The Term Structure and Cost Channel Effect of Monetary Policy

by
Myung-Soo Yie

A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Economics.

Chapel Hill
2007

Approved by:

Dr. Richard Froyen, Advisor

Dr. Stanley W. Black, Committee Member

Dr. Michael K. Salemi, Committee Member

Dr. William R. Parke, Committee Member

Dr. Oksana Leukhina, Committee Member

ABSTRACT

MYUNG-SOO YIE: The Term Structure and Cost Channel Effect of Monetary Policy. (Under the direction of Dr. Richard Froyen.)

Sims (1992) first recognized a puzzling protracted rise in the price level following a contractionary monetary policy shock. Two groups of studies have addressed this "price puzzle". The first group suggests that the price anomaly can be resolved by adding future inflation information to the policy rule, because they believe that this undesirable result comes from the omission of important information available to the monetary authority. The second group regards this price response as normal because of the cost channel effect of monetary policy.

Since the effectiveness of monetary policy depends critically on the correct identification of the policy transmission mechanism, the recognition of the existence of the cost channel is important for the policy makers. This paper provides evidence of the cost channel effect through a structural VAR analysis. Based on empirical evidence, I construct a dynamic stochastic general equilibrium model, which addresses the cost channel effect.

My model focuses on two related features by which monetary policy affects real variables. (1) The model derives the term structure of interest rates, which states that the monetary policy action changes the market's expectations on the current and future short rate path that, in turn, determine the long rates. Despite the closer relationship of macro variables to long rates than to short rates, the monetary authority adopts the short rate as a policy instrument based on the belief of the existence of a channel through which the short rate policy is transmitted to long rates. Moreover, many

studies fail to take into account the direct impact of long rates on the economy. In contrast, (2) my model highlights the role of long rates. I find that time lags in the capital formation and long-term financing contracts by firms enhance the cost channel effect, and generate the variables' staggered responses. The monetary policy action changes the short and long rates through the term structure of interest rates. Also the firms' borrowing pattern for both labor costs with short-term contracts and investment projects with long-term contracts link the nominal short- and long-term interest rates directly to firms' marginal costs.

This paper incorporates a simple cash in advance feature, sticky prices and wages, and habit formation. My model indicates that the price stickiness makes a limited contribution to generate persistent responses, but the sticky wage amplifies the inertial behavior of variables and ensures that the real wage responds in the direction that the cost channel effect of monetary policy predicts. Contrary to the studies by Fuhrer (2000) and Amato and Laubach (2004), in which they showed that habit formation helps to explain the gradual response of macro variables such as output and inflation to monetary policy shocks, habit formation in this paper only smoothes the response of consumption across time.

To my wife, Hyunju Oh, for dedicating her time and effort to taking care of me and my son, Dennis (Jungyong).

ACKNOWLEDGMENTS

First and foremost, I am grateful and would like to thank professor Richard Froyen, who is my advisor, for innumerable, thoughtful discussions on my thesis topics. Many of important features in my model came from these discussions. Without Dr. Froyen, this paper would not be what it is today. I would like to thank professor Michael K. Salemi for allowing me the time to learn various techniques on policy analysis. I also thank Hamilton Fout for many discussions and feedback. Finally, I thank my parents and in-laws for tremendous support with all their hearts and minds.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

Sims (1992) first recognized a puzzling protracted rise in the price level following a contractionary monetary policy shock. Two groups of studies have addressed this "price puzzle." The first group, which includes works such as Sims (1992) and Leeper, Sims, and Zha (1996), suggests that the price anomaly can be resolved by adding future inflation information in the policy rule, because they believe that this undesirable result comes from the omission of important information available to the monetary authority. According to Hanson's (2004) study, however, there is little correlation between an ability to forecast inflation and an ability to resolve the puzzle. The second group, such as Barth and Ramey (2001), regards this price response as normal because of the cost channel effect of monetary policy. Following the second group, this paper provides evidence of the cost channel effect of the monetary policy transmission through a structural vector autoregression (VAR) analysis. Based on empirical evidence, I construct a dynamic stochastic general equilibrium (DSGE) model which addresses the prolonged co-movement of price responses with short rates.

Since the effectiveness of monetary policy depends critically on the correct identification of the policy transmission mechanism, the recognition of the existence of the cost channel and the term structure channel is important for policymakers. As Ravenna and Walsh (2006) noticed, the cost channel effect depends on the direct relationship of nominal interest rates to the firms' marginal costs.[1] Christiano and Eichenbaum (1992a) and Christiano, Eichenbaum, and Evans (2005, hereafter CEE) link a firm's financing cost of labor to the nominal short-rate. Li and Chang (2004) connect the nominal interest rate to the production cost of capital by assuming that firms finance business investment. Even though these studies successfully generate a cost channel effect in the general equilibrium framework, they focus only on the short-term financing cost.

Contrary to previous cost channel models, this paper emphasizes the role of long rates for generating the cost channel effect and the persistent responses of the economy. This is based on the argument by Woodford (1999) and Kozicki and Tinsley (2002) that macro variables are more closely related to long rates than short rates. Therefore the term structure of interest rates is considered as an important monetary policy transmission channel which connects the policy action to long rates. But previous macroeconomic models regarding a term structure relationship have mainly focused on finding determinants of long rates and have paid less attention to the role of long rates in the economy. The most well-known theory about the term structure of interest rates is the expectations hypothesis, which states that the policy affects long rates by changing the average of current and future short-rate expectations. But, as Ellingsen and Söderström (2001, 2004) noticed, some puzzling results observed in the term structure data cannot be explained by the expectations theory. First, long-term interest rates respond more strongly to monetary policy innovation than the expected path of short rates does. Second, since an exogenous increase in short rates should lower inflation in the long run, a positive relationship between long and short rates is puzzling. Third, even though the average relationship is positive, the relationship between long and short rates varies over time. To resolve these puzzling results, recent studies such

[1] Chevalier and Scharfstein (1996) emphasized the role of capital market imperfections and showed that tighter liquidity constraints may generate counter-cyclical price movements through markups.

as Ellingsen and Söderström (2001, 2004) and Beechey (2004) rely on the asymmetric information between private agents and the monetary authority. This asymmetric information creates an inference problem for private agents, and the private agents' inference on unobserved shocks affects the expectation path of short rates, hence the behavior of long-term interest rates.

On the other hand, Kozicki and Tinsley (2001) and Gürkaynak et al. (2005) emphasize the shift in private agents' views of long-run inflation to explain the observed violations of the expectations hypothesis. They argued that long-term interest rates are more closely related to the market's expectations on long-run inflation, which is one of the goals for the monetary authority to stabilize. From their view, the Fisherian relationship between nominal interest rates and anticipated changes in prices is more important in determining the long-term interest rates.

Even though the empirical evidence is mixed, Cook and Hahn (1989) show that, on the average, the overall term structure of interest rates increases, but declines with maturity when the monetary authority raises short rates, which supports the expectations hypothesis of the term structure of interest rates. Their findings can be supported by Edelberg and Marshall (1996), and Evans and Marshall (2002), who argued that the long-rate responses following monetary policy shocks move in the direction that the expectations hypothesis implies. Favero (2005) also showed that the combination of a Taylor rule and the expectations theory provide considerable support for the expectations hypothesis of the term structure.

But these efforts to resolve the behavior of long rates are not fully based on the micro foundation. Moreover, they are all silent about the long rate's effect on the economy. Evans and Marshall's (1998) study successfully introduces the term structure of interest rates into the general equilibrium framework. But, by assuming that there is no relationship between long rates and other variables, long-term bonds in their model become redundant assets. Fuhrer and Moore (1995) analyze the role of wage contracts with a term structure relationship. The aggregate demand equation in their model links the output gap and the *ex ante* long-term interest rate which is calculated from the term structure equation. Their analysis, however, is not fully based on the micro founded model, and fails to explain how the long rate affects output and inflation.

The DSGE model developed here, on the other hand, focuses on two related channels through which monetary policy affects the economy. First, the model utilizes the term structure of interest rates as a monetary policy transmission channel. Monetary policy actions in the model change the market's expectations of the current and future short rate paths, which consequently determine long rates. The model states that the long-term interest rates are the sum of two parts: the average of expectations of current and future short rates and the term premium. The term premium is assumed to follow an exogenous *i.i.d.* stochastic process with no relation to a monetary policy shock or other macroeconomic shocks. This assumption implies that short-term interest rate policy affects long rates through the expectations hypothesis of the term structure. Some empirical evidence about this assumption will be presented by examining the impulse response functions of the term premium implied by the impulse responses of different maturity yields to macro-economic shocks. Second, as a cost channel of monetary policy, the change of both short and long rates affects macro variables such as output and inflation. The direct impact of long rates on the economy is considered one of the sources of staggered responses of macro-variables because the change of long rates alters the firm's long-run ability to produce output by investing in long-term investment projects.

Time lags in the formation of capital stock and long-term financing contracts of firms distinguish my model from previous cost channel models. They enhance the cost channel effect and generate the staggered response of the economy. A time-to-build feature that my paper adopts is introduced by Kydland and Prescott (1982) to explain aggregate investment behavior as an alternative model to a capital adjustment cost model. A capital adjustment cost model is intensively studied by Lucas (1967), Gould (1968), and Hayashi (1982), among others. While they fail both to separate the long- and short-run supply elasticities of capital and to recognize time lags in completion of investment projects, Kydland and Prescott (1982) argue that the multi-period formation of capital stock is a crucial factor for explaining aggregate fluctuations.

Financial intermediaries in my model are assumed to facilitate economic activity by providing interest-bearing assets to households and financing contracts to firms. Some behavioral assumptions on the financial market participants are made in order to avoid an identification problem while connecting the nominal short- and long-term interest rates directly to firms' marginal costs. These assumptions are based on the matching principle, which states that the maturity structure of debt matches the maturity of projects or assets held by profit-seeking economic agents. First, firms use both short-term loan contracts, for financing the cost of labor used in the production process every period, and long-term loan contracts for financing the whole cost of investment projects that take multiple periods to be used in the production process. Second, financial intermediaries allocate resources by matching maturities between the source of funds and the use of funds. Third, the loan markets are perfectly competitive markets. As a result, nominal returns on short- and long-term bonds are equal to the short- and long-term borrowing costs to firms, respectively. Hence, long-term bonds are not redundant assets.

There are many studies that try to explain why firms use different maturity financial contracts in their production process. These studies can be categorized into three groups: an agent or contracting cost hypothesis, a signal or liquidity risk hypothesis, and a tax-based hypothesis. First, a contracting cost hypothesis states that the debt maturity is used to control the conflict of interest between equity-holders (stockholders) and debt-holders (bond-holders). It predicts the inverse relationship between the debt maturity and growth opportunities, i.e., investment. Firms with risky debt (risky bond, hence vulnerability to default) have an incentive on behalf of equity-holders to reject projects with positive but low present value. This happens because even if equity-holders, the investment decision makers, undertake the entire cost of the projects including the risk of bankruptcy, they receive only a fraction of the returns by sharing it with debt-holders. In the view of equity-holders, debt-holders appropriate parts of their benefit created from bearing default risk. Therefore equity-holders will have an incentive not to undertake projects with positive present value whenever the value is lower than the amount of debt issued. This under-investment incentive can be reduced by issuing short-term debt, which matures before investment decisions are made. Therefore, firms prefer short-term debt to long-term debt. Debt-holders also will try to avoid such a suboptimal investment being realized by reducing the stated period of loan (Barclay and Smith 1995, Stohs and Mauer 1996, and Morgado and Pindado 2003).

Second, a signal or liquidity risk hypothesis states that, with positive transaction cost, lower-quality firms self-select into long-term debt if they cannot afford the cost of rolling over short-term debt, and high-quality firms signal their type by issuing short-term debt to minimize adverse selection cost (Barclay and Smith 1995, Stohs and Mauer 1996)). Firms with the highest and lowest credit risk issue short-term debt because firms with the highest credit ratings have small refinancing risk, and firms with very poor credit ratings are unable to borrow long-term because of the extreme adverse-selection costs. On the other hand, firms with intermediate credit risk issue long-term debt. Since lenders are reluctant to refinance the debt if bad news arrives, the firms with relatively low credit ratings prefer long-term debt to reduce the refinancing risk

(Barclay and Smith 1995).

Third, the tax-based model predicts that the interaction of borrowers' preferences for accelerating interest tax shields and lenders' preferences for delaying the recognition of interest income can cause borrowers to prefer long-term debt when the yield curve is upward sloping. Hence, companies will use more long-term debt when the yield curve is upward sloping (Barclay and Smith 1995).

Without theoretical background, we can also find some evidence that firms use long- and short-term debt in the production process in Demirgüç-Kunt and Maksimovic's (1999) study. They found by examining debt maturities of firms in 30 countries during 1980 and 1991 that large firms in developed countries have more long-term debt than short-term debt. Moreover, small firms in countries with a large banking sector have less short-term debt and their debt is of longer maturity. The authors conjecture that the economies of scale of financial intermediaries in obtaining information and in monitoring debtors would facilitate access to external finance, particularly among smaller firms. They also find that the high ratio of net fixed assets to total assets is positively correlated to the use of long-term debt, which implies that firms use their fixed assets (as collateral) to obtain long-term debt.

The model incorporates a simple cash-in-advance (CIA) feature, sticky prices and wages, and habit formation. In general, price and wage stickiness are thought to generate the persistent response of variables. But sticky wages turn out to be a more important factor than sticky prices in deepening the inertial behavior and the cost channel effect. Contrary to CEE (2005), who emphasize the role of variable capital utilization to generate persistence in output and inflation, the time-to-build technology and long-term loan contracts are crucial in my model. The studies by Fuhrer (2000) and Amato and Laubach (2004) show that habit formation helps to explain the gradual response of macro variables such as output and inflation to monetary policy shocks.

But habit formation in this paper only smoothes the response of consumption across time.

The rest of the paper is organized as follows. In Chapters 2 and 3, the preliminary data analysis of the US economy will be carried out using a structural VAR analysis. The evidence of a cost channel effect for monetary policy transmission and the role of the term premium in the term structure of interest rates shown in the US data will be discussed in these chapters. Chapter 4 presents the dynamic stochastic general equilibrium model, which addresses the prolonged co-movement of price responses with nominal interest rates. This chapter also includes the policy simulation exercises based on the model economy. The impulse responses of the model economy to monetary policy shocks will be compared to the empirical counterparts. Chapter 5 concludes.

Chapter 2

Preliminary Data Analysis of the US Economy

In this chapter, the impulse responses of the US economy following a monetary policy shock will be examined with a structural VAR method. The identification scheme and the well known puzzle concerning price movements will be discussed. This chapter also analyzes the direction of long-rate responses on different maturity bonds and examines what generates these long-rate responses to monetary policy shocks.

2.1 Identification

Two points must be checked in analyzing the effect of monetary policy shock with a VAR. The first is related to the stability of structural models. In general, the model estimated under a specific regime cannot be used in different monetary policy regimes. To avoid this problem, I re-do the impulse response analysis with two different sub-sample periods: the Pre-Volcker period and the Volcker-Greenspan period.

The second point is related to the identification problem of the policy instrument. The policy instrument consists of two parts: an endogenous or systematic relationship between the policy variables and non-policy variables and an unforecastable exogenous policy shock. Correct identification of the systematic part is required because the misspecification of the systematic part of the policy instrument produces puzzling anomalies (Hanson 2004). Since the dynamic analysis of a VAR system may yield reliable information on the monetary transmission mechanism only after exogenous policy actions are identified (Bagliano and Favero 1998), we also need to separate an unforecastable exogenous policy shock from the systematic part of the policy instrument.

Two different schemes for identifying the effect of policy innovation on the non-policy variables can be considered. First, the central bank is assumed to observe only past values of state variables when formulating the policy. That is, there is no feedback from the economy to the central bank's policy action within the period. We can achieve this type of identification by ordering the policy variables first in the state vector. The other identification method assumes that the central bank can observe current variables as well as a history of the entire economy when it formulates the policy rule. Therefore the central bank can react systematically to the change of current state variables. This identification scheme can be achieved by placing policy variables after the current observed state variables.

The model that I use for exploring the effect of the monetary policy shock adopts the second identification scheme, which is employed by Christiano, Eichenbaum, and Evans (1996, 1999). A VAR for a $k \times 1$ state vector of variables, X_t, is given by

$$X_t = \Phi(L)X_{t-1} + u_t, \qquad Eu_tu_t' = V \tag{2.1}$$

where L denotes a lag operator and u_t is a vector of residual shocks whose variance-covariance matrix is V. By pre-multiplying A_0 on both sides of (2.1), the structural VAR can be expressed by

$$A_0X_t = A_0\Phi(L)X_{t-1} + e_t, \qquad e_t = A_0u_t \tag{2.2}$$

where the structural shock vector e_t has a covariance matrix $Ee_te_t' = I$. After estimating (2.1) via ordinary least squares regressions, we can obtain A_0 matrix using the relationship between the covariance matrices u_t and e_t, $V = A_0^{-1}A_0^{-1'}$. That is, A_0 is the inverse of the lower triangular Cholesky factor of V.[1]

All variables that I use in this chapter are quarterly data from the FRED database provided by the Federal Reserve Bank of St. Louise for macro-variables and from the CRSP database for yields data. The state vector includes four types of variables: the monetary policy instrument, contemporaneous inputs to the feedback rule, the yield on a zero-coupon bond, and an additional explanatory variable. For the monetary policy instrument, the federal funds rate (FF_t) is used. I assume that the feedback rule incorporates contemporaneous values of the log of real gross domestic product ($RGDP_t$), the annualized inflation rate (PCE_t) measured as the difference in logs of the personal consumption expenditure deflator at time t and $t-4$, and the log of real wages (RW_t) measured by real compensation per hour in the business sector. Long-rates (YT_t) are used in a VAR one at a time with the 1- to 6-month, 1- to 5-year and 10-year maturity yields.[2] The quarterly financial data, the federal funds rate, and yields, are obtained by calculating 3-month averages of monthly data. Finally, the log of non-borrowed reserves (NBR_t) is used as an additional explanatory variable to measure the demand for credit in the economy. This variable measures the implementation of the federal funds rate target through open market operations (Edelberg and Marshall 1996). In summary, the state vector includes six individual variables and the ordering is given by $X_t = [RGDP_t, PCE_t, RW_t, FF_t, NBR_t, YT_t]$. All variables are de-trended

[1]This normalization on A_0 satisfies the assumption that the monetary policy shock is orthogonal to the information set of the monetary authority. Moreover, it ensures that the dynamic responses of the variables in X_t are invariant to the ordering of variables in contemporaneous variables and additional explanatory variables (CEE 1999).

[2]A 10-year constant maturity yield is used for the 10-year yield from the Federal Reserve Bank of St. Louis.

with the Hodrick-Prescott filter with a smoothing parameter of 1600 in order to see the responses of deviations from the steady state values. The data go from 1965:Q2 to 2005:Q4 and 6 lags are included in each equation.[3]

The policy instrument FF_t, which is one element of X_t, can be decomposed into a systematic component (the reaction function) and unforecastable policy shock. That is,

$$FF_t = f(\Omega_t) + e_{g,t} \tag{2.3}$$

where $e_{g,t}$ denotes exogenous policy shock, and Ω_t is a set of information available to the monetary authority at time t that consists of two parts: contemporaneous values of output, inflation, and real wage, and the entire history of the economy.

According to the theory of the term structure of the interest rates, market expectations about the future path of short rates induced by policy actions play a central role in determining long rates. After observing the policy action, the market participants form expectations about the future path of the short rates and formulate long-term rates. For this reason, the long-term bond yields come after the policy instrument. Since the feedback rule is a linear function of contemporaneous variables and lagged values of all variables in the economy, the policy decision affects reserves and bond yields contemporaneously and has an effect on the future realizations of all variables.

[3] I use data from 1965 because the policy instrument that I used here is the federal funds rate and the early 1960s are viewed as the evolutionary period for the federal funds rate to provide information concerning future movement in real activity relative to the non-borrowed reserve mix (Choi and Ratti 2004). Moreover, the federal funds rate continuously exceeds the discount rate only after 1965, hence it acts as the primary instrument of monetary policy thereafter (Fuhrer and Redebusch 2004).

2.2 Preliminary Analysis of the Data

In this section, I compute the first and the second moments of level data for two sample periods to obtain preliminary information. The results are summarized in Table 2.1. Panel A displays those with full sample data range, 1965:Q2-2005:Q4, and panel B summarizes the moment properties within the Volcker-Greenspan period.

The average yield curve is upward sloping in both sample periods, and the standard deviations of yields generally decrease as maturity increases. When we look up the correlation coefficients between inflation and financial data including the federal funds rate, we can see that the full sample period and the Volcker-Greenspan period are not much different. The correlation coefficients between inflation and the federal funds rate are similar across the two sample periods, with 61% in the full sample period and 69% in the post-Volcker period. The amount of correlation between inflation and short-term yields is similar, too, and decreases as maturity increases, even though the strength of correlation between inflation and long yields in the full sample period is much smaller than in the Volcker-Greenspan period. Specifically, the correlation between inflation and longest-term yields (10-year) is -62% in the Volcker-Greenspan period, compared to -45% in the full sample period.

The negative relationship between output and the financial data implies that when the interest rates increase, output falls. It suggests that the interest rates can be thought of as investment costs or production costs. The positive relationship between inflation and the financial data confirms this interpretation that when interest rates increase, the cost of production increases, hence the price goes up.

The correlations between output and financial data in the full sample period are smaller than the correlations between inflation and financial data. But in the Volcker-Greenspan period, the correlations between output and financial data are greater than the correlation between inflation and financial data. Particularly, the correlation between output and longest yield is -92% in the Volcker-Greenspan period and -19% in the full sample period. From these results, we can conjecture that output and financial data, including the federal funds rate, are highly positively correlated in the pre-Volcker period, which is contradictory to the traditional belief that there is a negative relationship between output and interest rate.

Table 2.2 shows the first and the second moment properties of de-trended data. Most patterns resemble those from the level data. But the correlation coefficient between output and financial data has a positive sign, which means that if the output gap increases, then the deviations of yields from their trends also move in the same direction as the output gap. The correlation of output or inflation with the yields decreases with maturity in both sample periods. From this table, we can conjecture that the feedback rule has positive signs for output and inflation gap because of the positive correlation of the federal funds rate with output and inflation gap, 35% and 47%, respectively in the full sample period; 46% and 27% in the post-Volcker period. The correlations between financial data including the federal funds rate remain high relative to other variables. Specifically, the correlations between the federal funds rate and 1-month yields are 92% in both periods, but those correlations drop below 70% at 10-year yield in both periods.

2.3 Model Specification Test

In this section, I test the model specification by checking the autocorrelations in the VAR residuals. Autocorrelation is frequently encountered in models estimated with time-series data. Since error terms pick up the influences of variables affecting the dependent variables that have not been included in the model, the persistent effect of excluded variables causes the OLS estimation to be unbiased but inefficient. Moreover the standard errors from OLS are estimated in the wrong way (Verbeek 2000). This section checks the model specification by testing serial correlation of VAR residuals using the Lagrange multiplier test explained in Davidson and MacKinnon (1993).

We wish to test the null hypothesis that the errors u_t in the model equation (2.1) are serially independent against the alternative that they follow AR(p) process. The test regression can be expressed as follows

$$\hat{u}_t = \tilde{\Phi}(L)X_{t-1} + \sum_{j=1}^{p} \rho_j \hat{u}_{t-j} + \epsilon_{u,t} \tag{2.4}$$

where $\hat{u}_t$ is the vector of estimated errors from VAR. The matrix of regressors in the original VAR equation is added because the lagged dependent variables in the regression function (2.1) are included in X_{t-1}. It is known that when the original model includes lagged dependent variables, the Lagrangian multiplier test should be applied based on equation (2.4) (Verbeek 2000). A test statistic can be computed as TR^2 where R^2 is the uncentered R^2 from the OLS regression of $\hat{u}_t$ upon their lags $\hat{u}_{t-1}$ and all explanatory variables. T denotes the effective number of observations. It has a χ^2 distribution with p degree of freedom under the null hypothesis. That is, if R^2 is close to zero, it means that the lagged residuals are not explaining current residuals.

Figure 2.1 depicts autocorrelation functions for each variable's residuals from the VAR estimation over 30 lags. Dotted lines represent $\pm\sqrt{T}1.96$. As shown in the figure, the autocorrelation functions move within 95% confidence intervals, which implies no serial correlation could be detected. Table 2.3 shows the serial correlation test results for each residual when $p = 1$. The table also reports F-test statistics in comparison with the χ^2 results. F-test statistics for $\rho_1 = \rho_2 ... = \rho_p = 0$ will have p and $T - k - p$ degrees of freedom where k is the order of VAR regression. Test results indicate that when VAR(6) is applied, then there is no first-order serial correlation for all variables. But as the order of autocorrelation (p) in (2.4) increases, the χ^2 test rejects the null hypothesis of $\rho_1 = \rho_2 ... = \rho_p = 0$, in particular, for inflation. When I apply the χ^2 test using TR^2 for test statistics, the null hypothesis of inflation is frequently rejected after $p \geq 2$. On the other hand, F-test states that inflation does not have serial correlation when the residual equation has less than 5 lags. Overall, we can conclude that the VAR specification with the 6th order does not bear the autocorrelation.

2.4 Impulse Response Functions

This section discusses the results of impulse responses to a monetary policy shock based on the identification scheme explained in the previous section. The positive relationship between interest rates and inflation will be discussed with the full sample period and two sub-sample periods for concerning the stability of the empirical model.

2.4.1 Full Sample Period

In Figure 2.2, the solid line denotes the impulse responses of state variables to one-standard deviation exogenous monetary policy shocks for 20 quarters. The dash-dot lines delineate 95% confidence intervals and the dotted lines depict 68% confidence intervals. These were computed using a bootstrap Monte Carlo procedure outlined in CEE (1999) with 1,000 bootstrap Monte Carlo draws. Five-year zero-coupon yields are used to estimate impulse response functions to the contractionary federal funds rate shock in Figure 2.2. The responses of variables with different yields are not different from Figure 2.2.

The upper left panel depicts the output response to a contractionary federal funds rate shock, and clearly shows the hump-shaped response. Output declines for approximately six quarters with a maximum drop by 0.25%, then tends to rise. The federal funds rate (FF) initially rises by approximately 60 basis points, but its response dies out before a year and a half. There is a persistent drop in non-borrowed reserves (NBR). Together with the upward response of the federal funds rate, this result implies that there is a significant liquidity effect in the economy. Real wages show an insignificant but pro-cyclical response to the monetary policy shock. Its maximum response is -0.11% six quarters after the shock, and it recovers the pre-shock level 13 quarters after the shock.

The upper right panel of Figure 1 represents the inflation response to a contractionary monetary policy shock. Inflation initially rises by 0.06% and tends to go down six quarters after the shock. When we analyze the monetary policy impact in VARs, many of these VAR specifications, particularly the ones without a commodity price, frequently generate the price puzzle which states that the contractionary monetary policy shock produces a substantial positive response of the aggregate price level for many periods. The conventional wisdom predicts that the reduction of the volume of non-borrowed reserves in the bank reduces the spending relying on bank credit. Hence, aggregate demand and price also must fall.

