. This is because an increase in supply allows the economy to reach a higher output level by maintaining the same price or to attain the same output level with a lower price level. Thus, the price will be less sensitive to policy shocks when supply shocks cause expansions, giving more room for the policy to influence the output. On the other hand, when negative supply shocks hit the economy, the shocks depress the output and inflate the price at the same time. As a result, the price is more sensitive and the output is less sensitive to policy shocks at recessions caused by supply shocks.

Finally, $Model4$ incorporates both the financial accelerator and the nonlinear Phillips curve. The model is approximated by the second-order perturbation method and the risk premium, s_t, is allowed to change. Responses to policy shocks at the steady state are shown in Figure 3.10. In addition, Figure 3.11 and Figure 3.12 show responses to policy shocks at expansions and recessions driven by demand and supply shocks, respectively.

Similar to $Model2$ and $Model3$, the responses in Figure 3.10 exhibit the asymmetric responses to the monetary policy shocks. As found in previous model settings, the main driving force of the asymmetry is the nonlinear Philips curve, while the financial accelerator amplifies the responses. The asymmetric responses of the output and the prices have a similar pattern to ones found in $Model3$ where only the nonlinear Phillips curve operates. Note that because the financial accelerator is also operating, the magnitudes of the responses in this model are greater than those of $Model3$. The increasing cost of output-inflation trade-off also generates the asymmetric responses in the risk premium, s_t, and the leverage ratio, $\frac{Q_t K_{t+1}}{N_{t+1}}$.

The responses during expansions and recessions are also similar to those of $Model3$, but with amplified magnitudes. The responses can be explained by a convex supply curve theory. Positive demand shocks drive expansions and put more pressure on the price level. Consequently, the variables that vary according to the prices respond more to the policy during expansions than recessions. These variables are inflation, risk premium and leverage ratio. On the other hand, supply shocks deflate the prices in general. Since there is less pressure on the prices, the policy shocks can influence the output without having a signficant impact on the prices. Thus, when supply shocks drive the business cycle, the output responds more to policy shocks during expansions than recessions, while inflation and other price-related variables respond less to policy shocks during expansions than recessions.

3.5.2 Robustness

The policy rule in the previous section puts weight on both the deviation of the output and the inflation, together with the policy smoothing parameters ($r^n_t = 0.9r^n_{t-1} + 1.5\pi_t + 0.5y_t$). In this section, the simple Taylor's rule is applied. The policy smoothing parameter is removed and will only focus on the deviation of the inflation from the steady state value (a version of the inflation targeting policy) $r^n_t = 1.5\pi_t$. The same experiments as in the previous section are conducted. Similar to the results in the previous section, the major source of the asymmetry is the nonlinear Phillips curve while the financial accelerator magnifies the effects. The asymmetric effects of the monetary policy are most prominent in $Model4$ in which both channels are operating. Thus, this section will only discuss the results from $Model4$.

The degree of asymmetry in the previous section decreases when the simple Taylor's rule is applied. There is barely asymmetric effects found in Figure 3.13. There are two changes in policy rules from the previous section: the AR parameter and the weight on the deviation of output are dropped. Putting less weight on the deviation of the output and the inflation intensifies the degree of asymmetry (the results are not shown here). By dropping theses two parameters, the asymmetry is expected to diminish. Instead, the less degree of asymmetry is observed, indicating an important role of the smoothing parameter in explaining the asymmetry. The policy's smoothing parameter and price stickiness work in similar manner. The more the degree of price stickiness increases, the more effective the monetary policy becomes. Without the smoothing parameter, the nominal interest rate promptly responds to the changes in the economy.

The effects of a convex supply curve can be observed in Figure 3.14 and Figure 3.15, albeit with smaller magnitudes. The output responds less to policy shocks at expansions than at recessions when demand shocks hit the economy, while other price-related variables respond more. On the other hand, when supply shocks hit the economy, the output is more sensitive to policy shocks during expansions, while other price-related variables become less sensitive to the policy shocks.

The last experiment investigates the role of size of the shocks (the results are not included). The degrees of the asymmetry found in the previous section are sensitive to the size of the shocks. The size of the shocks used in the previous section are ± 1 and ± 2 of the standard deviation of monetary policy shocks, which is equal to 0.0034. A higher standard deviation generates more asymmetry. This test suggests that the size of shocks is important. Theoretically, the model and its nonlinearity can produce the asymmetric responses associated with a certain set of parameters and the size of the shocks. However, the size of the policy shocks beyond 2 standard deviation seem to be unrealistic. Thus, it is possible that the theoretical mechanisms are not able to explain the asymmetry or the solution method fails to preserve enough nonlinearity of the model, or both.

3.6 Conclusion

It has been observed for many decades that while monetary policy is an effective tool to slow down a heating economy, it seems to fail to fight a recession. Milton Friedman compares these asymmetric effects of monetary policy to pushing a string: "you can keep pushing the string but nothing will happen". With the evidences of the asymmetry at the peaks of business cycle, researchers have attempted to investigate the asymmetry in other positions of business cycle and explored the study to other definitions of the asymmetry. In addition, attempts to explain the causes and the mechanisms by which the asymmetry is created have also been made. Although the results are mixed, empirical works have documented the asymmetric effects of monetary policy in many countries and many aspects. Those works are supported by three groups of theories: the convex supply curve, the financial friction and the economic outlook.

The linkage between the empirical and theoretical works is important. For empirical works, nonlinear econometrics is applied to capture the asymmetry. Traditionally, the estimable equations are linked to the theoretical models via a reduced-form model. Thus, the estimates cannot be fully linked to the parameters that govern the asymmetry. Consequently, although the theories seem to be able to explain the mechanism by which the asymmetry is created quite well, the extents to which they contribute to the asymmetry are unknown. As for the theoretical works, some potential models such as the menu cost, are constructed in a partial equilibrium framework. With a partial equilibrium framework, the analytical solutions can be obtained and tested. However, a conclusion of the model might be different when other parts of the economy are considered, as in a general equilibrium framework. A model in this framework itself is a highly nonlinear system. Due to its complexity, the analytical solutions cannot be obtained. Traditionally, the model will be linearized or log-linearized to find the solutions. However, by doing so, the nonlinearity of the model is canceled out. Therefore, the model is no longer capable of explaining asymmetric effects of the policy.

This paper applies the second-order perturbation method to find the solutions of the model and to preserve the nonlinearity. Two out of three groups of theories explaining the causes of the asymmetry are considered: the convex supple curve and the financial friction. The nonlinear Phillips curve, driven by Calvo pricing, is applied to create a convex supply and Bernanke et al. (1998)'s financial accelerator model is devised to produce financial friction. The model parameters are calibrated to the U.S. economy. Three types of asymmetric effects monetary policy shocks are tested: the difference between 1) expansionary and contractionary policies, 2) moderate and aggressive policies, and 3) policies implemented at expansions and recessions.

Even though the degree of the asymmetry is reduced when a simple Taylor's rule is applied, the asymmetric effects of the monetary policy are found when a standard policy rule is used. Between the two sources of the asymmetry, the financial friction amplifies the effects of monetary policy but does not explain the asymmetric responses. The source of asymmetry mostly comes from the nonlinear Phillips curve through a convex supply curve. The trading off between the output growth and the inflation drives the system to respond nonlinearly to policy shocks. As a result, expansionary policies are found to have greater effects on the price but smaller effects on the output. In contrast, the asymmetry between moderate and aggressive policies is not found. When compare the effects of the policies implemented at expansions and recessions, the direction of the asymmetry depends on the type of shocks that drive the business cycle. While both positive demand and supply shocks increase the output level, the demand shocks put more pressure on the prices while supply shock deflates the prices. With a lower (higher) price level, the monetary policy shocks can have higher (lower) effects on the output with less (more) effects on the price. Thus, monetary policy shocks have stronger effects on the output and weaker effects on the price, when the demand shocks drive the business cycle. The degree of the asymmetry also depends on the parameters of the policy rule. The degree of asymmetry increases when the policy puts less weight on the deviation of the output and the inflation, and when the smoothing parameter is higher.

3.6.1 Limitations and Future Research

The degree of the asymmetry also depends on other factors. The size of the shocks in this model lies with in ± 2 standard deviation of the monetary policy shocks. The asymmetry becomes more noticeable when a bigger size of the shocks is used. However, the shocks that are bigger than ± 2 standard deviation are unrealistic. This paper shows that when the existing model can partly account for the asymmetry when the nonlinearity is preserved. However, it could be possible that the model is highly nonlinear so the local approximation with a lower order cannot preserve enough nonlinearity. Other solution methods might also be considered to improve the approximation. An immediate alternative is to increase the approximation order. The second-order can preserve the nonlinearity but might not be appropriate if the model is highly nonlinear. In addition, it ignores the possibility of the time varying volatility. Besides, the projection method, Fernández-Villaverde and Rubio-Ramirez (2006) suggest an optimal change of variables with the perturbation method. With the proper transformation of variables, this method can significantly improve the accuracy while maintaining the simplicity of the perturbation method.

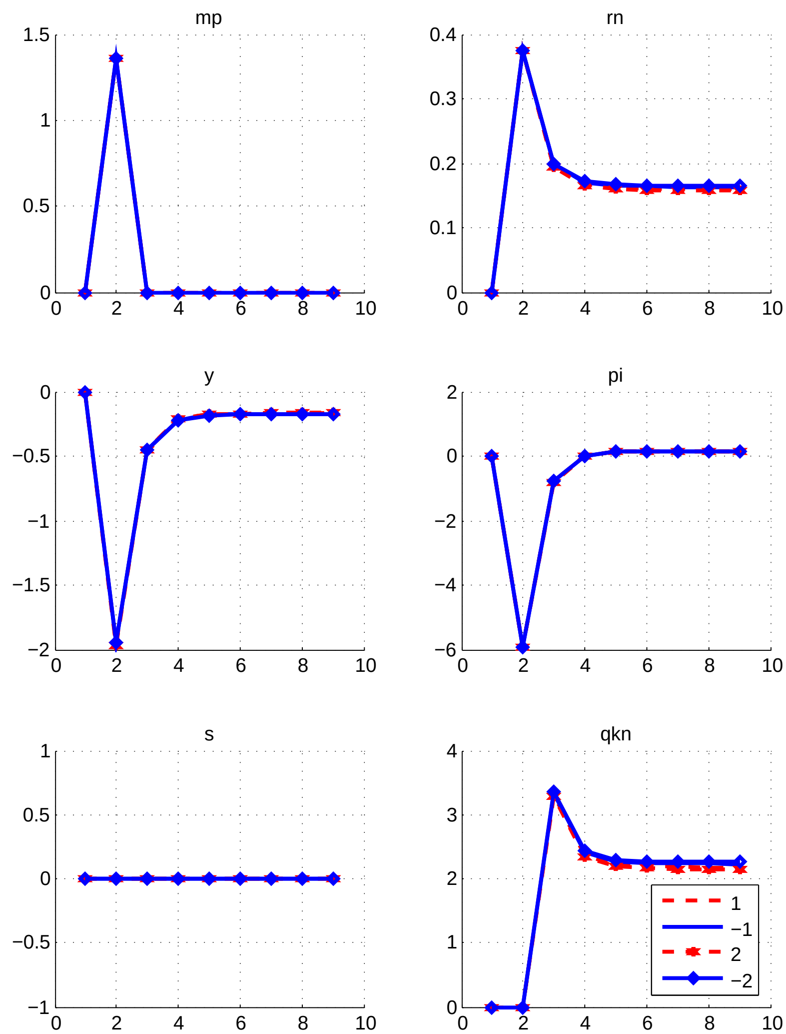
Besides the solution method, it is also possible to explore the alternative theoretical models. The mechanisms explaining the financial friction and the sticky price in this paper might not be flexible enough to explain the asymmetric responses. The BGG's financial accelerator does a good job in explaining the monetary transmission mechanism. However, the model assumes that the borrowing constraints binds at all time[7], while the effects of the monetary policy become stronger when the borrowing is binding. Assuming the borrowing constraints binds at all time might mitigate the role of financial friction in creating the asymmetric responses. Moreover, the leverage ratio in BGG is always higher during recessions because of the deterioration in net-worth. In fact, the leverage ratio could be lower during recessions because of the greater reduction in the investment rather than the reduction in net-worth. Thus, the role of the financial market friction and the degree of asymmetry might be suppressed[8]. Lastly, even though the Calvo pricing mechanism succeeds in producing the asymmetric responses, the degree of the asymmetry is not significant. This might be because the Calvo pricing assumes a fixed proportion of retailers who can change their prices. This assumption might be too rigid when the model is considered in a light of expansions or recessions. Alternative sticky price models might be used to allow a more flexible pricing behavior. For example, Rotemberg pricing scheme allows all retailers to make their decisions on prices with a quadratic cost.

[7]Kocherlakota (2000) shows that the monetary policy has little effects on the output when the borrowing constraints are not binding.

[8]Florio (2006) shows that the reduction of the loan demand during recessions weakens the effects of the monetary policy.

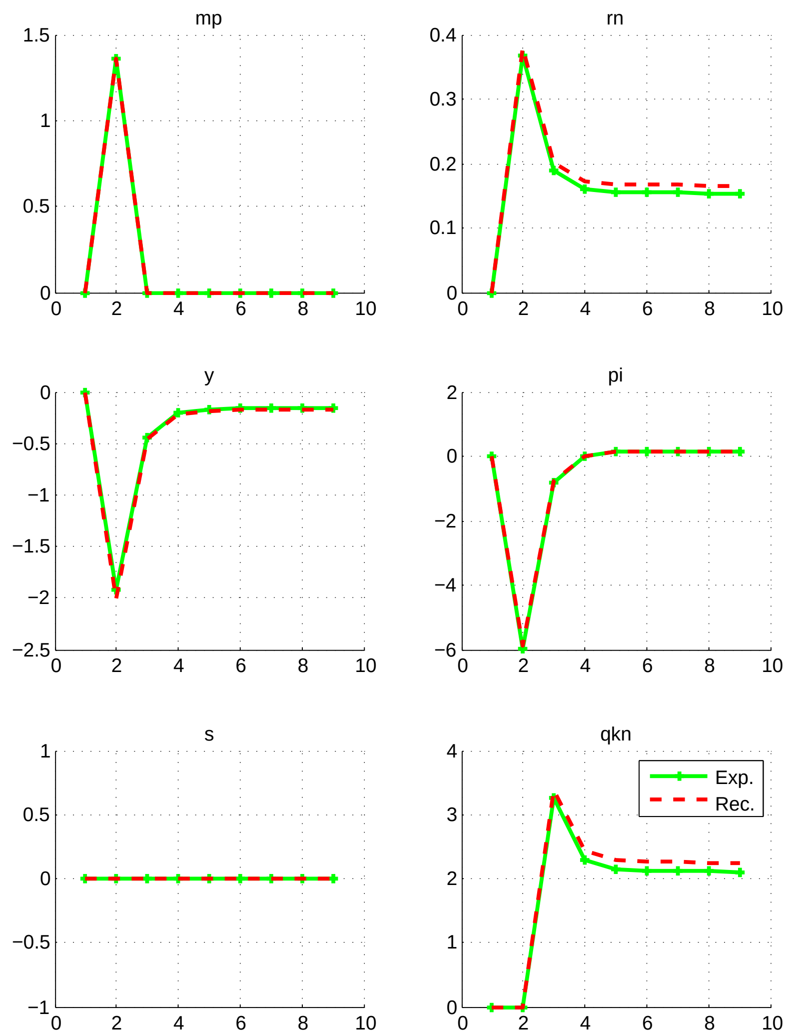
In summary, this paper attempts to theoretically access the causes of the asymmetric effects of the monetary policy, using a new Keynesian DSGE model. The second-order perturbation method is applied to find the solutions of the model and preserve its nonlinearity. The model is found to be able to explain some part of the asymmetry.

Figure 3.1: The Responses to Monetary Policy Shocks (mp), $Model1$



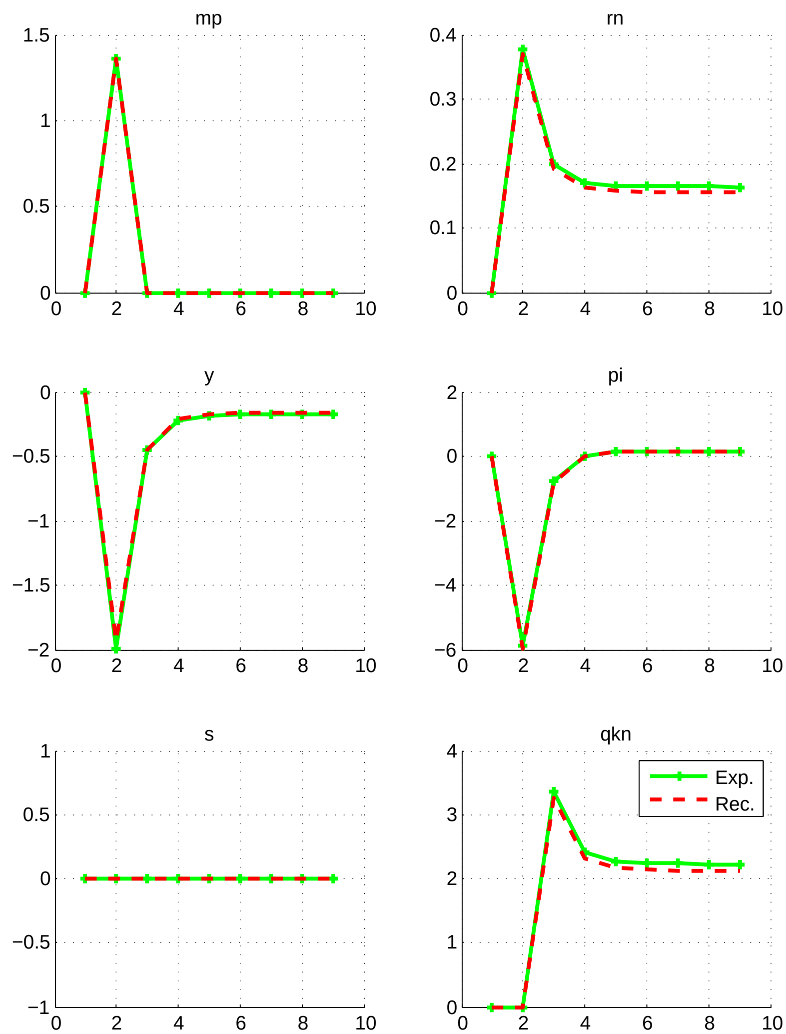
$Model1$**: Without Financial Accelerator, Linear Phillips Curve.** The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values. For comparison purpose, responses to two standard deviation of monetary policy shocks are divided by two, responses to a one- and two- negative standard deviation shocks are divided by -1 and -2, respectively.

Figure 3.2: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions : Demand Shocks, $Model1$



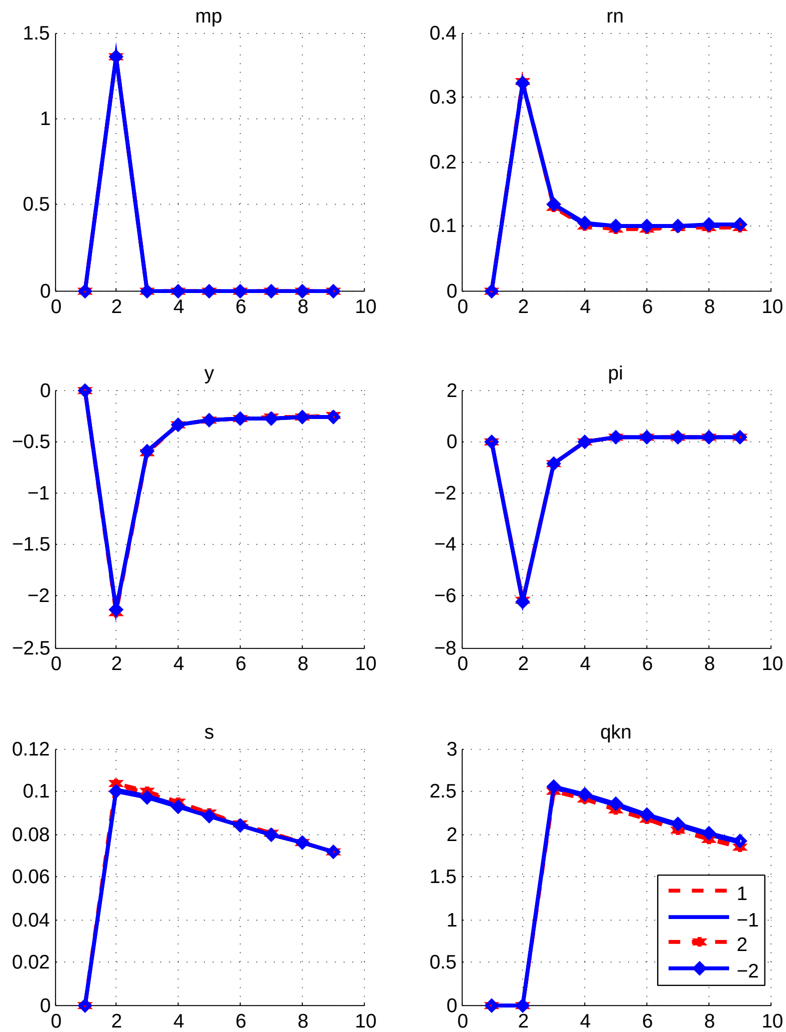
$Model1$**: Without Financial Accelerator, Linear Phillips Curve.** Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.3: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shock, $Model1$