Figure 2.3 shows the impulse response functions to a contractionary monetary policy shock when the state vector includes the commodity price index.[4] According to Sims (1992) and Leeper, Sims, and Zha (1996), the exclusion of a commodity price can result in a critical mis-specification of the model because it is important information to policymakers when policy decisions are made. But, as indicated by the impulse responses, even though the commodity price index is included in order to catch the future inflation information of the monetary authority, its statistical performance is only slightly improved, and the directional change is not observed. Hence, the claim by Sims (1992), that the mis-specification of the policy rule[5] induces the price anomaly, is

[4]The spot market price index from BEA is used to measure the commodity price index.

[5]Some studies, such as Hanson (2004), found that the policymaker's information omitted in the policy rule should be carefully chosen because not all leading indicators for inflation can resolve the

hard to replicate.

Moreover, there are alternative explanations of the counter-cyclical movement of prices such as that made by Chevalier and Scharfstein (1996). They focus on the test of the null hypothesis that a firm's markup is counter-cyclical when it is more financially constrained with firm level data. They emphasize the role of capital market imperfections so that tighter liquidity constraints may generate counter-cyclical movement of prices through markups. That is, the standard model predicts the lower marginal products in the boom implying lower marginal costs and factor prices. Hence the real factor prices become lower in the boom. On the other hand, capital market imperfections and a market share model can generate counter-cyclical movement of output prices relative to factor prices. In periods of lower demand, firms tend to rely more heavily on external financing as cash flow tends to fall faster than investment needs. Even if firms can raise future profit by increasing market share as they reduce output price, external financing firms are less inclined to reduce output price during economic downturns because the increased probability of liquidation makes them care less about the future. Hence, they have higher markups in recessions. Because of higher markups of externally financed firms, an increase in the number of externally financed firms in recessions will make markups even more counter-cyclical.

Another explanation of the price puzzle is the cost channel theory. When we recognize the cost channel effect of monetary policy, the co-movements of price and the federal funds rate are not puzzling. As Barth and Ramey (2001) noticed, the pro-cyclical response of real wages (RW) in Figure 2.2 is also the evidence of the dominance of cost channel effect over the demand channel effect. A negative monetary policy shock leads interest rates to increase. The increased interest rates, in turn, push

puzzle. Furthermore, Giordani (2004) argued that "the commodity price index mitigates the price puzzle mainly because it contains useful information about the output gap, not because it is a good predictor of future inflation." He suggested that the inclusion of a good measure of output gap can help mitigate the puzzle.

up the production cost by raising borrowing costs. The initial rise of price response to the contractionary monetary policy shock reflects the dominance of the cost channel effect relative to the demand channel effect. If a contractionary monetary policy has an effect on the economy mainly through a demand channel, output and real wages move in opposite directions because the decreased aggregate demand reduces output prices. On the other hand, if a cost channel is dominant, both output and real wages should fall because the decreased aggregate supply raises output prices. If both channels are strong enough, the response of the relative price would not move unambiguously in one direction.

The decrease of credit caused by the contractionary monetary policy shock reduces the private sector's demand for goods. The contractionary monetary policy shock also raises the cost of current and future production because firms need to finance labor and investments which will be used in the current and future production process with higher interest costs. Hence, the upward movements of the price and the downward movements of the output persist for some time. Therefore, the rise in inflation and the fall in real wages may indicate that the cost channel of monetary policy transmission dominates the demand channel in the economy.

The direction of long-term yield response in Figure 2.2 is the same as the response of the federal funds rates FF_t, but its effect is weaker than FF_t. Figure 2.4 shows the impulse response functions (IRFs) of all bond yields to monetary policy shocks. Each window represents a different yield (1- to 6-month, 1- to 5-year, and 10-year) starting from the upper left corner and proceeding to the bottom right. Each impulse response function is estimated by replacing YT_t in the state vector with a different maturity yield one at a time. The dashed lines delineate 95% confidence intervals. According to the point estimates, the initial responses of all bond yields are significantly greater than zero, but the amount of initial responses become smaller as maturity increases.

These results are similar to those of Edelberg and Marshall's (1996) study in that the magnitude of the effect declines at longer maturities.

The initial responses of 4-year and longer-term rates persist for approximately six quarters, which is slightly longer than the shorter-term bond yields. For example, the impacts on 1-year bond yield and shorter yields disappear within three quarters at the 5% significance level. This can be interpreted in two ways. One is the asset market imperfection from Andrés, López-Salido, and Nelson (ALN 2004). Since the asset markets could have some frictions, investors tend to pay more money for purchasing longer-term bonds. ALN considered the existence of transaction cost as an important factor for the market friction. The other interpretation can be found in the studies by Kozicki and Tinsley (2001) and Gürkaynak et.al. (2005). They argued that the change of long-term expectations on the inflation target by the central bank could affect the movements of long-term interest rates via the Fisher equation. That is, the movements of longer-term rates depend more on inflation expectations than on the short rate expectations. Hence both studies assert that the effect on long rates could remain over a longer horizon.

I will discuss the term structure of interest rates in a separate chapter by examining the term premium responses implied by long-rate responses to macroeconomic shocks. Here I examine the impulse responses to an asset market shock which can be thought of as risk premium shock. Figure 2.5 shows the impulse responses of macro variables to the longest-term (10-year) bond market shock. The risk premium shock does not significantly affect output and inflation at the 5% significance level. The results are no different when the long-term yield is ordered before the federal funds rate where the central bank can be thought to have the asset market information when the policy is formulated. This simply implies that the market participant fully absorbs the asset market shock or the market participant can diversify the market risk when they trade assets.

The co-movements of interest rates and price indicate that the cost channel effect dominates the credit channel effect, which suggests that the decrease of credit by the contractionary monetary policy shock reduces the private sector's demand for goods and hence price level. The contractionary monetary policy shock causes the federal funds rate and long-term interest rates to rise in the way that the expectations hypothesis predicts. The increased short- and long-term interest rates raise the cost of future production because firms need to finance investments which will be used in the future production process. Hence the upward movements of the price level persists for some time and the output decreases.

2.4.2 Sub-Sample Periods

Next, I examine the extent to which the impulse responses may change over the sample period. To this end, I split the full sample into the period 1965:Q2 to 1979:Q3 (the pre-Volcker period) and 1979:Q4 to 2005:Q4 (the Volcker-Greenspan period).

Figures 2.6 and 2.7 show the impulse responses of six variables to the contractionary monetary policy shock in the pre-Volcker period and the Volcker-Greenspan period, respectively. Again, the dashed line intervals and the dotted lines represent 95% and 68% confidence bands with the bootstrap Monte-Carlo procedure, respectively.

The results from the Volcker-Greenspan period are very similar to those from the full sample period and initial inflation response remains positive four quarters after the shock, which is shorter than the eight quarters in the full sample period. On the other hand, the inflation response to the exogenous policy shock with the pre-Volcker data fluctuates more across the entire forecast horizon than does that of the Volcker-Greenspan period or the full sample period. Moreover, even if its initial response is positive, it fluctuates around zero across the entire forecast horizon. Hence the demand

and cost channel effects are mixed; neither one appears dominant in the pre-Volcker period. According to Hanson's (2004) study, a price puzzle is related primarily to the pre-Volcker sub-sample period and most indicator variables about the future inflation information cannot resolve the price puzzle for this period. But my preliminary impulse response analysis finds that, contrary to Hanson's (2004) results, the demand and cost channel effect are both strong enough in the pre-Volcker period, and the inflation response during the Volcker-Greenspan period resembles the full sample response, which implies that the cost channel effect is dominant in this period.

Figures 2.8 and 2.9 show the responses of yields to the contractionary monetary policy shock in different sub-sample periods. Those results are very similar to the full sample responses but the magnitude of the responses become smaller across all maturities and the persistence of the effects is also shorter than that of the full sample period. We can even see that the 5-year yields are significant only for the two-quarter forecast horizon in both sub-sample periods.

Table 2.1: Summary statistics of level data

A. Full sample period, 1965:Q2-2005:Q4.

	mean	std	corrl						
			π_t	ff_t	nbr_t	1mth	1yr	5yr	10yr
y_t	8.6932	0.3517	-.4484	-.3227	.9265	-.3276	-.3374	-.2420	-.1900
π_t	4.0660	2.6647		.6114	-.4932	.6043	.5711	.4755	.4519
ff_t	6.6082	3.3079			-.3246	.9779	.9671	.8864	.8525
nbr_t	3.2885	0.5279				-.3276	-.3138	-.1906	-.1375
1mth	5.6412	2.6358					.9757	.8958	.8600
1yr	6.4810	2.7731						.9513	.9186
5yr	7.1266	2.4459							.9922
10yr	7.4735	2.4385							

B. Volcker-Greenspan period, 1979:Q4-2005:Q4.

	mean	std	corrl						
			π_t	ff_t	nbr_t	1mth	1yr	5yr	10yr
y_t	8.9114	0.2307	-.6182	-.8236	.7324	-.8062	-.8536	-.9105	-.9167
π_t	3.2792	2.3396		.6883	-.6556	.6783	.6651	.6238	.6224
ff_t	6.6837	3.8008			-.8068	.9847	.9798	.9258	.9091
nbr_t	3.6252	0.3324				-.7888	-.7963	-.8140	-.8204
1mth	5.6735	3.0824					.9782	.9242	.9027
1yr	6.5662	3.2912						.9692	.9502
5yr	7.4499	2.8784							.9948
10yr	7.8872	2.8208							

y_t, π_t, ff_t, nbr_t, 1_{mth}, 1_{yr}, 5_{yr}, and 10_{yr} represent real output, rate of inflation, federal funds rate, non-borrowed reserves, 1-month yield, 1-year yield, 5-year yield, and 10-year yield, respectively. Section A shows the summary statistics of level data from 1965:Q2 to 2005:Q4. Mean, standard deviation, and correlation coefficients for each variable are shown in the first, second, and third column, respectively. Section B shows the same summary statistics with data from 1979:Q4 to 2005:Q4.

Table 2.2: Summary statistics of filtered data

A. Full sample period, 1965:Q2-2005:Q4.

	mean $10^{-12}\times$	std	corrl π_t	ff_t	nbr_t	1mth	1yr	5yr	10yr
y_t	.115	0.0156	.2909	.3523	-.2000	.3828	.3554	.1044	.0118
π_t	.121	1.5409		.4670	-.2728	.4630	.4143	.2625	.1921
ff_t	-.001	1.6841			-.4233	.9257	.8993	.7065	.6362
nbr_t	-.047	0.0596				-.4519	-.4534	-.4392	-.4183
1mth	.049	1.2922					.9170	.7257	.6456
1yr	.141	1.1997						.8861	.8090
5yr	.125	0.8481							.9693
10yr	.211	0.8080							

B. Volcker-Greenspan period, 1979:Q4-2005:Q4.

	mean	std	corrl π_t	ff_t	nbr_t	1mth	1yr	5yr	10yr
y_t	-0.0008	0.0135	.3252	.4616	-.1554	.4441	.4571	.3000	.2251
π_t	0.0370	1.3570		.2689	-.1655	.3140	.3052	.2313	.1789
ff_t	0.1402	1.5633			-.3242	.9236	.9066	.7294	.6921
nbr_t	-0.0009	0.0696				-.3848	-.3952	-.4317	-.4370
1mth	0.0850	1.3420					.9048	.7371	.6733
1yr	0.0881	1.2684						.9037	.8441
5yr	0.0760	0.9307							.9743
10yr	0.0766	0.9065							

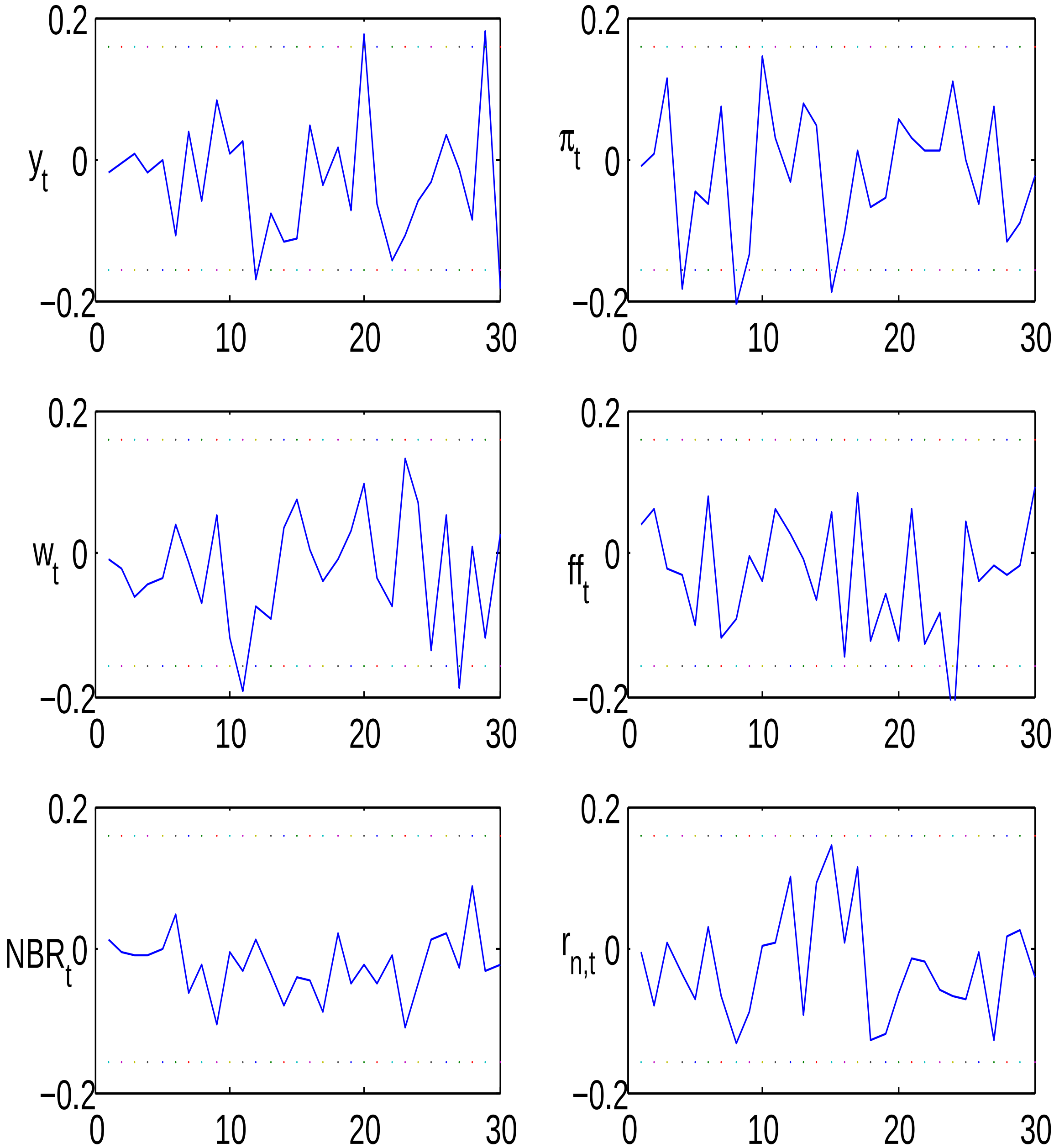
Section A shows the summary statistics of filtered data from 1965:Q2 to 2005:Q4. Mean, standard deviation, and correlation coefficients for each variable are shown in the first, second, and third column, respectively. Section B shows the same summary statistics with data from 1979:Q4 to 2005:Q4.

Table 2.3: Autocorrelation test result: $H_0 : \rho_1 = 0$

	ρ_1	t-stat	$Prob > \|t\|$	TR^2	$Pval > \chi^2(1)$	F-stat	$Pval > F$
y_t	-0.40762	-1.07138	0.28617	1.49061	0.22212	1.14786	0.28617
π_t	-0.23201	-0.74327	0.45878	0.74675	0.38751	0.55245	0.45878
w_t	-0.20131	-0.33436	0.73870	0.24652	0.61954	0.11180	0.73870
ff_t	0.38106	1.57984	0.11680	3.23812	0.07194	2.49590	0.11680
NBR_t	0.65434	1.37346	0.17219	2.49258	0.11438	1.88640	0.17219
$r_{n,t}$	0.02832	0.09293	0.92611	0.20576	0.65011	0.00864	0.92611

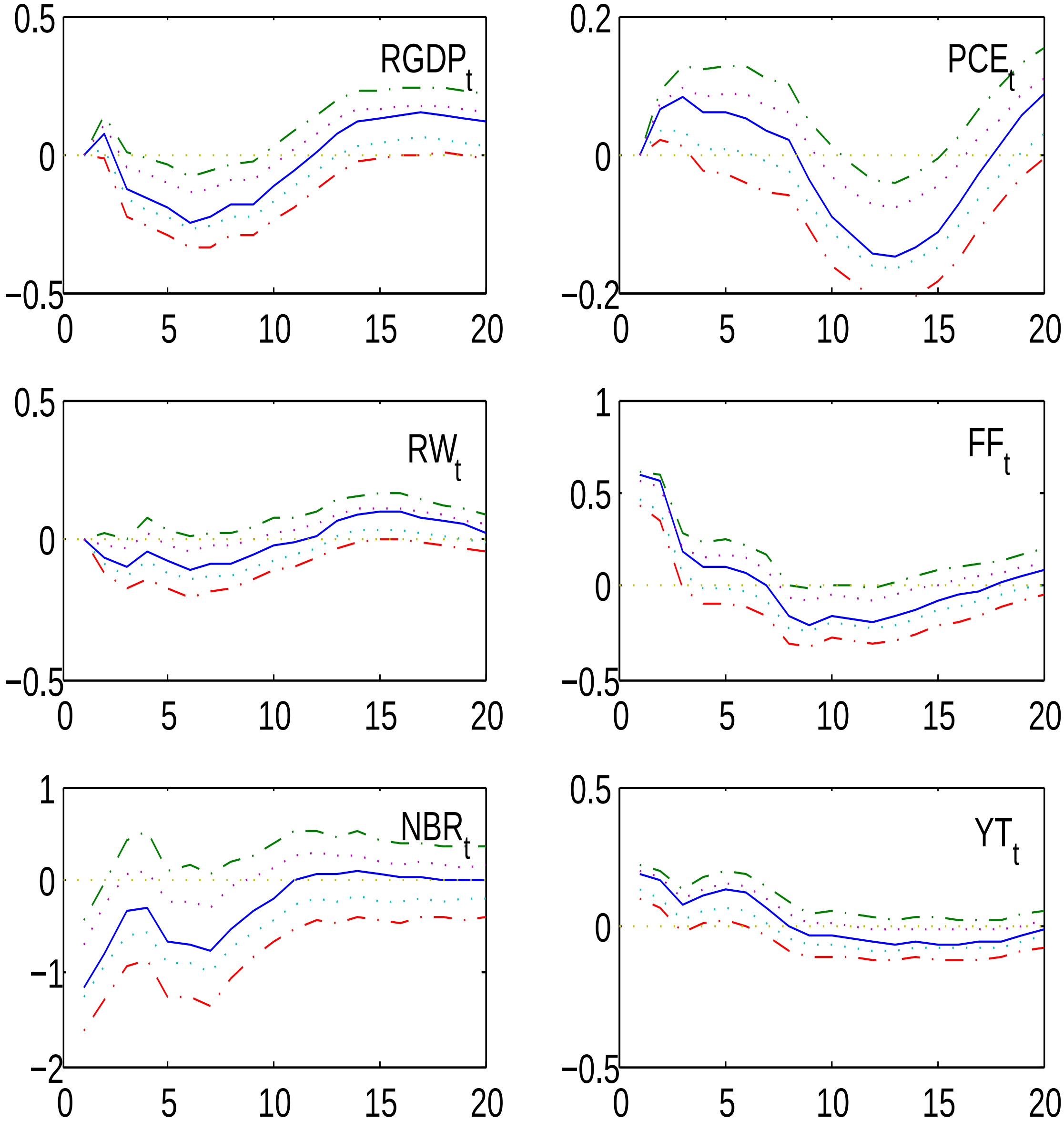
y_t, π_t, w_t, ff_t, NBR_t, and $r_{n,t}$ represent real output, rate of inflation, real wage, federal funds rate, non-borrowed reserves, and long-term interest rate. 5-year yield series are used for $r_{n,t}$. The first to third columns present AR(1) coefficients of residuals, their t-statistics, and their p-values, respectively. The fourth and fifth columns report the χ^2 statistics for testing serial correlations and their p-values. The last two columns report F-statistics and their p-values to test serial correlations.

Figure 2.1: Autocorrelation functions of VAR residuals I



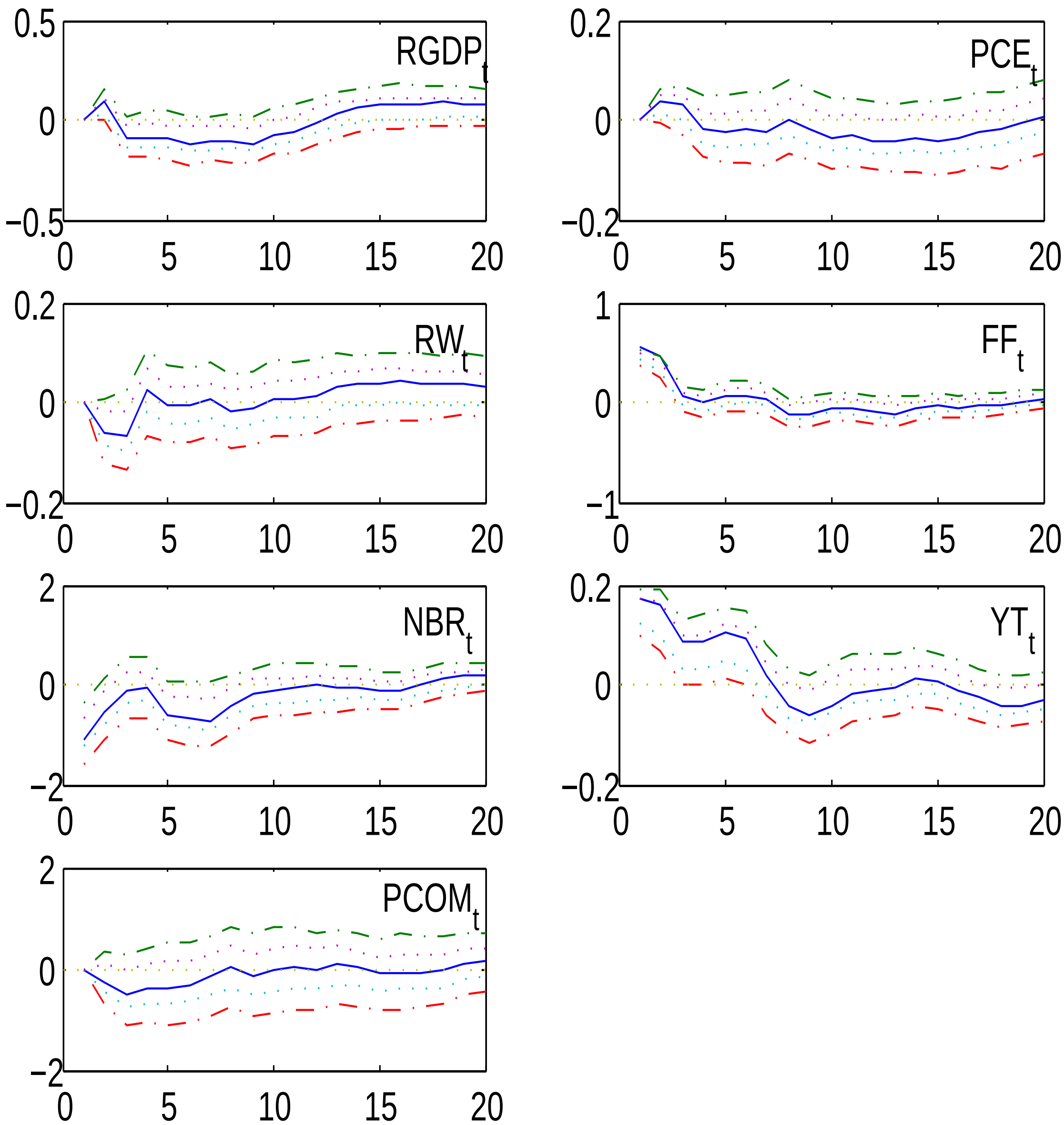
Autocorrelation functions of VAR(K) residual in which quarterly series are used. K = 6 is adopted. y_t, π_t, w_t, ff_t, NBR_t, and $r_{n,t}$ represent real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, and 5-year yield as a long rate, respectively. Dotted lines represent $\pm\sqrt{T}1.96$.

Figure 2.2: Impulse response functions to the federal funds rate shock



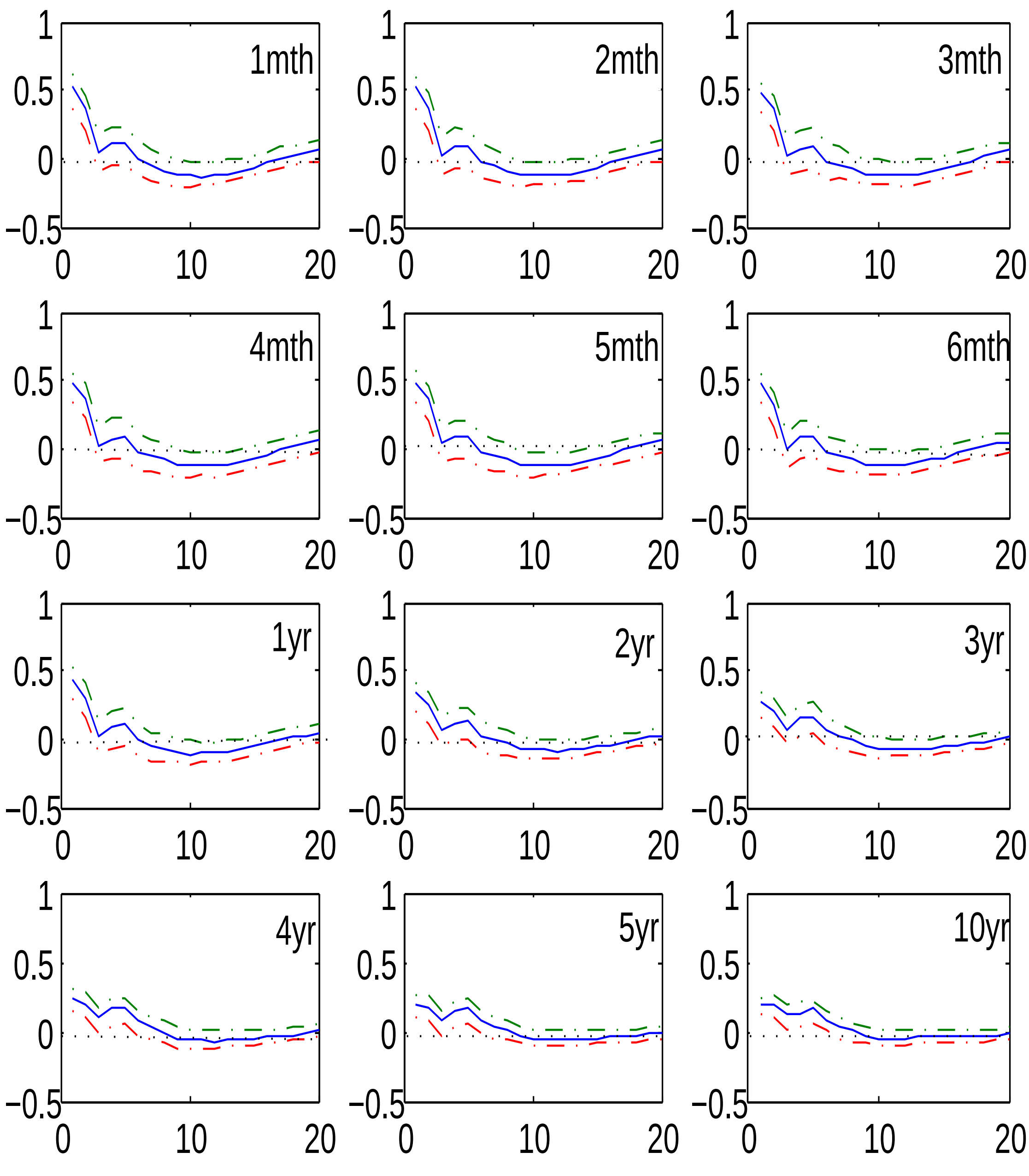
$RGDP_t$, PCE_t, RW_t, FF_t, NBR_t, and YT_t stand for real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, and 5-year yield as a long rate, respectively. The dash-dot lines represent 95% confidence intervals, and the dotted lines are 68% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 2005:Q4.

Figure 2.3: Impulse response functions to the federal funds rate shock with commodity price



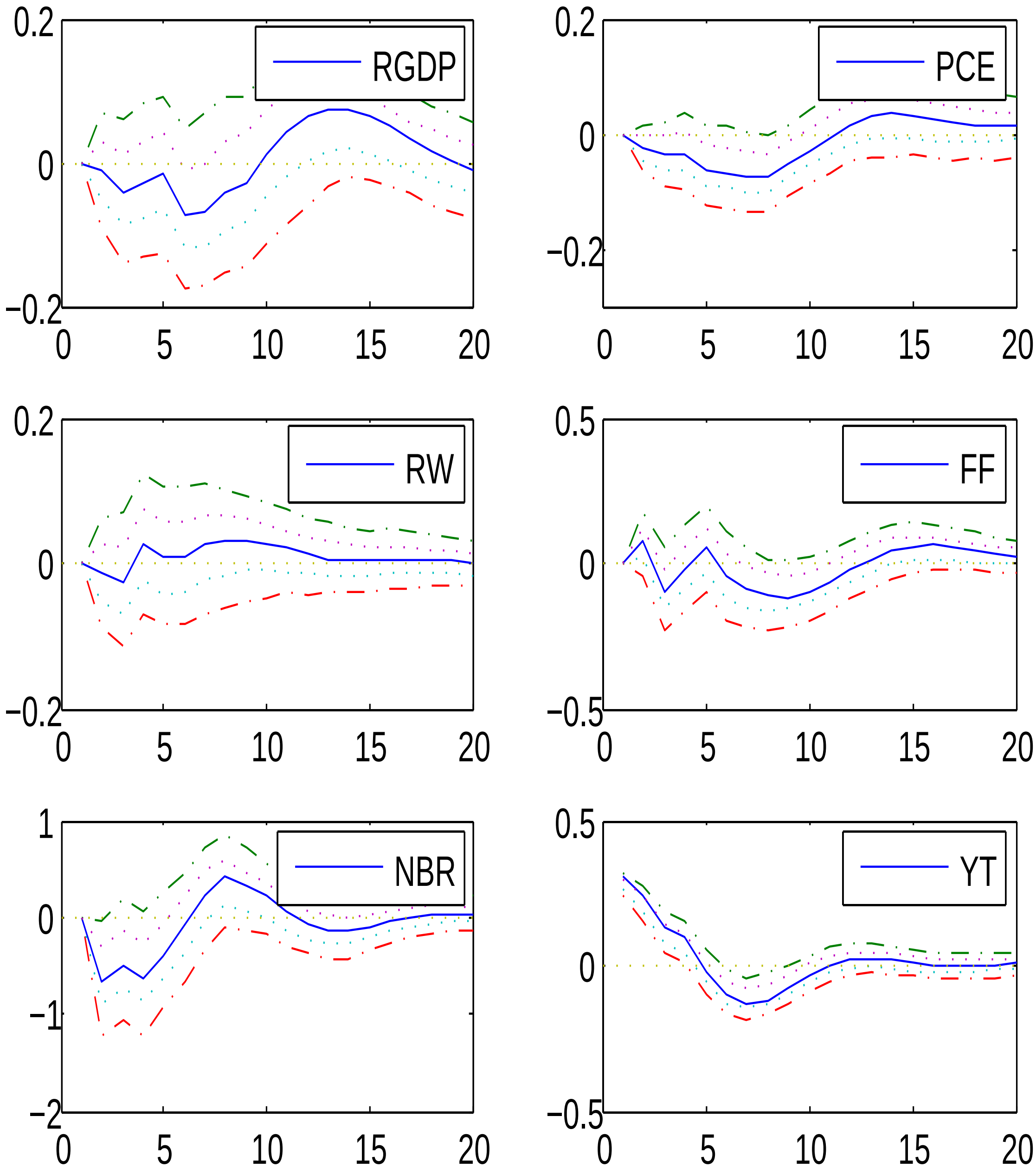
$RGDP_t$, PCE_t, RW_t, FF_t, NBR_t, YT_t, and $PCOM_t$ stand for real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, 5-year yield as a long rate, and commodity price index, respectively. The dash-dot lines represent 95% confidence intervals, and the dotted lines are 68% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 2005:Q4.

Figure 2.4: Impulse response functions of yields to the federal funds rate shock



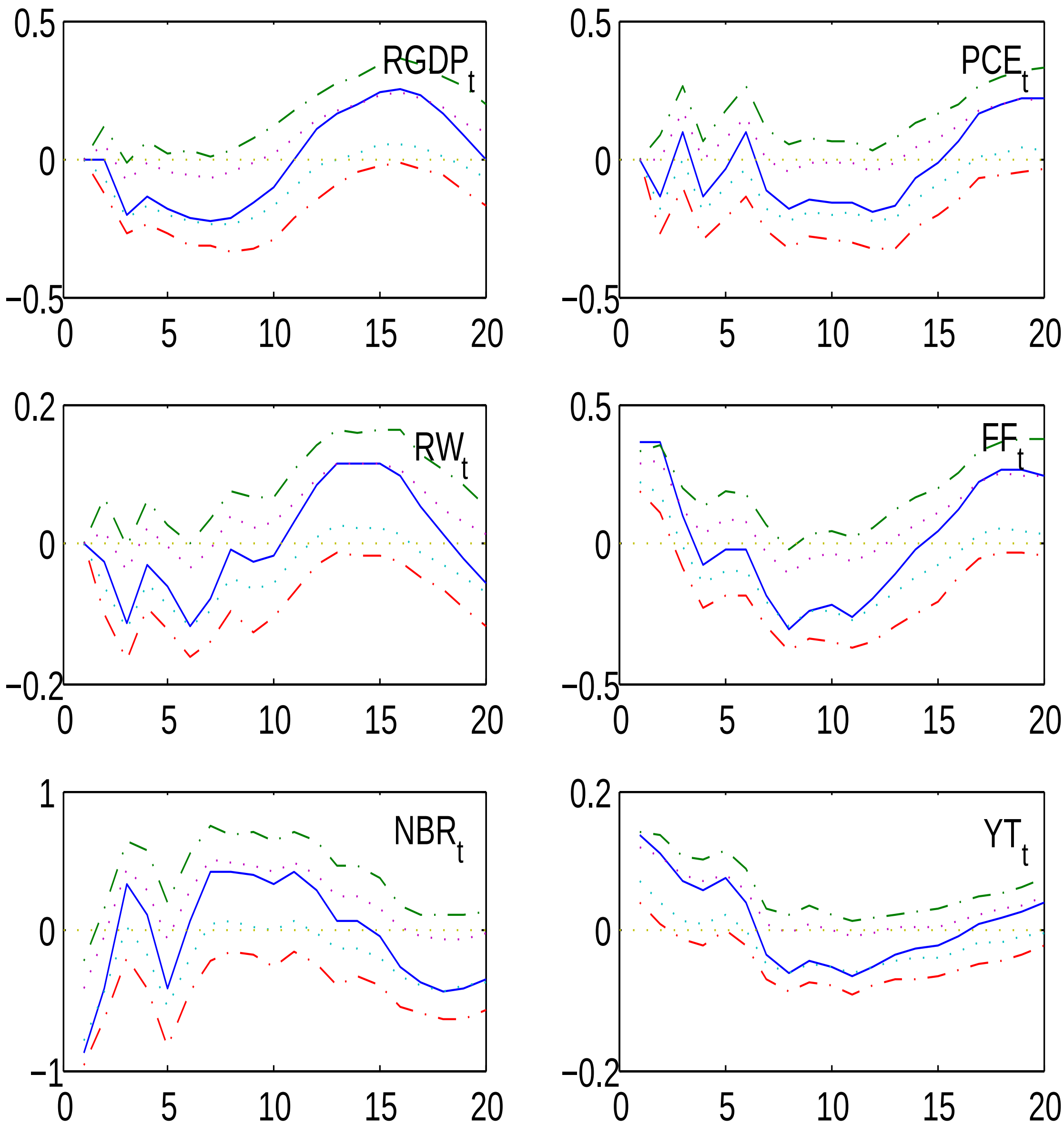
From the upper left corner to the bottom right, each window represents the impulse response functions of 1- to 6-month and 1- to 10-year maturity yields, respectively. The IRFs are obtained by switching the long-term bond yield, YT_t, in the state vector with different maturity yields one at a time. The dash-dot lines represent 95% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 2005:Q4.

Figure 2.5: Impulse responses to a term premium shock



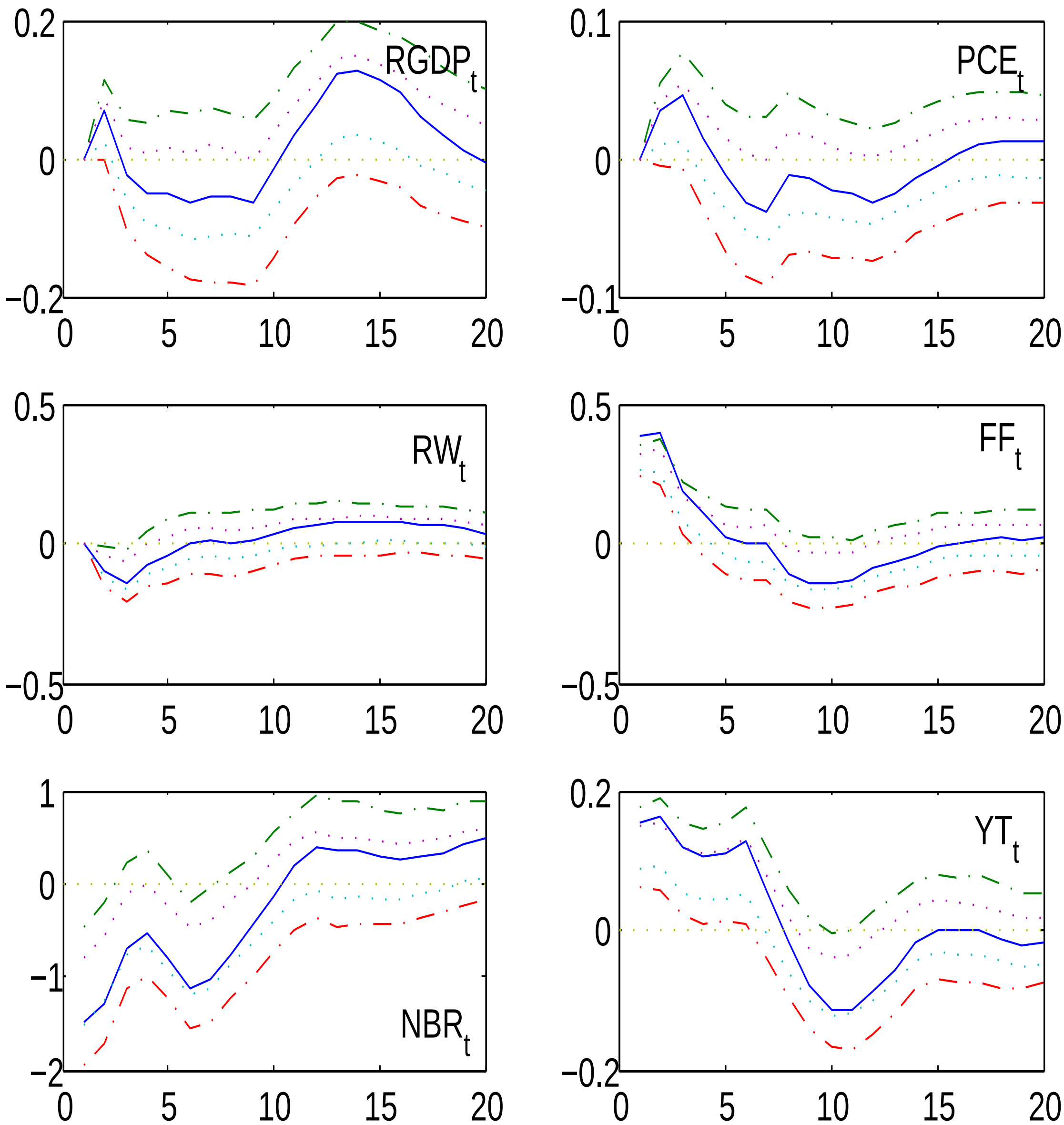
A one standard deviation long-term asset market shock is given. $RGDP_t$, PCE_t, RW_t, FF_t, NBR_t, and YT_t stand for real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, and 5-year yield as a long rate, respectively. The dash-dot lines represent 95% confidence intervals, and the dotted lines are 68% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 2005:Q4.

Figure 2.6: Impulse responses to the federal funds rate shock: pre-Volcker period, 1965:Q2-1979:Q3.



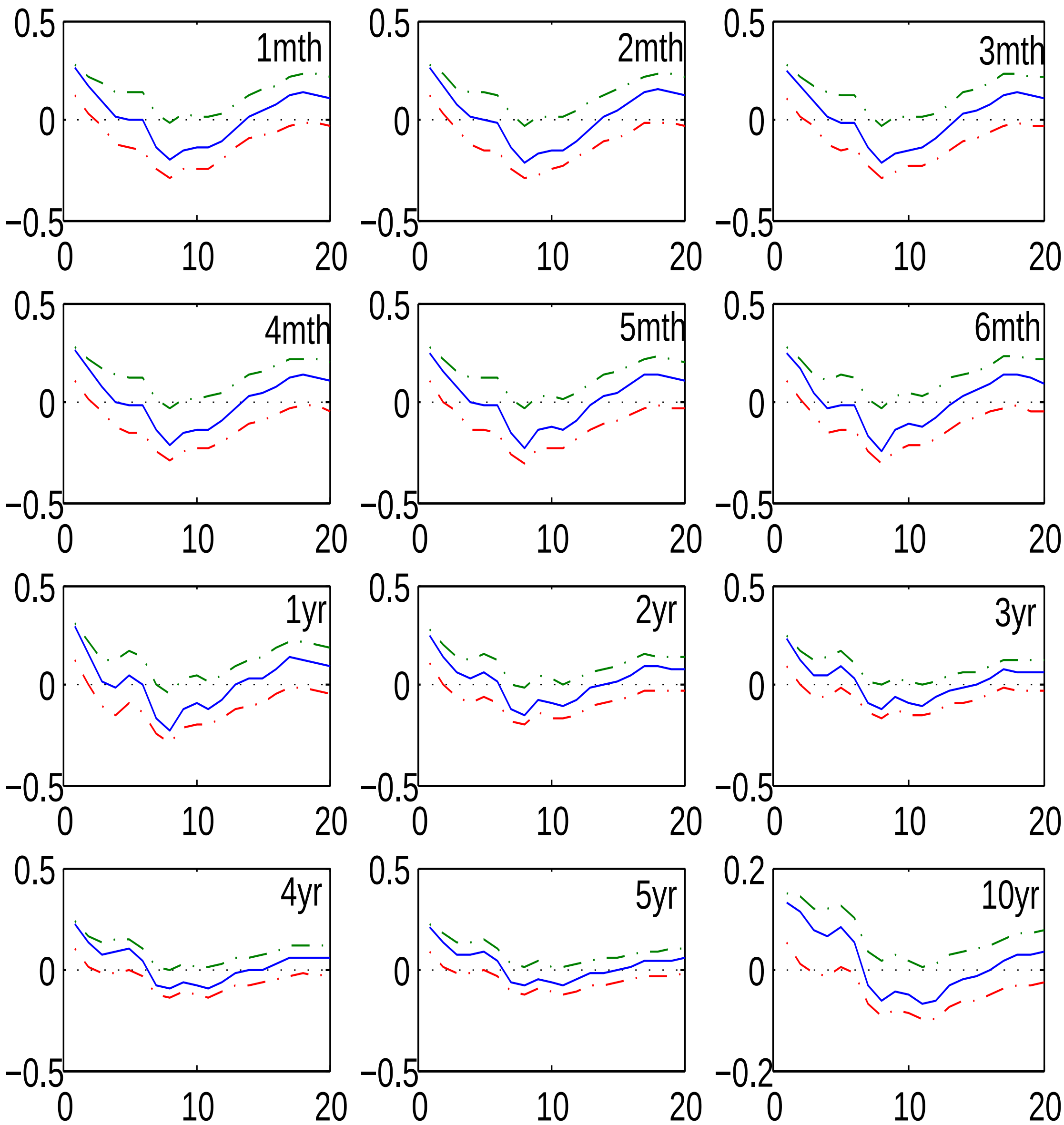
$RGDP_t$, PCE_t, RW_t, FF_t, NBR_t, and YT_t stand for real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, and 5-year yield as a long rate, respectively. The dash-dot lines represent 95% confidence intervals, and the dotted lines are 68% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 1979:Q3.

Figure 2.7: Impulse responses to the federal funds rate shock: Volcker-Greenspan period, 1979:Q4-2005:Q4.



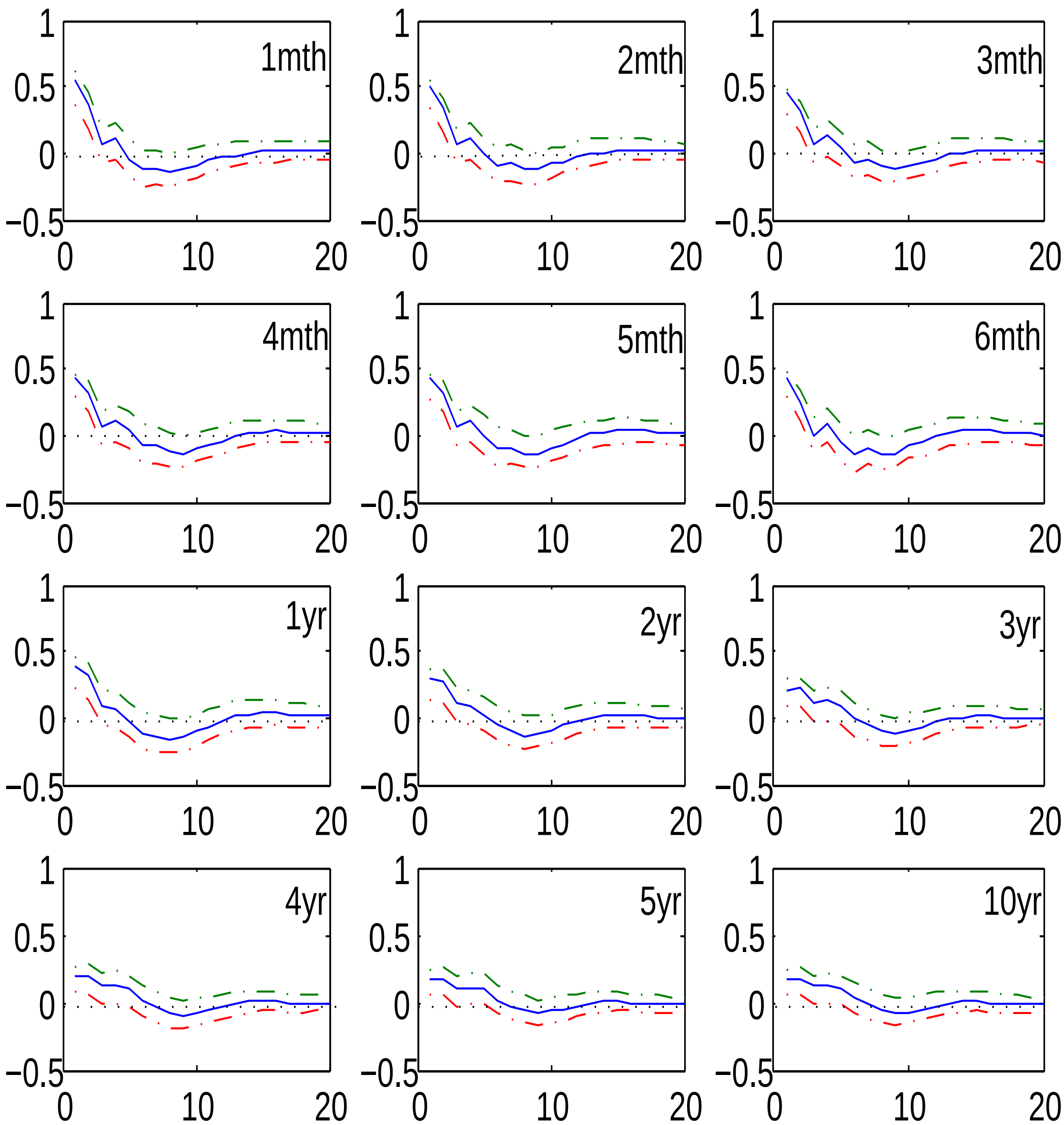
$RGDP_t$, PCE_t, RW_t, FF_t, NBR_t, and YT_t stand for real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, and 5-year yield as a long rate, respectively. The dash-dot lines represent 95% confidence intervals, and the dotted lines are 68% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1979:Q4 and 2005:Q4.

Figure 2.8: Impulse responses of yields to the federal funds rate shock: pre-Volcker period, 1965:Q2-1979:Q3.



From the upper left corner to the bottom right, each window represents the impulse responses of 1- to 6-month and 1- to 10-year maturity yields, respectively. The IRFs are obtained by switching the long-term bond yield, YT_t, in the state vector with different maturity yields one at a time. The dash-dot lines represent 95% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1965:Q2 and 1979:Q3.

Figure 2.9: Impulse responses of yields to the federal funds rate shock: Volcker-Greenspan period, 1979:Q4-2005:Q4.



From the upper left corner to the bottom right, each window represents the impulse responses of 1- to 6-month and 1- to 10-year maturity yields, respectively. The IRFs are obtained by switching the long-term bond yield, YT_t, in the state vector with different maturity yields one at a time. The dash-dot lines represent 95% confidence intervals using bootstrap Monte-Carlo draws. The sample period is between 1979:Q4 and 2005:Q4.

Chapter 3

The Term Premium Response to Macroeconomic Shocks

My dynamic stochastic general equilibrium (DSGE) model, which will be developed in the next chapter, incorporates the direct effect of short- and long-term interest rates on the current and future marginal cost of firms. Since the policy instrument in my model is a nominal short-term interest rate and the long-term bonds are not redundant assets, the term structure of interest rates becomes an important monetary policy transmission channel through which the short-rate monetary policy action has an effect on long rates. The linearized version of the term structure of interest rates derived in my DSGE model assumes that the term premium follows an exogenous stochastic white noise process which implies that the macroeconomic shocks do not affect the term premium, and the monetary policy shock changes long rates in the direction that the expectations hypothesis predicts.

The natural question would then be whether the real world data can support the above relationship between the term premium and the macroeconomic shocks, or whether the term premium movement with respect to other macroeconomic shocks is negligible enough to be ignored. To answer this question, this chapter examines the term premium response implied by the impulse response functions of different maturity yields to the macroeconomic shocks including the monetary policy shock.

In the next section, I will briefly explain the preliminary information on the yield curve over the business cycle. In sections 2 and 3, with the method used by Edelberg and Marshall (1996), I show that the expectations hypothesis does a good job of explaining the impulse response of different maturity yields to macroeconomic shocks. In section 4, the effects of macro variables on the three factors of the yield curve and on the term premium will be examined.

3.1 Behavior of the Yield Curve over the Business Cycle

Figure 3.1 displays the yield curve over the business cycle. For yields data, I used the CRSP data set from 1965:03 to 2005:12. The yields are 1- to 6-month and 1- to 5-year maturity yields. The 10-year Treasury constant maturity rate is used for 10-year yield. The slope is calculated as a difference between 5-year and 1-month zero-coupon bond yields. The solid line represents the 3-month average slope of yields and the dash-dot line plots the detrended log real GDP using the HP filter with the quarterly frequency smoothing parameter of 1600. The vertical dotted lines represent peaks and troughs announced by NBER.

As Figure 3.1 shows, there exists a negative relationship between the slope of the yield curve and the output. The correlation coefficient is -0.4347. In particular, the slope of the yield curve is strictly positive at the bottom of the business cycle. We also observe a strictly smaller slope at the peak than at the very next trough. According to Ang, Piazzesi, and Wei (2004, hereafter APW), the upward-sloping yield curve in recession is due to the counter-cyclical risk premium on long-term bonds and pro-cyclical behavior of short-term bond yields due to the Fed's effort to stimulate the economy.

3.2 The Term Premium Response to the Monetary Policy Shock

By changing the short rate, the monetary policy authority affects the long rates through the policy transmission path known as the term structure of interest rates. I start with the following well-known term structure equation, which is also derived in my DSGE model:

$$r_{n,t} = \frac{1}{n}\sum_{i=0}^{n-1} E_t r_{1,t+i} + TP_t^n \tag{3.1}$$

where TP_t^n denotes the time-varying term premium for n-period bond yield. Equation (3.1) states that the n-period bond yield, $r_{n,t}$, is determined as the sum of the average of expected current and future one-period yields up to n-periods and the time-varying term premium for the n-period bond. Hence, if a policy shock is transmitted through changing market expectations on future short rates, then the term premium on long-term bond yields should not be affected by the policy shock.