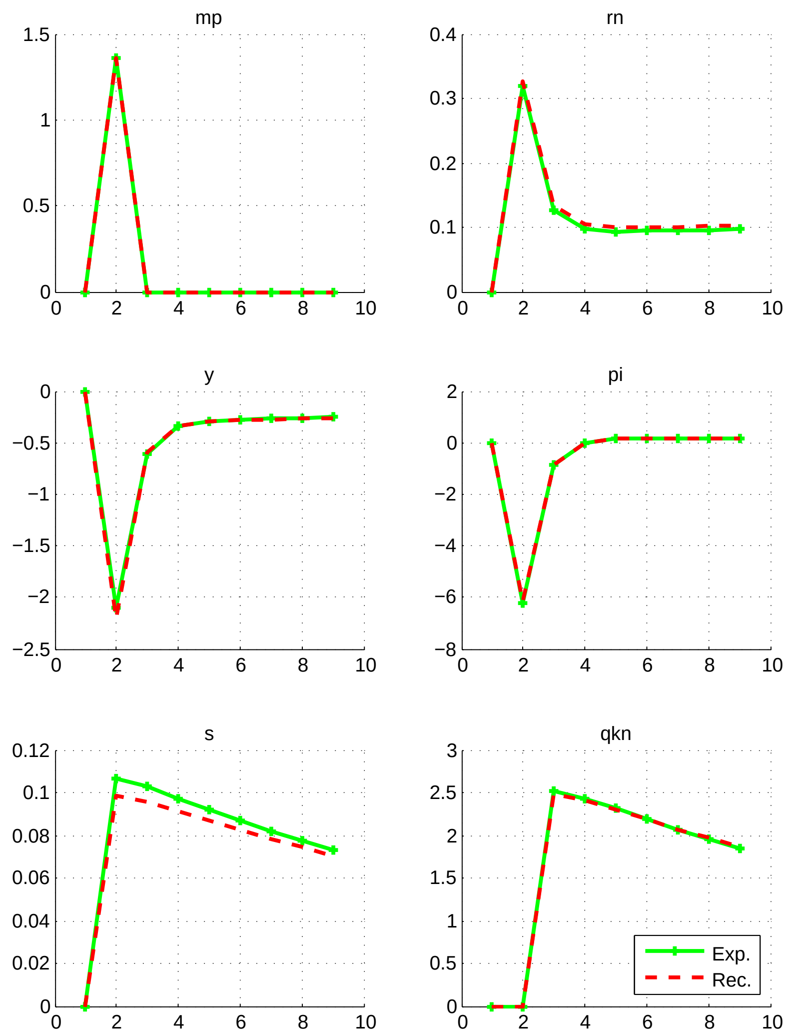
$Model1$**: Without Financial Accelerator, Linear Phillips Curve.** Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.4: The Response to Monetary Policy Shocks (mp), $Model2$



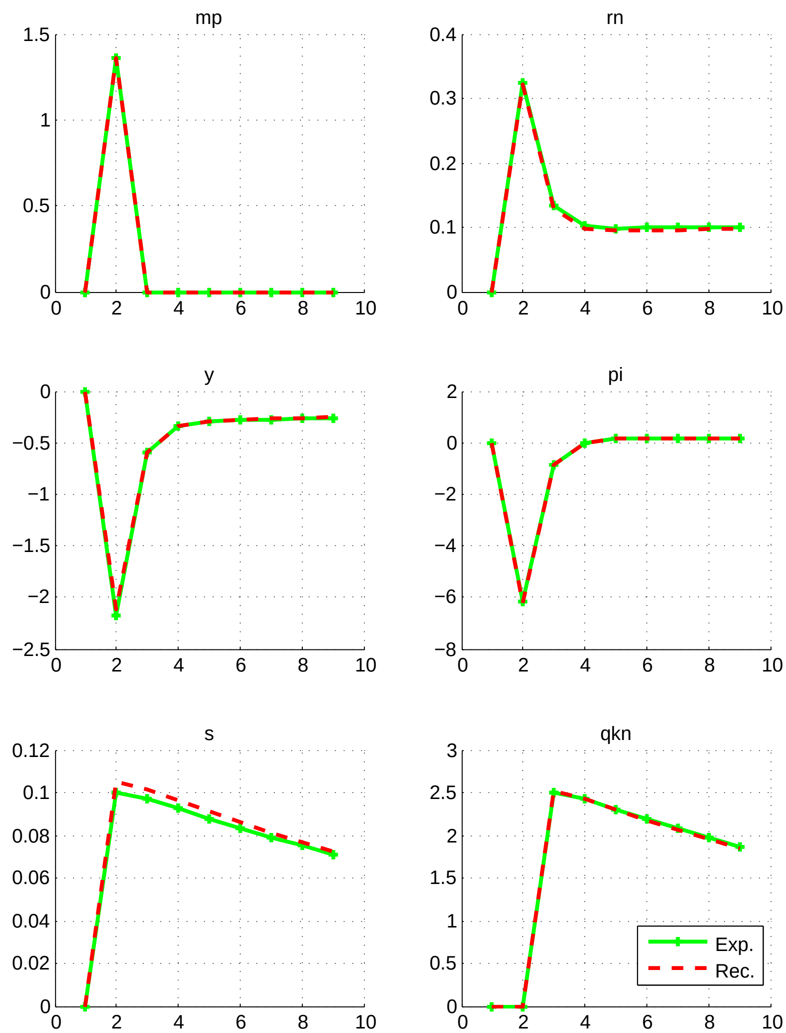
$Model2$**: With Financial Accelerator, Linear Phillips Curve.** The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values. For comparison purpose, responses to a two standard deviation of monetary policy shocks are divided by two, responses to a one- and two- negative standard deviation are divided by -1 and -2, respectively.

Figure 3.5: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions : Demand Shocks, $Model2$



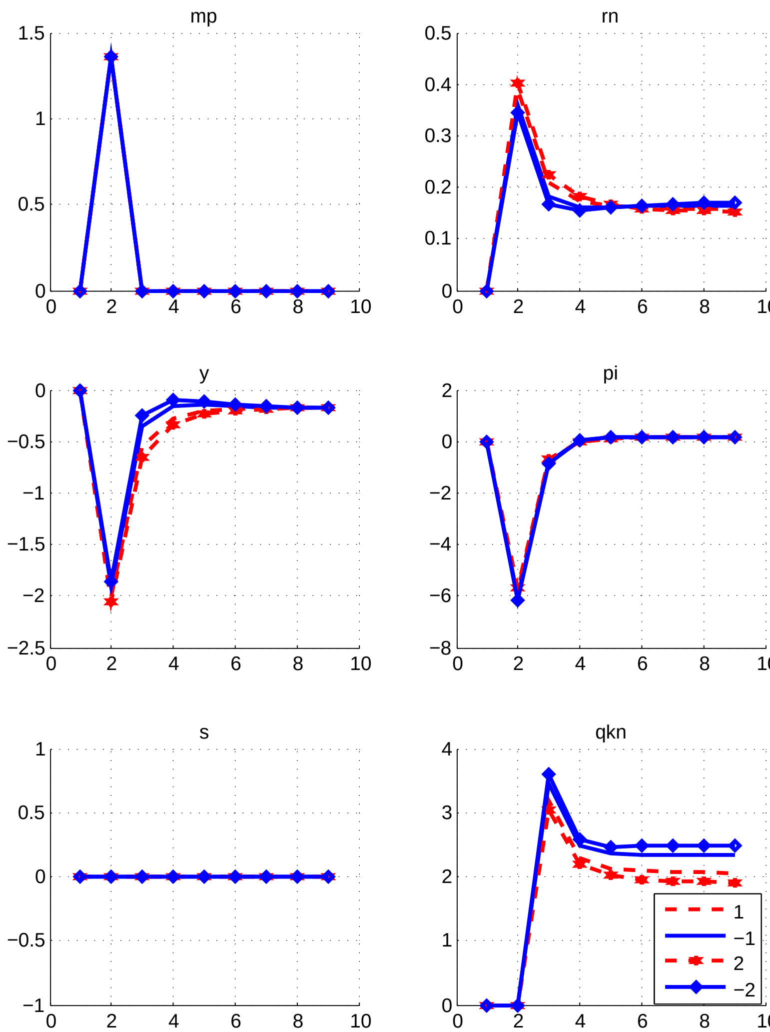
$Model2$**: With Financial Accelerator, Linear Phillips Curve.** Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.6: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions : Supply Shocks, $Model2$



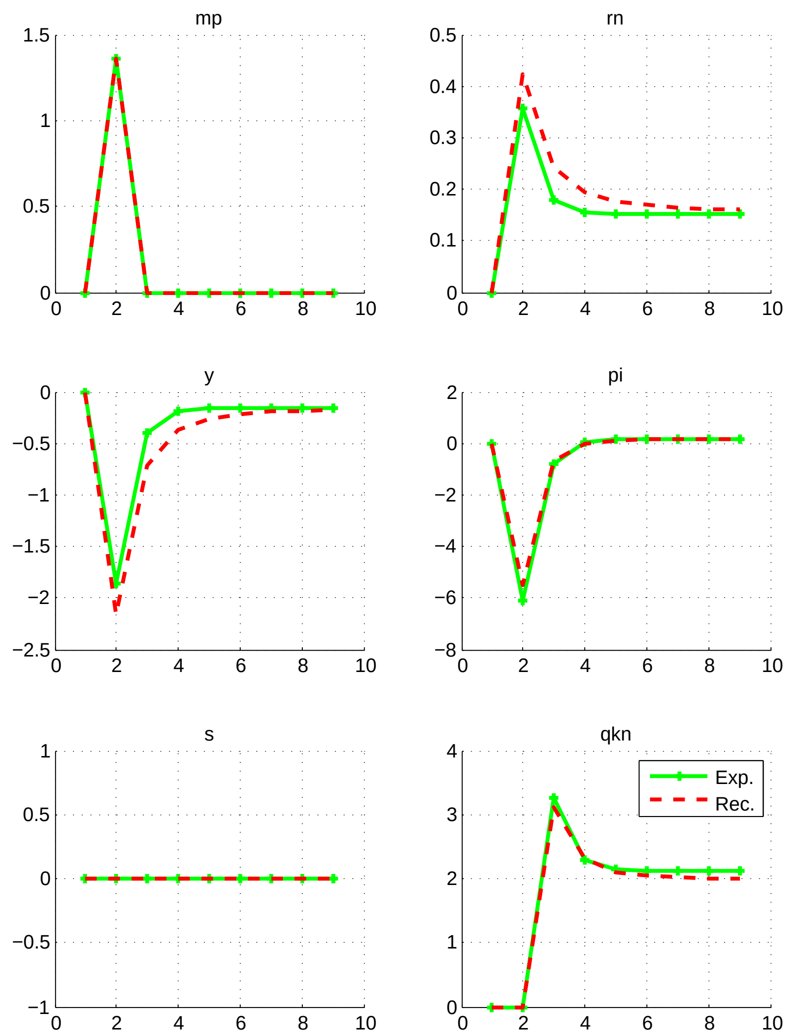
$Model2$**: With Financial Accelerator, Linear Phillips Curve.** Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.7: The Responses to Monetary Policy Shocks (mp), $Model3$



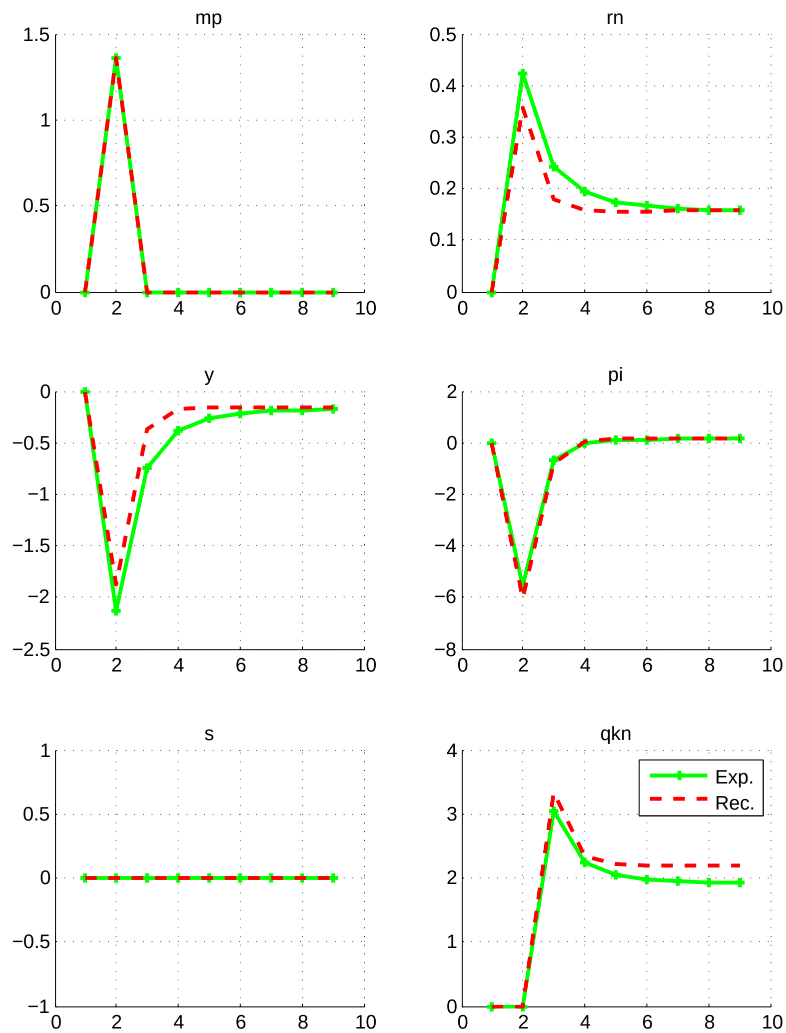
$Model3$ **: Without Financial Accelerator, Nonlinear Phillips Curve.** The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values. For comparison purpose, responses to a two standard deviation of monetary policy shocks are divided by two, responses to a one- and two- negative standard deviation are divided by -1 and -2, respectively.

Figure 3.8: The Responses to One Standard Deviation of Monetary Policy Shock in Expansions and Recessions : Demand Shocks, $Model3$



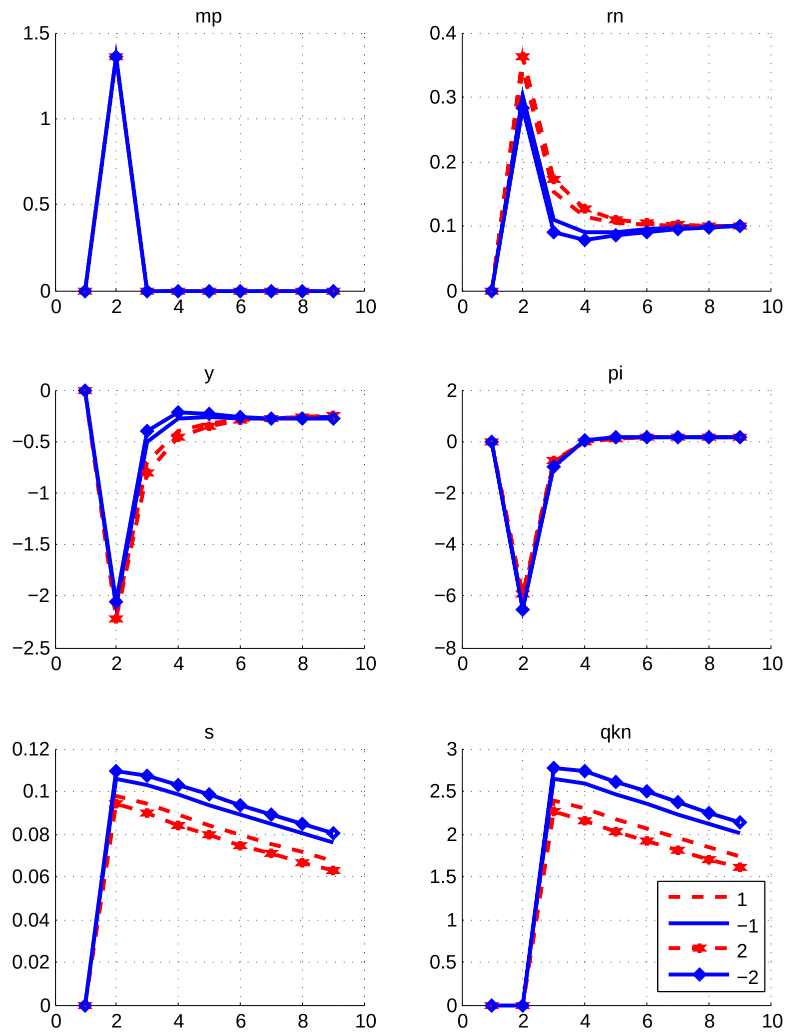
$Model3$**: Without Financial Accelerator, Nonlinear Phillips Curve.** Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.9: The Responses to One Standard Deviation of Monetary Policy Shock in Expansions and Recessions : Supply Shocks, $Model3$



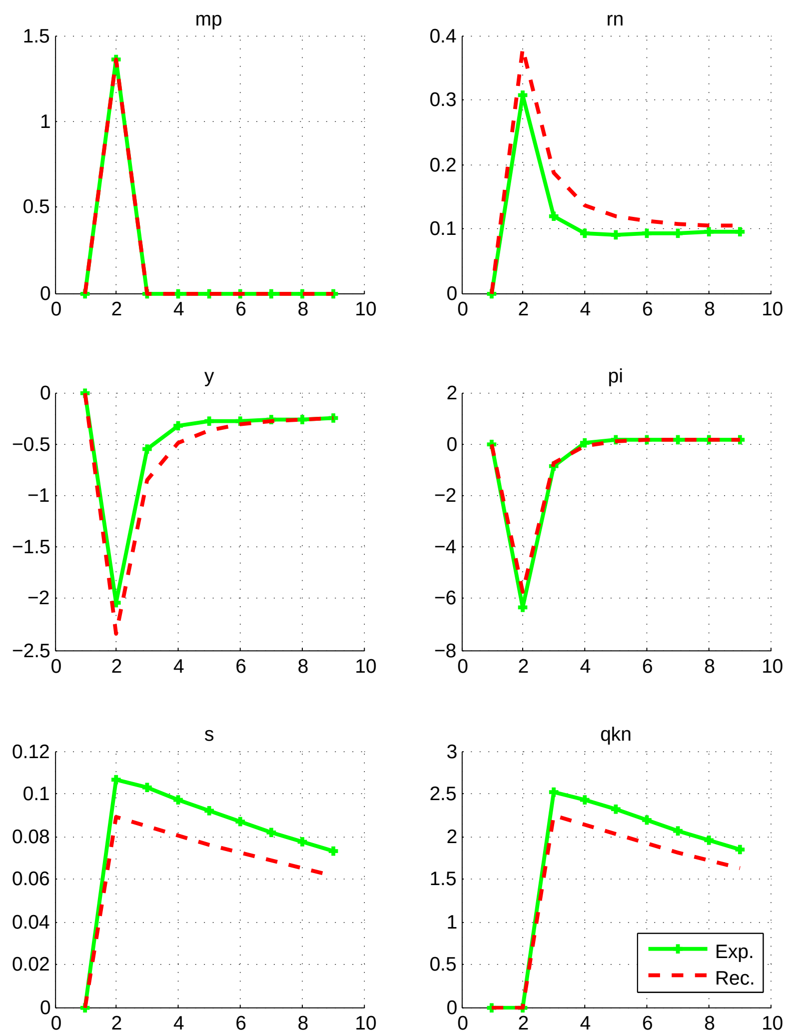
$Model3$**: Without Financial Accelerator, Nonlinear Phillips Curve.** Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.10: The Responses to Monetary Policy Shocks (mp), $Model4$



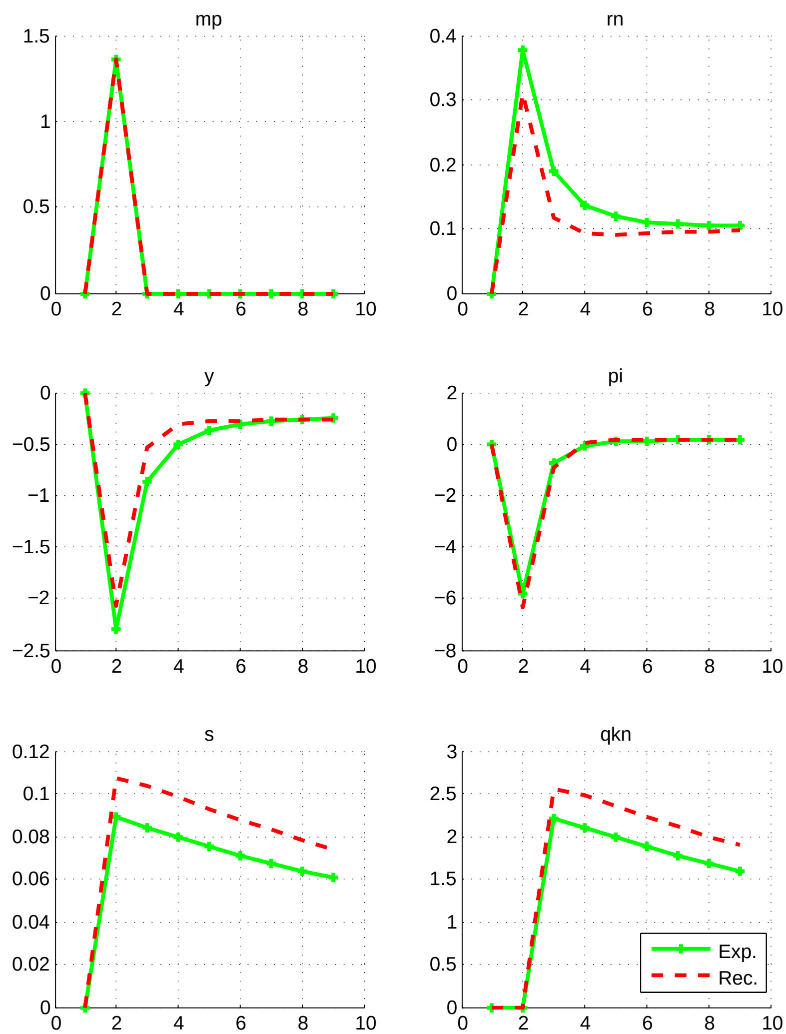
$Model$ **4: With Financial Accelerator, Nonlinear Phillips Curve.** The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values. For comparison purpose, responses to a two standard deviation of monetary policy shocks are divided by two, responses to a one- and two- negative standard deviation are divided by -1 and -2, respectively.