We can rewrite (3.1) with respect to the term premium for the n-period maturity bond as the difference between n-period maturity yield and the average of current and expected one-period maturity yields up to $(n-1)$-periods given by:

$$TP_t^n = r_{n,t} - \frac{1}{n}\sum_{i=0}^{n-1} E_t r_{1,t+i} \tag{3.2}$$

After taking one-period lead and time t expectation on both sides of (3.2), the expected value of the time $t+1$ term premium for the n-period maturity bond can be constructed by the difference between the expected value for time $t+1$ n-period maturity yield and the average of the expected values for one-period maturity yields from $t+1$ to $t+n$ as follows

$$E_t TP^n_{t+1} = E_t r_{n,t+1} - \frac{1}{n}\sum_{i=1}^{n} E_t r_{1,t+i} \tag{3.3}$$

The above equation implies that when the state vector in an empirical VAR model includes one- and n-period maturity yields, we can compute the time $t+1$ term premium response for the n-period maturity bond to the monetary policy shock as the difference between the time $t+1$ impulse response function of n-period maturity yield and the average of impulse response functions of one-period maturity yield from $t+1$ to $t+n$. So the state vector in this section includes two different maturity yields together, one- and n-period maturity yields, in order to calculate the impulse response of the term premium for the n-period maturity bond.

The state vector is given by

$$X_t = (IP_t, \pi_t, rw_t, FF_t, NBR_t, r_{1,t}, r_{n,t})'$$

In order to take a closer look into the dynamics of yields, monthly series are used to examine the behavior of the yield curve. Also, the impulse response analysis is performed with variables in levels and the VAR includes a constant vector. By estimating the system on the original data, without transforming the data into stationary form,[1] we can avoid a possible distortion about the long-run property in the system (Sims et al. 1990, Bagliano and Favero 1998), which could result in a faulty estimation of the term premium because of the contaminated long-horizon information on the short rate.

[1]Standard ADF tests of a unit root against the alternative of a linear trend and intercept suggest that a unit root cannot be rejected for all variables. The p-values are above 0.08 for IP_t, π_t, and FF_t. The p-values for NBR_t and rw_t are above 0.6. The p-values for all yields are above 0.1 except for a one-period yield. But the p-value for a one-period yield is still above 0.05.

The log of industrial production, IP_t, is used as a measure of output. The annualized inflation rate (PCE_t) is measured as the difference in logs of the chain-type price index for personal consumption expenditure at time t and $t-12$. Monthly real wages rw_t are measured by the interpolation of the log of quarterly real compensation per hour in the business sector. FF_t represents the federal funds rate and NBR_t denotes the log of non-borrowed reserves. Two zero-coupon bond yields, the 1-month yield, $r_{1,t}$, and the n-month yield, $r_{n,t}, n \geq 2$, are included in the state vector to estimate the term premium response for the n-period bond. Only $r_{n,t}$ will be replaced with different maturity yields one at a time. The same yields data as in Chapter 2 are used. Since, after observing the policy action, market participants form expectations of the future path of the short rates, the long bond yields are placed after the policy variable.

As in the previous chapter, the serial correlation of VAR residuals is tested based on the Lagrange multiplier test. $r_{n,t}$ represents the 5-year maturity bond yield. Figure 3.2 depicts autocorrelation functions for each variable's residuals from the 14th-order VAR estimation over 30 lags. Dotted lines represent $\pm\sqrt{T}1.96$. As shown in the figure, the autocorrelation functions move around 95% confidence intervals, which implies no serial correlation could be detected.

Section A of Table 3.1 reports the first-order serial correlation test results for each residual. Again, F-statistics are reported in comparison with the χ^2-test results. χ^2- and F-test results shows that the null hypothesis of no serial correlation cannot be rejected under the 1% significance level. The 1% critical value for a χ^2 with one degree of freedom is 6.63490. But the test statistics TR^2 for each residual are strictly less than the critical value. Moreover, F-statistics reveal that the autocorrelation parameters are statistically zero under the 5% significance level. These results of no first-order autocorrelation remain the same when the 5-year rates are replaced with other maturity yields.

However, when I increase the number of AR coefficients in the residuals, $r_{1,t}$ frequently rejects the null of no autocorrelation, while other variables have no higher-order serial correlations. Section B of Table 3.1 reports the second-order autocorrelation test results for the $r_{1,t}$ series in the VAR, replacing $r_{n,t}$ with different maturity yields. The null of no autocorrelation for $r_{1,t}$, $H_0 : \rho_1 = \rho_2 = 0$, is frequently rejected when a yield shorter than 1-year maturity is used for $r_{n,t}$. Overall, we can conclude that the residuals from VAR(14) do not have serial correlations when the yields longer than 1-year maturity are used for $r_{n,t}$. Therefore, I assume that the state vector follows a 14th-order VAR.

Before looking into the term premium response to monetary policy shocks, it will be useful to see the response of different maturity yields to monetary policy shocks. Figure 3.3 displays the impulse response functions of different maturity yields, 1 to 6 months, 1 to 5 years and 10 years, proceeding from the upper left corner to the lower right. The 1-month yield response in this figure comes from the results of a VAR with the 10-year yield. But the magnitude and the speed of returning to their pre-shock level of impulse response functions when using other yields for $r_{n,t}$ are similar to this figure. The dashed lines delineate 95% confidence interval bands. The confidence intervals are calculated from the 500 bootstrap Monte Carlo draws.[2] According to the point estimates, the initial responses of all bond yields to a one standard deviation monetary policy shock are significantly greater than zero, but the amount of initial response becomes smaller as the maturity increases. For example, the maximal response of the 1-month and 10-year yields to contractionary monetary policy shocks are 27.9 and 4.5 basis points, respectively.

Equation (3.1) implies that if the expectations hypothesis of the term structure

[2]In each loop, I calculate the term premium response for n-period bond using equation (3.3). After finishing 500 loops, I report the 487th highest value and the 13th lowest value of the term premium response for n-period bond for 95% confidence intervals.

holds, then the term premium response should be zero. Therefore, the expectations hypothesis of the term structure predicts the first-step response of $r_{n,t}$ to the monetary policy shock should be equal to the average of one to n-step responses of $r_{1,t}$ to the monetary policy shock. That is, from equation (3.3), the first step response of the term premium for n period bond should be zero statistically. Figure 3.4 plots the first step response of the term premium for all maturity bonds to the monetary policy shock calculated from equation (3.3). The confidence intervals are calculated from the 500 bootstrap Monte Carlo draws. According to Figure 3.4, the expectations hypothesis works well in explaining the pattern of impulse responses of yields to the monetary policy shock.[3] The difference between the first-step response of the long rates, $E_t r_{n,t+1}$, and the response predicted by the expectations hypothesis, $\frac{1}{n} E_t \sum_{i=1}^{n} r_{1,t+i}$, is less than 4 basis points across all maturities, and is statistically insignificant at the 5% significance level.

In order to see the robustness of the results, I check the $n(> 1)$-step impulse response functions of the term premium for each maturity yield. Figure 3.5 plots the responses of the term premium for n-period yields to the contractionary monetary policy shock up to 20 period horizons. Starting from the upper left corner and proceeding to the bottom right, each window represents the term premium response for a different yield (2-6 months and 1-5 years). For maturity yields less than one year, the term premium responses are slightly positive between 2 and 6 months, but the effects disappear quickly after 6 months. On the other hand, the term premium responses of yields with longer than 1-year maturity are statistically insignificant under 95% confidence bands for the entire horizon. In summary, the monetary policy shock changes different maturity yields, specifically, long rates move in the direction that the expectations hypothesis predicts.

[3] The results are robust to the change of the VAR order from 6 to 12. Also, when the yields are placed before the policy instrument, the results are not much different.

3.3 The Term Premium Response to Two Macroeconomic Shocks

The term premium, in my DSGE model, is assumed to follow an exogenous white noise process. At the end of the previous chapter, we found that the long-term asset market shock, which is considered a risk premium shock, does not have a significant effect on macro variables. Now, it is of interest to check whether the macroeconomic shocks, other than the monetary policy shock, affect the term premium. This section looks into the term premium response to two macroeconomic shocks: output and inflation shocks. I begin with a negative output shock and check the behavior of the term premium response in order to see whether the term premium responds to the business cycle movements.

Similar to Figure 3.4, Figure 3.6 displays the first-step response of the term premium for each maturity bond, $E_t TP_{n,t+1}$, to a one standard deviation output shock. The figure shows that a negative output shock affects term premia on shorter-term maturity bonds. Term premia for less than 1-year maturity bonds, specifically, have significant positive movements at the 5% significance level. On the other hand, the term premium is not an important determinant for the response of longer-term yields to output shocks. In general, when a negative output shock is detected, it affects policy decisions, so that the federal funds rate falls. According to APW (2004), a negative output shock also affects long bond yields directly by raising the term premium because investors tend to shun risk in bad times. Therefore, term premia on long bonds are inversely related to output movements. But this direct effect is statistically negligible for more than 1-year maturity bonds. The impulse response analysis indicates that the responses of term premia on longer-term bonds are insignificant at the 5% significance level, and they move toward zero as maturity increases.

Figure 3.7 displays the impulse response functions of the term premium for each maturity bond to one standard deviation negative output shocks up to a 20-month horizon. Each window shows two to six months and one to five years maturity bond term premium response starting from upper left corner to the right. Again, dashed lines represent 95% confidence bands. For all yields, the first 2 to 11 step responses of the term premium are not statistically different from zero at the 5% significance level.

Figures 3.8 and 3.9 plot the impulse response functions of the term premium to one standard deviation negative inflation shocks. The two figures display the first- and multi-step responses of term premia, respectively for different maturity bonds implied by the impulse responses of yields to negative inflation shocks. Figure 3.8 shows that when a negative inflation shock is detected, the first-step term premium responses tend to rise. For example, term premia for more than 1-year maturity bonds are significantly greater than zero at the 5% significance level. But, for all maturity bonds, the term premium responses are insignificant at the 1% significance level. In Figure 3.9, we find that the term premium responses for short-term bonds less than 1-year are statistically zero across all time horizons, and that the effects of the first-step responses of term premia for longer-term maturity bonds over 1 year disappear quickly. For example, the positive effects of negative inflation shocks on term premia for those bonds last at best 5 months and die out to zero after 6 months at the 5% significance level.

Since it is believed that inflation falls in the economic downturn and rises in the peak, the positive response of the term premium to a negative inflation shock can be interpreted as an element of the counter-business-cyclical movement of the term premium. But even though the positive responses of the term premia on long bonds are significant at the 5% level, the counter-cyclical response of the term premium is not significant at the 1% level, as shown in Figure 3.8.

Overall, we can conclude that a monetary policy shock has an effect on the economy through the expectations hypothesis without disturbing the bond market premium. Furthermore, negative output and inflation shocks change the term premium in a direction counter to the business cycle, but their effects are marginal and quickly disappear. This conclusion partially confirms Evans and Marshall's (2002) result that long rates are mostly affected by the change of the expectation path of short rates when monetary policy shocks are given, and that supply shocks can directly affect long-term yields by changing term premia. Therefore, the above results support the assumption used in my DSGE model that macroeconomic shocks do not affect the term premium.

3.4 Response of Three Factors of Yield Curve to Macroeconomic Shocks

This section investigates the effect of macro variables on the three factors of the yield curve−level, slope, and curvature−based on the studies by Evans and Marshall (2002) and Ang and Piazzesi (2003). It is of interest to check the response of the yield curve to macroeconomic shocks because empirical studies such as Dai and Singleton (2000) reveal that the greater part of the movements of bond yields is captured by these three factors. In a later chapter, the model-based impulse response functions of these three factors of the yield curve will be compared to their empirical counterparts estimated in this section.

In order to calculate these three factors of the yield curve, I use three different maturity yields together in the state vector from the previous VAR system. The state vector consists of two types of variables in the empirical VAR model. The first type is macro variables which include output, inflation, real wages, the federal funds rate, and non-borrowed reserves. I use the same data set as in the previous section for macro variables. The second type is three different maturity yields which represent short-, medium-, and long-term yields. I use the 1-month, 12-month, and 60-month yields used in Evans and Marshall (2002) and Ang and Piazzesi (2003). The state vector is given by

$$X_t = (IP_t, \pi_t, rw_t, FF_t, NBR_t, r_{1,t}, r_{12,t}, r_{60,t})'$$

In order to measure the three factors of the yield curve, I use Ang and Piazzesi's (2003) definitions. That is, the level of the yield curve is calculated as an equally weighted average of the 1-month, 12-month, and 60-month yields. The difference between the 60-month yield and the 1-month yield is used for measuring the slope of the yield curve. The measure of curvature is the sum of the 1-month and 60-month yields minus twice that of the 12-month yield. Again, the term premium for an n-period maturity bond is defined as in equation (3.2).

In Figure 3.10, the impulse response functions of three yields to different macroeconomic shocks are shown in the top three rows. Rows 4 to 6 display the responses of three factors of the yield curve, and the last two rows show the impulse response functions of the term premium for the 12-month and 60-month bonds to different macroeconomic shocks. For each window, the dash-dot lines represent the 95% confidence bands from 500 bootstrap Monte Carlo draws.

The positive output and inflation shocks shift all three yields upwards. The maximal responses of the 1-month, 1-year, and 5-year yields to one standard deviation output shocks are 32.5, 35.0, and 23.1 basis points, respectively. The corresponding maximal responses of the yields to the inflation shocks are 19.9, 19.5, and 17.8 basis points, which are similar to Evans and Marshall's (2002) result. The parallel responses of yields shift the level of the yield curve upwards. On the other hand, the slope and curvature respond little to the output and inflation shocks showing that the confidence bands roughly include the zero line. According to APW (2004) and equation (3.1), the term premium and the average expectation path of short rates have different directions in recession, hence long-term yields could rise or fall at the bottom of the business cycle. Even if they decrease, the amount of long-term yield movement shouldn't be bigger than the amount of short-rate fall induced by the policy action because of the positive term premium. Hence, the positive slope of the yield curve is observed in recessions. But, in Figure 3.10, the evidence of the counter-cyclical response of the slope to the output shock is significant at the 5% level.

According to the last two rows of Figure 3.10, the (positive) output shock induces a decrease in the 5-year term premium for the initial period, with a subsequent increase after 1 year. But the initial decrease of the term premium is insignificant at the 5% level. Similar results can be seen for inflation shocks. The decrease of the term premium from the inflation shock lasts longer than the response to the output shock, but its effect is insignificant at the 5% level. The term premium response for a 1-year bond to output and inflation shocks show a similar pattern to that of the 5-year maturity bond term premium. But their effects are insignificant across all periods, except for the first-period term premium response to the output shock. Hence, the counter-cyclical response of the term premium seems to be weak.

The positive federal funds rate shock induces an upward shift in the level of the yield curve and reduces the slope. But those effects disappear within a year. The effect on the curvature is again insignificant at the 5% significance level. The term premium response of the 1-year bond is positive but dies out quickly, and the 5-year term premium response is also positive but statistically insignificant at the 5% significance level.

Overall, the results of this section support the conclusion of the previous section. The monetary policy action affects the economy in the way that the expectations hypothesis predicts. Output and inflation shocks induce changes in the term premium only in the first few months, but their effects are insignificant or marginal.

3.5 Summary of Results

My dynamic stochastic general equilibrium model assumes that the term premium is an exogenous stochastic white noise process with no relation to other macroeconomic shocks. This assumption implies that the macroeconomic shocks including monetary policy shock do not affect the term premium. This chapter dealt with the question of whether this assumption is broadly consistent with the real data.

In the VAR model with two different maturity yields, the term premium does not show statistically non-zero responses to monetary policy shocks. Moreover, even if we observed the counter-cyclical responses of the term premium to the output and inflation shocks, their effects are marginal at the 5% significance level, but statistically insignificant at the 1% significance level.

When I used three different maturity yields in the VAR model, the 1-year maturity term premium shows the positive response to the contractionary federal funds rate shock, but its effect is marginal and disappears quickly. Moreover, the 5-year maturity term premium did not generate any significant response to the monetary policy shock for the entire horizon. The output and inflation shocks also do not have much effect on the term premium. Even though there are some effects, they are marginal and die out quickly. There is a substantial response of the yield curve only to the monetary policy shock. The positive response of the level of the yield curve and the negative response of the slope to the contractionary monetary policy shock are observed for less than 10 months.

From these two impulse response analyses, we can conclude that the macroeconomic shocks do not have significant and sustained effects on the term premium. Moreover, monetary policy affects the long-term interest rate as the expectations hypothesis of the term structure predicts.

Table 3.1: Autocorrelation test result

A. $H_0 : \rho_1 = 0$: Model with 5-year yield for $r_{n,t}$

	ρ_1	TR^2	$P_{val} > \chi^2(1)$	F-stat	$P_{val} > F$
y_t	-0.00030	4.71769	0.02985	3.75327	0.05345
	(-0.29743)				
π_t	-0.00000	2.70558	0.10000	2.09074	0.14903
	(-0.01200)				
r_t	0.00006	0.36665	0.54484	0.23275	0.62978
	(0.04706)				
ff_t	0.00856	0.36298	0.54685	0.28218	0.59559
	(0.12367)				
NBR_t	-0.00032	0.01349	0.90753	0.00996	0.92057
	(-0.06139)				
$r_{1,t}$	-0.01353	1.95499	0.16205	1.54941	0.21400
	(-0.13775)				
$r_{n,t}$	-0.02093	1.41531	0.23418	1.11992	0.29062
	(-0.33518)				

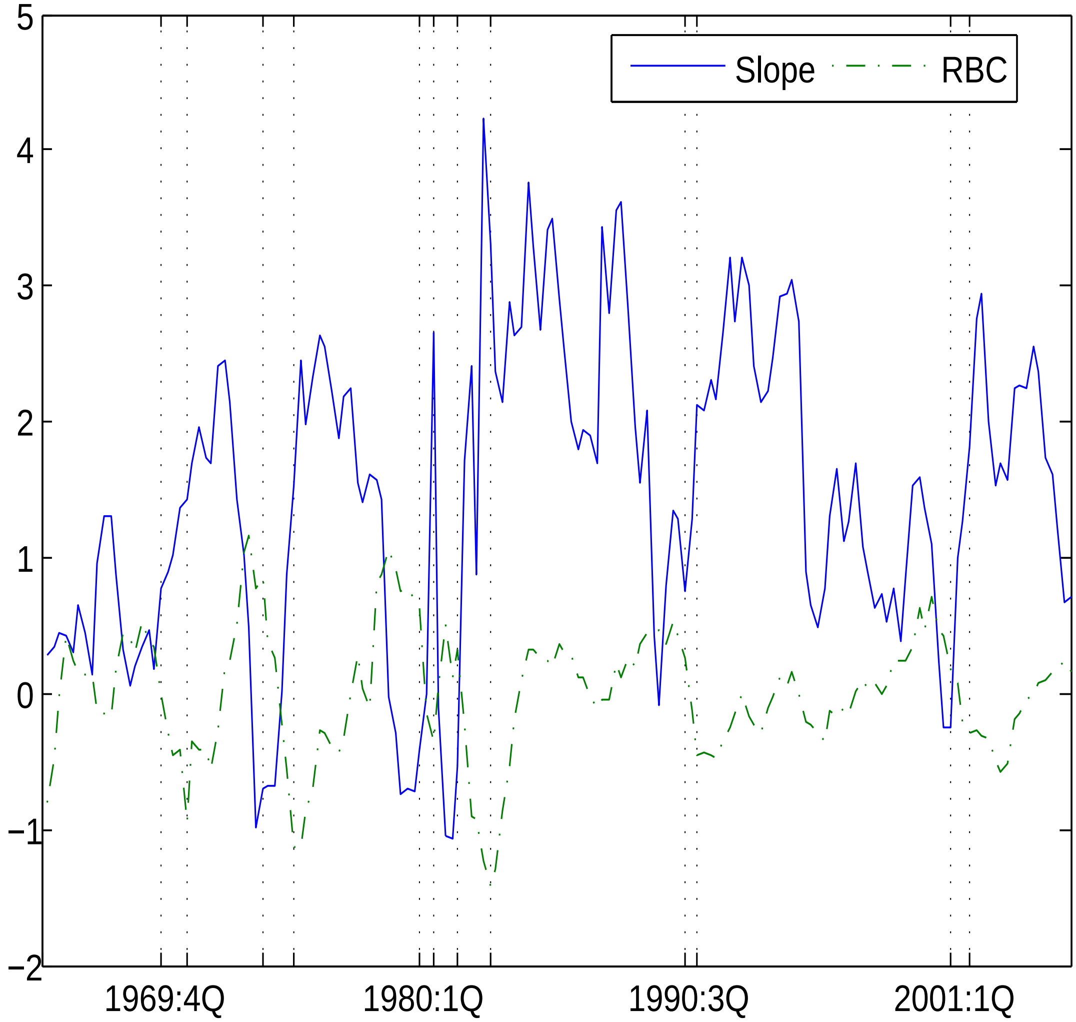
Table 3.1 Autocorrelation test result : continued.

B. $H_0 : \rho_1 = \rho_2 = 0$: Models with different yields for $r_{n,t}$

Model	ρ_1	ρ_2	TR^2	$P_{val} > \chi^2(2)$	F-stat	$P_{val} > F$
$r_{2m,t}$	0.11335	-0.06189	17.51551	0.00016	7.14241	0.00090
	(0.86111)	(-0.24149)				
$r_{3m,t}$	0.18637	-0.04874	16.39060	0.00028	6.67298	0.00142
	(1.37957)	(-0.16392)				
$r_{4m,t}$	0.02364	-0.23256	16.21854	0.00030	6.60134	0.00152
	(0.16507)	(-0.77454)				
$r_{5m,t}$	0.04875	-0.26879	11.97884	0.00251	4.83242	0.00847
	(0.34344)	(-0.94649)				
$r_{6m,t}$	0.01378	-0.40837	12.81463	0.00165	5.18118	0.00603
	(0.20933)	(-1.61327)				
$r_{1y,t}$	-0.02302	-0.20090	1.65084	0.43805	0.64981	0.52273
	(-0.19390)	(-0.70091)				
$r_{2y,t}$	-0.02338	-0.37475	3.16202	0.20577	1.25155	0.28726
	(-0.21409)	(-1.22407)				
$r_{3y,t}$	-0.01062	-0.32978	2.58730	0.27427	1.02262	0.36066
	(-0.10269)	(-1.15967)				
$r_{4y,t}$	0.01304	-0.33474	3.13382	0.20869	1.24118	0.29023
	(0.13423)	(-1.08326)				
$r_{5y,t}$	0.02691	-0.35018	3.42247	0.18064	1.35556	0.25907
	(0.25539)	(-1.17395)				

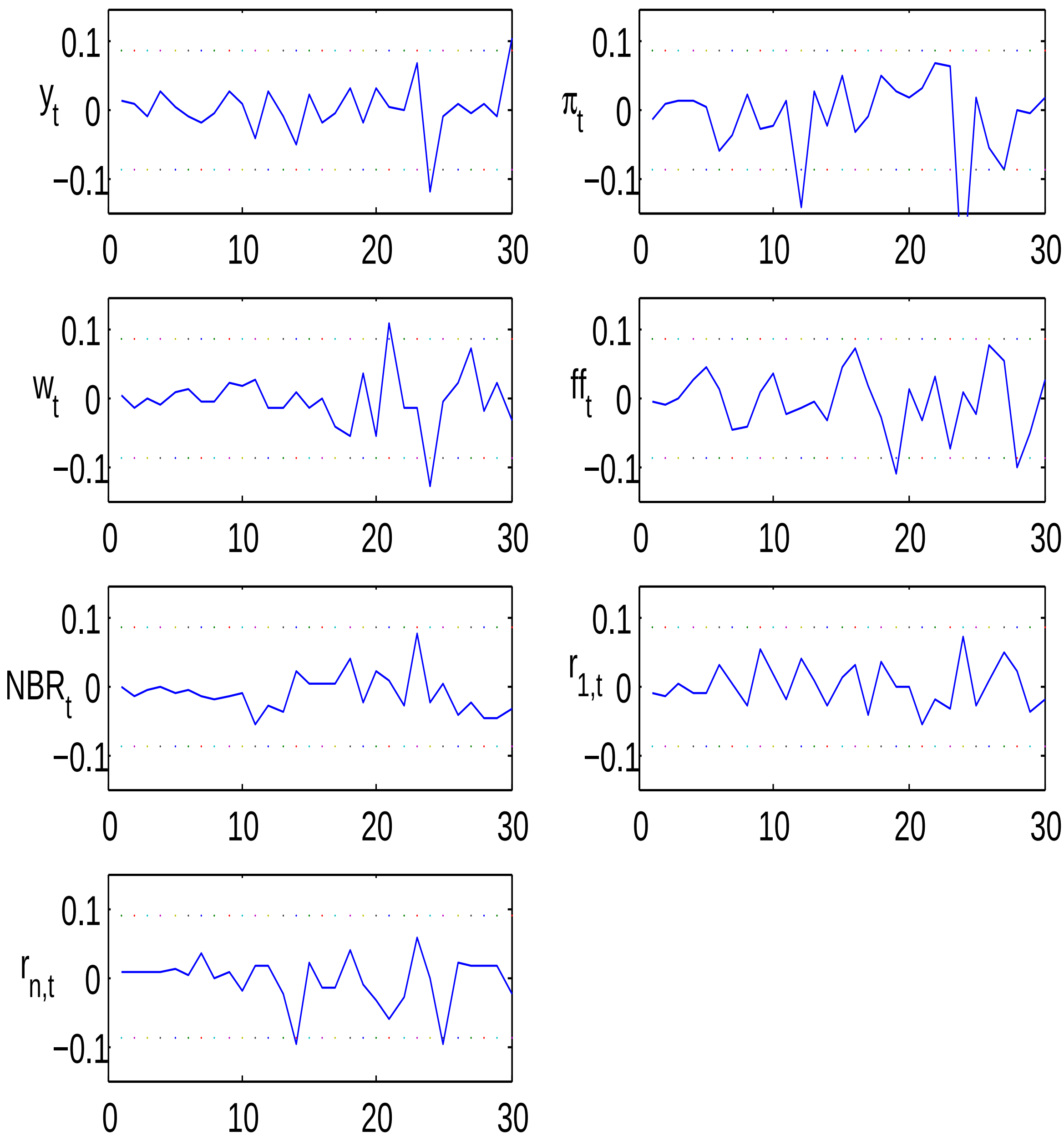
The numbers in parentheses represent t-statistics. Section A tests the first-order autocorrelation for the model in which a 5-year maturity yield is used for $r_{n,t}$. The first column represents AR(1) coefficients of residuals. The second and fourth columns represent the Lagrange multiplier test statistics and F-statistics, respectively. The third and fifth columns report there p-values. y_t, π_t, w_t, ff_t, NBR_t, $r_{1,t}$, and $r_{n,t}$ represent real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, one-period bond yield, and 5-year bond yield, respectively. Section B reports the test results of the first- and second-order serial correlation jointly for $r_{1,t}$ residual, replacing different bond yields for $r_{n,t}$. The first row represents the test results for $r_{1,t}$ residual, in which $r_{2,t}$ is used for the long rate. $r_{2m,t}$ to $r_{6m,t}$ represent two- to six-period bond yields, and $r_{1y,t}$ to $r_{5y,t}$ stand for 1- to 5-year bond yields, respectively.