Figure 3.11: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions : Demand Shock (mp), $Model4$



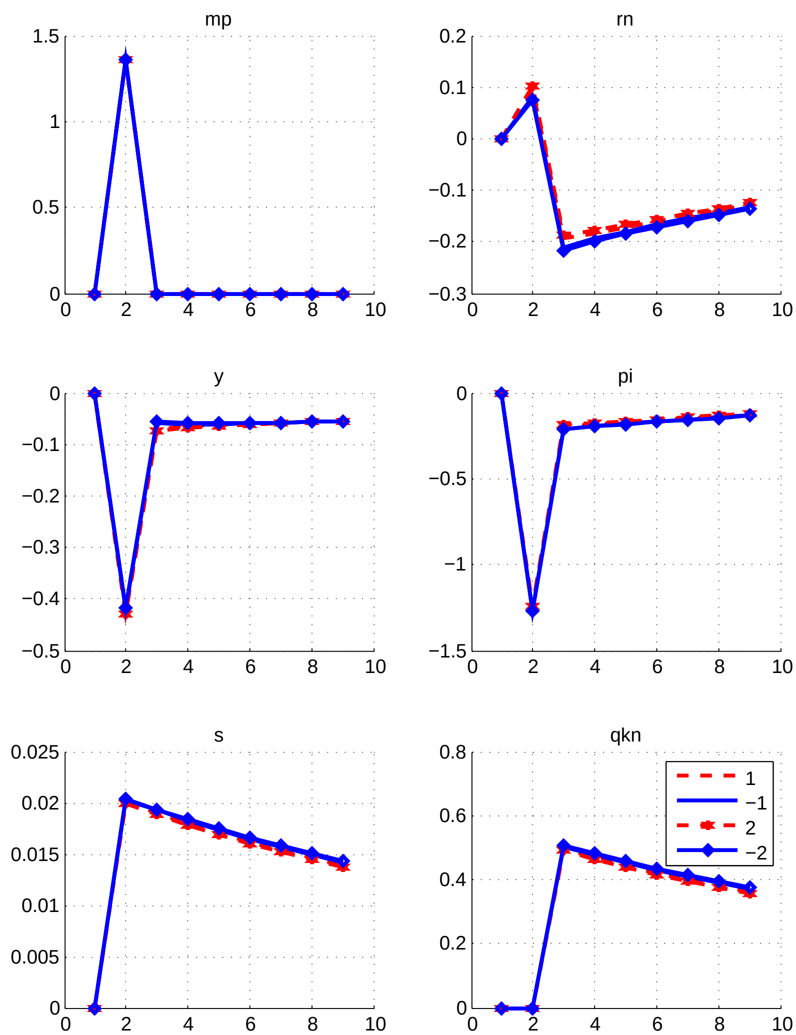
$Model4$**: With Financial Accelerator, Nonlinear Phillips Curve.** Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.12: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions : Supply Shock (mp), $Model4$



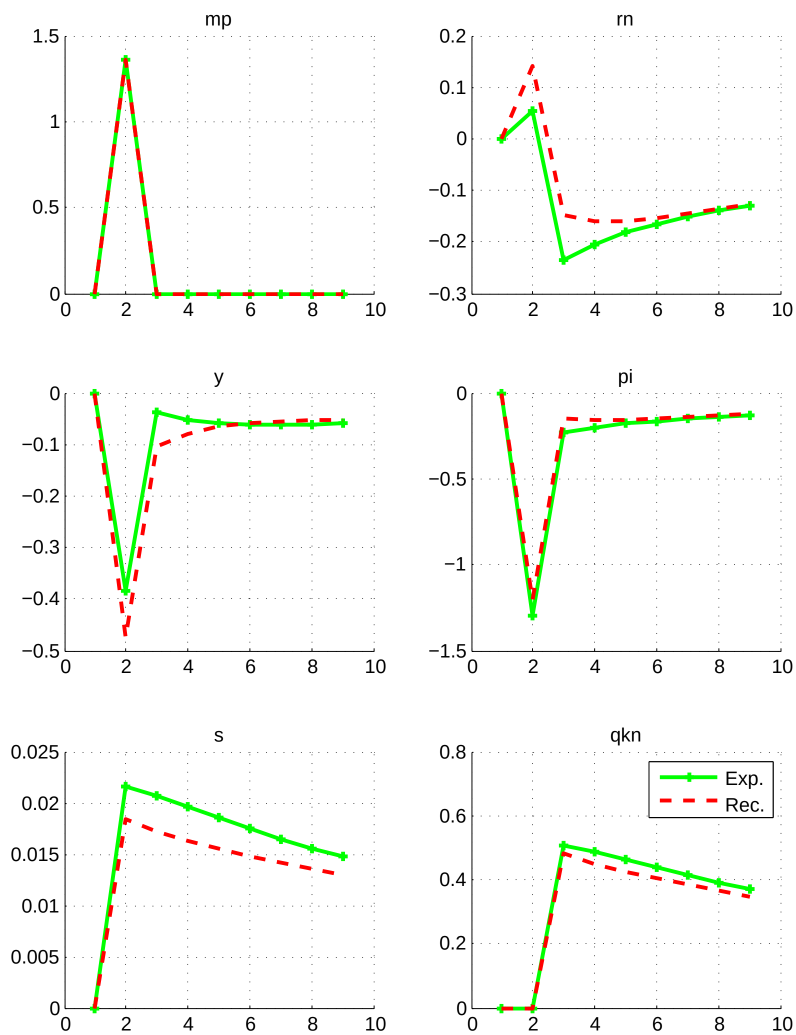
$Model4$**: With Financial Accelerator, Nonlinear Phillips Curve.** Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \bar{R}\left(\frac{R_{t-1}^n}{\bar{R}}\right)^{0.9}\left(\left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}\left(\frac{Y}{\bar{Y}}\right)^{0.5}\right)^{0.1}$, where variables with bar are steady state values.

Figure 3.13: The Responses to Monetary Policy Shocks (mp), $Model4$ (Simple Taylor's Rule)



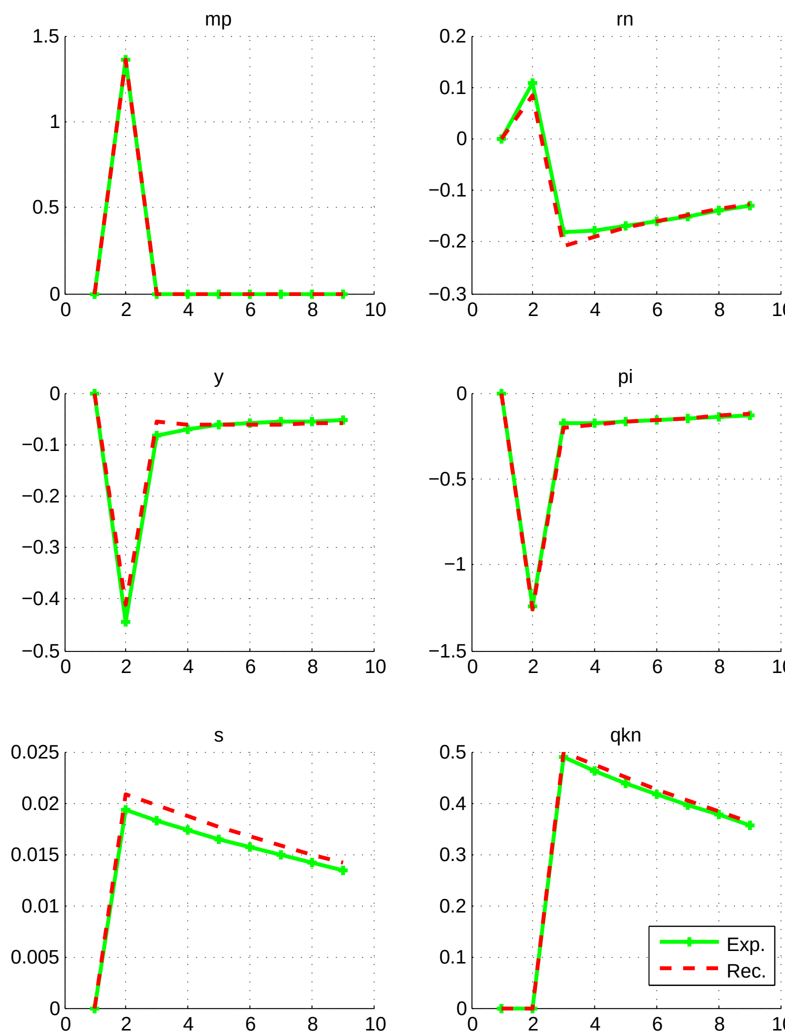
$Model4$**: With Financial Accelerator, Nonlinear Phillips Curve.** The monetary policy is $R_t^n = \left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}$, where variables with bar are steady state values. For comparison purpose, responses to a two standard deviation of monetary policy shocks are divided by two, responses to a one- and two- negative standard deviation are divided by -1 and -2, respectively.

Figure 3.14: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Demand Shocks, $Model4$ (Simple Taylor's Rule)



$Model4$**: With Financial Accelerator, Nonlinear Phillips Curve.** Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}$, where variables with bar are steady state values.

Figure 3.15: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shocks, $Model4$ (Simple Taylor's Rule)



$Model4$**: With Financial Accelerator, Nonlinear Phillips Curve.** Supply shock are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual). The monetary policy is $R_t^n = \left(\frac{\Pi}{\bar{\Pi}}\right)^{1.5}$, where variables with bar are steady state values.

Chapter 4

Asymmetric Effects of Monetary Policy in an Estimate DSGE Model

"Monetary policy was a string: You could pull on it to stop inflation but you could not push on it to halt recession. You could lead a horse to water but you could not make him drink". In 1967, Milton Friedman coined the word "pushing a string" to conceptually explain the notion of asymmetric effects of monetary policy shedding the light on this aspect of monetary policy which has been ignored for decades.

In the U.S. economy, many researchers document the asymmetric effects of the monetary policy. Foremost, Cover (1992), Morgan (1993) and Romer and Romer (1989) find that contractionary policies have a stronger impact on output than expansionary policies. Later on, other types of the asymmetry are recovered. In spite of asymmetric effects between contractionary and expansionary policies, Rhee and Rich (1995), Ravn and Sola (1997) and Senda (2001) find that moderate and aggressive policies have unproportionately scaled effects on the economy.

Regarding to the phases of business cycle, the above conclusions are made from an unconditional point of view. In the other word, the effects of the policy are considered regardless of the conditions of the economy. However, most expansionary policies are implemented during recessions and contractionary policies are used at expansions. Condition on the phases of business cycle, Thoma (1994) finds that contractionary policies have a stronger effect on the output during high-growth periods, while the effects of easy policies are the same throughout the business cycle. Weise (1999) finds that money supply has a stronger effect on the output with a small effect on prices when the output growth is low. Garcia and Schaller (1995) find that contractionary policies are more effective in general and the monetary policy will have stronger effects at recessions.

Besides the abundance of the evidences of the asymmetry, there is no consensus about its attributes. The aspects of the asymmetry are found differently when the different econometric techniques are used. Nonetheless, there are possible theoretical explanations for the causes of each aspect of the asymmetry.

Morgan (1993) classifies the theories into three groups: 1) convex supply curve, 2) credit constraints and 3) changing in economic outlook. A convex supply curve arises when price is more sticky downward. The process could be a result of a costly price adjustment process (e.g. Rotemberg (1982) and Ball and Mankiw (1994)), or that firms cannot adjust their prices frequently (e.g Calvo (1983)). The convex supply curve predicts that the policy implemented at recessions will have a greater (less) effect on output (price). Moreover, aggressive expansionary policies generally have a less (more) impact on output (price). Additionally, Ball and Mankiw (1994)'s menu cost theory casts that there is a threshold size of the monetary policy that makes the policy effective. Beyond this threshold, firms will not see any benefits to hold their prices. Thus, the effects of aggressive policies will go to the prices, leaving no room for the authority to interfere the real sector.

Second, the credit market friction creates the credit channel of the monetary policy. Carlstrom and Fuerst (1997), Bernanke et al. (1998), Kocherlakota (2000), and Florio (2006) show that the effects of monetary policy are amplified when financial market is tight. This hypothesis has two important implications on the asymmetric effects of the policy. First, the market is generally tight during booms making the policy more effective during those situations. Second, at any points of business cycle, contractionary policies put more pressure on the market. Consequently, contractionary policies are expected to have stronger effects than expansionary ones. However, the tightness of the market is not the only factor determining the role of financial friction, but the market risk is also a key factor to determine the risk premium, which ultimately influences the effects of the policy. For example, even though the market is not tight during recessions, an extra loan premium could be charged to compensate a lower successful chance of project. This mechanism, in turn, strengthens the role of the credit channel. Thus, the total effect of the credit constraints to the effectiveness of the policy is arbitrary depending on the total effect of the aggregate factors that determine the risk premium.

The third group of theories is changing economic outlook. The micro-founded theories that explain how the economic prospect can create asymmetric effects of the policy have not been seriously developed. The argument of this group of theories is based on people's attitudes toward the future states of the economy. Pessimism at recessions deteriorates the effectiveness of the policy to boost the economy. While optimism at expansions makes an over heated economy difficult to be controlled. The asymmetric effects of the policy will arise only if there are asymmetric effects between optimistic and pessimistic (Morgan (1993)).

The missing piece of the literatures is the link between the empirical works and the theoretical explanations. Mathematically, the asymmetric effects are the results of nonlinear interactions among the variables. On the one hand, a nonlinear econometric method is imperative to the empirical examining of the asymmetric effects of the policy. However, because of its complexity, the findings of the asymmetry will be supported by a reduced-form or a partial equilibrium model leaving the mechanism by which the asymmetric effects are created unclear (for example, Weise (1999)). On the other hand, applying a theoretical model to accounting for the observed asymmetry is also challenging. A partial equilibrium model, (for instance, Ball and Mankiw (1994)), ignores interaction among the economic sectors. Even though extending a theory to a general equilibrium is straightforward, obtaining a nonlinear solution and implementing it to explain the asymmetry are demanding. Moreover, the results of the model with a nonlinear solution cannot directly be applied to access the observed asymmetry.

The main objective of this paper is to evaluate the ability of a particular theory to explain the observed asymmetric effects of the monetary policy. Among other nonlinear econometric techniques, smooth transition auto regression (STVAR) is used to empirically examine the asymmetry. The structural model is constructed in a dynamic stochastic general equilibrium model to incorporate the interactions among economic sectors. Two sources of the asymmetry are considered: a convex supply curve and a financial friction, hypothesized by the Calvo (1983) pricing mechanism and Bernanke et al. (1998) financial accelerator, respectively. To preserve the nonlinearity of the model, the second-order perturbation method is used to obtain nonlinear solutions of the model. The parameters of the model cannot be obtained by the conventional maximum likelihood procedure with Kalman filtering. The conventional procedure requires (assumes) the likelihood function of the model to be correctly specified. In order to specify the likelihood function, the model has to be written in a state-space representation. However, the state-space representation can only be obtained when the solution method is the log-linearization, linearization, or the first-order perturbation method. Therefore, this paper adopts the indirect inference method that does not require a correctly specified likelihood function. The method is applicable to a nonlinear structure and a non-Gaussian shock structure. Finally, generalized impulse response functions are used to access and compare the asymmetric effects of the policy implied by the model and data.

The rest of the paper is organized as follows. The first section discusses STVAR and the empirical asymmetry. The second section briefly discusses the structural model. The third section describes the indirect inference estimators, the estimation procedure and the parameter estimates. The theoretical impulse response functions of the estimated model is presented in the forth section. The last section investigates the implications of the model in relation to the asymmetric effects of the monetary policy. Then, the implied impulse responses of the estimated model are compared to the empirical impulse responses to evaluate the ability of the model to explain the observed asymmetry.

4.1 Empirical Asymmetric Effects

This section empirically examines the asymmetric effects of monetary policy. Since the asymmetric effects of the policy deal directly to nonlinear relationships among variables, a nonlinear econometric model is essential to the analysis. A smooth tradition vector auto regression (STVAR) is employed to statistically describe the data. Then, the resultant generalized impulse responses (GIRFs) will be used to characterize the observed asymmetric effects of the policy.

STVAR combines two distinct VAR systems by a transition function $f(s_t)$, whose value depends on a switching variable s_t. The structure of STVAR is described in Equation 4.1a.

$$
\begin{aligned}
Y_t &= (1 - f(s_t))\,(A_0 + A(L)Y_{t-1}) + f(s_t)\,(C_0 + C(L)Y_{t-1}) + u_t, &\quad (4.1a)\\
Y_t &= A_0 + A(L)Y_{t-1} + f(s_t)(\underbrace{C_0 - A_0}_{B_0} + \underbrace{(C(L) - A(L))}_{B(L)}Y_{t-1}) + u_t, &\quad (4.1b)\\
Y_t &= A_0 + A(L)Y_{t-1} + f(s_t)(B_0 + B(L)Y_{t-1}) + u_t. &\quad (4.1c)
\end{aligned}
$$

The system composes of two VAR systems: regime A and regime C. The transition function, $f(s_t)$, whose value is between zero and one, switches between these two regimes. Equation 4.1c states the STVAR in a more comprehensible way. When the value of the transition function is zero, the model collapses to a convention VAR model, which is regime A. The transition from regime A to regime C is explained by the incremental values expressed in the lag polynomial $B(L)$.

How the system migrates from regime A to C depends on both value of the switching variable, s_t and the type of the transition function $f_t(\cdot)$. The choices of the switching variable in this paper are the variables in the VAR system and their lags up to the forth lag. Two types of the transition functions are considered: the first- and the second-order logistic function, represented in Equation 4.2 and Equation 4.3, respectively. The first-order logistic function captures two distinct extreme regimes attributing to a bipolar regime, while the second-order logistic function describes an intermediate and two extreme regimes. Besides the switching variable s_t, the value of the transition function depends on the scale parameter γ, and the locator parameter c for the first-order logistic and $\{c_1, c_2\}$ for the second-order logistic function.

$$f(s_t) = \left(1 + exp\left\{\frac{-\gamma(s_t - c)}{\sigma_{s_t}}\right\}\right)^{-1}; \gamma > 0. \tag{4.2}$$

$$f(s_t) = \left(1 + exp\left\{\frac{-\gamma(s_t - c_1)(s_t - c_2)}{\sigma_{s_t}}\right\}\right)^{-1}; \gamma > 0, c_1 \leq c_2. \tag{4.3}$$

Setting up a STVAR involves two steps. The first step is testing the nonlinearity of the model to verify the necessity of a nonlinear model. Once a nonlinear model is validated, the type of transition will be chosen. These procedures essentially test whether the polynomial B in Equation 4.1c is zero. Equivalently, the procedures test whether the scale parameter γ equals to zero. Luukkonen et al. (1988) and Teräsvirta and Anderson (1992) design a sequence of nested procedure test for nonlinearity test and choosing the switching variable. The procedure is as follows,

1. Run the standard regression to get the residual $\hat{\mathbf{u}}_t$

$$X_t = A_0 + \sum_{i=1}^{p} A_{1i} X_{t-i} + \mathbf{u_t}$$

2. Run the auxiliary regression to get the residual $\hat{\mathbf{v}}_t$

$$\begin{aligned} \hat{\mathbf{u_t}} = \Gamma_0 \quad &+ \quad \sum_{i=1}^{p} \Gamma_{1i} X_{t-i} + \sum_{i=1}^{p} \Gamma_{2i} s_t \iota'(n) X_{t-1} \\ &+ \quad \sum_{i=1}^{p} \Gamma_{3i} s_t^2 \iota'(n) X_{t-1} + \sum_{i=1}^{p} \Gamma_{4i} s_t^3 \iota'(n) X_{t-1} + \mathbf{v}_t \end{aligned} \tag{4.4}$$

The sequence nested hypotheses are,

1. $H_{01} : \Gamma_2 = 0 | \Gamma_3 = \Gamma_4 = 0$,

2. $H_{02} : \Gamma_3 = 0 | \Gamma_4 = 0$,

3. $H_{03} : \Gamma_4 = 0,$

The test statistic is a traditional LR, which has the asymptotic $\chi^2(pk^2)$ distribution, where p is the VAR order and k is the number of variables in the VAR system. The first hypothesis is the linearity test. Then, conditional on rejecting the linearity hypothesis, the logistic function should be chosen if H_{03} is rejected. The second-order logistic function should be chosen if H_{03} is not rejected and H_{02} is rejected. If only the linearity hypothesis is rejected, the function with the lowest p-value should be chosen.

The baseline VAR model in this study contains four variables. The variables are real the GDP, Y_t, real investment, Inv_t, GDP deflator based inflation, π_t, and the federal funds rate, rn_t. All variables, except the federal funds rate, are transformed by log differencing to make them stationary and to remove stochastic trends. The data are annualized and expressed in percentage numbers. Moreover, the data are filtered to remove possible structural breaks. Four possible structural break points are considered. The first break is the oil shock of October 1973. The second break is the changing in the policy regime of the Volcker period, when the Fed abandoned interest rate targeting in favor of money supply targeting. The third break is the evidence of a sharp decline in output volatility in 1985.[1] However, the timing of the third break is about as same as the starting period of Greenspan. To avoid too much filtering, only 1985 is selected. The last possible structural change is at the starting of 2008, marked by the sharp drop in the federal funds rate in response to the subprime crisis. The data are regressed on constant, dummies for post- 72, post- 79, post- 84, post- 08 periods, a time trend and the time trend interacted with structure break dummies.

AIC and Schwarz criterion suggest a VAR system with either one or four lag structure. Ruge-Murcia (2007) discusses the implication of the stochastic singularity on the VAR representation of a DSGE model. The stochastic singularity casts restrictions on both the number of variables in the VAR system and the lag structure. For a three-structural-shock model, the variance matrix of a system that contains more than 4 variables will be singular. The valid

[1]See more detail in Kahn et al. (2002), Blanchard and Simon (2001), and Stock and Watson (2002).

VAR structures would be either a system of two variables with one or two lags or a system of 4 variables with one lag. Thus, a one-lag VAR model, which is VAR(1) of $\{Y, Inv, \pi, rn\}_t$, is chosen.

Table 4.1 reports the nonlinearity tests. The linearity hypotheses are rejected in all models. The second-order logistic are chosen to be the switching variable in 10 out of 16 cases. Sorting by the highest LR statistic, the first three switcher candidates are $Y(-2)$ with, $Y(-1)$, and $Inv(-2)$, respectively.

The next step of setting the STVAR is finding the scale γ and the locator $\{c1, c2\}$ parameters. The standard maximum likelihood method could be used to obtain the estimates. However, the system is very sensitive to γ and $\{c1, c2\}$ making the estimation a very time consuming process. Alternatively, this paper applies a grid search method, similar to Weise (1999), to obtain the estimates. By fixing γ and $\{c1, c2\}$ the system becomes a traditional VAR. Thus, the ordinary least square can be used to find the parameters and the likelihood function. The grid is constructed by combinations of γ, $c1$ and $c2$. The grid of γ ranges from 0 to 100 with a 0.1 step length. The grid of $c1$ and $c2$ are constructed by the sorted true value of Y conditioning on that $c1$ is less than or equals to $c2$. In order to have enough observations in each regime, only the observations of the switcher that fall into 20 and 80 quantile are used.

After obtaining the STVAR parameters, the model can also be used to construct the generalized impulse response functions (GIRFs), developed by Koop et al. (1996), which can be used to examine the asymmetric effects of the policy. The procedure to construct the GIRFs is summarized as follows,

1. Set the initial state by picking a part of actual data, denoted as Ω_{t-1}^k.

2. Design a hypothesized shock, e.g. the policy shock, denoted as ϵ_0^*.

3. Generate a q-period shocks from a multivariate normal distribution with zero mean and variance of the estimated residuals, denoted by ϵ_t^j, which have a dimension qk.[2]

[2]The procedure to pick up shocks is flexible. Koop et al. (1996) suggests to randomly draw with replacement

Table 4.1: Lagrange Multiplier Tests for Linearity

Switching	F Statistic : Dependent Variable is							Transition
Variable	Y	Inv	π	rn	LR	H_{02}	H_{03}	Function
Y(-1)	1.364	1.986	1.579	1.991	130.734	97.485	128.460	L1
	(0.165)	(0.017)	(0.079)	(0.016)	(0.000)	(0.004)	(0.000)	
Y(-2)	2.165	1.607	2.045	2.711	142.083	106.227	118.127	L1
	(0.008)	(0.071)	(0.013)	(0.001)	(0.000)	(0.001)	(0.000)	
Y(-3)	1.431	0.776	1.470	2.530	110.733	125.939	87.145	L2
	(0.133)	(0.711)	(0.116)	(0.002)	(0.000)	(0.000)	(0.029)	
Y(-4)	1.266	1.486	1.392	0.896	93.209	112.542	103.409	L2
	(0.224)	(0.110)	(0.151)	(0.574)	(0.010)	(0.000)	(0.001)	
Inv(-1)	0.822	1.426	1.626	1.563	96.188	124.279	78.393	L2
	(0.660)	(0.135)	(0.067)	(0.084)	(0.006)	(0.000)	(0.106)	
Inv(-2)	1.196	1.415	2.162	2.987	126.855	107.641	100.911	L2
	(0.276)	(0.140)	(0.008)	(0.000)	(0.000)	(0.001)	(0.002)	
Inv(-3)	0.903	0.784	1.600	2.467	100.683	84.065	79.201	L2
	(0.567)	(0.702)	(0.073)	(0.002)	(0.002)	(0.047)	(0.095)	
Inv(-4)	1.074	1.149	2.555	0.997	101.868	66.822	76.357	L1
	(0.383)	(0.314)	(0.001)	(0.462)	(0.002)	(0.380)	(0.139)	
π(-1)	0.929	1.300	2.362	2.228	126.652	136.511	96.471	L2
	(0.537)	(0.202)	(0.003)	(0.006)	(0.000)	(0.000)	(0.005)	
π(-2)	1.372	1.176	1.406	2.145	102.206	110.559	82.948	L2
	(0.161)	(0.292)	(0.144)	(0.009)	(0.002)	(0.000)	(0.056)	
π(-3)	1.598	1.452	1.598	1.805	102.761	85.243	95.689	L1
	(0.074)	(0.123)	(0.074)	(0.034)	(0.002)	(0.039)	(0.006)	
π(-4)	1.394	0.979	1.971	2.283	106.242	105.244	122.585	L1
	(0.150)	(0.482)	(0.018)	(0.005)	(0.001)	(0.001)	(0.000)	
rn(-1)	1.481	0.994	1.733	1.793	98.584	88.285	64.188	L2
	(0.112)	(0.465)	(0.045)	(0.036)	(0.004)	(0.024)	(0.470)	
rn(-2)	1.527	1.206	1.152	1.076	86.944	94.629	74.879	L2
	(0.095)	(0.268)	(0.312)	(0.381)	(0.030)	(0.008)	(0.166)	
rn(-3)	1.506	1.365	1.449	2.240	111.726	52.915	99.953	L1
	(0.103)	(0.165)	(0.125)	(0.006)	(0.000)	(0.837)	(0.003)	
rn(-4)	1.362	1.159	1.529	1.322	92.691	77.253	108.028	L1
	(0.166)	(0.306)	(0.095)	(0.189)	(0.011)	(0.124)	(0.000)	
dπ(-1)	0.680	2.090	1.970	1.177	121.323	95.886	85.207	L2
	(0.811)	(0.011)	(0.018)	(0.291)	(0.000)	(0.006)	(0.039)	
dπ(-2)	1.694	1.104	1.411	2.146	112.113	85.434	82.197	L2
	(0.052)	(0.355)	(0.142)	(0.009)	(0.000)	(0.038)	(0.062)	
dπ(-3)	1.065	1.390	2.151	0.922	91.670	96.820	74.827	L2
	(0.392)	(0.152)	(0.008)	(0.545)	(0.013)	(0.005)	(0.167)	
dπ(-4)	1.125	1.136	1.598	1.438	85.312	80.635	96.504	L1
	(0.336)	(0.326)	(0.074)	(0.129)	(0.039)	(0.078)	(0.005)	

p-value is in the parenthesis. Column 5 (LR) reports linearity test for the whole system. $H_{02} : \Gamma_3 = 0|\Gamma_4 = 0$, $H_{03} : \Gamma_4 = 0$. If the p-value of H_{02} is less than one of H_{03}, the second-order logistic function is chosen, represented by "L2". Otherwise, the first-order logistic is chosen, represented by "L1".

from the estimated residual. With a large number of random draws, the results from both methods converge.

4. Construct a benchmark path by feeding the model a zero shock at period $t = 0$ and ϵ_t^q later on, denoted by $GI_0^{ki}(\Omega_{t-1}^k, 0, \epsilon_t^j)$.

5. Construct a hypothesized path by feeding the model a hypothesized shock, ϵ_0^j, at period $t = 0$ and ϵ_t^q later on, denoted by $GI_1^k(\Omega_{t-1}^{ki}, \epsilon_0^*, \epsilon_t^j)$.

6. Repeat step 2-4 B times.

7. Repeat step 1-5 R times.

8. Compute an average impulse response function GI by $\sum_k^R \sum_j^B (GI_1^k((\Omega_{t-1}^{ki}, \epsilon_0^*, \epsilon_t^j) - GI_0^{ki}(\Omega_{t-1}^k, 0, \epsilon_t^j))/BR.$

The initial states are classified as expansion and recession periods. The expansion periods are determined by the output growth exceeding 4 percent annual (about +1 standard deviation of the output growth). Similarly, the negative output growth (about -1 standard deviation of the output growth) determines recession periods. In the second step, a one standard deviation size of the monetary policy shock will be used to construct the responses. The lower triangular matrix of the Cholesky decomposition, the conventional procedure, is used to identify the structural shocks implying that the output is the most independent variable and the policy is the least independent variable. The repetition in the sixth step is set to 200. All samples in each period are used in the seventh step.

GIRFs are also used as another diagnostic tool to select the switcher for STVAR model. Even thought $Y(-2)$ and $Y(-1)$ yield the highest values of LR statistic indicating that they can explain the omitting nonlinearity better than other variables, their resultant GIRFs exhibit certain degree of instability. On the other hand, $Inv(-2)$ has a comparable value of LR statistic while its resultant GIRFs are more stable. Hence, $Inv(-2)$ with the second-order logistic function is chosen as the switcher and the switching function. The locator and slope parameters are $\{-7.81, 0.69\}$ and 84, respectively.

Figure 4.13 displays the unconditional GIRFs. All data points are used as the initial states. The responses of the observed data are displayed in panel A. Panel B displayed the ones of the simulated data whose derivation procedure and the implications will be explained later. To make the responses comparable, the responses to expansionary policies will be flipped, upward or downward depending on the base case responses, by multiplying the responses by -1. The responses to aggressive policies will be scaled down by dividing by 2. Should the monetary policy have symmetric effects, the impulse responses to different policies will lie on top of each other.

The asymmetric effects of the monetary policy are barely noticed in every variable. Nevertheless, contractionary policies tend to have stronger effects than expansionary ones. To test the effects of the monetary policy throughout the business cycle, the same policies are implemented at recessions and expansions. The similar observations are found at both phases of business cycle: neither asymmetric effects between a different size of the policies nor the type of the policies are found. These findings support that the monetary policy does not have asymmetric effects on the economy when it is implemented at particular phases of business cycle. To conserve the space, the results are not omitted.

Another step is to examine different effects of a particular policy when it is implemented at the different phases of the business cycle. Since any policy implemented at a given phase of business cycle has no asymmetric effects, focusing on only one type of the policy is sufficeint. Using a moderate contractionary policy (+1 s.d. policy shock), panel A of Figure 4.14 examines the effects of the monetary policy when it is implemented at recessions and expansions. The policy implemented at recessions is found to have stronger impacts on all variables.

In summary, the only detectable type of the asymmetry observed from the data is the asymmetric effects of the policy implemented at different phases of business cycle. The policy implemented at recessions is found to have stronger effects than one implemented at expansions.

4.2 Structural Model

The implication of the structural model in regard to the asymmetric effects of monetary policy is investigated in this section. The model is a standard new Keynesian DSGE model augmented by Bernanke et al. (1998)'s financial accelerator model. It is equipped with two sources of the asymmetry, which are a convex supply curve and a financial friction.

The full description of the model can be found in the previous chapter. To direct attention to investigate the ability of the model to explain the asymmetric effects of the policy, only the first order conditions are presented here. The first order conditions can be classified into 7 groups: exogenous shocks, households, government sector, retailers, entrepreneurs, resource constraints, and the financial contract problem.

There are three exogenous shocks in the model: technological shock A_t, government expenditure shock G_t, and monetary policy shock, mp_t. All shocks are described by AR processes and assumed independent from each other. For $i \in \{A, G, mp\}_t$, the random variable ε_t^i is i.i.d. normal with zero mean and σ^i standard deviation.

Government conducts both fiscal $G_t - T_t$ and monetary policy. The interest rate R_t^n is the policy instrument following a Taylor rule to stabilize output and inflation. Thus, money supply M_t and lump-sum tax T_t are determined endogenously by the money demand function in Equation 4.10 and government budget constraint in Equation 4.11.

Households live infinitely and make decisions on consumption expenditure C_t, supply labor service H_t, and holding real money balance $\frac{M_t}{P_t}$. They receive wage payment W_t, benefit from deposit $R_t D_t$, and receive dividend F_t from the retailers, and pay lump-sum tax. The households' utility function is $U(\cdot) = \frac{(C_t - \psi \bar{C})^{1-\sigma_c}}{1-\sigma_c} + \rho \frac{(1-H_t)^{1-\sigma_n}}{1-\sigma_n} + \xi \ln(\frac{M_t}{P_t})$.

Retailers, owned by households, buy identical products Y from entrepreneurs at a wholesale price. Then, they differentiate and resale the products at a higher price in a monopolistic competition market. The pricing dynamics is assumed to follow the Calvo pricing mechanism. At each period, only fraction $1-\theta$ of all retailers can change their prices. Once the opportunity to change the price comes, retailers choose the optimal prices to maximize their expected profits knowing that their chances to change the prices at each period is $1 - \theta$. Thus, the optimal prices do not only balance today costs and revenues but also the expected future circumstances. Together with the nonlinear relationships in the Euler's conditions, Calvo pricing ultimately creates a nonlinear input-inflation tradeoff, so called nonlinear Phillips curve. The structure of the nonlinear Phillips curve is written in a recursive way to summarize the infinite sum. Moreover, the price dispersion dynamics is preserved and described in Equation 4.18. Should the model be linearized, the price dispersion is not relevant in choosing the optimal prices. However, the model in this study is approximated by the second-order perturbation method. Thus, the price dispersion and its dynamics are important.

Carlstrom and Fuerst (1997) and Bernanke et al. (1998) introduce entrepreneur sector to create a financial friction. The infinite numbers of entrepreneurs are exposed to the same production technology. They combine the capital goods K_t and labor service H_t to produce the wholesale goods and sell those to retailers. They also supply their own labor service H_t^e and consume the consumption goods C_t^e. However, their net worth NW_t are not enough to acquire the adequate amount of capital goods. In additional, there is a γ chance that they might not survive to next period. These two assumptions force entrepreneurs to borrow from the bank and guarantee the existing of the financial contract. If the investment projects are fruitful, entrepreneurs can pay back the loans. Otherwise, the loans will be default. The project returns contain a general market risk R_t^k and idiosyncratic risk ω_t^i. The ability to pay back the loans of each entrepreneur depends on the leverage ratio $\frac{Q_t K_{t+1}}{N_{t+1}}$ and the idiosyncratic risk. The bank charges an extra premium S_t on the risk free rate R_t to compensate this default risk. However, the idiosyncratic risk is entrepreneurs' private information. Thus, the bank has to design a financial contract that makes entrepreneurs report truthfully and the bank can obtain the maximized profit. This process establishes the financial accelerator. It amplifies the effects of the monetary policy via the credit channel by influencing the optimal the risk premium.

Lastly, the resource constraint summarizes how the resources can be used. The total consumption goods $Y^f = Y_t \Delta_t$ is allocated to total consumption $C_t + C_t^e$, investment I_t, government expenditure G_t and total verifying cost $\int_0^{\overline{\omega}_t^j} \mu(\omega_t^j) dF(\omega_t^j)$. Moreover, the investment is subjected to a quadratic investment adjustment cost.

This system of first order conditions defines the dynamics of the model. The system is, however, a highly nonlinear system. Thus, the exact solutions of the model cannot be analytically obtained. Instead, the solutions of the model are obtained by the second-order perturbation method to preserve the nonlinearity of the model.

Shocks:

$$\begin{aligned} ln(A_{t+1}) &= \rho_a ln(\frac{A_t}{\bar{A}}) + \varepsilon^a_{t+1}, & (4.5)\\ ln(G_{t+1}) &= \rho_g ln(\frac{G_t}{\bar{G}}) + \varepsilon^g_{t+1}, & (4.6)\\ ln(mp_{t+1}) &= \rho_{mp} ln(\frac{mp_t}{\bar{mp}}) + \varepsilon^{mp}_{t+1}. & (4.7) \end{aligned}$$

Households:

$$\begin{aligned} U_{C_t} &= E_t(\beta U'_{C_{t+1}})R_{t+1}, & (4.8)\\ -\frac{U_{H_t}}{U_{C_t}} &= W_t, & (4.9)\\ \frac{U_{M_t/P_t}}{U_{C_t}} &= \left(\frac{R^n_{t+1}-1}{R^n_{t+1}}\right)^{-1}. & (4.10) \end{aligned}$$

Government Sector:

$$\begin{aligned} G_t &= \frac{M_t - M_{t-1}}{P_t} + T_t, & (4.11)\\ \Pi_t &= \frac{P_t}{P_{t-1}}, & (4.12)\\ R^n_t &= R_t \Pi_t, & (4.13)\\ R^n_t &= \overline{R}\left(\frac{R^n_{t-1}}{\overline{R}}\right)^{\rho_r}\left(\frac{\Pi_{t-1}}{\overline{\Pi}}\right)^{\rho_\pi}\left(\frac{Y_{t-1}}{\overline{Y}}\right)^{\rho_y} mp_t. & (4.14) \end{aligned}$$

Retailers (Phillips Curve):

$$\begin{aligned} \theta\Pi_t^{\varepsilon-1} &= 1-(1-\theta)\left(\frac{N_t}{D_t}\right)^{1-\varepsilon}, & (4.15)\\ N_t &= \mu U_{C_t} MC_t Y^f_t + \theta\beta E_t\left[\Pi^{\varepsilon}_{t+1} N_{t+1}\right], & (4.16)\\ D_t &= U_{C_t} Y^f_t + \theta\beta E_t\left[\Pi^{\varepsilon-1}_{t+1} D_{t+1}\right], & (4.17)\\ \Delta_t &= \theta\Delta_{t-1}\Pi^{\varepsilon}_t + (1-\theta)\left(\frac{N_t}{D_t}\right)^{-\varepsilon}. & (4.18) \end{aligned}$$

Entrepernuers:

$$
\begin{aligned}
Y_t &= A_t K_t^{\alpha} H_t^{\Omega(1-\alpha)}, && (4.19)\\
R_t^k &= \frac{\alpha \frac{Y_t}{K_t} MC_t + Q_t(1-\delta)}{Q_{t-1}}, && (4.20)\\
W_t &= (1-\alpha)\Omega \frac{Y_t}{H_t} MC_t, && (4.21)\\
W_t^e &= (1-\alpha)(1-\Omega)\frac{Y_t}{H_t^e} MC_t, && (4.22)\\
N_{t+1} &= R_t^k f_t(\overline{\omega}_t^j)\frac{1}{(1-\frac{R_t^k}{R_t} g_t)}\gamma + W_t^e, && (4.23)\\
C_t^e &= R_t^k f_t(\overline{\omega}_t^j)\frac{1}{(1-\frac{R_t^k}{R_t} g_t)}(1-\gamma). && (4.24)
\end{aligned}
$$

Financial Contract:

$$
\begin{aligned}
E_t(R_{t+1}^k) &= S_t R_{t+1}, && (4.25)\\
\frac{1}{S_t} &= f_{t+1} + g_{t+1} + cost'_{t+1}\frac{f_{t+1}}{F(\overline{\omega}_{t+1}^j) - 1}, && (4.26)\\
\frac{Q_t K_{t+1}}{N_{t+1}} &= \frac{1}{(1 - S_t g_{t+1}),} && (4.27)\\
f_{t+1} &= \int_{\overline{\omega}_{t+1}^j}^{\infty} \omega_{t+1}^j dF(\omega_{t+1}^j) - \int_{\overline{\omega}_{t+1}^j}^{\infty} \overline{\omega}_{t+1}^j dF, && (4.28)\\
g_{t+1} &= \int_0^{\overline{\omega}_{t+1}^j} \omega_{t+1}^j dF(\omega_{t+1}^j) + \int_{\overline{\omega}_{t+1}^j}^{\infty} \overline{\omega}_{t+1}^j dF - \mu \int_0^{\overline{\omega}_{t+1}^j} \omega_{t+1}^j dF(\omega_{t+1}^j). && (4.29)
\end{aligned}
$$

Resource Constraint and Investment Dynamics:

$$
\begin{aligned}
Y_t \Delta_t &= C_t + C_t^e + G_t + I_t + \int_0^{\overline{\omega}_t^j} \mu(\omega_t^j) dF(\omega_t^j), && (4.30)\\
K_{t+1} &= \Phi\left(\frac{I_t}{K_t}\right) + (1-\delta)K_t, && (4.31)\\
\Phi\left(\frac{I_t}{K_t}\right) &= \left(\frac{I_t}{K_t} - \frac{\Psi}{2}(\frac{I_t}{K_t} - \delta)^2\right) K_t, && (4.32)\\
Q_t &= \left[\Phi'\left(\frac{I_t}{K_t}\right)\right]^{-1}. && (4.33)
\end{aligned}
$$

4.3 Indirect Inference Estimator

Considering a particular model, there are two characters of the model that contribute to the asymmetric effects of the policy. The first factor is the interaction between sectors in the model that creates the transmission mechanism. The second factor is the curvature of the model governed by the model parameters. The parameters in this paper are estimated by indirect inference using the U.S. data.

The indirect inference estimator, also referred to as the extended method of simulated moments (EMSM), is developed by Smith Jr (1993), Gourieroux et al. (1993), Gallant and Tauchen (1996), and Keane and Smith (2003). The indirect inference estimator is a simulation-based method. Instead of an accurate description similar to a likelihood function, it uses an arbitrary auxiliary function to form a criterion function. If the auxiliary function is the likelihood function itself, the indirect inference estimator and the maximum likelihood estimator are identical. Otherwise, the indirect inference estimator is a version of a quasi-maximum likelihood estimator, which is a consistent estimator. Thus, the method is suitable when the likelihood function is difficult to be obtained and the data can be simulated by the structural model.

The method applies the auxiliary function to both actual data, $\boldsymbol{X}_T$, and simulated data, $\boldsymbol{X}_S$. The length of the simulated data is at least equal to the length of the actual data, $S \geq T$ and the number of the auxiliary parameters, k, has be at least equal to the number of the structural parameters, $n; k \geq n$. Then, the $n \times 1$ vector of the structural parameters, $\boldsymbol{\theta}$, is estimated by minimizing the distance between these two auxiliary functions. First, the $k \times 1$ vector of the auxiliary parameters $\hat{\boldsymbol{\beta}}_T$ is estimated by an optimization procedure. In particular, if the auxiliary function is the log-likelihood function $f(\boldsymbol{\beta}, \boldsymbol{X})$, the vector $\hat{\boldsymbol{\beta}}_T$ is defined by,

$$\hat{\boldsymbol{\beta}}_T = \max_{\boldsymbol{\beta}} f(\boldsymbol{\beta}, \boldsymbol{X}_T).$$

Gourieroux et al. (1993) and Keane and Smith (2003) discuss approaches to the indirect inference. First, the auxiliary parameters of the simulated data, $\tilde{\boldsymbol{\beta}}_S$, can be estimated by two alternative procedures. Both procedures apply the same maximum likelihood routine. The first procedure simulates τ replications of $\boldsymbol{X}_T$. The vector $\hat{\boldsymbol{\beta}}_i$ is estimated for each replication. Then the auxiliary parameters are defined by a simple average of the estimates, $\tilde{\boldsymbol{\beta}}_S = \frac{1}{\tau}\sum_i^{\tau}\hat{\boldsymbol{\beta}}_i$. Another procedure simulates one large data set of length $\tau \times T$. Then the auxiliary parameters are estimated by maximizing the log-likelihood, $\tilde{\boldsymbol{\beta}}_S = \max_{\boldsymbol{\beta}} f(\boldsymbol{\beta}, \boldsymbol{X}_{\tau\times T})$. These two procedures have the same statistical properties. This paper adopts the second procedure owning to its numerical advantage.

Second, three types of the metric can be used to define the distance between the data set in estimation process: Wald, LM and LR approach. Should the auxiliary function be statistically correctly specified, all three approaches will have the same asymptotic properties. While the Wald and LM approach use a quadratic distance function as the metric, the LR approach employs the log-likelihood function itself as the metric.

The Wald approach directly applies a quadratic distance function to the auxiliary parameters. The indirect inference estimator is defined by,

$$\hat{\boldsymbol{\theta}}_{Wald} = \underset{\boldsymbol{\theta}}{\operatorname{argmin}} \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}) - \hat{\boldsymbol{\beta}_T}\right)' W \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}) - \hat{\boldsymbol{\beta}_T}\right), \tag{4.34}$$

where W is a positive definite weighting matrix.

On the other hand, the LM approach applies a quadratic distance function to the score vector. The log-likelihood function is evaluated by using the simulated data and the auxiliary parameters from the actual data. The indirect inference estimator from this approach is defined by,

$$\hat{\boldsymbol{\theta}}_{LM} = \underset{\boldsymbol{\theta}}{\operatorname{argmin}} \frac{\partial f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_S(\boldsymbol{\theta}))}{\partial \boldsymbol{\beta}'} V \frac{\partial f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_S(\boldsymbol{\theta}))}{\partial \boldsymbol{\beta}},$$

where V is a positive definite weighting matrix. Gallant and Tauchen (1996) and Gourieroux et al. (1993) show that the LM and LR approach are equivalent when the auxiliary function is correctly specified in terms of the statistical description. This approach to the indirect inference estimator is also referred to as efficient method of moment (EMM).