Figure 3.1: Slope of yields over the business cycle



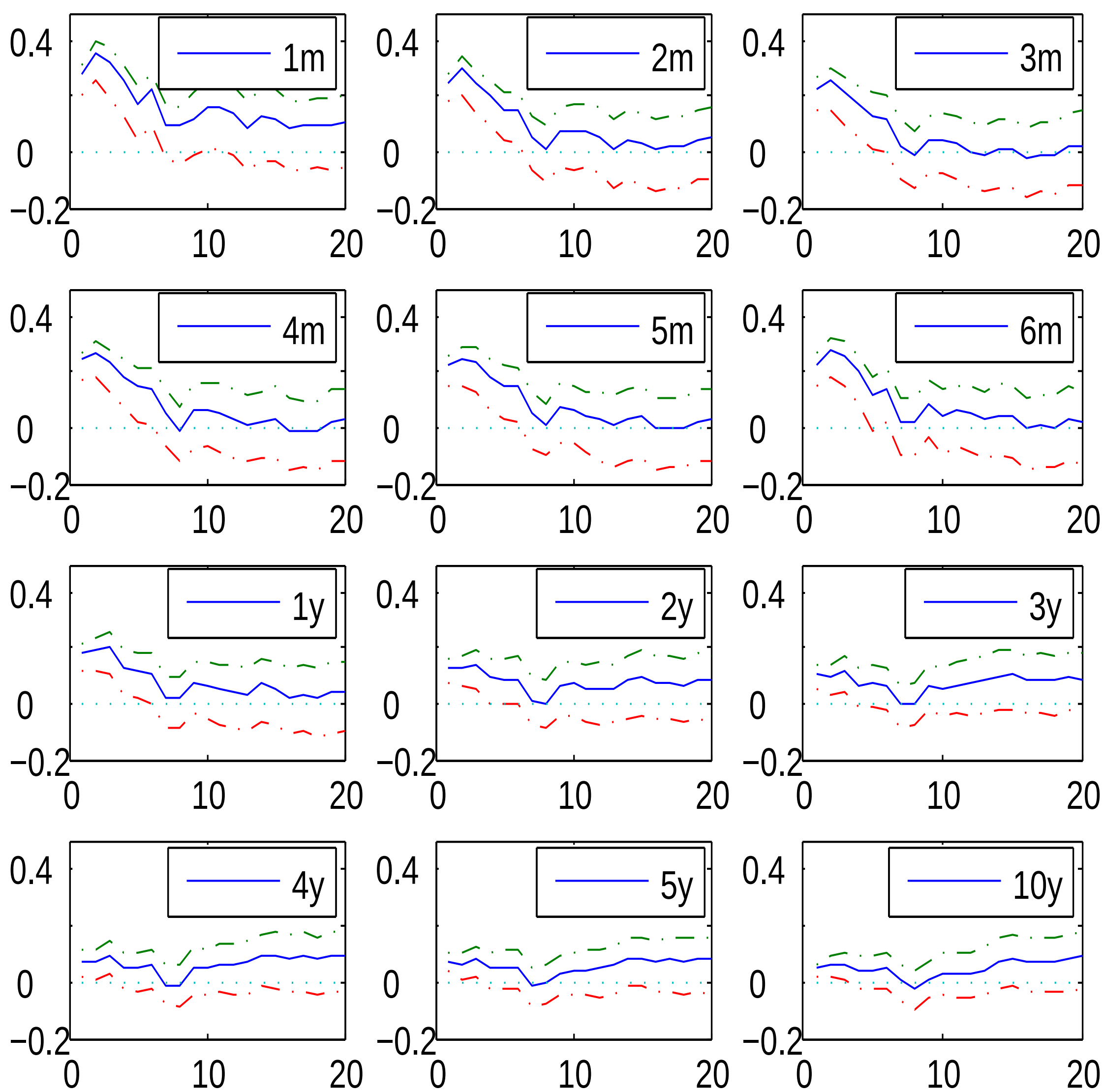
Solid line represents the 3-month average slope of yields calculated as the difference between the 5-year rate and the 1-month rate, and the dash-dot line (RBC) is the detrended log of real GDP using the HP filter with the quarterly frequency smoothing parameter of 1600. Vertical dotted lines represent peaks and troughs announced by NBER.

Figure 3.2: Autocorrelation functions of VAR residuals II



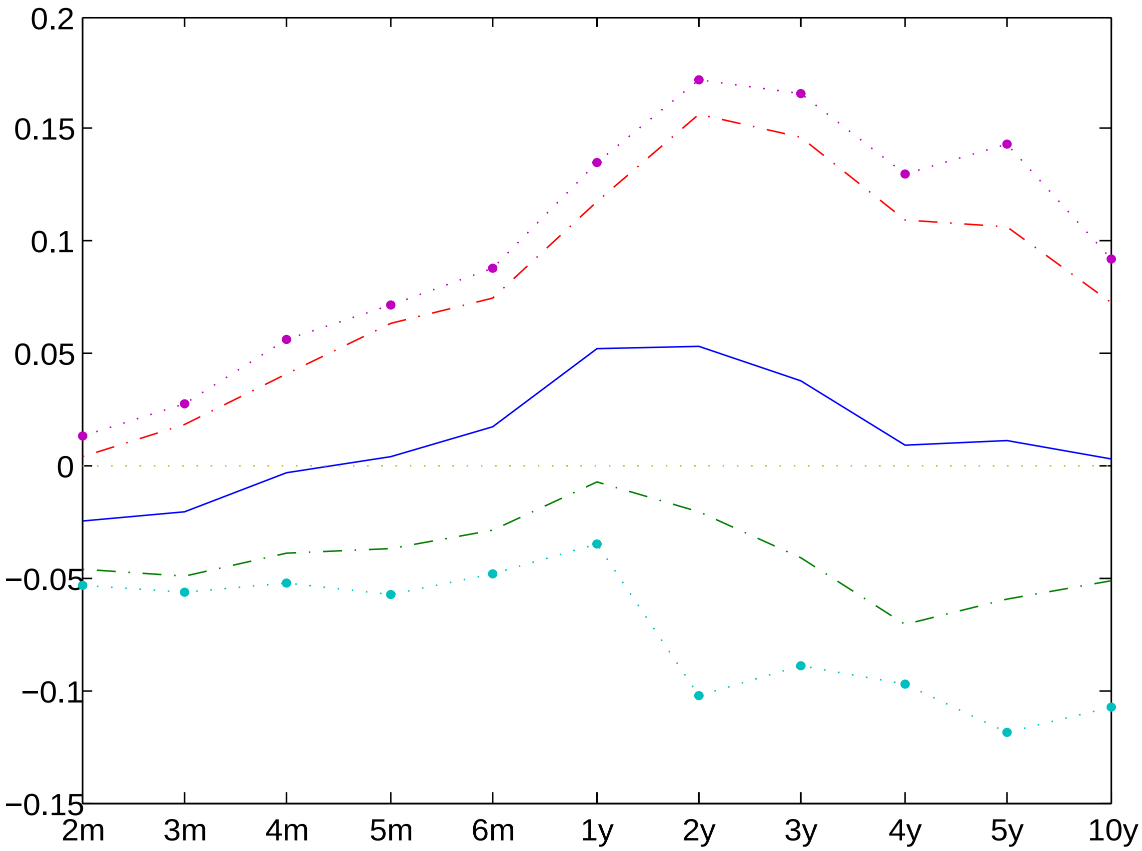
Autocorrelation functions of VAR(K) residuals in which monthly series are used. K = 14 is adopted. y_t, π_t, w_t, ff_t, NBR_t, and $r_{n,t}$ represent real output, rate of inflation, real wages, federal funds rate, non-borrowed reserves, 1-period yield, and 5-year yield as a long rate, respectively. Dotted lines represent $\pm\sqrt{T}1.96$.

Figure 3.3: Yield response to the contractionary federal funds rate shock



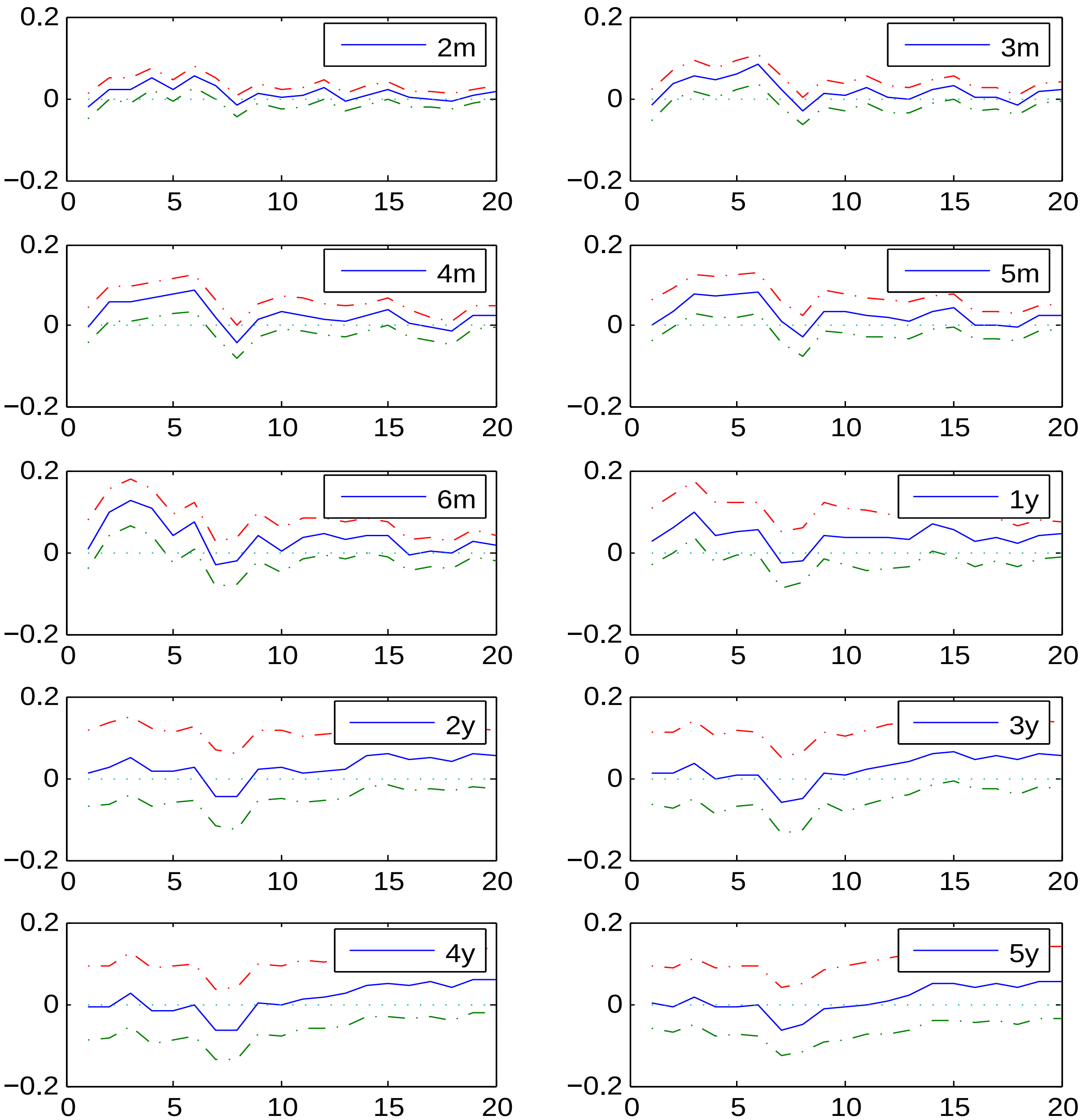
Solid lines are the response of yields to the one standard deviation contractionary federal funds rate shock. Yields are 1- to 6-month, 1- to 5-year, and 10-year yields starting from the upper left corner to the bottom right. The impulse response of 1-month yield in this figure comes from the results of the VAR with 5-year yield. The dotted lines plot 95% confidence bands with 500 bootstrap Monte Carlo draws.

Figure 3.4: The first-step term premium responses for all maturity yields to the contractionary monetary policy shock



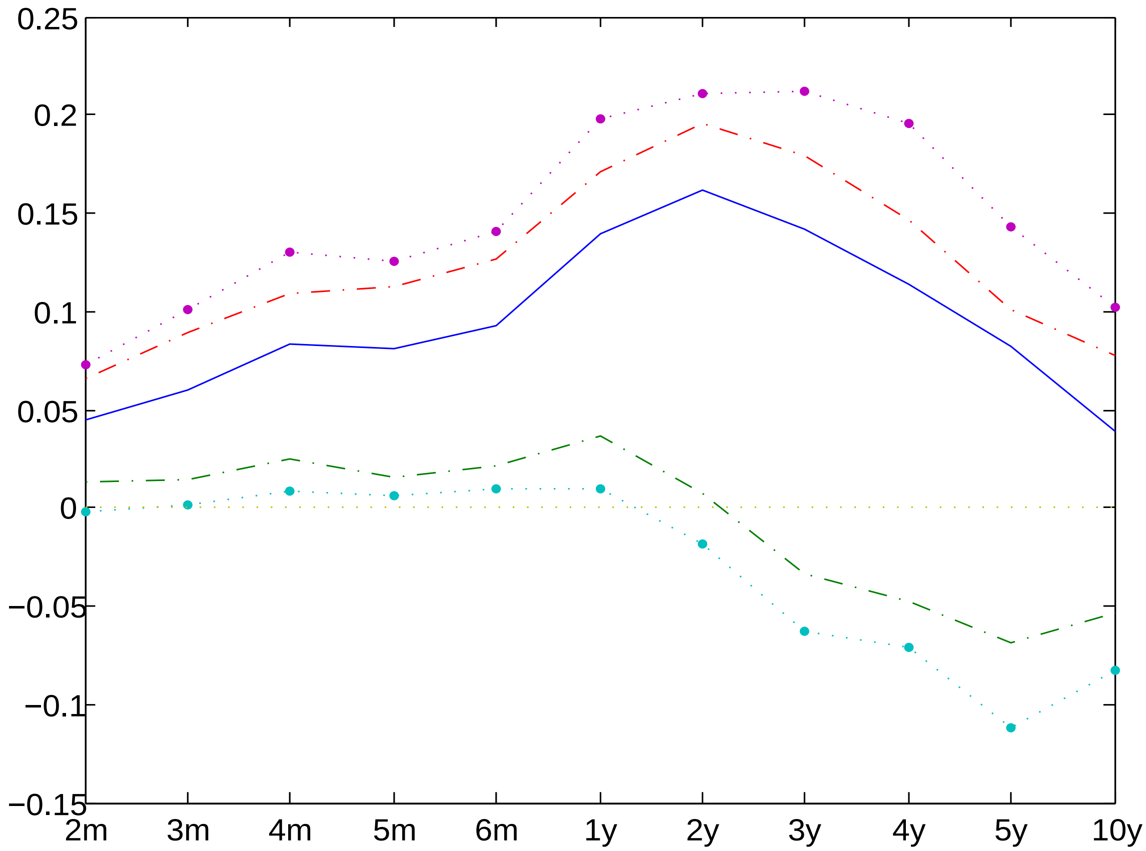
The X-axis represents the maturity(n) of yields. The solid line plots the estimated first-step response of the term premium with maturity n, $E_t TP^n_{t+1}$, which is constructed as the difference between the first-step response of n-period yield and the average of one-period yield responses from $t+1$ to $t+n$. Dash-dotted lines and dotted lines display 95 and 99% confidence bands, respectively.

Figure 3.5: Term premium response to the federal funds rate shock for each maturity yield.



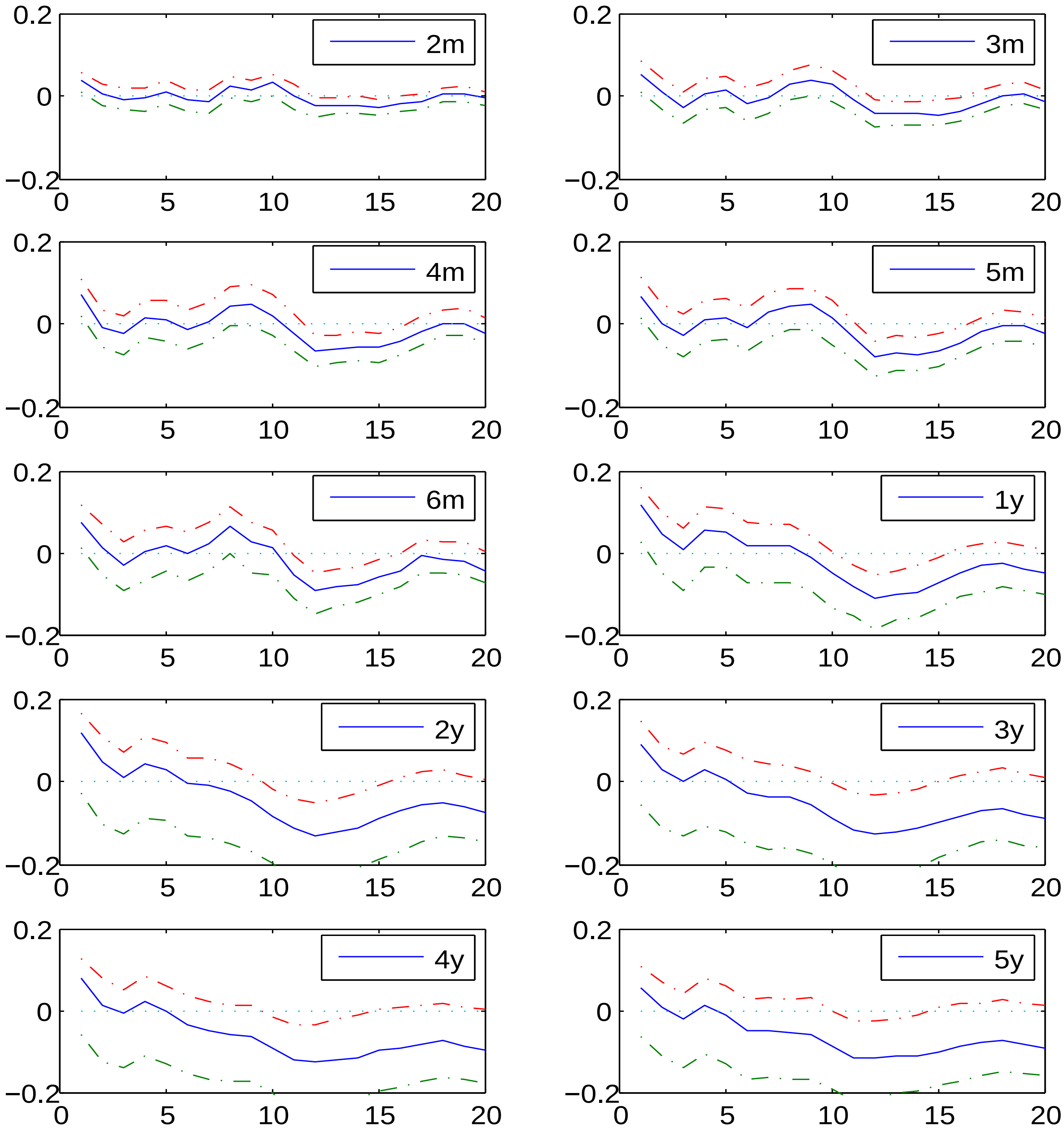
Starting from the upper left corner to the bottom right, each window represents term premium responses to the contractionary monetary policy shock up to 20 months after the shock for 2- to 6-month and 1- to 5-year yields, respectively. The dash-dotted lines plot 95 percent confidence intervals.

Figure 3.6: The first-step responses of the term premium for different maturity bonds to the negative output shock



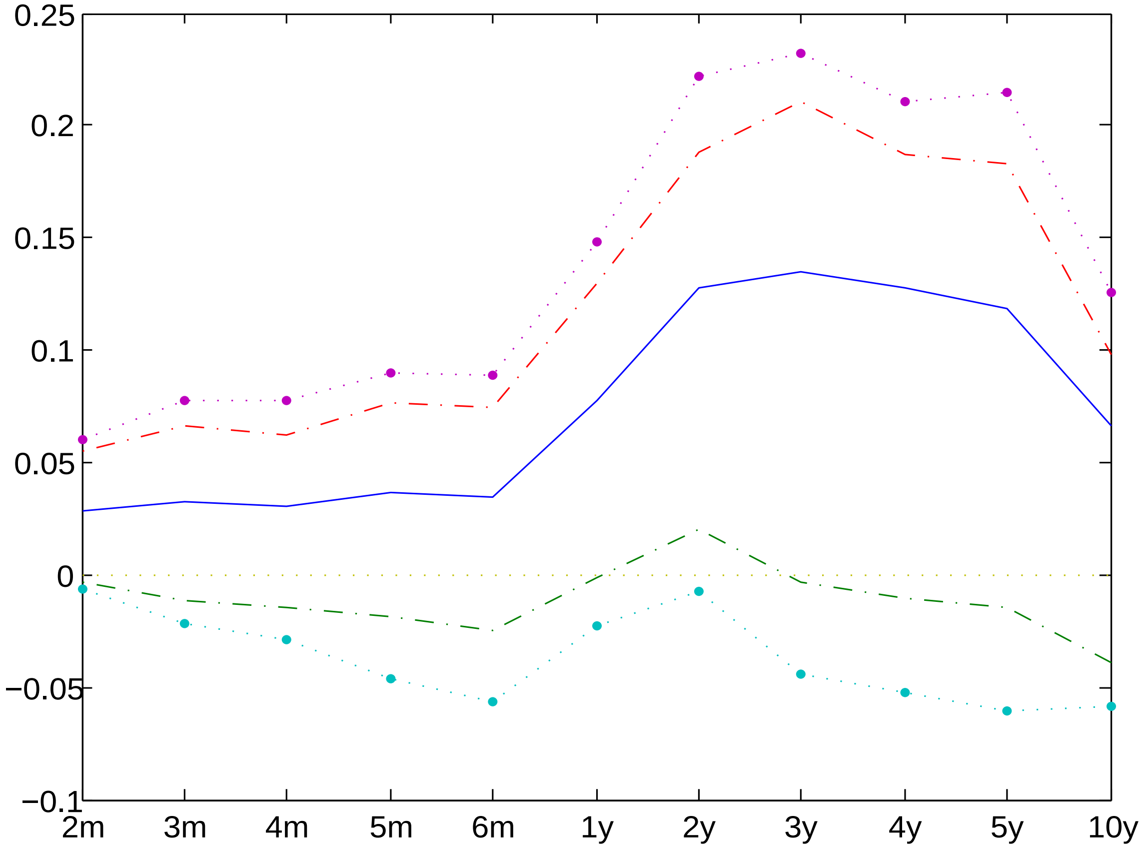
The X-axis represents the maturity(n) of yields. The dotted line with stars plots the estimated first-step response of the term premium with maturity n, $E_t TP^n_{t+1}$, which is constructed as the difference between the first-step response of n-period yield and the average of one-period yield responses from $t+1$ to $t+n$. Dash-dotted lines and dotted lines plot 95 and 99% confidence bands, respectively.

Figure 3.7: Term premium response to the negative output shock for each maturity yield.



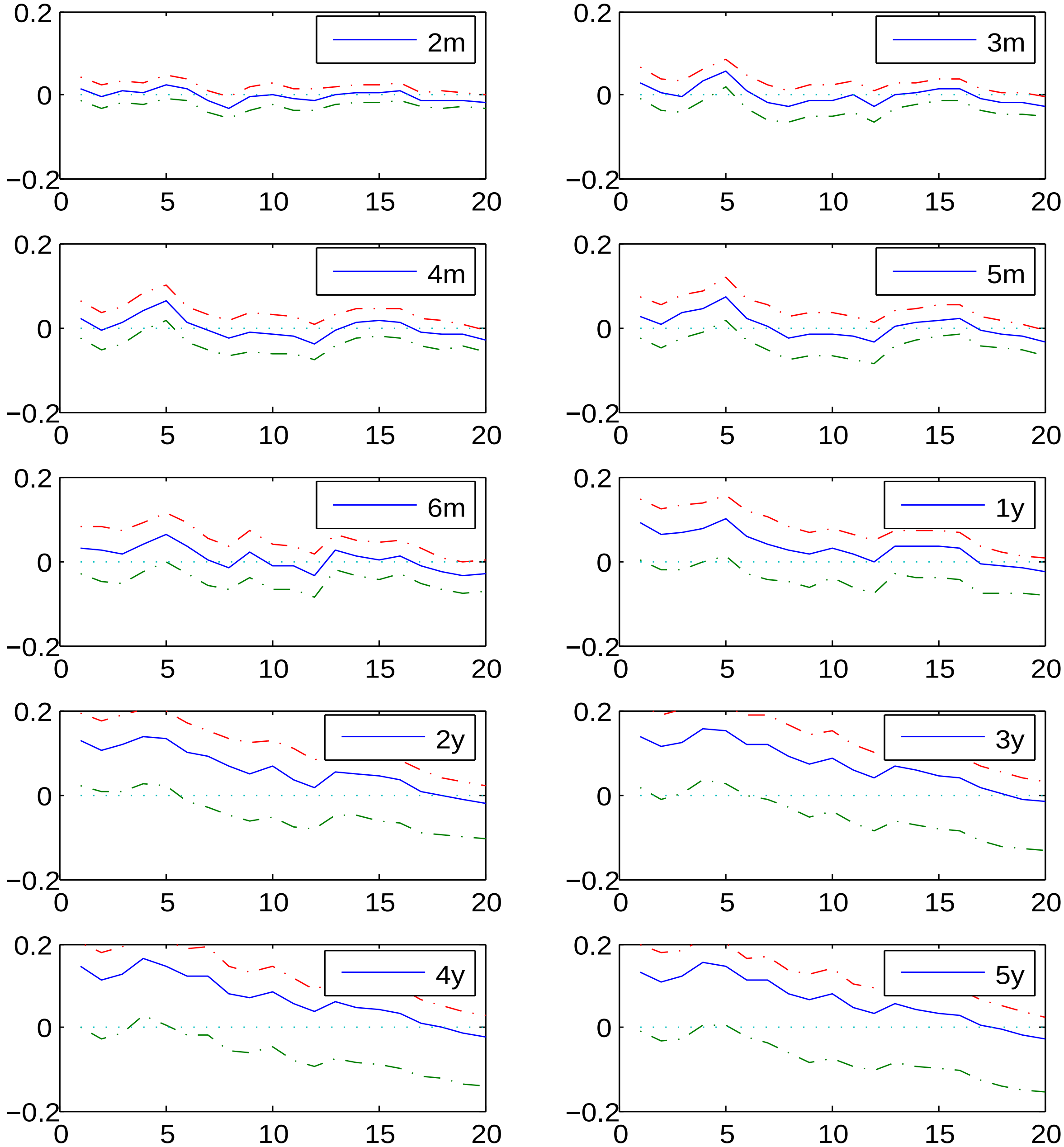
Starting from the upper left corner to the bottom right, each window represents term premium responses to the contractionary monetary policy shock up to 20 periods for 2- to 6-month and 1- to 5-year yields, respectively. The dash-dotted lines plot 95% confidence intervals.