Lastly, the LR approach also evaluates the log-likelihood function in the same way as the LM approach, which uses the actual data and the parameters from the simulated data. The simulated data are a function of the structural parameters. Then, the structural parameters are chosen to maximize the log-likelihood function. The advantage of the LR approach is that the weighting matrix is not required. However, it is less efficient than the other approaches. The LR approach to the indirect inference is formally defined as,[3]

$$\hat{\boldsymbol{\theta}}_{LR} = \underset{\boldsymbol{\theta}}{\operatorname{argmax}}\, f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_S(\boldsymbol{\theta})).$$

The weighting matrix is required in Wald and LM approach. Similar to the general method of moment (GMM) estimator, the purpose of the optimal weighing matrix is to minimize the asymptotic variance of the estimator. When the weighting matrix is properly chosen, the objective function of the Wald approach yields another interesting quantity. It takes the Hansen (1982)'s J-static form, which can be used to test the specification of a model. By this virtue, this paper uses the Wald approach to the indirect inference estimator. The weighting matrix is the inverse of covariance matrix of the auxiliary parameter $\Sigma(\boldsymbol{\beta}_0)^{-1}$, which will be shown shortly that it is also the optimal weighing matrix.

Under the regularity conditions, the auxiliary parameter $\hat{\boldsymbol{\beta}}_T$ has the following asymptotic properties,

$$\begin{aligned} \operatorname*{plim}_{T\to\infty} \hat{\boldsymbol{\beta}}_T &\to \boldsymbol{\beta}_0, \\ \sqrt{T}(\hat{\boldsymbol{\beta}}_T - \boldsymbol{\beta}_0) &\to \mathcal{N}\left(0, \Sigma_{\boldsymbol{\beta}_0}\right), \end{aligned}$$

[3]Smith Jr (1993) also proposes the simulated quasi-maximum likelihood (SQML) estimator. The estimator has a similar form as the LR approach to the indirect inference estimator except that the source of data and the parameters are swapped. The SQML estimator evaluates the log-likelihood by using the actual data and the parameter estimates from the simulated data. Formally, $\boldsymbol{\theta}^*_{SQML} = \max_{\boldsymbol{\theta}} f(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}), \boldsymbol{X}_T)$. Gourieroux et al. (1993) shows that the SQML is a consistent but not an efficient estimator.

where,

$$
\begin{aligned}
\Sigma_{\boldsymbol{\beta}_0} &= A(\boldsymbol{\beta}_0)^{-1} B(\boldsymbol{\beta}_0) A(\boldsymbol{\beta}_0)^{-1}, \\
A(\boldsymbol{\beta}_0) &= \mathbb{E}\, \nabla^2 f(\boldsymbol{\beta}_0, \boldsymbol{X}_{t\in[1,T]}), \\
B(\boldsymbol{\beta}_0) &= \Gamma_0(\boldsymbol{\beta}_0) + \sum_{k=1}^{\infty} \left(\Gamma_k(\boldsymbol{\beta}_0) + \Gamma_k(\boldsymbol{\beta}_0)' \right), \\
\Gamma_k(\boldsymbol{\beta}_0) &= \mathbb{E}\left[\nabla f(\boldsymbol{\beta}_0, \boldsymbol{X}_{t\in[1,T]}) \nabla f(\boldsymbol{\beta}_0, \boldsymbol{X}_{t\in[1,T-k]})' \right].
\end{aligned}
$$

The indirect estimator is a function of the auxiliary parameters. Its asymptotic properties are linked to ones of the auxiliary parameters. Accordingly, under the regular conditions, the indirect inference estimator has the following properties,

$$
\begin{aligned}
\operatorname*{plim}_{T\to\infty} \hat{\boldsymbol{\theta}} &\to \boldsymbol{\theta}_0, \\
\sqrt{T}(\hat{\boldsymbol{\theta}} - \boldsymbol{\theta}_0) &\to \mathcal{N}\left(0, (1 + 1/\tau)\Sigma_{\boldsymbol{\theta}_0}\right),
\end{aligned}
$$

where

$$
\begin{aligned}
\Sigma_{\boldsymbol{\theta}_0} &= \left[J(\boldsymbol{\theta}_0)' \Sigma_{\boldsymbol{\beta}_0}^{-1} J(\boldsymbol{\theta}_0) \right]^{-1}, \\
J(\boldsymbol{\theta}_0) &= \mathbb{E}\, \nabla \tilde{\boldsymbol{\beta}}(\boldsymbol{\theta}_0).
\end{aligned}
$$

The specification test examines how well the structural model can explain the empirical data. If the model can perfectly explain the data, the auxiliary parameters of the empirical and the simulated data coincide. This null hypothesis is verified by using an over specification test. The test converges in probability to chi-square distribution of $(k-n)$ degree of freedom.

$$
T(1 - \frac{1}{\tau})^{-1} \left(\tilde{\boldsymbol{\beta}}_S(\hat{\boldsymbol{\theta}}) - \hat{\boldsymbol{\beta}}_T \right)' \underbrace{A(\hat{\boldsymbol{\beta}}_T) B(\hat{\boldsymbol{\beta}}_T)^{-1} A(\hat{\boldsymbol{\beta}}_T)}_{\hat{\Sigma}_{\boldsymbol{\beta}_0}^{-1}(\hat{\boldsymbol{\beta}}_T)} \left(\tilde{\boldsymbol{\beta}}_S(\hat{\boldsymbol{\theta}}) - \hat{\boldsymbol{\beta}}_T \right) \to \chi^2(k-n). \tag{4.35}
$$

The Wald approach to the indirect inference in Equation 4.34 has a similar form to the over identification test. The only difference is the replacement of the weighting matrix by the inverse of the estimated variance matrix of $\hat{\boldsymbol{\beta}}_T$ together with a scale parameter $T(1-1/\tau)^{-1}$. Clearly, the optimal choice for the weighing matrix of the Wald approach is the inverse of the variance matrix of $\boldsymbol{\beta}_0$,

$$W = A(\boldsymbol{\beta}_0)B(\boldsymbol{\beta}_0)^{-1}A(\boldsymbol{\beta}_0). \tag{4.36}$$

The weighting matrix W, which is composed of matrix A and B, is estimated by using the observable data $\boldsymbol{X}_T$. In particular, the variance of $\boldsymbol{\beta}_0$ is estimated by the Newey-West estimator (Newey and West (1987) and Newey and West (1994)) as follows,

$$\begin{aligned}
\hat{W}_T &= A(\hat{\boldsymbol{\beta}}_T)B(\hat{\boldsymbol{\beta}}_T)^{-1}A(\hat{\boldsymbol{\beta}}_T),\\
A(\hat{\boldsymbol{\beta}}_T) &= \frac{1}{T}\nabla^2 f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_{t\in[1,T]}),\\
B(\hat{\boldsymbol{\beta}}_T) &= \Gamma_0(\hat{\boldsymbol{\beta}}_T) + \sum_{k=1}^{m}\left(1-\frac{k}{m+1}\right)\left(\Gamma_k(\hat{\boldsymbol{\beta}}_T)+\Gamma_k(\hat{\boldsymbol{\beta}}_T)'\right),\\
\Gamma_k(\hat{\boldsymbol{\beta}}_T) &= \frac{1}{T}\sum_{k=1}^{T}\left[\nabla f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_{t\in[1,T-1]})\nabla f(\hat{\boldsymbol{\beta}}_T, \boldsymbol{X}_{t\in[1,T-1-k]})'\right].
\end{aligned}$$

The convergence rate of the estimates $B(\hat{\boldsymbol{\beta}}_T)$ depends on the bandwidth size $m+1$. However the estimate is consistent if $\lim_{(M\to\infty,T\to\infty)} m/T^{1/2} = 0$. This paper uses $m = 8$ as it is the largest possible integer that satisfies the convergence condition and gives positive definite variance covariance matrices. Besides these matrices which are analytically obtained, the matrix $J(\hat{\boldsymbol{\theta}}) = \nabla\tilde{\boldsymbol{\beta}}(\hat{\boldsymbol{\theta}})$ is calculated by a numerical derivative in the final step.

4.3.1 Auxiliary Functions

The auxiliary functions in this paper are the log-likelihood function of a vector auto regression (VAR) model and one of the smooth transition vector auto regression (STVAR) model. VAR model has been a standard tool to describe the dynamics of macro variables. Derived from the estimated VAR model, the impulse response functions are used to analyze the impacts of the monetary policy to the economy in various ways. For this reason, the VAR model is a natural choice to be used as the auxiliary model in this study. The auxiliary function serves as a bridge between empirical and simulated data. Thus, the estimator does not require the likelihood function to be correctly specified. In this regard, a linear auxiliary function, a VAR model in this case, has a capability to recover a nonlinear data generating process.

Since the asymmetric effects of monetary policy deal directly to nonlinear relationships among variables, nonlinear econometric models are used to investigate this aspect. STVAR is a nonlinear model modified from the conventional VAR. Even though the indirect inference does not need a nonlinear auxiliary model to recover a nonlinear structure, STVAR is used as another auxiliary model for the robustness check. The STVAR model used in this section is the same as the one implemented in the empirical section, which is a VAR(1) structure extended by the second-order logistic transformation function. The switcher is Inv_{t-2}. Its slope and locator are 84 and $\{-7.81, 0.69\}$, respectively.

4.3.2 Estimation

The formal procedure of the indirect inference applied in this paper can be summarized as follows.

1. Using the actual data of length T=205, X_T, to estimate the parameter of the auxiliary model, $\hat{\boldsymbol{\beta}}_T$. The auxiliary parameter $\hat{\boldsymbol{\beta}}$ is the vector of VAR (STVAR) coefficients and its lower triangular of the variance matrix.[4]

2. The structural shock $\boldsymbol{\varepsilon}_{k\times S}$ is drawn from the i.i.d normal distribution, where k is the number of the structural shocks and S is the length of the simulated data. In this study, S is set to $205 * 20 + 200 = 4,300$.

3. Given the structural shock $\boldsymbol{\varepsilon}_{k\times S}$, a set of structural parameter $\boldsymbol{\theta}_i$ is used to generate an artificial data $X_S(\boldsymbol{\theta}_i)$.

4. The auxiliary model is estimated the same way as in the first step using $X_S(\boldsymbol{\theta}_i)$ to get

[4] The estimation using the lower triangular matrix from Chelosky decomposition yields almost twice as higher the objective function.

$\tilde{\boldsymbol{\beta}}(\boldsymbol{\theta}_i)$.

5. The objective function L_{Wald} is calculated,

$$L_{Wald}(\boldsymbol{\theta}_i) = \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}_i) - \hat{\boldsymbol{\beta}}\right)' \hat{W}_T \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}_i) - \hat{\boldsymbol{\beta}}\right),$$

6. Repeat *Step 2* to *Step 5* until the minimum value of L_{Wald} is obtained. Then, the estimates $\hat{\boldsymbol{\theta}}_{Wald}$ is defined by,

$$\hat{\boldsymbol{\theta}}_{Wald} = \underset{\boldsymbol{\theta}_i}{\operatorname{argmin}} \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}_i) - \hat{\boldsymbol{\beta}}\right)' \hat{W}_T \left(\tilde{\boldsymbol{\beta}}_S(\boldsymbol{\theta}_i) - \hat{\boldsymbol{\beta}}\right).$$

The length of the structural shocks in *Step* 2 is chosen to be 20 times larger than the size of the data: $S = \tau T$, $\tau = 20$. To minimize the effects of the initial conditions, another 200 data are added as a burn-in procedure and dropped later. The size of the simulated data will affect the asymptotic variance by factor $(1 + 1/\tau)^{1/2}$. By choosing $\tau = 20$ the asymptotic variance is blown up by 2.47%.

Estimating Procedure

Due to the identification problem, the optimization routine tends to offer only a local optimum. Moreover, different parameter sets could yield similar values of the objective function. In other words, the same value of the objective function can be interpreted in many ways. Some of them might not have economically meaningful interpretations. A two-step procedure is developed to search over a feasible large domain trying to recover a "global" optimum and obtain an economically meaningful set of parameters.

The first step of the procedure is designed to find potential starting values to feed into the second step. Then the second step applies BFGS algorithm to those starting values to find a local optimum. Finally, the optimized value will be filtered to get the estimates.

Step 1: Finding Starting Values

1. Randomly draw 40,000 initial guesses from parameter's range will be discussed shortly.

2. Sort the initial guesses by the consumption habit parameters, ψ. Then stratify the initial guess into 40 groups.

3. Evaluate the objective function of each initial guess.

4. Select the best initial guesses from each group (40 in total) and another 10 best initial guesses from all initial guesses as starting values. Thus, there will be 50 starting values in total.

The sorting and grouping of the value of the initial guesses in this step is designed to prevent the exclusion of potential values of the consumption habit, ψ. The dynamics of the model is sensitive to the consumption habit whose value does not deviate significantly from the starting values in the optimization process.

Step 2: Optimization and choosing the estimates

1. For each starting value in $Step 1$, the standard BFGS optimization algorithm is applied to minimize the objective function, which is a quadratic distance function.

2. The optimized parameters are filtered by the following conditions,

   (a) **Model stability**: All structural shocks will be fed into the model to find the impulse responses at steady state, expansions and recessions. Stability condition requires convergence of the responses.

   (b) **Economically meaningful**: Different combinations of parameters can yield similar values of the objective function because of the identification problem. For example, with a combination of other parameters, a set of parameters with low degree price stickiness, for example $\theta = 0.3$, and ones with a medium degree $\theta = 0.6$, could yield a similar value of the objective function. The model with $\theta = 0.3$ is filtered out because it is considered too low for the U.S. economy.

Parameter Estimates

There are 24 structural parameters in this model. Technically, it is possible to estimate all 24 parameters. However, it is not efficient in practice. Some parameters have small reasonable ranges and they do not have much variation in the optimization routine. For examples, the discount factor, β, and the capital income share, α. Fixing these parameters constant frees more computational resources for estimation process but does not alter the main conclusion of the model. These parameters will be calibrated to the U.S. economy.[5] Table 4.2 shows the calibrated parameters in bold letters and the ranges of parameters to be used in the estimation process.

Table 4.2: Parameters' Range

Discount Factor	β	**0.995**
Consumption Habit	ψ	[0,1]
Inv. Inter temporal Elasticity of Substitution	σ_c	[1,4]
Inv. Labor Supply Elasticity	σ_n	[1,4]
Slope: Labor Disutility	ρ	(0,3]
Capital Share	α	**0.350**
Entrepreneur Labor Inc. Share	$(1-\alpha)(1-\Omega)$	**0.010**
Depreciation Rate	δ	**0.025**
Price Stickiness	θ	[0.2, 0.9]
Elasticity of Substitution	ε	[2, 16]
Inv. Adj. Cost	Ψ	[2,50]
Taylor Rule : Interest Rate Smoothing	ρ_{rn}	[0,1]
Taylor Rule : Inflation Coefficient	ρ_π	(1,2.5]
Taylor Rule : GDP Coefficient	ρ_y	[0,1]
Autocorr. Monetary Shock	$\rho_{\varepsilon^{mp}}$	[0,1]
Autocorr. Technology Shock	ρ_a	[0,1]
Autocorr. Government Shock	ρ_g	[0,1]
Std.Dev. Monetary Shock	σ_{mp}	(0,0.1]
Std.Dev. Technology Shock	σ_a	(0,0.1]
Std.Dev. Government Shock	σ_g	(0,0.1]
Verifying Cost	μ	**0.120**
Std.Dev. Market Risk	σ_ω	**0.270**
Entrepreneur surviving rate	γ	**0.984**

The capital income share, α, and capital depreciation rate, δ, are set to conventional values: 0.35 and 0.025, respectively. The labor income share for the entrepreneurs, $(1-\alpha)(1-\Omega)$, is set to 0.01 to make the model comparable to a standard New Keynesian Phillips curve

[5]Fixing some parameters to acceptable values is a convention way to improve the optimization procedure.

model. However, a small positive share is necessary to guarantee positive income when the entrepreneurs' projects fail.

Unlike the standard calibration practice that sets the steady state inflation rate, $\bar{\pi}$, to zero, this paper sets the inflation rate to the historical average at 3.43 % annual. Not only does a positive inflation rate influence the firms' pricing strategies, it also affects the price dispersion dynamics. The effects of the price dispersion on the output and the price level are cancelled when the model is linearized. This paper applies the second-order approximation. Thus, the functional of the price dispersion is preserved and it is important to incorporate the positive inflation rate into the calibration. Regarding the positive inflation rate, the quarterly subjective discount factor, β, is set to 0.9947. This adjustment is required to keep the model internally consistent to the Fisher equation. The discount factor is solved to match the historical average of the inflation at 3.43 % annual and the federal funds rate at 5.56 %.

The financial sector is calibrated in the same way as Bernanke et al. (1998). The parameters are set to imply the following steady state quantities: the expected risk premium at 2 % annual, the expected business failure at 3 % annual and the capital to net worth ratio, $\frac{N}{K}$ at 2. The structural parameters regarding financial contract are set as follow. The verifying cost, μ, is set to 0.12, the standard deviation of the idiosyncratic risk, σ_ω, is set to 0.270[6], and the entrepreneurs' surviving rate, γ, is set to 0.984. It should be noted that the values of σ_ω and γ are slightly different from the previous chapter owing to a slight change in β.

The other parameters are estimated by using the indirect inference method. The values of the parameters are restricted to certain ranges, which are broad enough to cover the possible values of parameters. This restriction not only limits the values of the parameters to a meaningful set but also facilitates the optimization process. It narrows down the optimization space so that the optimization procedure could spend more time on the relevance space.[7]

[6] ω is lognormally distributed. Since the idiosyncratic risk is only specific to entrepreneurs and averaged out at the bank level, the expected value of the ω is endogenously solved to be 1 as a function of the variance.

[7] The first round of the estimation uses a wider range of parameter value. The estimates from those range mostly yield higher objective value and make the model unstable. The ranges reported here are used in the final estimation round.

All the AR coefficients are bounded to $[0,1]$. These parameters are, consumption habit, ψ, interest rate smoothing coefficient, ρ_{rn}, AR coefficients of the government policy shock, of the technology shock, and of the monetary policy shock, ρ_g, ρ_a, and $\rho_{\varepsilon^{mp}}$, respectively. The policy rule for the change in the output, ρ_y, is also set to $[0,1]$. Even though the policy rule coefficient could be of any positive value, the empirical value is observed around 0.25 to 0.5. Thus, setting the range at $[0,1]$ allows the estimates to get closer to the empirical values. The policy response to the inflation has to be greater than one. Otherwise, the model will fall into an indeterminacy region. For this reason, the range of the policy response to the inflation rate, ρ_π, is set to $(1,2.5]$. The standard deviations of all the structural shocks $\{\sigma_a, \sigma_g, \sigma_{mp}\}$ are assumed to be in $(0,0.1]$. By definition, the shocks must have positive standard deviations. At the same time, a quarterly standard deviation that is bigger than 0.1 is very unlikely. The lowest value of the inverses of the elasticity in utility function, σ_c and σ_n are one where the utility is collapsed to log-utility. The inverses of the elasticity are small positive numbers and set to be less than 4. The slope of the labor disutility, ρ is set to $(0,3]$. A positive value of ρ is required. Thus, a small positive number is assigned to ρ.

The range of the Calvo parameter, the elasticity of substitution of the final goods and the investment adjustment cost, Ψ are fixed at $[0.2,0.9]$, $[2,16]$, and $[2,50]$, respectively. These parameters play important roles in determining the price dynamics including the inflation rate, π_t and the capital price, q_t. The price stickiness is generally around 0.4 to 0.8. The elasticity of the substitution of the final goods determines the gross mark up price, $\frac{\varepsilon}{\varepsilon-1}$. This range covers the mark up price from 2 to 40 percent. Lastly, the investment adjustment cost adds rigidity to the investment expenditure. The investment expenditure becomes less elastic when the adjustment cost is higher. The range covers the elasticity of the investment to the capital price from 2 to 50 percent.

Table 4.3 reports the parameter estimates from the indirect inference method. The estimates using VAR and STVAR as the auxiliary function are reported in the third and the fifth column. The parameter values used in the previous chapter are included in the second column for comparison purpose. Except the parameters governing the utility function, most parameter estimates from both auxiliary models are in comparable ranges.

The over identification tests and their critical values are reported in the last two rows. For both auxiliary models, the tests reject the null hypothesis that the structural model can replicate the data. By comparing p-value, using the STVAR as the auxiliary model yields a slightly better fitness. However, the p-values of both models, which are not reported here, are virtually zero. Thus, in term of the fitness of the model, both auxiliary models are not significantly different from each other.[8]

However, these rejections are not unexpected. First, a DSGE model is a complex nonlinear system making it difficult to capture the whole structure of the economy. Hence, it can only be constructed in a parsimonious way by including only the features of interested and leaving the others. Second, for a given model, many choices of functional forms to be used in each element of the model are available. Thus, it is likely that a given DSGE model will fail to fit the data. Nevertheless, besides these drawbacks, a DSGE model is still considered an important tool for analyzing the mechanisms of economic sectors and evaluating the impacts of the policy.

[8]The other alternative models are also explored to try to improve the model fitness. They are VAR(4), STVAR with other switching variables, VARMA, VARX(1) using a nonlinear exogenous variable and VAR(1) containing Y, C, π, rn. However, those models do not improve the over identification tests.

Table 4.3: Estimates

Description	Previous Paper	VAR	t-stat	SVAR	t-stat
ξ	**1.000**				
β	**0.990**				
ψ	0.400	0.632	132.785	0.793	191.755
σ_c	2.000	3.886	49.737	2.807	60.510
σ_n	2.000	1.763	2.552	2.629	11.047
ρ	1.000	1.949	18.592	2.289	17.917
α	**0.350**				
$(1-\alpha)(1-\Omega)$	**0.010**				
δ	**0.025**				
θ	0.500	0.774	288.084	0.744	540.435
ε	7.000	8.474	49.430	7.767	99.678
Ψ	10.480	10.608	9.749	12.952	40.947
ρ_{rn}	0.900	0.802	79.916	0.614	118.479
ρ_{π}	1.500	2.499	37.839	2.087	147.401
ρ_y	0.500	0.434	10.402	0.571	47.100
$\rho_{\varepsilon^{mp}}$	0.000	0.062	1.089	0.181	15.232
$\rho_a{}^*$	0.000	0.303	9.728	0.207	6.989
$\rho_g{}^*$	0.000	0.205	4.329	0.392	62.184
σ_{mp}	0.003	0.001	20.065	0.002	63.014
σ_a	0.009	0.006	21.539	0.002	41.416
σ_g	0.009	0.077	45.775	0.037	43.694
μ	**0.120**				
σ_ω	**0.271**				
γ	**0.979**				
Test Statistic		222.022		435.664	
Critical value :$\chi^2_{\alpha=.01}$		29.141		56.061	

Remark: *These parameters are set to zero later to examine the effects of their temporary shocks.

4.4 Results

The estimated model is used to access the ability of the theory to explain the asymmetry in two ways. First, the theoretical impulse responses are constructed. This conventional method facilitates a noise free environment to study the implications of the theory in both qualitative and quantitative aspect. Second, the implied impulse responses from the model will be used to access the ability of the model to account for the observed asymmetry.

4.4.1 Theoretical Impulse Responses

The model is set up in four versions to study the role of the model's curvature, the financial accelerator and the nonlinear Phillips curve. $Model1$ tests the ability of the standard model to create the asymmetric effects. Both financial accelerator and nonlinear Phillips are turned off. Thus, the only possible source of the asymmetry comes from the curvature of the model itself. Then $Model2$ considers only the role of financial accelerator. The model allows the risk premium to change while keeping the Phillips curve linearized. On the other hand, $Model3$ considers only the nonlinear Phillips while fixing the risk premium constant at the steady state level. Finally, $Model4$ analyzes the full version of the model in which both financial accelerator and nonlinear Phillips curve are operating.

For each model setting, three types of asymmetry are studied. They are asymmetric effects between different policy intensity: moderate and aggressive policies, asymmetric effects between the direction of the policy: contractionary and expansionary policies, and asymmetric effects the policies implemented at recessions and expansions.

The asymmetric effects of the policy are examined by the impulse response functions of the interested variables. Moderate and aggressive policies are defined by one- and two-standard deviation size of the policy shocks, respectively. The base cases are the responses to moderate contractionary policies.

To make the responses comparable, the responses to expansionary policies will be flipped, upward or downward depending on the base case responses, by multiplying the responses by -1. The responses to aggressive policies will be scaled down by being divided by 2. Should the monetary policy have symmetric effects, the impulse responses to different policies will lie on top of each other.

Three positions of the business cycle are considered: at the steady state, at recessions and at expansions. The recessions and the expansions are defined by a 4 percent (annual) deviation from the steady state of the output growth. The deviation from the steady state could happen from either demand or supply shocks. Both demand and supply shocks are taken into accout and hypothesized by the government expenditure shocks and the production technological shocks, respectively. To consider only temporary shocks, the AR parameters of both the government expenditure shocks and of the production technological shocks are set to zero.

The asymmetric effects of the monetary policy are results of nonlinear intersections among the variables in the model. Additional frictions and sectors will modify the nonlinearity of the model and ultimately influence (either increasing or decreasing) the asymmetric effects of the monetary policy. The main sources of the asymmetry considered in the structural model are the nonlinear Phillips curve and the financial accelerator.

A standard DSGE model inherits nonlinearities from the utility and production function. The degree of asymmetry depends on the curvature of the model. However, using reasonable set of parameters, the standard model generally doesn't have enough curvature to create noticeable asymmetric effects of monetary policy.

The nonlinear Phillips curve intensifies the asymmetric effects of the standard model. Should any asymmetry be detected in the standard model, it will have the same characteristics as ones produced by a model with nonlinear Phillips curve. This is because the fundamental structures of both models are the same: they both rely on the same production function and stochastic discount factor derived from the utility function. However, the exact dynamics of both models is not necessary the same. The firms' profit maximization problems depend on markets' structures, i.e. both degree of price stickiness and elasticity of substitution. These additional structures attribute to the output-inflation trade-off mechanism, which augments another source of nonlinearity to the model.

The financial accelerator, on the other hand, amplifies the effects of the monetary policy through an extra risk premium charged on the borrowing rate. The premium is determined by the leverage ratio, which depends on the capital return structure and the investment dynamics. Thus, it will increase (decrease) the degree of asymmetry to the variables that positively (negatively) correlate to the risk premium. Hence, the financial accelerator mechanism intensifies the existing nonlinear of the model.

All above propositions are found in both the previous chapter with the calibrated parameters and this chapter with the parameter estimates of some variations. First, the standard model, without neither the financial accelerator nor the nonlinear Phillip curve, shows a minimal degree of asymmetry. However, with the parameter estimates, there is a case that the asymmetric responses are noticeable. When supply shocks deviate the economy from the steady state, the monetary policy is found to have asymmetric effects on the leverage ratio, qkn, as shown in bottom-right of Figure 4.3. Three main parameters accounting for a higher curvature of the model are the consumption habit, ψ, the price stickiness, θ, and the investment adjustment cost coefficient, Ψ. Moreover, the asymmetric effects of the policy on the leverage ratio are found in all model settings when supply shocks deviate the economy (Figure 4.6, Figure 4.9, and Figure 4.12).

Second, besides those of the leverage ratio, the asymmetric responses are noticeable only when the nonlinear Phillips curve is operating, in $Model3$ and $Model4$, and are most prominent in $Model4$, where both financial accelerator and nonlinear Phillips curve are operating (Figure 4.10 to Figure 4.12). This finding signifies the role of nonlinear Phillips curve in explaining the asymmetric effects of the monetary policy. In contrast with the results found in the previous chapter, the asymmetric effects at the steady state become less noticeable in every case.

The interaction between the financial accelerator and the nonlinear Phillips curve, which shapes the asymmetric effects of monetary policy, becomes more noticeable with the parameter estimates. First, the role of the financial accelerator in amplifying the effects of the monetary policy can be seen by comparing the impulse responses of $Model1$ to $Model2$. Even though the asymmetric responses are not found, the magnitudes of the responses of $Model2$, (Figure 4.4 to Figure 4.6), in which the financial accelerator is operating, are stronger than those of the responses of $Model1$ (Figure 4.1 to Figure 4.3). Similar attribute can also be observed when the financial accelerator is added to the model with the nonlinear Phillips curve, from $Model3$ (Figure 4.7 to Figure 4.9) to $Model4$ (Figure 4.10 to Figure 4.12).

As pointed out earlier, the financial accelerator does not necessarily increase the degree of the asymmetric responses. This proposition can be verified by comparing the responses of $Model3$ and those of $Model4$. The focus will be on the asymmetric effects of the monetary policy implemented at expansions and recessions, in which the asymmetric effects are prominent, when supply shocks are the driving forces.

Figure 4.9 shows the responses from $Model3$. Responses to moderate contractionary policies at recessions and expansions are indicated by red-dash lines and green-bold lines, respectively. Firstly, the implication of the convex supply curved generated by the nonlinear Phillips curve can be observed from the output, y_t, and the inflation, pi_t, responses. Positive supply shocks stimulate the economy and put less pressure on the price. Consequently, further policies implemented at expansions, which are caused by a supply shocks, will have less impact on the price and more impact on the output. Conversely, the policy implemented at recessions will have less effect on the output and more effect on the price. As a result, when a business cycle is driven by the supply shocks, the effects of the monetary policy on the output (price) will be stronger (weaker) at expansions than at recessions. This type of asymmetry is demonstrated in Figure 4.9. The whole range of the output responses at recessions lies above ones at expansions, and those of the inflation lie below. The gap between the lines approximately indicates the degree of the asymmetry.[9]

Turning attention to the effects of the financial accelerator on the asymmetric effects of the monetary policy, Figure 4.12, an extra risk premium is required to compensate a higher risk for a higher leverage. Thus, the leverage ratio determines the risk premium and ultimately determines the amplification degree of the financial accelerator. The monetary policy is observed to have asymmetric effects on the leverage ratio in the same way as it does on the inflation. So do the risk premium, s_t, and the effects of the financial accelerator. The financial accelerator intensifies the effects of the policy at expansions and recessions asymmetrically. Since the monetary policy has greater effects on the risk premium at recessions, the effects of

[9]Besides comparing the effects of the same policy at the different phases of business cycle, based on the simulation results (not shown here), any policies that are implemented at the same points of business cycle have similar patterns of asymmetric effects to the ones implemented at the steady state.

the policy on any variables at recessions will be more amplified by the financial accelerator. As a result, the degree of asymmetric effects on the inflation will be greater while the same will be lower for the output. Graphically, the responses of the output and the inflation will be stretched further down with additional effects for the red-dash lines. Thus, the gap between these two lines of the inflation is escalated while that of the output is tightened. Moreover, the effects on the output are strong enough to briefly reverse the direction of asymmetry at the initial period. A similar impacts of the financial accelerator can also be found when the demand shocks deviate the economy, albeit less obvious.

4.4.2 Implied Impulse Responses

This section implements the estimated model to explain the observed asymmetry. The model is used to generate a set of artificial data. Then the GIRFs will be used to examine the asymmetric effects. Lastly, the implied asymmetry by the simulated data will be compared to ones implied by the observed data.

There are two approaches to construct the counter parts of the observed impulse responses from the simulated data. A straightforward approach is to proceed the standard procedures of setting up a STVAR model described earlier. However, as a nonlinear model, the results from the STVAR are sensitive to both the choice of switcher and its locator and slope parameters. As a result, even though following the standard procedure is justifiable, the resultant impulse responses might not be useful to access the ability of the model to explain the observed asymmetry. To make the results comparable, the same switcher and its STVAR parameters obtained by the observed data will be applied for the simulated data. However, because the moments of the corresponding switchers might be different, the value of the locator parameter cannot be used directly. Instead, the quantile rank of the locator will be used. Accordingly, the functional of the transition function will be the same for both observed and simulated data.

Figure 4.13 displays the unconditional GIRFs. All data points are used as the initial states. The responses of the observed data and the simulated data are displayed in panel A and panel B, respectively. They are scaled in a similar way as the previous section to make them comparable. The qualitative of the responses of both models is similar: the output and the investment negatively respond to the shocks while the price positively respond to the shocks, exhibiting the price puzzle. This finding is interesting. The prize puzzle is not observed in the theoretical responses. However, using the same structural model, the implied responses produce the prize puzzle as it is observed in the observed data. It suggests that the conventional VAR and the identification regime could be the cause of the prize puzzle.

The quantitative is, however, different. Using the observed data, the monetary policy has stronger effects on the output and the inflation. Nevertheless, the differences are comparable. This is a direct consequence from that the model fails to fit the data as a whole. Recall that the parameter estimates from the indirect inference in this paper minimizes a quadratic distance between the VAR coefficients and its variances. The failure to fit the data directly implies that those parameters are different. As a result, either quantitative or qualitative or both will be different. The asymmetric effects of the monetary policy are barely noticed in both cases.

Panel B of Figure 4.14 reports the GIRFs of the simulated data when moderate contractionary policies (+1 s.d. policy shocks) are implemented at different phases of business cycle. The effects are compared to ones of the observed data displayed in panel A. Except the effect on the investment, the simulated data agree with the observed data that the monetary policy has stronger effects during recessions. Moreover, the observed data suggest a higher degree of asymmetry than the simulated data. The similar observations are found in the case of moderate expansionary policies (-1 s.d. policy shocks) as well.

Then, the implied and the empirical asymmetry are compared to verify the ability of the model to account for the empirical asymmetry. The foremost step is to normalize the initial different quantitative of both actual and simulated data. Instead of using a plain deviation to define the degree of asymmetry, the percentage differences using the response to moderate contractionary policies as the base responses will be used. Figure 4.15 exhibits the degree of the asymmetry implied by the observed data and the simulated data in panel A and panel

B, respectively. The simulated data fail to replicate the asymmetric effects on the investment and the nominal interested rate but partially explain the asymmetry observed in output and inflation. Thus, the analysis will limit to the effects on the output and the inflation. Figure 4.16 merges the asymmetry reported in Figure 4.15 to focus on the effects on the output and the inflation. The shaded area is the remaining part of the asymmetry that the model cannot explain. The model can partially explain the asymmetric effects on the output while the data agree quite well with the simulated data for the inflation.

4.5 Conclusions

This paper systematically assesses the asymmetric effects of the monetary policy in the U.S. between 1960Q1 to 2011Q1.

Three types of the asymmetry are investigated: 1) between moderate and aggressive policies, 2) between contractionary and expansionary policies, 3) between the policies implemented recessions and expansions, and combinations of them.

The effects of the policy are examined in three approaches. First, the monetary policy is empirically investigated by using smooth transition vector auto regression (STVAR). Second, two possible sources of the asymmetry, which are convex supply curve and the financial friction, are analyzed by using an estimated DSGE model and the theoretical impulse responses. Lastly, the estimated mode is implemented to explain the observed asymmetry. Using the simulated data, the implied asymmetric effects, which are constructed from the implied impulse response functions, are compared to the empirical asymmetry.

The advantage of using the theoretical impulse responses is that it directly demonstrates the implications of the model without dealing with the identification problem. Moreover, the analysis also allows the isolating and differentiating the effects of demand and supply shocks.

The analysis by using the implied impulse responses is also important. It establishes the link between the empirical observations and the mechanism by which the theory implies. The comparisons of the empirical and the implied asymmetry reveal how much the theory can explain the observed asymmetry.

The empirical examinations using STVAR and GIRFs find no asymmetric effects between contractionary and expansionary policies, nor between moderate and aggressive policies. The only asymmetric effects of the policy found in this paper are the asymmetric effects between the monetary policy implemented at recessions and expansions. The policy implemented at recessions is found to have stronger effects on both the output and the inflation.

The analysis of the theoretical impulse responses is based on an estimated DSGE model. The model is solved by the second-order perturbation method to preserve the nonlinearity of the model. The sources of the asymmetry in the model are the nonlinear Phillips curve, devised by a Calvo pricing mechanism, and the financial friction by Bernanke et al. (1998)'s financial accelerator model. Then, the model is estimated by the indirect inference estimator, using the U.S. data.

Generally, the asymmetric effects of the policy are not noticeable, except for the effect on the capital to net worth ratio. The asymmetry becomes noticeable only when the nonlinear Phillips curve is operating emphasizing the major role of the convex supply curve in generating the asymmetric effects. The most noticeable case is the asymmetry between the policies implemented at different phases of business cycle where the supply shocks are the driving force. The monetary policy is found to have greater (lesser) effects on the output (inflation) during expansions than recessions.

The amplification role of the financial accelerator is found in all cases. However, whether it intensifies or mitigates the degree of the asymmetry depends on initial conditions of the asymmetry and the degree of amplification. When supply shocks deviate the economy, the financial accelerator has stronger amplifications during recessions than expansions. Thus, the effects of the policy on both the inflation and the output are stronger reinforced during recessions. As a result, the degree of asymmetry are intensified in the case of the output but mitigated in the case of the inflation.

The observed and the simulated data agree quite well in general when the implied impulse responses are compared. The simulated data support that there is only one detectable type of the asymmetry: the one between the policies implemented at recessions and expansions. Moreover, the prize puzzle is found in both data sets. Note that with the same structural model, the prize puzzle is not previously detected by using the theoretical impulse responses. This suggests that the prize puzzle might be a consequence of the traditional identification strategy, which employs the lower triangular of Cholesky decomposition.

Lastly, the implied asymmetry of the simulated data is compared to one of the observed data. The degrees of the asymmetry from the simulated and the observed data are not comparable in the case of investment and the nominal interest rate. However, the model can partially explain the asymmetric effect on the output and can account most parts of the inflation.

Note that the model presented in this paper fails to fit the data in general. However, this failure is not unexpected. First, with the complexity of a DSGE model, the model can only capture a part of economy and leave the other parts unexplained. In particular, among the choices of theoretical model to be the sources of the asymmetry, the model hypothesizes the nonlinear Phillips curve and the financial accelerator in a specific way by using a Calvo pricing mechanism and Bernanke et al. (1998)'s financial accelerator model.

The knowledge obtained from this study suggests further theoretical investigations of the causes of the asymmetry. The research methodology applied in this study can also be used to access the performance of other alternative models along these lines.

1. **Change In Economic Outlook:** This group of theories has not been much explored. It deals with people's attitudes toward the economic situations. A conventional way to observe people's preference is to observe their pricing behaviors. The asset pricing literatures explain this relationship through a stochastic discount factors (SDFs). If the SDFs can be stated as a state-contingent function, it could be used to rationalize people preferences toward the phases of business cycle. Recently the asset pricing literatures extend the SDFs from using the standard expected utility to an Epstein-Zin style utility

function.[10] The Epstein-Zin preference not only takes into the account of standard changes in marginal utility dues to the consumption level, but it also considers the importance of the position on the phases of business cycle. Thus, the welfare cost of the business cycle would be treated differently across the phases of business cycle. Applying the Epstien-Zin utility function would capture the effects of the economic outlook in explaining the asymmetric effects of the policy.

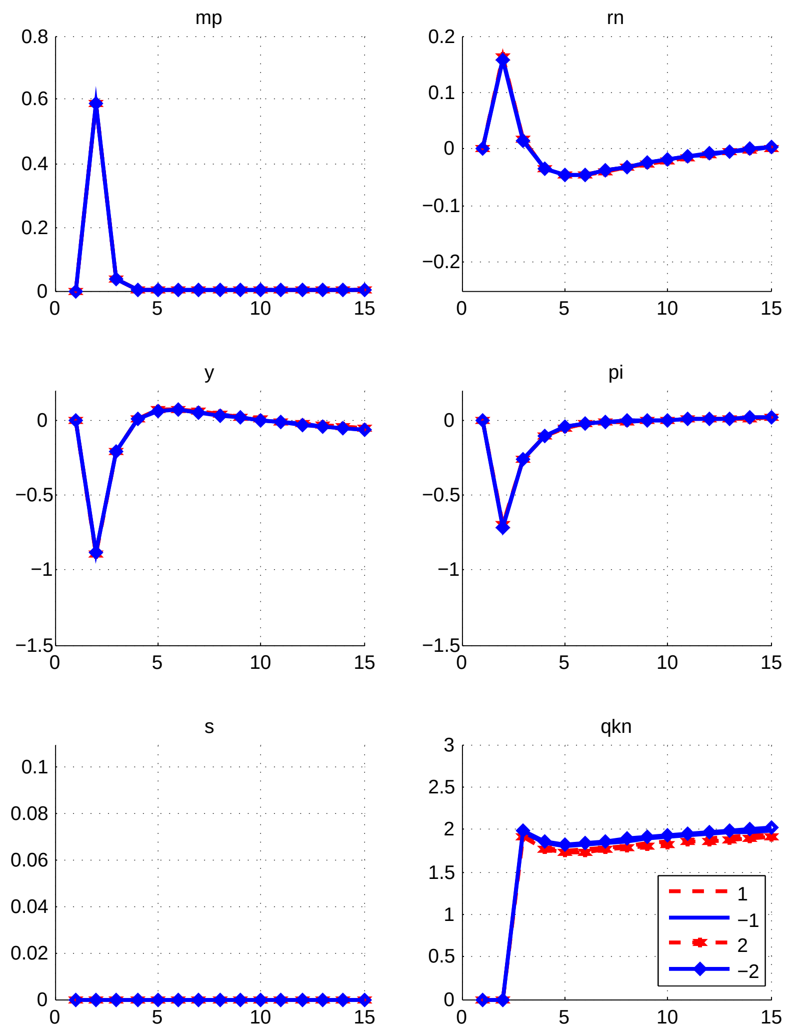
2. **Financial Friction:** The notion of the "string theory", implying that the policy seems to be successful in fighting a heated economy but fails to recover it from a crisis, is partially explained by the model presented in this chapter, especially when only the nonlinear Philips curve is operating. However, the model loses its ability to replicate the asymmetric effects on the output when the financial sector is taken into account. Bernanke et al. (1998)'s financial accelerator is successful in explaining the amplification effects of the financial sector. The limitation of model is that the degree of the amplification depends on the risk premium which moves counter cyclical. Thus, it predicts stronger effects of the policy during recessions than expansions. This implication undermines the role of convex curve in explaining a weaker impact of the policy on the output at recessions. Alternatively, Florio (2006) explains the financial friction by a matching and bargaining process between the borrowers and lenders. In this case, the risk premium not only depends on the default risk but also on the opportunity cost of matching. Thus, it also considers changes in financial market conditions. This alternative mechanism provides an alternative role of financial market friction in creating the asymmetry.

3. **Convex Supply Curve:** Even though the Calvo pricing mechanism succeeds in producing the asymmetric responses, Calvo pricing assumes a fixed proportion of retailers who can change their prices. This assumption might be too rigid when the model is considered in a light of business cycle. Alternative sticky price models might be used to allow a more flexible pricing behavior. For example, Rotemberg (1982) pricing scheme allows all retailers to make their decisions on prices with a quadratic cost.

[10] Epstein and Zin (1989) and Epstein and Zin (1991)

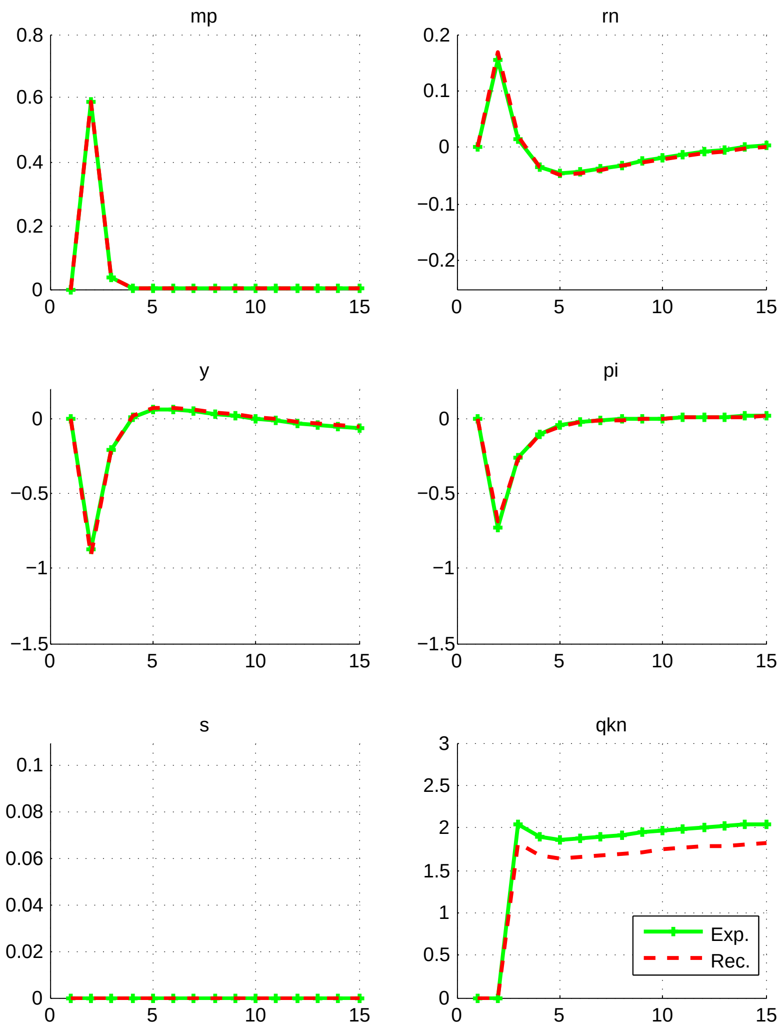
In conclusion, this paper implements a procedure to evaluate a particular theory to explain the asymmetric effects of money policy. It finds that most portions of the observed asymmetry still cannot be explained by a new Keynesian DSGE model with finical accelerator. Thus, the further research using other choices of theories and nonlinear econometric techniques might be investigated to improve the understandings of the asymmetric effects of monetary policy.