Figure 3.8: The first-step responses of the term premium for different maturity bonds to the negative inflation shock



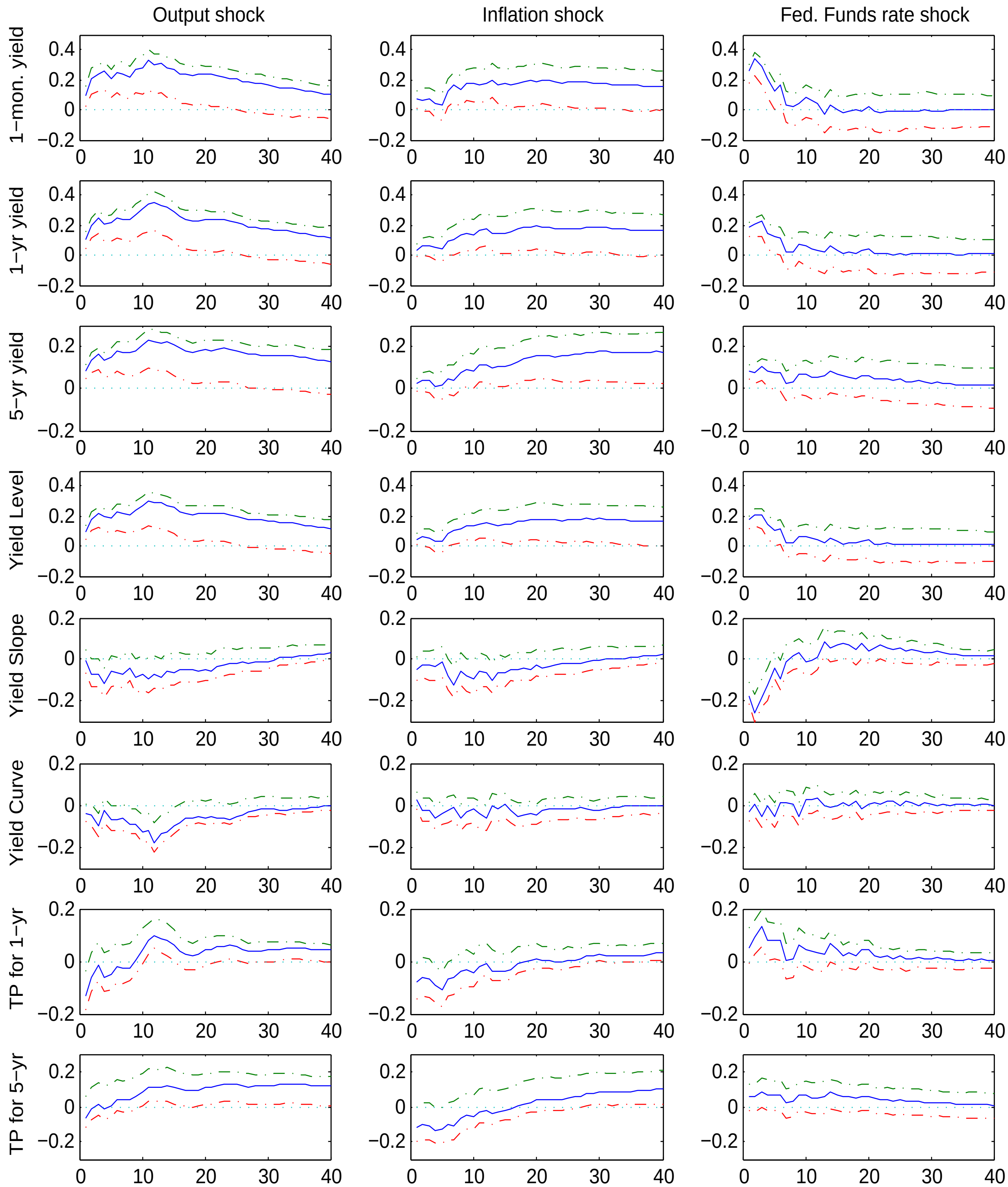
The X-axis represents the maturity(n) of yields. The solid line plots the estimated first-step impulse response functions of the term premium with maturity n, $E_tTP_{t+1}^n$, which is constructed as the difference between the first-step response of n-period yield and the average of one-period yield responses from $t+1$ to $t+n$. Dash-dotted lines and dotted lines plot 95 and 99% confidence bands, respectively.

Figure 3.9: Term premium response to the negative inflation shock for each maturity yield.



Starting from the upper left corner to the bottom right, each window represents term premium responses to the contractionary monetary policy shock up to 20 periods for 2- to 6-month and 1- to 5-year yields, respectively. The dotted lines plot 95% confidence intervals.

Figure 3.10: Effects of the macroeconomic shocks on the yield curve



Positive one standard deviation shocks are given for the first and second column(output and inflation shocks). A one standard deviation of contractionary federal funds rate shock is given for the last column. Dash-dot lines plot 95% confidence bands. The first three rows plot the impulse response functions of 1-month, 1-year, and 5-year yields, respectively. The fourth to sixth rows represent the impulse response functions of the level, slope, and curvature of the yield curve. The last two rows represent the impulse response functions of the term premium for 1- and 5-year bonds.

Chapter 4

The Model Economy and Policy Simulation

The empirical VAR analyses in the previous chapters suggest that a contractionary monetary policy shock generates the following results

- There are protracted rises in inflation and persistent drops in real wages, which suggest the existence of a cost channel effect.
- Output shows a hump-shaped response.
- The term premium response to the policy shock does not help much to explain the long-rate response, which suggests that the monetary policy shock is transmitted to the economy by changing the expectations of the current and future path of short rates.

This chapter derives a DSGE model which incorporates these empirical findings. In particular, the direct relationship between interest rates and production costs is considered to explain the co-movements of interest rates and inflation. The decisions which are encountered by each economic agent will be discussed. This includes optimal allocation of wealth by households and optimal choice of factor inputs and output prices by firms. In addition, the model economy includes the behavior of financial intermediaries and the monetary authority.

The model economy, after log-linearizing non-linear equations, will be solved with Klein's algorithm. The policy simulation exercises will be carried out based on the model economy and the results will be compared to the empirical counterparts. The role of nominal rigidities in explaining the persistent behavior of the economy will also be discussed in comparison to the role of time-to-build lags and the long-term loan market.

4.1 The Model Economy

4.1.1 Households

Time Schedule of Households

The household h is indexed on the unit interval. The household supplies a differentiated labor service $N_{h,t}$. It begins time t economic activity with money balance $M_{h,t-1}$ from period $t-1$. At the beginning of period t, the asset market opens first. After the asset market closes then the goods market opens. Before observing the economy-wide shocks (monetary policy shock and technology shock), the representative household splits up the money balance held at the beginning of period t into two parts, $H_{h,t}$ and $Q_{h,t}$, where $H_{h,t}$ goes to the financial intermediary for trading bonds and $Q_{h,t}$ goes to the goods market for purchasing goods. Hence the money allocation equation of the household at the beginning of period t is given by $M_{h,t-1} = H_{h,t} + Q_{h,t}$.

I follow Svensson's (1985) timing of economic transactions in that cash is set aside for purchasing goods before the current state of the economy is known to the representative household. Hence, after determining the amount of $Q_{h,t}$ dollars to finance goods, the representative household brings its remaining assets, $M_{h,t-1} - Q_{h,t}$, to the financial market for purchasing financial assets. But, after observing economy-wide shocks, the household rearranges its cash position and portfolio of bonds. For analytical simplicity, I assume that there exist only one- and two-period discount bonds in the financial asset market. Moreover the household is assumed to hold bonds until they are matured, and bonds are always redeemed at the end of their maturity dates. Hence one-period bonds purchased in period t and two-period bonds from period $t-1$ will be redeemed at the end of the period t.

I allow an exogenous stochastic process of transaction costs for long-term bonds, ε_t with a mean value ε^*. So the household pays $1+\varepsilon_t$ instead of 1 for each dollar of long-term bond in period t. This reflects the existence of imperfect substitution between different financial assets. Andrés, López-Salido, and Nelson (ALN 2004) introduce two types of frictions in the asset markets: time-varying stochastic transaction costs in the long-bond market and endogenous transaction costs involving liquidity risk in the long-bond market to create an extra channel of monetary policy. Because the endogenous factor could be affected by the policy action, it becomes another channel of monetary policy other than changing market expectations in the term structure of interest rates. By introducing stochastic transaction costs in the model, we can have a more general version of the term structure even after linearizing the model equations. However, the empirical impulse response functions in the previous chapter (see Figure 2.5) imply that the long-term asset market shock, which can be interpreted as the term premium shock, does not affect the variables other than the long-term interest rates. Also, the empirical analysis in Chapter 3 indicated that macroeconomic shocks do not have a significant effect on the term premium. In order to take into account the lack of a relationship between macro shocks and the term premium in the model, I posit that the stochastic transaction costs for long-term bonds ε_t follow *i.i.d.*, a white noise process which implies that macroeconomic shocks do not affect the term premium. This assumption ensures that the monetary policy shock changes long rates in the direction that the expectations hypothesis of the term structure predicts in the linearized version of the economy.

Denote $B^h_{1,t}$ and $B^h_{2,t}$ as the amount of zero-coupon bonds purchased by household h which are redeemed for one unit of money under every state of nature at the end of time t and $t+1$, respectively. Define $q_{1,t}$ and $q_{2,t}$ as the discounted prices of one- and two-period bonds. Then, the portfolio constraint is given by

$$q_{1,t}B^h_{1,t} + (1+\varepsilon_t)q_{2,t}B^h_{2,t} \leq M_{h,t-1} - Q_{h,t} \tag{4.1}$$

The right hand side of (4.1) is the money wealth carried over from period $t-1$ net of cash set aside for purchasing goods. The portfolio constraint (4.1) tells us that the amount of money in used for purchasing one- and two-period bonds and the cash set aside for purchasing consumption goods should not exceed the money wealth from $t-1$. Moreover, as we will see later in this chapter, the portfolio constraint is binding when the price of one-period bonds is less than one. That is, the household sells its remaining money holdings ($H_{h,t}$, net of money holdings for purchasing consumption goods) into the financial market as long as the nominal short rate is positive.

The suppliers of one- and two-period bonds are financial intermediaries. The monetary authority also participates in the short-term bond market in order to achieve its policy goal by selling or purchasing one-period bonds. Let $B^c_{1,t}$ denote the amount of net supply of one-period bonds by the monetary authority, then the negative value of $B^c_{1,t}$ implies net purchase by the monetary authority. Define $B_{1,t}$ as the amount of one-period bonds supplied by financial intermediaries. Then the total supply of one-period bonds becomes $B_{1,t} + B^c_{1,t}$.

Capital goods in our economy are long-term capital goods in the sense that it takes many periods to construct them. While many studies assume that households invest their wealth for maintaining the capital goods against depreciation and rent them to firms, the investment for capital goods is carried out by firms in my model.

During the time when asset trading markets are open, the state of the economy is revealed.[1] Having observed shocks in the economy, the household h makes its consumption decision and nominal wage contract with the full information on the current state of the economy. The household purchases consumption goods c_t with its time$-t$ cash holdings plus labor income from the production sector. Wage bills are pre-paid in money that can be used to purchase consumption goods. Therefore, the cash-in-advance constraint is given by

$$P_t c_{h,t} \leq Q_{h,t} + W_{h,t} N_{h,t} \tag{4.2}$$

where P_t and $W_{h,t}$ denote the price level of consumption goods and nominal wages, respectively.

Each household owns the same portion of claims on profits from period t economic activities of firms and financial intermediaries, and a market for claims to those profits is assumed not to exist in the economy for simplicity's sake. Hence, at the end of period t, after closing the goods market, household h, the owner of firms and financial intermediaries, receives the equally divided portion of aggregate profits $\Pi_{h,t}$ from firms and $DIV_{h,t}$ from financial intermediaries as dividends.

Financial intermediaries redeem all maturity bonds $B_{1,t}$ and $B_{2,t-1}$ at the end of period t. When the monetary authority sells one-period bonds, household h also receives $B_{1,t}^{c,h}$ from the monetary authority, where $B_{1,t}^{c} = \int_0^1 B_{1,t}^{c,h} dh$. Even if we assume that bonds purchased at the period t market are redeemed at the beginning of the maturity date, the results are the same as the following schedule where one-period bonds purchased in the period t asset market and two-period bonds purchased in $t-1$ period asset market are paid out at the end of period t. We do not lose generality because,

[1]The asset market shock is assumed to be observed during the time when asset markets are open.

for both schedules, each household knows with certainty the amount of payoffs $B^h_{1,t}$ and $B^h_{2,t-1}$ from period t and $t-1$ bond markets, and they do not affect the period t consumption decision. That is, getting payoff at the end of period t or at the beginning of period $t+1$ does not affect the period t CIA constraint because time t consumption is restricted not to be a function of payoffs $B^h_{1,t} + B^h_{2,t-1}$ at the end of period t, nor at the beginning of period $t+1$. Rather, those payoffs, $B^h_{1,t} + B^h_{2,t-1}$, affect time $t+1$ consumption decisions via next-period portfolio constraint.

The household h allocates the remaining wealth to the money balances, M_t to purchase period $t+1$ assets and goods. The end of period t money balance is given by

$$M_{h,t} = \Pi_{h,t} + DIV_{h,t} + B^h_{1,t} + B^h_{2,t-1} + Q_{h,t} + W_{h,t}N_{h,t} - P_t c_{h,t} + T_{h,t} \tag{4.3}$$

where $T_{h,t} = P_t \tau_{h,t}$ denotes nominal lump-sum money transfer made to the household h from the monetary authority. If it is negative, $T_{h,t}$ is lump-sum tax to the monetary authority.

Let n be a term from time t to the maturity date t+n. The nominal interest rates will appear in our economy through the relation to bond prices $q_{n,t} = e^{-ni_{n,t}}$. The condition states that the price of bonds is a discounted value of one dollar with a constant rate to the maturity date. A discrete version of this equation is $q_{n,t} = (1 + i_{n,t})^{-n}$, and the two expressions lead us to the following equation

$$i_{n,t} = -\frac{1}{n}\ln q_{n,t} \tag{4.4}$$

The Wage Decision

As in Erceg et al. (2000), the monopolistically competitive household supplies its labor service and nominal wages are assumed to be determined in staggered contracts. Household wage-decision behavior enables real wages to move in the direction that the cost channel effect predicts in my model. The household sells a differentiated labor service, $N_{h,t}$, to a representative firm that transforms this service into aggregate labor input, N_t, with the following Dixit-Stigliz technology:

$$N_t = \left[\int_0^1 N_{h,t}^{\frac{\theta_n - 1}{\theta_n}} dh\right]^{\frac{\theta_n}{\theta_n - 1}} \tag{4.5}$$

where $\theta_n > 1$. This firm minimizes the cost of producing N_t given the nominal wage rate $W_{h,t}$ and sells the aggregate labor to the intermediate goods-producing firms with aggregate wage rate W_t, which is defined as

$$W_t = \left[\int_0^1 W_{h,t}^{1-\theta_n} dh\right]^{\frac{1}{1-\theta_n}} \tag{4.6}$$

Then, the total demand for the household h's labor service by the production sector is given by

$$N_{h,t} = \left(\frac{W_{h,t}}{W_t}\right)^{-\theta_n} N_t \tag{4.7}$$

Households set their wage according to a variant of firms' Calvo-type price-setting. A constant fraction $(1 - \omega_n)$ of households re-optimizes the nominal wage, and ω_n of them simply set their wage based on past inflation times their past wages as follows

$$W_{h,t} = \pi_{t-1} W_{h,t-1} \tag{4.8}$$

where inflation is defined as $\pi_t = \frac{P_t}{P_{t-1}}$ throughout this paper. Therefore, when household h has not re-optimized since time t, its wage in period $t + j$ becomes $W_{h,t+j} =$

$\pi_j W_{h,t}$, where

$$\pi_j = \{ \begin{array}{ll} \pi_t \times \pi_{t+1} \times \cdots \times \pi_{t+j-1} & \texttt{if} \quad j \geq 1 \\ 1 & \texttt{if} \quad j = 0 \end{array} \tag{4.9}$$

Optimization

Under the constraints (4.1) through (4.3) and taking N_t and W_t as given, household h decides on the amount of bonds, consumption demand, nominal wage rate, and demand for money to maximize its time t expected utility function given by

$$E_t \sum_{j=0}^{\infty} \beta^j U(c_{h,t+j}, Z_{h,t+j}, N_{h,t+j}; \nu_{t+j}) \tag{4.10}$$

where β denotes a time discount factor satisfying $\beta \in (0, 1)$, and ν_t is a preference shock which follows an AR(1) process with white noise $\epsilon_{\nu,t} \sim (0, \sigma_\nu)$ given by

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \epsilon_{\nu,t} \tag{4.11}$$

$Z_{h,t}$ represents the habit formation reference consumption level of household h. I assume the second-order habit persistence which implies that the reference consumption level depends on the weighted average of the past two periods' consumption levels:

$$Z_{h,t} = \rho_c c_{h,t-1} + (1 - \rho_c) c_{h,t-2}$$

As the memory parameter converges to unity, $\rho_c \to 1$, only the last period's consumption is important.

Define $\eta > 0$ and $\psi > 0$ as the inverse of the elasticity of labor supply (with respect to real wages) and the labor (leisure) share or scale parameter in the utility, respectively.

Then, the period utility function of this household is given by

$$U(c_{h,t}, Z_{h,t}, N_{h,t}; \nu_t) = \frac{\nu_t}{1-\sigma}\left(\frac{c_{h,t}}{Z_{h,t}^{\zeta}}\right)^{1-\sigma} - \psi\frac{N_{h,t}^{1+\eta}}{1+\eta} \tag{4.12}$$

where σ denotes the inverse of elasticity of the intertemporal substitution with respect to consumption. The habit persistence parameter is restricted to be $0 \leq \zeta \leq 1$. $\zeta > 1$ is not allowed because of negative steady state marginal utility of consumption. If $\zeta = 1$, the relative consumption to the reference level of consumption matters to this household. σ is restricted to be greater than one if $\zeta \neq 0$, and $\sigma > 0$ if $\zeta = 0$ in order for the marginal utility of Z_t to be positive.

Denote Λ^a, Λ^b, and Λ^c as Lagrangian multipliers for (4.1), (4.2), and (4.3), respectively. Then, the first-order conditions are given by

$$\begin{array}{lll}
(a) & c_t & : U_{c,t} = P_t(\Lambda_t^b + \Lambda_t^c) \\
(b) & W_{h,t} & : E_t \sum_{j=0}^{\infty}(\omega_n\beta)^j\{\frac{1-\theta_n}{\theta_n}\pi_j W_{h,t}(\Lambda_{t+j}^b + \Lambda_{t+j}^c) - U_{N_h,t+j}\}N_{h,t+j} = 0 \\
(c) & B_{1,t}^H & : \Lambda_t^c = q_{1,t}\Lambda_t^a \\
(d) & B_{2,t} & : \beta E_t \Lambda_{t+1}^c = (1+\varepsilon_t)q_{2,t}\Lambda_t^a \\
(e) & M_t & : \beta E_t \Lambda_{t+1}^a = \Lambda_t^c \\
(f) & Q_t & : \Lambda_t^a = \Lambda_t^b + \Lambda_t^c
\end{array}$$

where the marginal utility of consumption is defined as

$$\begin{aligned} U_{c,t} = \; & \nu_t Z_t^{-\zeta(1-\sigma)} c_t^{-\sigma} - \zeta\beta E_t \nu_{t+1} c_{t+1}^{1-\sigma} Z_{t+1}^{-1-\zeta(1-\sigma)}\rho_c \\ & -\zeta\beta^2 E_t \nu_{t+2} c_{t+2}^{1-\sigma} Z_{t+2}^{-1-\zeta(1-\sigma)}(1-\rho_c) \end{aligned} \tag{4.13}$$

From Erceg et al. (2000), Amato and Laubach (2004), and CEE (2005), we know that the existence of complete state contingent claims markets for consumption ensures that households have identical consumption in each period. Hence, the omission of a household-specific term in (a) and $(c) \sim (f)$ reflects the assumption of the existence of complete state contingent claims markets. From (a) and (b), we obtain the following consumption-labor-related equation

$$E_t \sum_{j=0}^{\infty} (\omega_n \beta)^j \{ \frac{1-\theta_n}{\theta_n} \frac{\pi_j W_{h,t}}{P_{t+j}} U_{c,t+j} - U_{N_h,t+j} \} N_{h,t+j} = 0 \tag{4.14}$$

Equation (4.14) implies that the household sets its wage so that the discounted marginal utility of the income from an additional unit of labor is equal to its discounted marginal disutility from supplying labor (Erceg et al. 2000). It collapses to the familiar condition that real wages are equal to the marginal rate of substitution between consumption and leisure when all households re-optimize their wages in every period, $\omega_n \to 0$:

$$\frac{1-\theta_n}{\theta_n} \frac{W_{h,t}}{P_t} = -\frac{U_{N,t}}{U_{c,t}} \tag{4.15}$$

Using (c), (d), (e), and (f), we obtain the standard asset pricing equations for discount bonds as follow

$$\begin{aligned} (\Lambda_t^b + \Lambda_t^c) q_{1,t} &= E_t \beta (\Lambda_{t+1}^b + \Lambda_{t+1}^c) \\ (1+\varepsilon_t)(\Lambda_t^b + \Lambda_t^c) q_{2,t} &= E_t \beta^2 (\Lambda_{t+2}^b + \Lambda_{t+2}^c) \end{aligned} \tag{4.16}$$

The above asset pricing equations tell us that, at the optimum, the utility from purchasing one unit of bonds (the left-hand side) must be equal to the discounted expected utility that the household will be paid out in the next period from those bond holdings (the right-hand side). With the explicit utility function (4.12), equation (4.16) can be expressed as the ratio of each period's marginal utility as follows:

$$q_{1,t} = \beta E_t \tfrac{P_t}{P_{t+1}} \tfrac{U_{c,t+1}}{U_{c,t}} \tag{4.17}$$

$$(1+\varepsilon_t) q_{2,t} = \beta^2 E_t \tfrac{P_t}{P_{t+2}} \tfrac{U_{c,t+2}}{U_{c,t}} \tag{4.18}$$

Equation (4.18) involves a stochastic transaction cost which reflects the existence of imperfect substitution between different maturity bonds as used in ALN (2004). When the exogenous transaction cost shock is detected in the long-term bond markets, households pay more than one dollar for one unit of long-term bond purchases in time t even though the amount of payoffs from holding these bonds is the same. Hence, the long-term bond markets face an excess supply, and the price of bonds $q_{2,t}$ falls to recover the equilibrium state.

The term structure of interest rates can be derived from (4.17) and (4.18). Using the law of iterated expectation, (4.18) becomes

$$(1+\varepsilon_t)q_{2,t} = q_{1,t}E_t q_{1,t+1} + Cov_t\left(\beta \frac{P_t}{P_{t+1}}\frac{U_{c,t+1}}{U_{c,t}}, q_{1,t+1}\right) \tag{4.19}$$

Using the relationship between the bond prices and interest rates, equation (4.4), the log linearized expression of (4.19), becomes

$$\hat{i}_{2,t} = \frac{1}{2}\hat{i}_{1,t} + \frac{1}{2}E_t\hat{i}_{1,t+1} + \frac{1}{2}\hat{\varepsilon}_t \tag{4.20}$$

The two-period interest rate is the average of the current and expected future one-period interest rates plus stochastic term premium. Since the empirical analyses in the previous chapters suggested that the term premium is not an important factor in explaining the long-rate response to macroeconomic shocks, the covariance term is dropped out in equation (4.20). But even if the covariance term is dropped out of the equation by the log-linearization, the long rate still involves the stochastic term premium, which is from imperfect substitution between two different maturity bonds.

From (c) and (f), we get $q_{1,t} = \frac{\Lambda_t^c}{\Lambda_t^b+\Lambda_t^c}$, and from (4.4)

$$r_{1,t} = \ln\left(1+\frac{\Lambda_t^b}{\Lambda_t^c}\right) \tag{4.21}$$

This equation states that the nominal short rate is non-negative and strictly positive when the value of liquidity service is positive. The first-order condition (c) for the short-term bond implies that Λ_t^c, the expected marginal utility of the beginning of period $t+1$ money balance evaluated at t, is equal to the marginal utility of the beginning of period t money balance evaluated with $q_{1,t}$. Moreover we can see from (a) that the marginal utility of consumption exceeds the expected marginal utility of the beginning of period $t+1$ money balance evaluated at t by the value of liquidity service Λ_t^b.

4.1.2 A Final Good Producing Firm

A final good y_t is produced by a representative, perfectly competitive firm using the following production technology:

$$y_t = \left(\int_0^1 y_{i,t}^{\frac{\theta_\pi - 1}{\theta_\pi}} \, di \right)^{\frac{\theta_\pi}{\theta_\pi - 1}} \tag{4.22}$$

where $y_{i,t}$ is an intermediate good produced by intermediate-goods producing firm $i \in (0,1)$. The parameter $\theta_\pi > 1$ is the price elasticity of demand for the individual good i. The higher θ_π implies the closer substitutes between the individual goods. The final good producing firm maximizes its profit given its output price P_t and input price $P_{i,t}$. The demand for good i is driven by the Euler equation and output price can be obtained as follows:

$$y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\theta_\pi} y_t \tag{4.23}$$

$$P_t = \left(\int_0^1 P_{i,t}^{1-\theta_\pi} di \right)^{\frac{1}{1-\theta_\pi}} \tag{4.24}$$

4.1.3 Intermediate Good Producing Firms

A monopolistically competitive firm $i \in (0,1)$ produces an intermediate good $y_{i,t}$ with labor and capital inputs. Labor $N_{i,t}$ is supplied by a representative firm which transforms a differentiated labor service from households into aggregate labor N_t. The labor cost is financed from financial intermediaries and paid to workers in advance of production. Each firm is assumed to own its capital stock. The construction of investment projects requires multiple periods before they can be used as capital in the production process. The firms are restricted not to use their own goods. Hence, they purchase investment goods in the goods market. Each firm also finances these investment projects from financial intermediaries.

Let $K_{i,t}$ denote the capital stock of firm i at the beginning of period t. A single firm uses the following production technology and produces a differentiated good

$$y_{i,t} = \{ \begin{array}{cc} \xi_t N_{i,t}^{\alpha} K_{i,t}^{(1-\alpha)} - \bar{Y} & \texttt{if} \;\; \xi_t N_{i,t}^{\alpha} K_{i,t}^{(1-\alpha)} \geq \bar{Y} \\ 0 & o.w. \end{array} \tag{4.25}$$

where $\bar{Y} > 0$ denotes the fixed cost of production. This CES (Constant Elasticity of Substitution) technology results in the steady state labor share α, and capital share $1 - \alpha$ of output. ξ_t is an economy-wide technology shock with a highly persistent stochastic process as in many studies of real business cycles,

$$\ln \xi_t = (1 - \rho_\xi) \ln \xi + \rho_\xi \ln \xi_{t-1} + \epsilon_{\xi,t} \tag{4.26}$$

where $\xi > 0$ and $|\rho_\xi| < 1$. The serially uncorrelated innovation $\epsilon_{\xi,t}$ follows an *i.i.d.* white noise process with variance σ_ξ.