Figure 4.1: The Responses to Monetary Policy Shocks (mp). $Model1$: Without Financial Accelerator, Linear Phillips Curve.



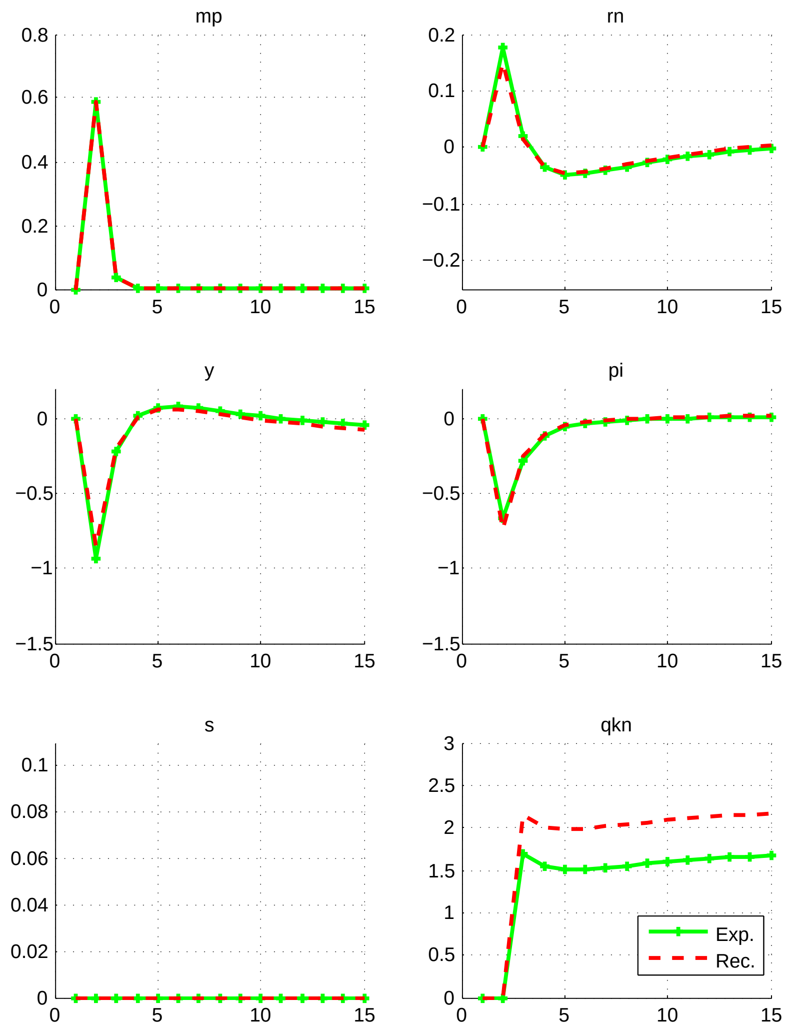
For comparison purpose, responses to two standard deviation of monetary policy shocks are divided by two, responses to one- and two- negative standard deviation shocks are divided by -1 and -2, respectively.

Figure 4.2: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Demand Shocks (government expenditure), $Model1$: Without Financial Accelerator, Linear Phillips Curve.



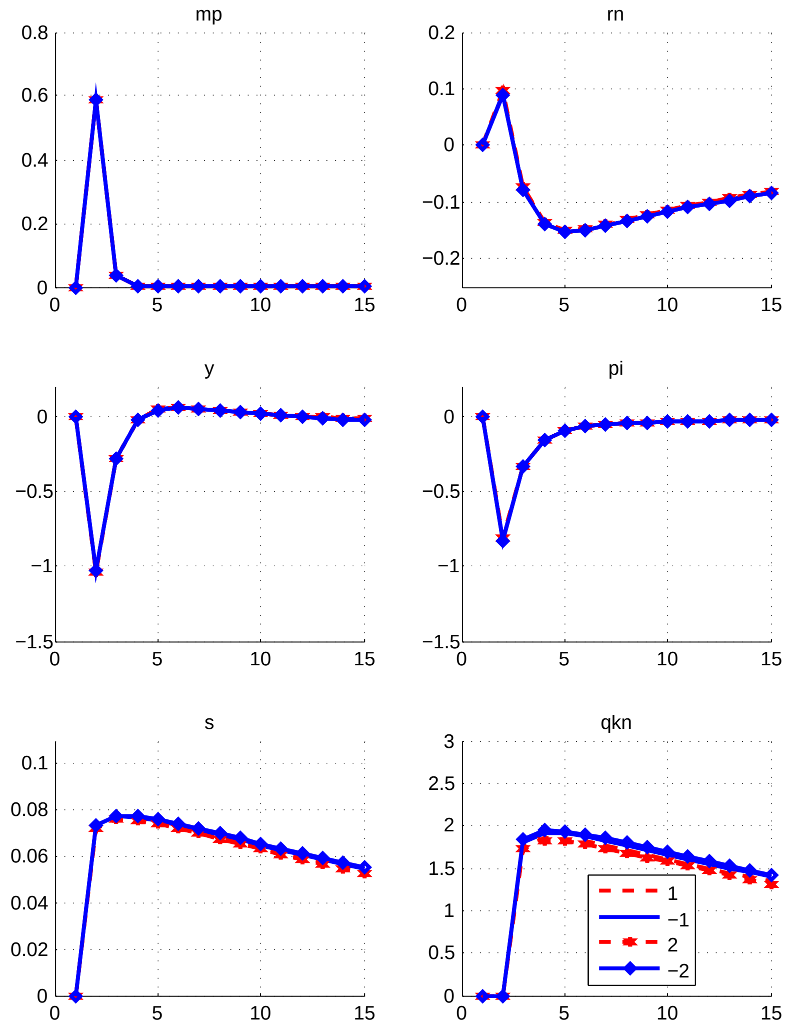
Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.3: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shocks (technology), $Model1$: Without Financial Accelerator, Linear Phillips Curve.



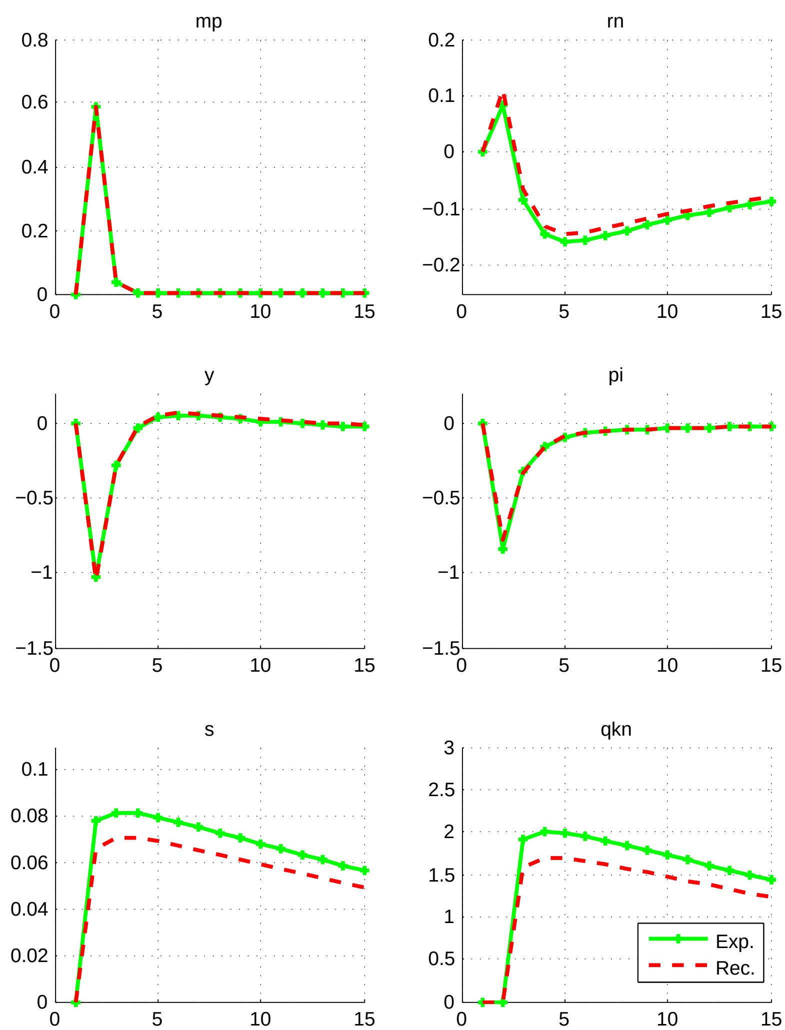
Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.4: The Responses to Monetary Policy Shocks (mp). $Model2$: With Financial Accelerator, Linear Phillips Curve.



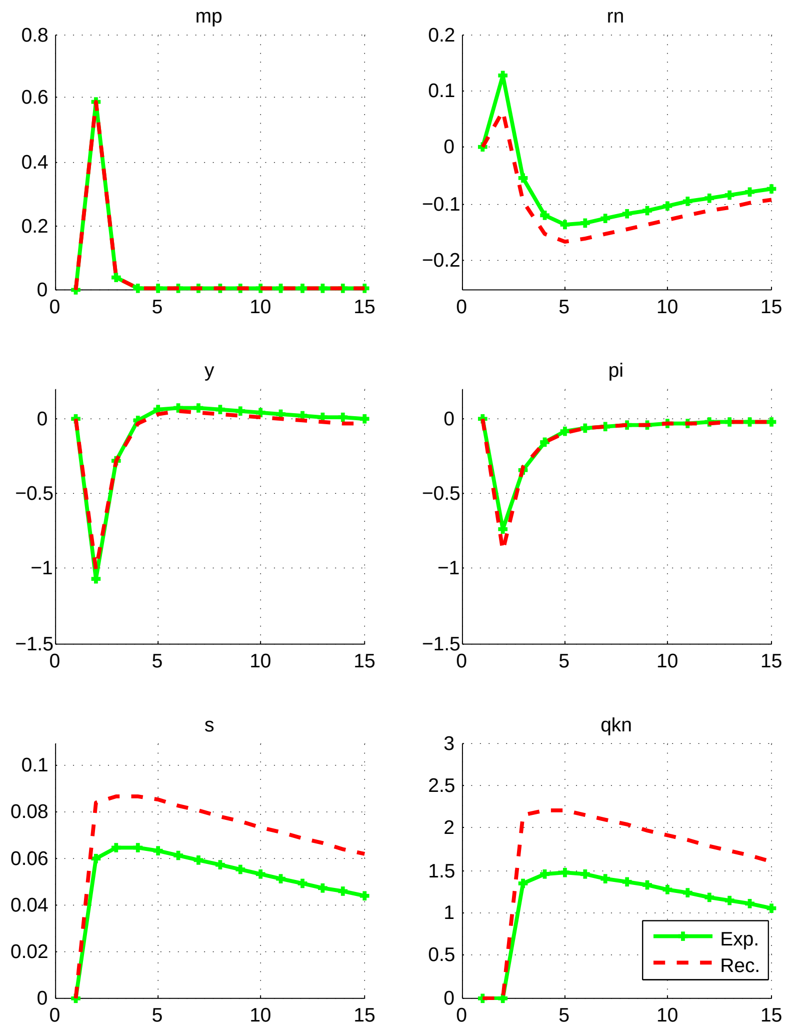
For comparison purpose, responses to two standard deviation of monetary policy shocks are divided by two, responses to one- and two- negative standard deviation shocks are divided by -1 and -2, respectively.

Figure 4.5: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Demand Shocks (government expenditure), $Model2$: With Financial Accelerator, Linear Phillips Curve.



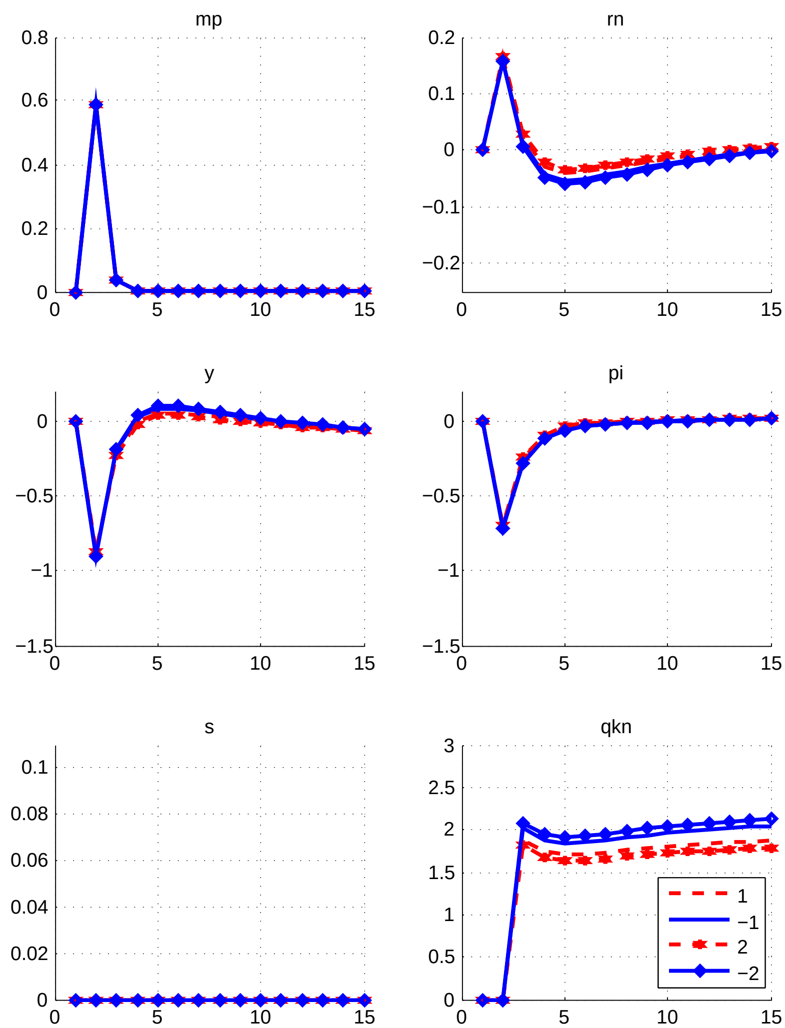
Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.6: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shocks (technology), $Model2$: With Financial Accelerator, Linear Phillips Curve.



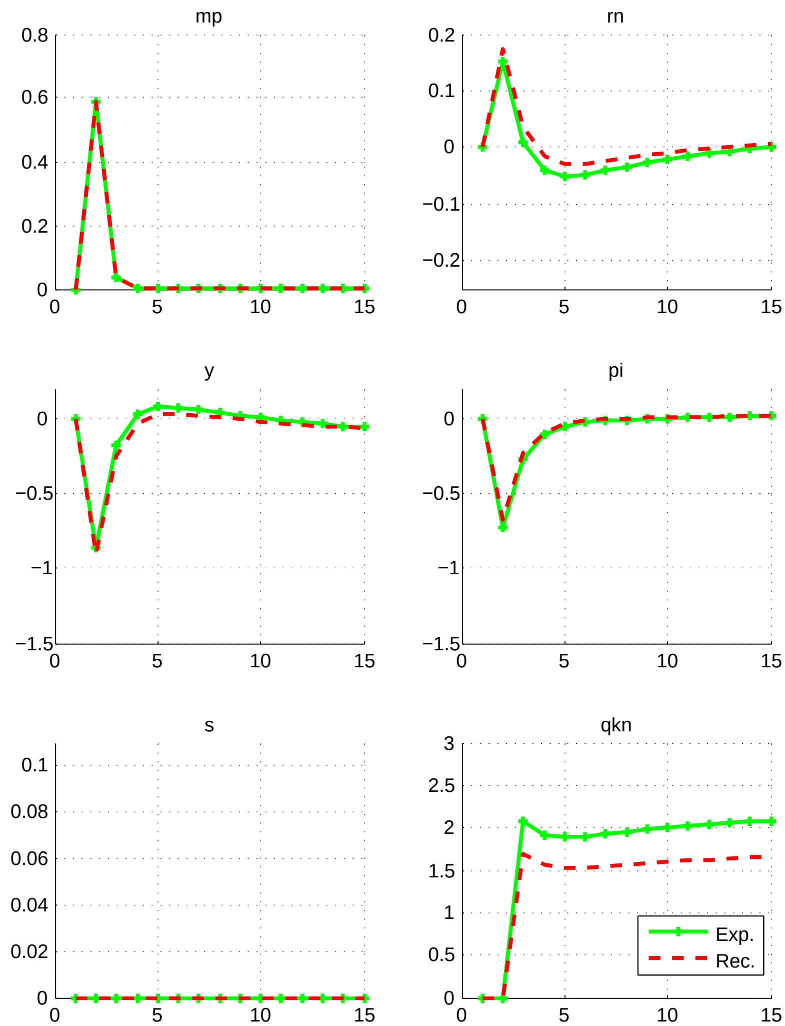
Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.7: The Responses to Monetary Policy Shocks (mp). $Model3$: Without Financial Accelerator, Nonlinear Phillips Curve.



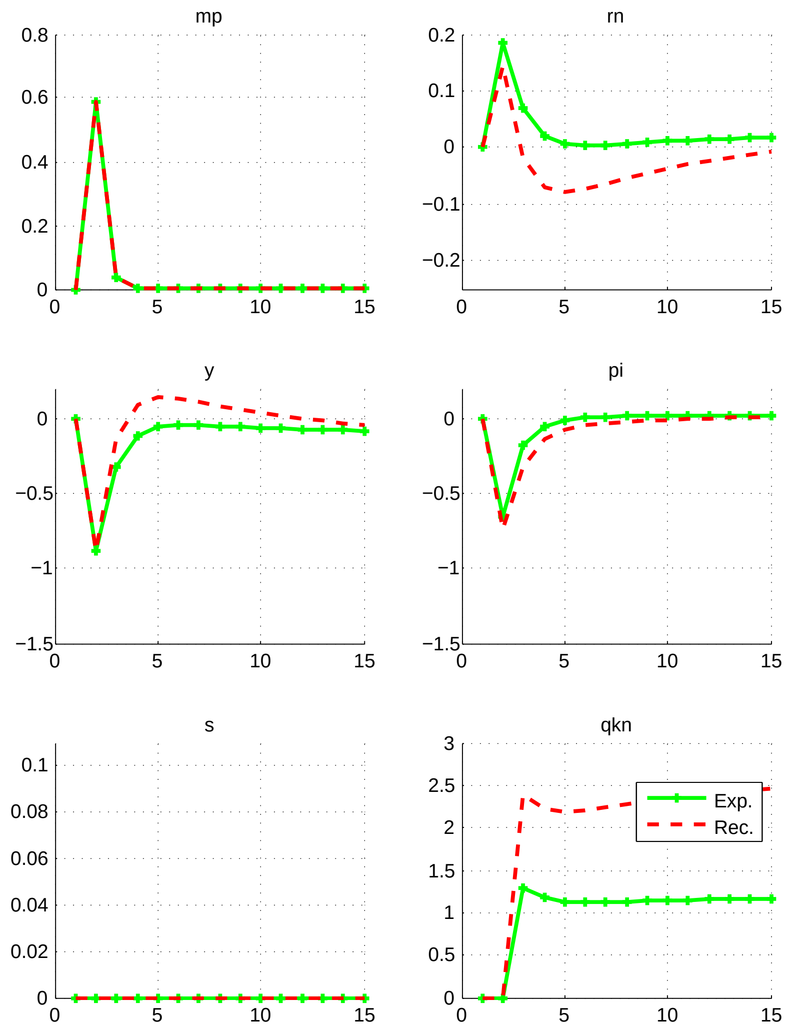
For comparison purpose, responses to two standard deviation of monetary policy shocks are divided by two, responses to one- and two- negative standard deviation shocks are divided by -1 and -2, respectively.

Figure 4.8: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Demand Shocks (government expenditure), $Model3$: Without Financial Accelerator, Nonlinear Phillips Curve.



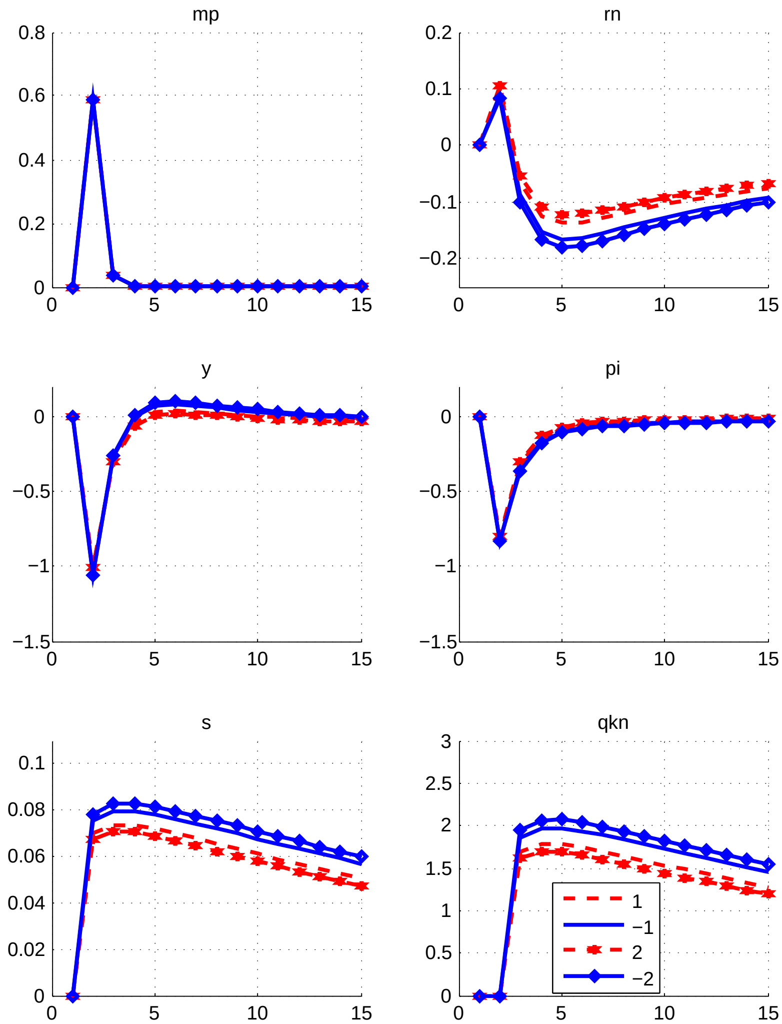
Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.9: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shocks (technology), $Model3$: Without Financial Accelerator, Nonlinear Phillips Curve.