There exist time lags in the production process between the moment when investment decisions are made and the moment when the investment projects or machines are used in capital. One reason for the time delay in completion of capital stock might be the requirement of time to design, research, and construct investment projects. Kydland and Prescott's (1982) time-to-build technology is adopted in order to incorporate this type of time gap in the model. Let $s^i_{j,t}, j = 1...J$ denote the number of investment projects of firm i which require j periods to be completed at time t. For example, investment projects launched at time t, $s^i_{J,t}$, require J periods in order to be used in the productive capital stock $K_{i,t+J}$, hence in $t+J$ production. Therefore, $s^i_{j,t}$ for $j = 2...J$, are not used in the productive capital stock. Hereafter, I assume $J = 2$[2] for the sake of simplicity. Let φ_j for $j = 1, 2$ denote the fraction of resources allocated in $s^i_{j,t}$. Then, the total investment implemented by firm i in period t becomes $iv_{i,t} = \sum_{j=1}^{2} \varphi_j s^i_{j,t}$. This implies that each firm cannot purchase $\varphi_1 s^i_{1,t+1}$ during period t. The transition law of productive capital stock is then given by

$$K_{i,t+1} = (1-\delta)K_{i,t} + s^i_{1,t} \tag{4.27}$$

$$s^i_{1,t+1} = s^i_{2,t} \tag{4.28}$$

where δ denotes a depreciation rate. Equation (4.27) says that newly launched projects in period $t-1$ are used for the productive capital $K_{i,t+1}$ hence for time $t+1$ production. Equation (4.28) simply states investment projects launched at time t require two periods to be constructed and, at time $t+1$, these projects need only one period to be completed.

Since workers must be paid in advance of production, firms need to finance the wage bill in the loan market at the beginning of time t. Firm i also finances the cost of long-term investment projects in order to ensure the whole cost of projects. These financial costs add to production costs. Firms are assumed to use different maturity of loan contracts for different purposes. Short-term loans are used for the payment of

[2] We can expand the model in a way that each firm has a different time horizon to complete its projects and finances the projects with firm-specific n-period loan contracts.

labor costs in every period, and long-term loans go for covering the cost of long-term investment projects. The reason that firms match the maturity of debts and the period of using the factor cost and construction cost can be justified as follows. Firms have no incentive to borrow money with long-term contracts for financing time t and future labor costs because of the risk of price change. On the other hand, the construction cost for investment projects takes two periods to be exhausted and the cost is determined when the project decisions are made. By borrowing money with a long-term contract which has the same maturity as construction periods, firms can protect money from the risk of failing to roll over the maturity and hence failing to complete the project.[3] Hence, firms finance investment projects in a way that covers the whole cost of the projects up to completion. That is, they are not allowed to finance ongoing projects or periodic investment expenditure on the productive capital, $P_t iv_{i,t}$. Since new projects require two periods to be constructed, firm i makes 2-period loan contracts. I rule out entry and exit into the production sector.

Let $A_{i,t}$ denote the amount of long-term loans by firm i. φ_2 fraction of the investment projects will be paid at time t at the time t price, and φ_1 fraction of them will be charged at time $t+1$ at the time $t+1$ price. Since firms cannot observe the time $t+1$ price at time t, the long-term financing process involves firms' expectations of the time $t+1$ price. But when the time t long-term financing decision is made, firms can observe the prediction error from the decision made in time $t-1$, $\varphi_1 s^i_{2,t-1} P_t - \varphi_1 s^i_{2,t-1} E_{t-1} P_t \equiv \epsilon_t$. This follows from the assumption that the state of the economy is revealed to all agents during the period when asset markets are open. So firms can add the difference

[3] We can consider another borrowing strategy to finance long-term projects other than matching borrowing periods to construction periods. After 2 construction periods, investment projects produce positive cash flow for longer periods, say 10 periods whose length depends on the rate of depreciation of the projects. Firms can make 12-period financing contracts to cover 2 periods of negative cash flow, which promises paying out the construction costs after the investment projects start producing positive cash flow. But this strategy requires long lines of interest payment sequence in the firm's optimization process, which is burdensome to solve the model. For the sake of simplicity, I adopt a 2-period borrowing strategy in this paper and leave the 12-period contract strategy for a future study.

between the amount of investment expenditure at time $t-1$ and the actual investment expenditure in the new fund to finance period t investment projects. Therefore, the borrowing constraint of firm i is given by

$$A_{i,t} \geq \varphi_2 s^i_{2,t} P_t + \varphi_1 s^i_{1,t+1} E_t P_{t+1} + \epsilon_t \quad (4.29)$$

The long-term borrowing constraint states that the amount of long-term borrowing, $A_{i,t}$, should not be less than the total cost of time t-launched investment projects plus the error correction amount for φ_1 fraction of investment projects to be completed in period t. Now, it is natural to define money holdings by the firm i as $M^f_{i,t} \equiv \varphi_1 s^i_{2,t} E_t P_{t+1}$. $M^f_{i,t}$ amount of money will be used in purchasing φ_1 fraction of $s^i_{2,t}$ in the next period. Because of the assumption on the time schedule of the economy, firms cannot purchase bonds for $M^f_{i,t}$ in the period t bond market. Then, the borrowing constraint for financing long-term projects can be rewritten as follows:

$$M^f_{i,t} \leq A_{i,t} - \varphi_2 s^i_{2,t} P_t - \varphi_1 s^i_{1,t} P_t + M^f_{i,t-1}$$

which states that the money balance of firm i at the end of time t is determined as a residual after paying out φ_2 fraction of time t-launched projects from time t borrowing, and φ_1 fraction of time $t-1$-launched projects that require one more period to be completed in period t, from money holdings of previous period $M^f_{i,t-1}$.

Each firm follows a two-step optimization procedure. First, it minimizes its time-discounted total cost given the output and its price level. Second, it maximizes time-discounted profit with respect to its price with the cost function and the output price as given. Given the production function (4.25), productive capital evolution equation (4.27), (4.28), and the project financing constraint (4.29), the firm chooses its labor input, production, and investment levels by minimizing its time-discounted expected total cost.

$$E_t \sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} TC_{i,t+j} \tag{4.30}$$

The periodic total cost of each firm $TC_{i,t}$ consists of two parts: labor and investment project financing cost minus money holdings for purchasing a fraction of time t launched projects in the next period. Let $D_{i,t}$ denote the amount of short-term loans by firm i, and define $R_{N,t}$ and $R_{A,t}$ as the gross rate of interest for short- and long-term loans, respectively. The amount of short-term loans equals the total wage bill, $D_{i,t} = W_t N_{i,t}$. The loaned money will be repaid with the gross interest rate $R_{N,t}$ at the end of period t from time t sales revenue. Hence, time t total borrowing costs to finance labor input of firm i becomes $R_{N,t} W_{N,t} N_{i,t}$. It also has to pay out financing costs for the projects launched at $t-1$, $R_{A,t-1} A_{i,t-1}$. Then, the total financing costs at the end of time t become $R_{N,t} W_{N,t} N_{i,t} + R_{A,t-1} A_{i,t-1}$ (no coupon interest is assumed), because the money borrowed with long-term contracts at the beginning of period $t-1$ will be redeemed at the end of period t.[4] The periodic total cost will be expressed as

$$TC_{i,t} \equiv R_{N,t} W_t N_{i,t} + R_{A,t-1} A_{i,t-1} - M^f_{i,t}$$

Money holdings with a negative sign enter time t total cost because they provide positive cash flow to the firm as a residual from long-term borrowing and investment payments, $A_{i,t} - \varphi_2 s^i_{2,t} P_t - \varphi_1 s^i_{2,t-1} P_t + \varphi_1 s^i_{2,t-1} E_{t-1} P_t - R_{A,t-1} A_{i,t-1} = -R_{A,t-1} A_{i,t-1} + M^f_{i,t}$.[5] Since

[4]Even if we adopt the time schedule that a firm pays out its liability at the beginning of period $t+1$ instead of at the end of period t, period $t+1$ production will not be used to pay out the financial costs which are incurred in period t for short-term loans and in period $t-1$ for long-term loans. It is because a representative firm should pay out its liabilities at the beginning of $t+1$ but the period $t+1$ sales revenue arrives at the end of the period.

[5]Money holdings by firms bear no interest earnings because the interest earnings from the asset market arrive after the goods market is closed. That is, if firm i intends to purchase bonds in the time $t+1$ bond markets for $M^f_{i,t}$, it cannot purchase the φ_1 fraction of investment projects $\varphi_1 s^i_{1,t+1}$ for

firms are owned by households, all economic activities by firms should be evaluated as the households' value. Λ_t is the Lagrangian multiplier on the households' budget constraint. It denotes a marginal value of one dollar to the household,[6] and from $(e), (f)$, and (a), it is given by

$$\Lambda_t \equiv \Lambda_t^c = E_t \beta \frac{U_{c,t+1}}{P_{t+1}}$$

Since households face a cash-in-advance constraint in the goods market, one dollar to households in time t from firms will be used in purchasing time $t+1$ goods. Hence, the marginal value of one dollar at the end of period t is associated with time $t+1$ marginal utility of consumption.

Let Υ_t and Φ_t denote the Lagrange multipliers associated with the production function and borrowing constraint. The firm's cost minimization with respect to $N_{i,t}$, $A_{i,t}$, $s_{2,t}^i$, and Φ_t results in four first-order conditions as follows:

(A) $N_{i,t} : R_{N,t} W_t = \Upsilon_t Y_{N,t}$

(B) $A_{i,t} : \beta R_{A,t} \Lambda_{t+1} = \Lambda_t \Phi_t$

(C) $s_{2,t}^i :$ $\begin{array}{l} \Lambda_t \Phi_t \varphi_2 P_t + \Lambda_t \Phi_t \varphi_1 E_t P_{t+1} + \beta \varphi_1 E_t \{\Lambda_{t+1} \Phi_{t+1} (P_{t+1} - E_t P_{t+1})\} \\ -\varphi_1 \Lambda_t E_t P_{t+1} = \sum_{j=2}^{\infty} \beta^j (1-\delta)^{j-2} E_t \Lambda_{t+j} \Upsilon_{t+j} Y_{K,t+j} \end{array}$

(D) $\Phi_t : A_t = \varphi_2 s_{2,t} P_t + \varphi_1 s_{2,t} E_t P_{t+1} + \epsilon_t$

Rewriting (A) and combining (B), (C), and (D), we have

$$W_t R_{N,t} = \alpha \Upsilon_t Y_{N,t} \tag{4.31}$$

$$\begin{array}{c} \beta R_{A,t} E_t \Lambda_{t+1} (\varphi_2 P_t + \varphi_1 E_t P_{t+1}) + \beta^2 \varphi_1 E_t \{R_{A,t+1} \Lambda_{t+2} (P_{t+1} - E_t P_{t+1})\} \\ -\varphi_1 \Lambda_t E_t P_{t+1} = \sum_{j=2}^{\infty} \beta^j (1-\delta)^{j-2} E_t \Lambda_{t+j} \Upsilon_{t+j} Y_{K,t+j} \end{array} \tag{4.32}$$

$M_{i,t}^f$ because all interest-bearing bonds are redeemed at the end of each period after the goods market is closed.

[6]This type of discount factor expression is used in many general equilibrium studies, including CEE (2005), Jung (2004), Christiano and Eichenbaum (1995), and Dotsey and Ireland (1995).

$$a_t = \varphi_2 s_{2,t} + \varphi_1 s_{2,t} E_t \pi_{t+1} + \varphi_1 s_{2,t-1} \left(1 - \epsilon_{a,t}\right) \tag{4.33}$$

where $\epsilon_{a,t} = \frac{E_{t-1}P_t}{P_t}$ denotes the amount of time t-realized price prediction error. $a_t = \frac{A_t}{P_t}$ denotes the real amount of borrowing with long-term contracts, and $Y_{N,t}$ and $Y_{K,t}$ represent the marginal product of labor and capital input. The firm-specific subscriptions are dropped because the equilibrium labor-capital ratio is the same across all firms. From equation (4.31), it is clear that marginal products of financing labor should be the same as the marginal costs of financing labor at the optimum. The left-hand side of (4.32) represents the time t shadow price of new projects (or marginal cost of new projects) launched at the beginning of time t expressed with the amount of borrowing costs. The negative sign of the last term on the left-hand side (4.32) represents the marginal benefit from carrying money to the next period. The right-hand side of condition (4.32) involves the stream of future marginal products of capital because the factories or machines constructed with new investment projects of time t operate until the production process stops. More precisely, it is because, from (4.27) and (4.28), the evolution of time t productive capital can be expressed by the history of the initial ($j = 2$) stages of all projects over production periods: $K_t = \sum_{i=2}^{\infty}(1-\delta)^{i-2} s_{2,t-i}$. Therefore, (4.32) states that the marginal products of investment projects should equal the marginal costs of the projects at the optimum. It is clear from equation (4.31) and (4.32) that the nominal interest rates affect the marginal cost.

Firms are assumed to adjust their prices based on the Calvo-type pricing mechanism. $1 - \omega_\pi$ fraction of all firms re-optimize their price, but the remaining fraction of them simply set their price as past inflation times previous level of their prices as follows (CEE 2005):

$$P_{i,t} = \pi_{t-1} P_{i,t-1} \tag{4.34}$$

The above equation implies that, when firm i does not re-optimize after time t, its price in the period $t+j$ becomes $P_{i,t+j} = \pi_j P_{i,t}$. Let P_t^* denote the equilibrium price level chosen by price re-optimizing firms. Then the average price in period t becomes, from (4.24):

$$P_t^{1-\theta_\pi} = (1-\omega_\pi) P_t^{*(1-\theta_\pi)} + \omega_\pi (\pi_{t-1} P_{t-1})^{1-\theta_\pi} \tag{4.35}$$

Then, each firm's pricing decision involves choosing $P_{i,t}$ to maximize cash flow

$$E_t \sum_{j=0}^{\infty} (\omega_\pi \beta)^j \Lambda_{t+j} (\pi_j P_{i,t} y_{i,t+j} - TC_{i,t+j}) \tag{4.36}$$

By using (4.23), (4.31), and (4.32) dropping out the unrelated terms to $P_{i,t}$, the above objective function can be re-arranged as:

$$\begin{aligned} &E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \lambda_{t+j} \left(\frac{\pi_j P_{i,t}}{P_{t+j}} \right)^{1-\theta_\pi} y_{t+j} - \alpha E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \lambda_{t+j} \phi_{t+j} \left(\frac{\pi_j P_{i,t}}{P_{t+j}} \right)^{-\theta_\pi} y_{t+j} \\ &-(1-\alpha) E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \textstyle\sum_{k=2}^{\infty} \beta^k (1-\delta)^{k-2} \lambda_{t+j+k} \phi_{t+j+k} \left(\frac{\pi_{j+k} P_{i,t}}{P_{t+j+k}} \right)^{-\theta_\pi} y_{t+j+k} \frac{s_{t+j}^i}{K_{i,t+j+k}} \end{aligned}$$

where $\lambda_t = P_t \Lambda_t$ denotes the marginal value of P_t units of currency (CEE 2005) and $\phi_t = \Upsilon_t / P_t$ is the real marginal cost. The first term in the above objective function is cash in-flow from the sales revenue. The second term is the fraction of real total cost due to the labor cost, and the third term is cash out-flow from the investment expenditure.

The first-order condition is then given by

$$\begin{aligned} &E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \lambda_{t+j} (\frac{\pi_j}{P_{t+j}})^{1-\theta_\pi} y_{t+j} P_t^* \\ &= \frac{\theta_\pi}{\theta_\pi - 1} \{ \alpha E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \lambda_{t+j} \phi_{t+j} (\frac{\pi_j}{P_{t+j}})^{-\theta_\pi} y_{t+j} \\ &+(1-\alpha) E_t \textstyle\sum_{j=0}^{\infty} (\omega_\pi \beta)^j \textstyle\sum_{k=2}^{\infty} \beta^k (1-\delta)^{k-2} \lambda_{t+j+k} \phi_{t+j+k} (\frac{\pi_{j+k}}{P_{t+j+k}})^{-\theta_\pi} y_{t+j+k} \frac{s_{2,t+j}}{K_{t+j+k}} \} \end{aligned} \tag{4.37}$$

I assume the symmetric equilibrium so that the firm-specific notation is dropped in the fraction of $\frac{s_{2,t+j}}{K_{t+j+k}}$ for all j and k. The above equation states that the firm sets its contract price so that discounted real marginal revenue is equal to discounted real marginal cost.

4.1.4 Financial Intermediaries

Financial intermediaries trade one-period discount bonds with the households and the monetary authority whose prices are $q_{1,t}$ and two-period bonds with the households whose price is $q_{2,t}$. Net amount of funds from households and government is $M_{t-1} - Q_t - q_{1,t}B^c_{1,t}$, where $M_t = \int_0^1 M_{h,t}dh$ and $Q_t = \int_0^1 Q_{h,t}dh$. The first two terms are from households, and the other term is net supply of one-period bonds from the monetary authority. Since equation (4.1) implies $M_{t-1} - Q_t = q_{1,t}B^H_{1,t} + (1+\varepsilon_t)q_{2,t}B_{2,t}$, where $B^H_{1,t} = \int_0^1 B^h_{1,t}dh$ and $B_{2,t} = \int_0^1 B^h_{2,t}dh$, the amount of funds can be rewritten as $q_{1,t}(B^H_{1,t} - B^c_{1,t}) + (1+\varepsilon_t)q_{2,t}B_{2,t}$. These funds become the source of the supply of loanable funds.

Financial intermediaries use these funds to make two types of loan contracts with intermediate goods producing firms: the short-term loan contracts with which firms finance the wage bill with gross interest rate $R_{N,t}$, and the long-term loan contracts with which firms finance the whole cost of new projects launched at time t with gross interest rate $R_{A,t}$ for two periods. The total demand for loans by firms becomes $D_t + A_t$ where $D_t = \int_0^1 D_{i,t}di = W_tN_t$, $A_t = \int_0^1 A_{i,t}di = \varphi_2 s_{2,t}P_t + \varphi_1 s_{2,t}E_tP_{t+1} + \epsilon_t$, and $s_{2,t} = \int_0^1 s^i_{2,t}di$. Then, the resource constraint is given by

$$D_t + A_t = q_{1t}(B^H_{1,t} - B^c_{1,t}) + (1+\varepsilon_t)q_{2t}B_{2,t} \quad (4.38)$$

For the sake of simplicity, financial intermediaries are assumed to match maturities between assets and debts. That is, financial intermediaries use short-term loan contracts for lending money to firms with funds from selling short-term bonds, and they use long-term loan contracts for lending money with funds from selling long-term bonds. This assumption can be justified from the "matching principle" of the corporate debt maturity theory which is empirically supported in many studies, such as Emery (2001) and Stohs and Mauer (1996) for U.S. data, and Ozkan (2002) for UK data, among others. It states that firms should match the maturity of their liabilities to their asset maturity because if debt maturity is shorter than asset maturity, firms may not have enough cash on hand to repay the principal at the due date. Moreover, if the maturity of debt is longer than asset maturity, then cash in-flow from holding assets stops, while firms still have unpaid debt obligations. By matching maturities, firms can reduce these risks and expected costs of financial distress (Stohs and Mauer 1996). The matching principle can be applied to financial intermediaries because their main purpose is to seek profit as private firms do. The loan market separation together with the perfect competition in the loan markets guarantee that we can identify the equilibrium amount of short- and long-term borrowings. Now, each resource constraint becomes

$$D_t = q_{1,t} B_{1,t} \tag{4.39}$$

$$A_t = (1 + \varepsilon_t) q_{2,t} B_{2,t} \tag{4.40}$$

where $B_{1,t}$ denotes the supply of one-period bonds by financial intermediaries. The left-hand sides of (4.39) and (4.40) are the supplies of short- and long-term funds, respectively, and the right-hand sides represent the sources of funds.

At the end of period t, financial intermediaries receive payoffs (principal plus interest) from the short-term loan contracts made at the beginning of the period and from the long-term loan contracts made at the beginning of period $t-1$. After reimbursing all maturing bonds $B_{1,t}$ and $B_{2,t-1}$ to households (and to the monetary authority if $B^c_{1,t} < 0$), financial intermediaries distribute their end-of-period net cash position to the household as a dividend DIV_t given by

$$DIV_t = R_{N,t}D_t + R_{A,t-1}A_{t-1} - (B_{1,t} + B_{2,t-1}).$$

Financial intermediaries maximize the present value of the profit stream subject to (4.39) and (4.40) with respect to $D_t, A_t, B_{1,t}$, and $B_{2,t}$ given the perfect loan market competition, i.e., given $R_{N,t}$ and $R_{A,t}$. This can be expressed as

$$E_t \sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} DIV_{t+j}$$

Again, the discount factor, Λ_t, is defined the same way as in the firms' problem.

The first-order conditions result in the following two equations.

$$R_{L,t} = \tfrac{1}{q_{1,t}} \tag{4.41}$$

$$R_{A,t} = \tfrac{1}{(1+\varepsilon_t)q_{2,t}} \tag{4.42}$$

Financial intermediaries earn zero profit on funds received from selling one- and two-period bonds to the household[7] (Christiano and Eichenbaum 1995, Dotsey and Ireland 1995). From (26), (27), (29), and (30), the zero profit conditions become

$$R_{N,t}D_t = B_{1,t} \tag{4.43}$$

$$R_{A,t}A_t = B_{2,t} \tag{4.44}$$

for all periods t. The left-hand sides of (4.43) and (4.44) represent the cash inflows from

[7] Again, if the monetary authority purchases one-period bonds, the financial intermediary earns zero profit on funds received from selling one-period bonds to the household and the monetary authority.

lending money in the short and long term to the firms at the end of the period t and $t+1$, respectively. And the right-hand sides are cash outflows at the end of the period t and $t+1$, respectively, to the household from selling bonds. Hence, the dividend to the households at the end of period t becomes $DIV_t = 0$.

4.1.5 Monetary Authority

The public sector's monetary-fiscal policy regime has to be specified to identify the money supply M_t^s, the net supply of short-term bonds by the central bank $B_{1,t}^c$, lump sum transfers to the households T_t, and the price of the short-term bonds under the government budget constraint. No government expenditure is assumed in the model. Hence, T_t can be interpreted as net money transfer payment or lump-sum money transfer to the private sector, $T_t = G_t - Tax_t + TP_t = TP_t - Tax_t$, where G_t, Tax_t, and TP_t denote government expenditure, tax revenue and transfer payments such as social security, pension, etc., respectively. If $T_t > 0$, lump-sum money is transferred to households, and $T_t < 0$ means lump-sum tax from households. Since the monetary authority issues one-period bonds at the beginning of period t which pay one dollar at the end of the period for each unit of bonds, the budget constraint of the monetary authority becomes

$$M_t^s + q_{1,t}B_{1,t}^c = M_{t-1}^s + B_{1,t}^c + T_t \tag{4.45}$$

The budget constraint implies that the lump-sum money transfers are financed with seigniorage revenues and issuing one-period bonds. $B_{1,t}^c$ in the right-hand side in the government budget constraint implies that the government redeems time t one-period bonds at the end of period t.

In order to identify the money supply in the economy rigorously, we have to specify the relationship between monetary and fiscal policy. The open market operation procedure is given by

$$q_{1,t}B_{1,t}^{c} = -\Delta M_t^s \tag{4.46}$$

Equation (4.46) implies that when the monetary authority wants to raise short rates, it supplies one-period bonds in the open market and withdraws the exact same amount of money from the market for selling bonds. Now, the money supply is endogenously determined from the open market operation condition in the economy. Equations (4.45) and (4.46) imply that

$$T_t = -B_{1,t}^{c} \tag{4.47}$$

That is, the fiscal authority levies tax by the amount of payout for one-period bonds at the end of time t. When the monetary authority purchases one-period bonds, $B_{1,t}^{c} < 0$, the money supply increases and the lump-sum money transfer is made to the households.

The monetary authority's target rate can be achieved by adjusting the net supply of one-period bonds through the short-term asset market. That is, the total demand for one-period bonds can be obtained in equation (4.1) given by

$$q_{1,t}B_{1,t}^{H} = M_{t-1} - Q_t - (1+\varepsilon_t)q_{2,t}B_{2,t}$$

The one-period bond supply by financial intermediaries is given from equation (4.39) as follows

$$q_{1,t}B_{1,t} = D_t$$

Assume, for example, that the one-period bond market is at its equilibrium with the equilibrium rate $r^*_{1,t}$ without intervention by the central bank, hence $B^H_{1,t} = B_{1,t}$. When the central bank wants to raise the target rate to $r^1_{1,t}$, then there will be excess demand for one-period bonds in the market at the new target rate. Using long-term financial market optimality condition (4.44), the amount of excess demand for one-period bonds at the target rate in the market becomes

$$B^H_{1,t} - B_{1,t} = \widetilde{q}^{-1}_{1,t}(M_{t-1} - Q_t - D_t - A_t)$$

where $\widetilde{q}_t$ denotes the new equilibrium price of a one-period bond corresponding to $r^1_{1,t}$. This excess demand should be eliminated by the central bank by supplying one-period bonds $B^c_{1,t}$. Hence, the amount of one-period bonds supplied by the central bank to achieve its target rate becomes

$$B^c_{1,t} = \widetilde{q}^{-1}_{1,t}(M_{t-1} - Q_t - D_t - A_t) \tag{4.48}$$

Therefore, when the central bank sets the target rate, $B^c_{1,t}$ is determined endogenously as the excess demand for one-period bonds in the market at the target rate. In summary, when the central bank intends to raise short rates, it can be achieved by supplying one-period bonds by the excess demand at the target rate in the market.

Without financial intermediaries, the only supplier of the short-term bonds will be the central bank. According to Woodford (1994), in the case of interest rate policy instead of money supply policy, the budget constraint of the central bank is given by (4.45) and the money supply and net bond supply are no longer exogenously determined. But our model introduces financial intermediaries and the central bank is one of the participants in the short-term bond market. From the open market operation condition, we can see that the steady state value of one-period bonds supplied by the monetary authority becomes zero because of $\Delta M^s = 0$ in the steady state.