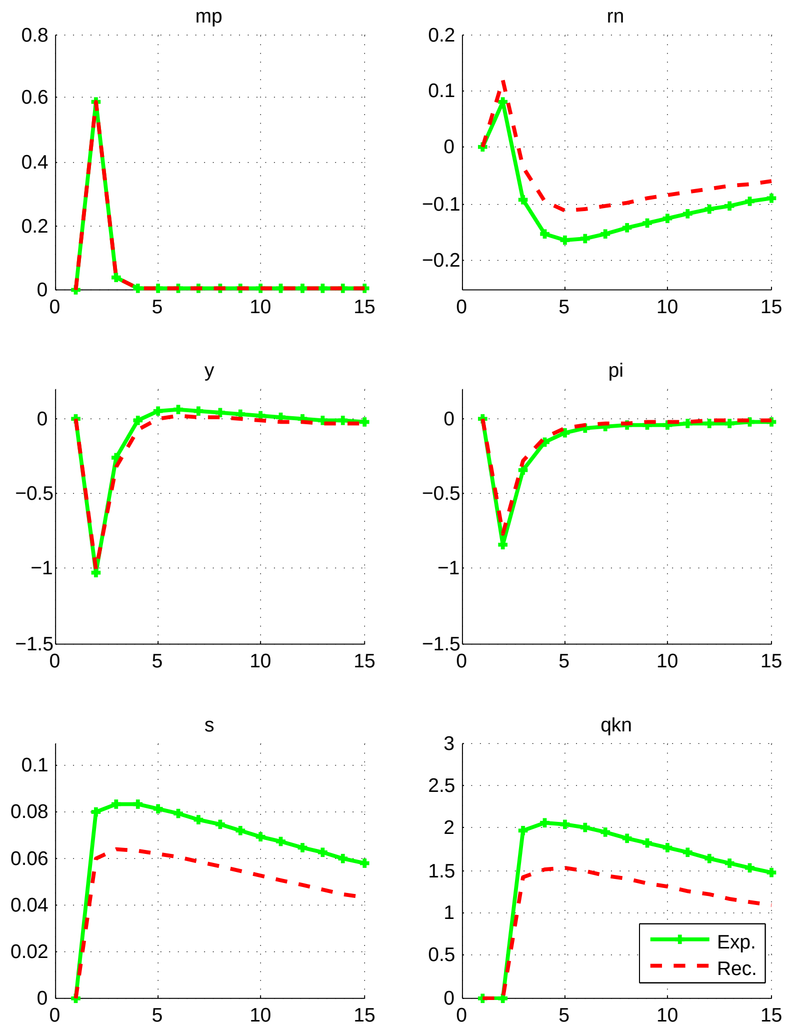
Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.10: The Responses to Monetary Policy Shocks (mp). $Model4$: With Financial Accelerator, Nonlinear Phillips Curve.



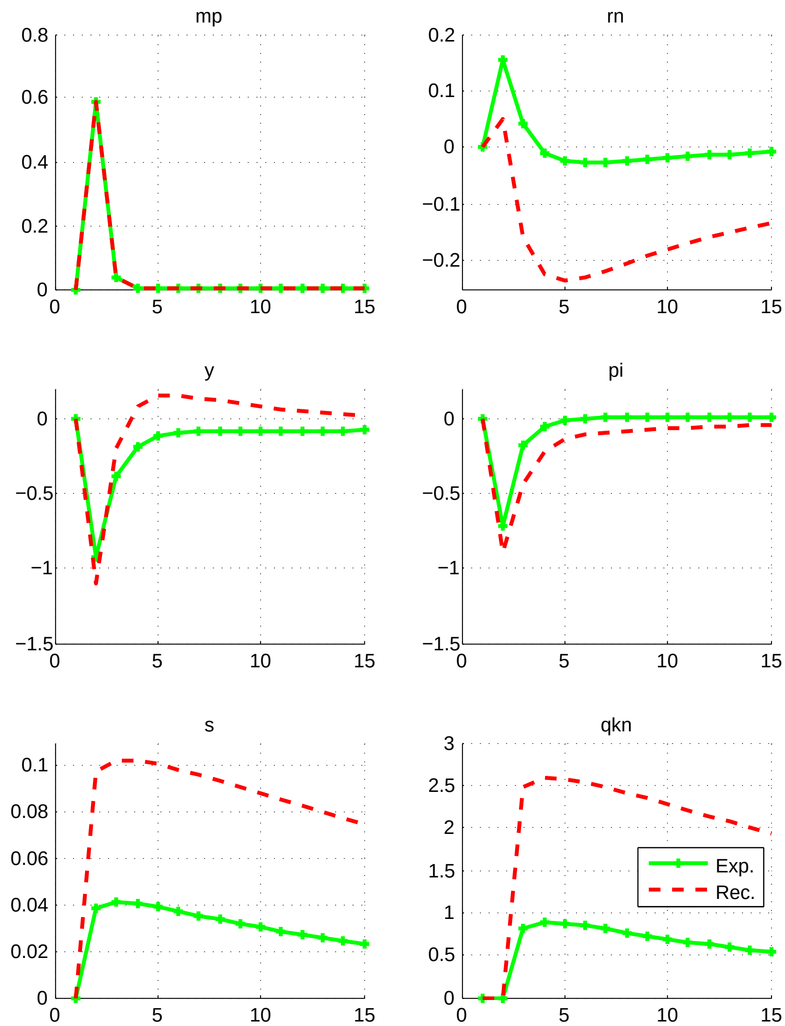
For comparison purpose, responses to two standard deviation of monetary policy shocks are divided by two, responses to one- and two- negative standard deviation shocks are divided by -1 and -2, respectively.

Figure 4.11: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Demand Shocks (government expenditure), $Model4$: With Financial Accelerator, Nonlinear Phillips Curve.



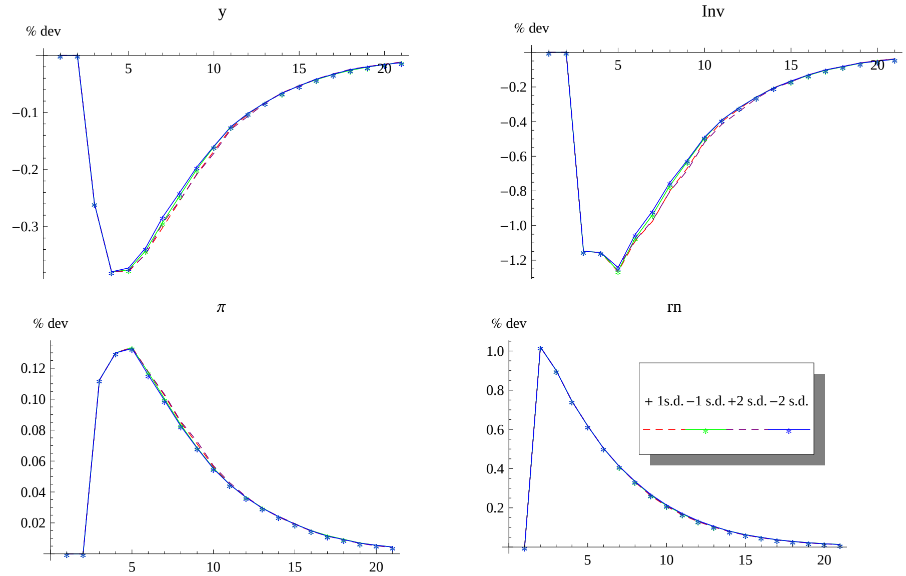
Demand shocks are driven by government expenditure shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.12: The Responses to One Standard Deviation of Monetary Policy Shocks in Expansions and Recessions: Supply Shocks (technology), *Model4*: With Financial Accelerator, Nonlinear Phillips Curve.

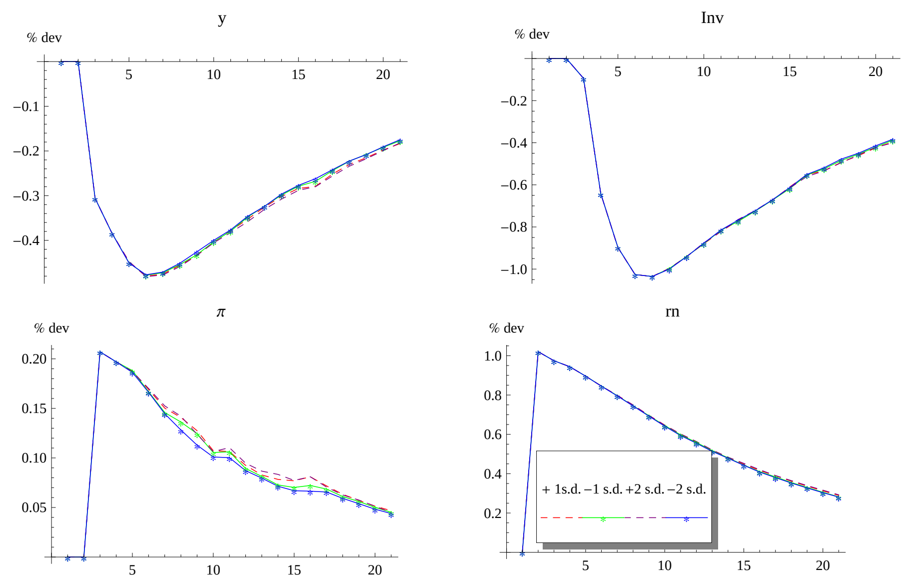


Supply shocks are driven by production technology shocks. Because of the nonlinearity of the model, the shocks are calibrated to deviate the output growth from steady state by 4 percent (annual).

Figure 4.13: Unconditional Impulse Responses



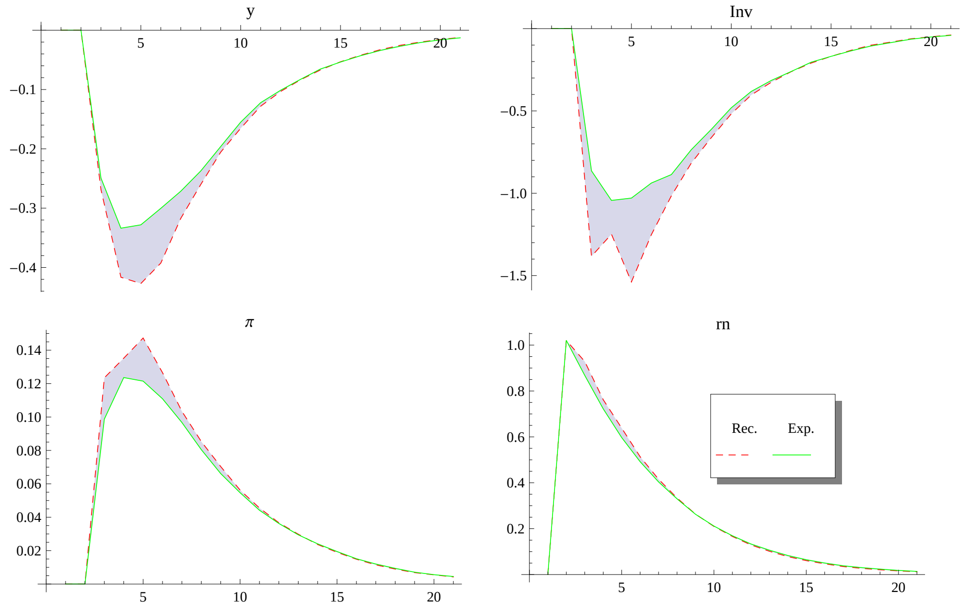
A) Observed Data



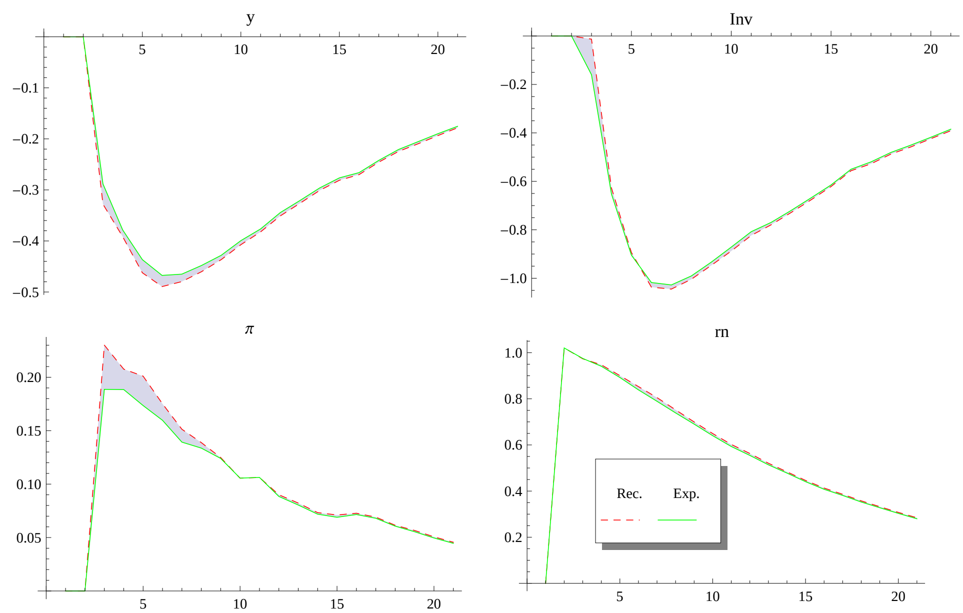
B) Simulated Data

The generalized impulse responses of the observed data, and of the simulated data are displayed in panel A and panel B, respectively. The responses are constructed by using the average responses of the initial states with 200 bootstrapping for each initial state. All data points are used as the initial state to calculate unconditional responses. The base responses are ones respond to +1 s.d. policy shocks. To make the responses comparable, ones respond to -1 s.d., +2 s.d. , -2 s.d, policy shocks are multiplied by -1, 0.5 and -0.5 , respectively. Should the effects of monetary policy be symmetric, the responses will lie on top of each other.

Figure 4.14: Impulse Responses to Moderate Contractionary Policies Implemented at Recessions and Expansions



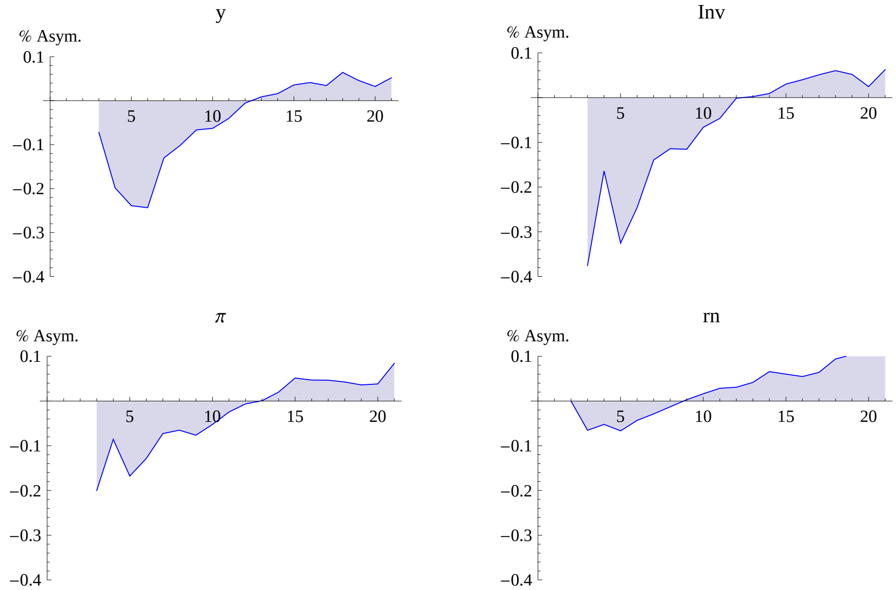
A) Observed Data



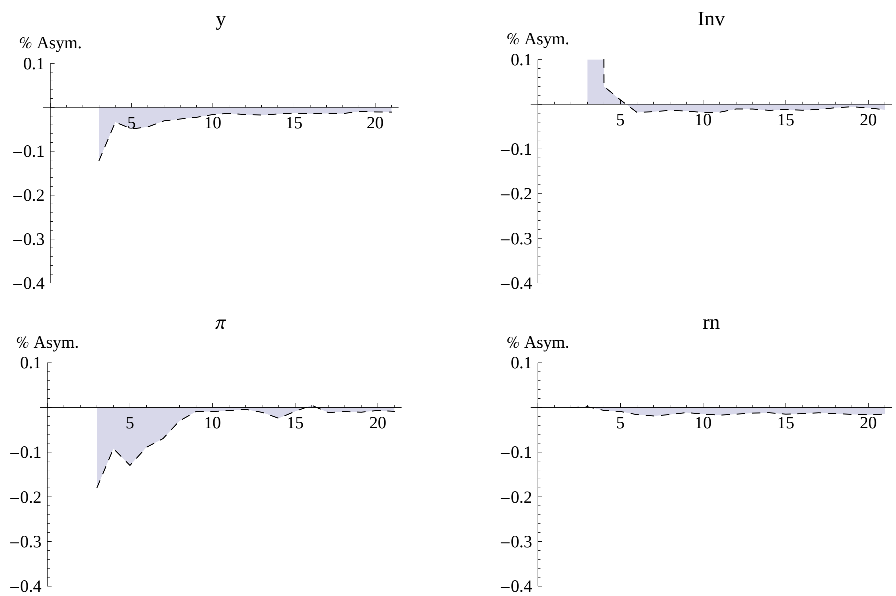
B) Simulated Data

The generalized impulse responses to moderate contractionary policies (+1 s.d. policy shocks) of the observed data, and of the simulated data are displayed in panel A and panel B, respectively. The responses are constructed by using the average responses of the initial states with 200 bootstrapping for each initial state. The expansions and recessions phases are characterized by the initial states that have the output growth greater than 4 percent (about +1 s.d.) and less than 0 (about -1 s.d.), respectively. The responses to the policies implemented at recessions and expansions are displayed by dashed lines and bold lines, respectively. Should the effects of monetary policy be symmetric, the responses will lie on top of each other. The shaded area indicates the asymmetric effects of the monetary policy during recessions and expansions.

Figure 4.15: Asymmetric Effects of Contractionary Policies : Expansions over Recessions



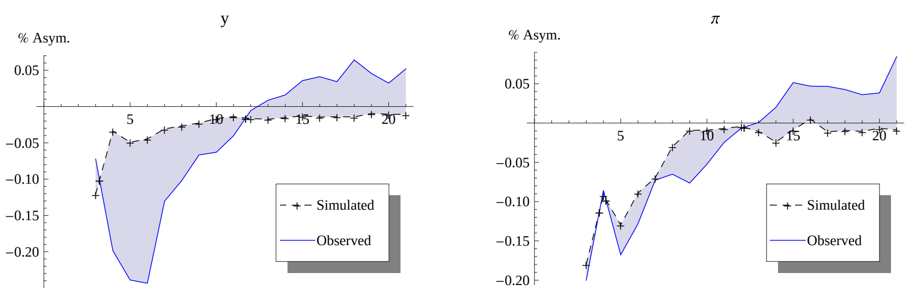
A) Observed Data



B) Simulated Data

The asymmetry is presented in a percentage differences to normalize the differences of the base responses. The base responses are ones respond to moderate contractionary policies (+1 s.d. policy shocks) at recessions. Thus, these are the asymmetric effects of the monetary policy implemented at expansions over those of recessions. The asymmetric effects of monetary implied by the observed data and the simulated data are displayed in panel A and panel B, respectively.

Figure 4.16: Unexplained Asymmetric Effects of a Contractionary Policies: Expansions Over Recessions



The asymmetry is presented in a percentage differences to normalize the differences of the base responses. The base responses are ones respond to moderate contractionary policies (+1 s.d. policy shocks) at recessions. The bold line displays the empirical asymmetry. The dashed line displays the implied asymmetry by the model. The shaded area shows the remaining part of the asymmetry that cannot be explained by the model.

Chapter 5

Conclusion

This study empirically and theoretically examines three types of asymmetric effects of monetary policy: 1) expansionary versus contractionary policies; 2) moderate versus aggressive policies; and 3) policies implemented in recessions versus ones implemented in expansions.

Chapter 1 uses a smooth transition VAR to empirically examine the effects of monetary policy. The monetary policy does not have the asymmetric effects in general. The only noticeable asymmetry is that the policies implemented at recessions seems to have a stronger effect than ones implemented at expansions.

Chapter 2 and Chapter 3 analyze asymmetric effects of monetary policy in a new Keynesian dynamic stochastic equilibrium model. The model has two potential sources of the asymmetry which are a convex supply curve and the financial friction, devised by Calvo (1983) pricing mechanism and Bernanke et al. (1998)'s financial accelerator, respectively.

Asymmetric effects of monetary policy are not found when the solutions of the model are obtained by the first-order perturbation method. This failure is a direct result of a linearization, which cancels out the nonlinearity of the model. Using the second-order perturbation, the nonlinearity of the model and its potential to explain the asymmetric effects are preserved. The simulation exercises using certain ranges of parameter values display a certain degree of the asymmetric effects of monetary policy and demonstrate the potential of the model. The main source of the asymmetric effects comes from the nonlinear Phillips curve while the financial accelerator only amplifies the effects of the policy.

However, the financial accelerator does not produce asymmetric effects of monetary policy as formerly expected. Using a partial equilibrium framework analysis, the convex risk premium curve, which is a result of the financial friction, is expected to create asymmetric effects of monetary policy. The simulation results exhibit a convex risk premium curve, which verifies the function of financial acceleration mechanism. However, with a general equilibrium, the potential cause of asymmetric effects is canceled out through the interaction among other sectors.

Subsequently, the model parameters are both calibrated and estimated by indirect inference using the U.S. data. However, with either calibrated or estimated parameters, the previously found asymmetric effects are diminished. The only observable asymmetric effects are the different effects of the policy implemented at the different phases of business cycle. Moreover, the degree of asymmetry is minimal. These findings suggest that monetary policy does not have asymmetric effects in general.

The asymmetric effects of monetary policy are found only when the parameters are set to certain ranges. However, those ranges are quite different from the estimated values suggesting that the asymmetric effects of monetary policy could arise only in some extreme conditions. The great depression and the recent financial crisis might be the cases of those extreme conditions. In both cases, the interest rate was approaching its zero bound where it cannot be dropped further. In this situation, the standard policy and theories cannot be directly applied.

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