To complete our model economy, we need to specify the monetary policy rule. Two types of monetary policy rules can be considered in order to evaluate the effect of monetary policy: the money supply rule and the interest rate rule. Many recent leading papers in macroeconomics follow the Taylor-type interest rule. Since the objective of this paper is to evaluate the movement of interest rates as the source of the economic dynamics through cost channel, the interest rate smoothing rule is used. The central bank is assumed to respond by adjusting the short-rate target to the average expected inflation and output deviations from their steady state values by using the following feedback rule suggested by Erceg et al. (2000) and Amato and Laubach (2004),

$$i_{1,t} = (1-\rho_g)\{i_1^* + a_\pi E_t \bar{\pi}_{t+1} + a_w \pi_t^w + a_y x_t\} + \rho_g i_{1,t-1} + \epsilon_{g,t} \tag{4.49}$$

where $i_{1,t}$ denotes the short rate in period t set by the monetary authority, and i_1^* is the desired level of short rate when inflation and output meet their target levels. $\bar{\pi}_{t,k}$ denotes the percentage change in price level between period t and $t+k$, $\bar{\pi}_{t,k} = \frac{P_{t+k}-P_t}{P_t}$. $\pi_t^w = \frac{\bar{W}_t - \bar{W}_{t-1}}{\bar{W}_{t-1}}$ denotes wage inflation, and $x_{t,q}$ is a measure of the average output deviation from steady state (or trend) between period t and $t+q-1$. $\epsilon_{g,t}$ is a mean zero and serially uncorrelated shock to policy. As the error term is added in the policy rule, we can capture the unforecastable shock to the interest rate when the monetary authority formulates policy. Hence, this feedback rule consists of the sum of systematic responses by the central bank to economic conditions and uncontrolled shock. The lag of the short rate implies that the monetary authority reacts smoothly to deviations from the steady state or to the shock.

By using the short-term interest rate as the policy instrument, the central bank sets the federal funds rate target to achieve the final goal of output, price inflation, and wage inflation stabilizations. In order to meet the operating target rate, the central bank uses the short-term bond market, i.e., by selling or purchasing one-period bonds by the excess demand or supply of this bond in the market at the target rate.

4.1.6 Aggregate Resource Constraint and Market Clearing Conditions

The intermediate good producing firm i confronts the following resource constraint at time t:

$$c_{i,t} + iv_{i,t} = y_{i,t}$$

where $c_{i,t}$ and $iv_{i,t} = \sum_{j=1}^{2} \varphi_j s^i_{j,t}$ are the total consumption demand for goods produced by firm i and the economy-wide demand for investment goods produced by firm i, respectively.

Hence, from (4.23), the time t total demand in this economy can be obtained by summing over the total demand for differentiated intermediate goods, and the total resource will be obtained by summing over the output produced by each intermediate good producing firm. Hence, the aggregate resource constraint will be:

$$c_t + \varphi_1 s_{1,t} + \varphi_2 s_{2,t} = \left(\frac{\bar{P}_t}{P_t}\right)^{\theta_\pi} \bar{y}_t \tag{4.50}$$

where $\bar{P}_t \doteq \left(\int_0^1 P_{i,t}^{-\theta_\pi} di\right)^{-\frac{1}{\theta_\pi}}$ and $\bar{y}_t = \int_0^1 y_{i,t} di$. Since the labor-capital ratio is the same for all intermediate good producing firms, $\bar{y}_t$ can be expressed as:

$$\bar{y}_t = \xi_t \left(\frac{N_t}{K_t}\right)^{\alpha} \int_0^1 K_{i,t} di - \bar{Y} = \xi_t N_t^{\alpha} K_t^{1-\alpha} - \bar{Y}$$

where $K_t \doteq \int_0^1 K_{i,t} di$ and $N_t \doteq \int_0^1 N_{i,t} di$. In order to express the labor input as measured in the real world data (CEE), define new total labor $L_t = \int_0^1 N_{h,t} dh$ as measured in the data. Using (4.7), the complete $\bar{y}_t$ equation becomes

$$\bar{y}_t = \xi_t \left(\frac{\bar{W}_t}{W_t} \right)^{\alpha\theta_n} L_t^{\alpha} K_t^{1-\alpha} - \bar{Y} \tag{4.51}$$

where $\bar{W}_t \doteq \left(\int_0^1 W_{h,t}^{-\theta_n} dh \right)^{-\frac{1}{\theta_n}}$.

The money market clearing condition is given by

$$m_t^s = m_t + m_t^f \tag{4.52}$$

where $m_t^f = \frac{M_t^f}{P_t} = \frac{1}{P_t} \int_0^1 M_{i,t}^f di$. The money market clearing condition states that the period t real money supply by the central bank should be the same as the sum of the amount of real money held by all households and firms at the end of period t.

The short-term bond market should also be cleared and its condition becomes

$$B_{1,t} = B_{1,t}^H - B_{1,t}^c \tag{4.53}$$

The short-term bond market clearing condition states that the total supply for one-period bonds by financial intermediaries, $B_{1,t}$, should be equal to the demand for one-period bonds by households, $B_{1,t}^H$, minus net supply of one-period bonds by the monetary authority, $B_{1,t}^c$.

4.2 Solving the Model

This section explains how to solve the model. The first subsection collects structural equations. The second subsection computes the steady state and the third subsection presents log-linearized formulas of the non-linear version of the economy. In the final subsection, the model is solved with Klein's (2000) algorithm.

4.2.1 Model Equations

We have five equations from the first-order conditions for households' optimization process: a consumption-labor relation equation, two asset pricing equations, a habit formation, and the stochastic process of preference shock.

$$E_t \sum_{j=0}^{\infty} (\omega_n \beta)^j \{ \tfrac{1-\theta_n}{\theta_n} \tfrac{\pi_j W_{h,t}}{P_{t+j}} U_{c,t+j} - U_{N_h,t+j} \} N_{h,t+j} = 0 \tag{4.54}$$

$$q_{1t} = \beta E_t \tfrac{P_t}{P_{t+1}} \tfrac{U_{c,t+1}}{U_{c,t}} \tag{4.55}$$

$$(1+\varepsilon_t) q_{2t} = \beta^2 E_t \tfrac{P_t}{P_{t+2}} \tfrac{U_{c,t+2}}{U_{c,t}} \tag{4.56}$$

$$\begin{aligned} U_{c,t} = \; & \nu_t Z_t^{-\zeta(1-\sigma)} c_t^{-\sigma} - \zeta \beta E_t \nu_{t+1} c_{t+1}^{1-\sigma} Z_{t+1}^{-1-\zeta(1-\sigma)} \rho_c \\ & - \zeta \beta^2 E_t \nu_{t+2} c_{t+2}^{1-\sigma} Z_{t+2}^{-1-\zeta(1-\sigma)} (1-\rho_c) \end{aligned} \tag{4.57}$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \epsilon_{\nu,t} \tag{4.58}$$

We have seven equations from the production sector: the definition of stochastic discount factor, the production technology, the law of motion of capital stock, the stochastic process of output shock, and three equations from the first-order conditions with respect to labor, investment projects, and price.

$$\Lambda_t = E_t \beta \tfrac{U_{c,t+1}}{P_{t+1}} \tag{4.59}$$

$$\bar{y}_t = \xi_t \left(\tfrac{\bar{W}_t}{W_t} \right)^{\alpha \theta_n} L_t^{\alpha} K_t^{1-\alpha} - \bar{Y} \tag{4.60}$$

$$K_{t+1} = (1-\delta) K_t + s_{2,t-1} \tag{4.61}$$

$$\ln \xi_t = (1-\rho_\xi) \ln \xi + \rho_\xi \ln \xi_{t-1} + \epsilon_{\xi,t} \tag{4.62}$$

$$\tfrac{W_t}{q_{1,t}} = \alpha \Upsilon_t Y_{N,t} \tag{4.63}$$

$$\begin{aligned} & -\varphi_1 \Lambda_t E_t P_{t+1} \beta \tfrac{1}{(1+\varepsilon_t) q_{2,t}} E_t \Lambda_{t+1} (\varphi_2 P_t + \varphi_1 E_t P_{t+1}) \\ & + \beta^2 \varphi_1 E_t \{ \tfrac{1}{(1+\varepsilon_{t+1}) q_{2,t+1}} \Lambda_{t+2} (P_{t+1} - E_t P_{t+1}) \} = \sum_{j=2}^{\infty} \beta^j (1-\delta)^{j-2} E_t \Lambda_{t+j} \Upsilon_{t+j} Y_{K,t+j} \end{aligned} \tag{4.64}$$

$$P_t^* = \frac{\theta_\pi}{\theta_\pi - 1}\Big\{\frac{\alpha E_t \sum_{j=0}^{\infty}(\omega_\pi\beta)^j \lambda_{t+j}\phi_{t+j}\pi_j^{-\theta_\pi} P_{t+j}^{\theta_\pi} y_{t+j}}{E_t \sum_{j=0}^{\infty}(\omega_\pi\beta)^j \lambda_{t+j}\pi_j^{1-\theta_\pi} P_{t+j}^{\theta_\pi - 1} y_{t+j}} + \frac{(1-\alpha)E_t \sum_{j=0}^{\infty}(\omega_\pi\beta)^j \sum_{k=2}^{\infty}\beta^k(1-\delta)^{k-2}\lambda_{t+j+k}\phi_{t+j+k}\pi_{j+k}^{-\theta_\pi} P_{t+j+k}^{\theta_\pi} y_{t+j+k}\frac{s_{2,t+j}}{K_{t+j+k}}}{E_t \sum_{j=0}^{\infty}(\omega_\pi\beta)^j \lambda_{t+j}\pi_j^{1-\theta_\pi} P_{t+j}^{\theta_\pi - 1} y_{t+j}}\Big\} \tag{4.65}$$

where (4.41) and (4.42) are used for $R_{N,t}$ and $R_{A,t}$.

Rewrite the interest rate policy rule and aggregate resource constraint

$$i_{1,t} = (1-\rho_g)\{i_1^* + a_\pi E_t \bar{\pi}_{t+1} + a_w \pi_t^w + a_y x_t\} + \rho_g i_{1,t-1} + \epsilon_{g,t} \tag{4.66}$$

$$c_t + \varphi_1 s_{2,t-1} + \varphi_2 s_{2,t} = \bar{y}_t \tag{4.67}$$

Other endogenous variables can be calculated from optimization constraints and market clearing conditions.

4.2.2 Steady State

I use the superscript '*' for the steady state value of variables. The steady state values of one- and two-period bond prices can be calculated from equation (4.55) and (4.56) as $q_1^* = R_N^{*-1} = \beta$ and $q_2^* = R_A^{*-1} = \frac{\beta^2}{1+\varepsilon^*}$ where ε^* denotes the steady state value of the stochastic term premium. The steady state consumption-labor equation becomes

$$\frac{\theta_n - 1}{\theta_n} w^* c^{*\sigma(\zeta-1)-\zeta}[1 - \zeta\beta\rho_c - \zeta\beta^2(1-\rho_c)] = \psi L^{*\eta} \tag{4.68}$$

where w^* denotes the steady state of real wages, $w_t = \frac{W_t}{P_t}$, and $\psi L^{*\eta}$ in the right-hand side of (4.68) is the negative steady state marginal utility of labor. Since $W_{h,t} = W_h^* = W^*$ in the steady state, $\bar{W}_t = W_t$ holds in the steady state, and $N^* = L^*$ is used in (4.68).

From the production sector, we have five steady state equations. They correspond to equations (4.60), (4.61), (4.63) to (4.65), and the zero profit condition holds in the steady state.

$$y^* = L^{*\alpha} K^{*1-\alpha} - \bar{Y} \tag{4.69}$$

$$K^* = \delta s_2^* \tag{4.70}$$

$$w^* R_N^* = \alpha \phi^* \left(\tfrac{L^*}{K^*}\right)^{1-\alpha} \tag{4.71}$$

$$-\varphi_1 + \beta R_A^* = \tfrac{1-\alpha}{1-\beta(1-\delta)} \beta^2 \phi^* \left(\tfrac{L^*}{K^*}\right)^{\alpha} \tag{4.72}$$

$$1 = \tfrac{\theta_\pi}{\theta_\pi - 1} \phi^* \left(\alpha + (1-\alpha) \tfrac{\beta^2}{1-\beta(1-\delta)} \tfrac{s_2^*}{K^*}\right) \tag{4.73}$$

$$y^* = R_N^* w^* L^* + R_A^* s_2^* \tag{4.74}$$

where ϕ^* denotes the steady state real marginal cost. Since $\bar{P}_t = P_t$ in the steady state, $\bar{y}^* = y^*$ is used in (4.69) and (4.74).

The steady state aggregate resource constraint becomes

$$c^* + s_2^* = y^* \tag{4.75}$$

because $\varphi_1 + \varphi_2 = 1$ and $s_{1,t} = s_{2,t}$ in the steady state.

4.2.3 Linearization of the Model

The log-linearized values around their steady state values are applied for the linear approximation expression. The symbol '^' denotes a small deviation from the steady state value. The linearizing expression for equations (4.54) to (4.67) becomes

$$b_1 \hat{L}_t - b_2 \hat{U}_{c,t} + b_3 \hat{w}_t + b_4 \hat{w}_{t-1} + b_5 E_t \hat{w}_{t+1} + b_6 \hat{\pi}_t + b_4 \hat{\pi}_{t-1} + b_5 E_t \hat{\pi}_{t+1} = 0 \tag{4.76}$$

$$\hat{U}_{c,t} + \hat{q}_{1,t} = E_t \hat{U}_{c,t+1} - E_t \hat{\pi}_{t+1} \tag{4.77}$$

$$\hat{U}_{c,t} + \tfrac{1}{1+\varepsilon} \hat{\varepsilon}_t + \hat{q}_{2,t} = E_t \hat{U}_{c,t+2} - E_t \hat{\pi}_{t+1} - E_t \hat{\pi}_{t+2} \tag{4.78}$$

$$\hat{U}_{c,t} = c_1 \hat{\nu}_t + c_2 \hat{c}_{t-2} + c_3 \hat{c}_{t-1} + c_4 \hat{c}_t + c_5 E_t \hat{c}_{t+1} + c_6 E_t \hat{c}_{t+2} \tag{4.79}$$

$$\hat{\nu}_t = \rho_\nu \hat{\nu}_{t-1} + \epsilon_{\nu,t} \tag{4.80}$$

$$\hat{\lambda}_t = E_t \hat{U}_{c,t+1} - E_t \hat{\pi}_{t+1} \tag{4.81}$$

$$y^* \hat{y}_t = L^{*\alpha} K^{*1-\alpha} (\hat{\xi}_t + \alpha \hat{L}_t + (1-\alpha)\hat{K}_t) \tag{4.82}$$

$$\hat{K}_{t+2} = (1-\delta)\hat{K}_{t+1} + \delta \hat{s}_{2,t} \tag{4.83}$$

$$\hat{\xi}_t = \rho_\xi \hat{\xi}_{t-1} + \epsilon_{\xi,t} \tag{4.84}$$

$$\hat{\phi}_t = -\hat{\xi}_t - \hat{q}_{1,t} + \hat{w}_t + (1-\alpha)\hat{L}_t - (1-\alpha)\hat{K}_t \tag{4.85}$$

$$\begin{aligned} d_1 \hat{\lambda}_t + d_2 E_t \hat{\lambda}_{t+1} + d_3 E_t \hat{\lambda}_{t+2} = d_4 E_t \hat{\pi}_{t+1} + d_5 E_t \hat{\pi}_{t+2} \\ + d_6 E_t \left(\hat{\phi}_{t+2} + \rho_\xi^2 \hat{\xi}_t + \alpha(\hat{L}_{t+2} - \hat{K}_{t+2}) \right) + d_7 \hat{R}_{A,t} + d_8 E_t \hat{R}_{A,t+1} \end{aligned} \tag{4.86}$$

$$\begin{aligned} a_1 \hat{\pi}_t + a_2 \hat{\pi}_{t-1} + a_3 E_t \hat{\pi}_{t+1} + a_4 E_t \hat{\pi}_{t+2} \\ = a_5 \hat{s}_{2,t} + a_6 E_t \hat{2}_{2,t+1} + a_7 \hat{K}_{t+2} + a_8 \hat{\phi}_t + a_9 \left(\hat{\lambda}_t + \hat{y}_t \right) \\ + a_{10} E_t \hat{\phi}_{t+1} + a_{11} E_t \left(\hat{\lambda}_{t+1} + \hat{y}_{t+1} \right) + a_{12} E_t \left(\hat{\lambda}_{t+2} + \hat{\phi}_{t+2} + \hat{y}_{t+2} \right) \end{aligned} \tag{4.87}$$

$$c^* \hat{c}_t + \varphi_1 s_2^* \hat{s}_{2,t-1} + \varphi_2 s_2^* \hat{s}_{2,t} = y^* \hat{y}_t \tag{4.88}$$

$$-\hat{q}_{1,t} = h_1 E_t \hat{\pi}_{t+1} + h_2 \hat{y}_t + h_3 \hat{\pi}_t^w - \rho_g \hat{q}_{1,t-1} + \epsilon_{g,t} \tag{4.89}$$

where appropriate parameters are used for a_j, b_j, c_j and d_j. $\hat{\lambda}_t$ denotes the small deviation of the marginal utility of P_t units of currency from its steady state, and is from $\lambda_t = \Lambda_t P_t$.

One thing should be noted regarding (4.76), (4.82), (4.85), (4.86), and (4.88). Rewrite the Calvo-type price evolution equation (4.35) using $\bar{q}_t = \frac{\bar{P}_t}{P_t}$:

$$\bar{q}_t^{-\theta_\pi} = (1-\omega_\pi) q_t^{-\theta_\pi} + \omega_\pi \pi_{t-1}^{-\theta_\pi} \bar{q}_t^{-\theta_\pi} \pi_t^{\theta_\pi} \tag{4.90}$$

where $q_t = \frac{P_t^*}{P_t}$. The linearized expression for (4.90) will be reduced to

$$\hat{\bar{q}}_t = \omega_\pi \hat{\bar{q}}_{t-1} \tag{4.91}$$

Equation (4.91) implies that, when we start from the steady state, then $\hat{\bar{q}}_t = 0$ for all t (CEE).

With the same logic, the linearized form of the Calvo-type wage evolution equation will be reduced to

$$\hat{\bar{w}}_t = \omega_n \hat{\bar{w}}_{t-1} \tag{4.92}$$

where $\bar{w}_t = \frac{\bar{W}_t}{W_t} = \frac{\tilde{\bar{w}}_t}{w_t}$ and $\tilde{\bar{w}}_t = \frac{\bar{W}_t}{P_t}$ implying $\hat{\bar{w}}_t = 0$ for all t if we assume $\hat{\bar{w}}_0 = 0$. Therefore, $\hat{\bar{w}}_t = \hat{w}_t$.

Since $\hat{\bar{y}}_t = -\theta_\pi \hat{\bar{q}}_t + \hat{y}_t$, $\hat{L}_t = -\theta_n \hat{\bar{w}}_t + \hat{N}_t$, $y^* = \bar{y}^*$, and $L^* = N^*$, I drop $\hat{\bar{q}}_t$ and $\hat{\bar{w}}_t$, and replace $\hat{\bar{y}}_t$ with $\hat{y}_t$, and $\hat{N}_t$ with $\hat{L}_t$ conveniently in (4.76), (4.82), (4.85), (4.86), and (4.88) by assuming $\hat{\bar{q}}_0 = 0$ and $\hat{\bar{w}}_0 = 0$.

4.2.4 The Solution Algorithm

After log-linearizing the structural equations, the model is solved with Klein's (2000) algorithm. Let X_t^M denote a vector of endogenous variables. The linear rational expectations model is expressed with the linear difference system,

$$AE_t X_{t+1}^M = BX_t^M + Cz_t$$

where $z_t = (\epsilon_{\xi,t}, \epsilon_{\nu,t}, \varepsilon_t, \epsilon_{g,t})'$ is a vector of exogenous variables and A, B, and C are matrices of coefficients with the dimensions of 33×33, 33×33, and 33×4 respectively. Let k_t and d_t denote a pre-determined variable vector and forward-looking variable vector, respectively. Then, the endogenous variable vector can be decomposed with

$$x_t = \begin{bmatrix} k_t \\ d_t \end{bmatrix}$$

.

By applying Klein's (2000) solution, the pre-determined variable vector and forward looking variable vector will be given by

$$d_t = Fk_t + Nz_t$$

$$k_{t+1} = Rk_t + Lz_t$$

In order to have a unique solution, the model has to satisfy following conditions: (i) the number of stable eigenvalues of matrix pair (A,B)= the number of pre-determined variables ($n_s = n_k$), (ii) there is no complex number z with $|z| = 1$ and $|Az - B| = 0$, (iii) there exists a complex number z such that $|Az - B| \neq 0$, and (iv) Z11 is invertible where the generalized Schür form is given by $QAZ = S$ and $QBZ = T$, and Z11 is the upper left-hand $n_s \times n_k$ block of Z.

4.3 Policy Simulation

4.3.1 Calibration

Parameter values are chosen to closely follow the equilibrium real-business-cycle literature. The value of labor share α in the Cobb-Douglas production technology is set to be 0.64. β is set to be $1.03^{-1/4}$, implying a 3% annual rate of interest in the steady state. The parameter value of η is set to be 0.5, which implies that the wage elasticity of labor supply is 2. This value is greater than 1, which is used by Jung (2004) and CEE (2005), but smaller than 4 which Yun (1996) adopts.

The scale parameter ψ is set to imply that non-stochastic steady state employment is normalized to unity. This calibration results in $\psi = 0.1087$. I set the fixed cost $\bar{Y}$ so that profits are zero in steady state. The rate of depreciation δ is set to be 0.026, implying that the annual rate of depreciation becomes 0.1. The inverse of intertemporal elasticity of consumption is chosen to be 10.2 and the habit formation parameter ζ is set to be 0.8. Empirical estimations on habit formation by Fuhrer (2000) suggest relatively high values of σ and ζ. His GMM estimates result in 13.02 and 0.9 for σ and ζ, respectively. ρ_c, the weight on time $t-1$ consumption in the reference consumption level, Z_t, is set to be 0.6, which implies that households put more weight on time $t-1$ consumption than consumption further back in time.

I set $\varphi_1 = 0.7$. This fraction implies that the time-to-build technology requires more resources in physical construction of investment projects than in designing the projects. By comparing to Kydland and Prescott's (1982) general four-period time-to-build technology, this value might be the sum of fractions of resources allocated in investment projects 1 to 3 periods away from completion, φ_1, φ_2, and φ_3.

The price and wage stickiness parameters ω_π and ω_n are set to be 0.3. They are smaller than the 0.6 that is used in CEE (2005). But, according to the study by Bils et.al. (2003), the degree of price stickiness differs across consumption categories. The median duration of prices across the 350 categories is 4.3 months, which corresponds to $\omega_\pi = 0.3575$, and prices are more flexible for goods, whose duration is 3.2 months or $\omega_\pi = 0.27$, than for services (7.8 months). The price elasticity of demand for good i, θ_π, and the wage elasticity of demand for labor h, θ_n, are set to be 1.7 and 23, respectively. Those from CEE (2005) are 6 and 21, respectively.

Parameters in the interest rate smoothing rule are utilized as shown in the following equation.

$$\hat{i}_{1,t} = 0.56\hat{i}_{1,t-1} + 0.44(1.15E_t\hat{\pi}_{t+1} + 0.7\hat{y}_t + 0.03\hat{\pi}_t^w)$$

$a_\pi = 1.15$ is much smaller than the estimate of 2.15 by Clarida et al. (2000). But both numbers imply an active monetary policy fighting inflation by raising the nominal short-rate by more than the increase of inflation. Moreover, $(1-\rho_g)a_\pi = 0.5060$ of my model is greater than the 0.4515 in Clarida et al. (2000). As the estimation results by Amato and Laubach (2004) suggest, the relatively small but positive weight on wage inflation $a_w = 0.03$ is used. The parameter values and their description can be found in Table 4.1.

4.3.2 Impulse Responses to a Monetary Policy Shock in the Baseline Model

Figure 4.1 displays the IRFs of various macroeconomic aggregates in the baseline model. A contractionary monetary policy shock is given to generate an initial increase in the short rate of approximately 60 basis points, whose value corresponds to the empirical counterpart of the initial response of the federal funds rate in the previous chapter.

The results are qualitatively similar to the empirical responses shown in Figure 2.2 in that output shows a hump-shaped movement and inflation increases at first. Output drops by a maximum of 0.66% four quarters after the shock and inflation increases by a maximum of 0.77% three quarters after the shock. The response of inflation clearly reflects the dominance of the cost channel effect of monetary policy. Figure 4.2 compares the performance of two different measures of inflation. In the top panel, the dotted line represents inflation measured as the difference in log of price level at time t and $t-1$, and the solid line displays the difference in log of price level at time t and $t-4$ which is used in the empirical analysis. The bottom panel of the figure plots two different real short-term rates based on two different inflation definitions. The empirical counterpart inflation, $\hat{\pi}_{4t} = \hat{P}_t - \hat{P}_{t-4}$, shows more gradual increase and its maximum response is over 3%. The real short-term interest rate $\hat{r4}_{1,t}$ also shows a larger and more persistent response than $\hat{r}_{1,t}$. These results emphasize that the model's implications for inflation exceed the empirical response.

The initial response of the short rate to the monetary policy shock raises long rates in the direction that the expectations hypothesis of the term structure predicts. The initial increase in the two-period rate is 58 basis points. These increased interest rates push up the production cost and reduce labor demand and long-term investment projects. Those reduced factor inputs restrict current and future output, and the increased production cost raises inflation. The long rate shown in Figure 4.1 is the 5-year rate response which is implied by the model. That is, the first-step response of the 5-year rate is computed as the average of one- to 61-step responses of the one-period rate. A contractionary monetary policy raises the 5-year rate in the direction which the expectations hypothesis predicts.

In Figure 4.1, co-movements of real wages with output also imply that the cost channel effect is dominant in the model economy. The reduced labor demand from higher financing costs induces real wages to fall by a maximum of 0.29%. The increased nominal short rate due to the policy shock also changes the labor supply curve as shown in (4.14) for sticky wages or in (4.15) for flexible wages. The negative response of real interest rates to the policy shock (we will return to this subject later in this section) reduces the marginal utility of consumption. Hence, the labor supply curve shifts in, and the equilibrium amount of labor falls. Reduced real wages reflect the fact that the drop in labor demand caused by the cost channel is greater than the reduction of labor supply effected by the demand channel.

Note that while the increased short rate plays a dominant role in the initial movement of inflation, the persistence of the cost channel effect comes from the existence of time-to-build lags and the long-term loan market. The raised short rate from a contractionary monetary policy shock reduces labor input due to higher short-term borrowing cost. Hence output falls and inflation rises. The short-rate response to the initial policy shock also affects the long-term interest rate that, in turn, restricts the investment behavior of firms because of higher financing cost. The capital stock falls, too, with time lags which reflect the time-to-build technology. Hence, more expensive investment projects reduce future aggregate output and raise future inflation.

The upward response of consumption to a contractionary monetary policy shock needs more explanation. A standard demand channel theory of monetary policy transmission predicts consumption will respond in the same direction as output. In the cost channel dominant economy, a contractionary policy shock causes aggregate demand to fall through the following mechanism. Because of the higher financing cost of investment projects from a contractionary monetary policy shock, demand for $s_{2,t}$ falls. Due to the time-to-build lags, today's drop in investment projects decreases future output which, in turn, reduces future aggregate supply. Contrary to the reliance of investment projects on the nominal long rate, the response of consumption, which consists of aggregate demand together with investments, is related to the change of real interest rates defined as $\hat{r}_{1,t} = \hat{i}_{1,t} - E_t\hat{\pi}_{t+1}$. Since inflation rises more than the drop in nominal short rate, real interest rates fall and consumption increases. To be precise, when the investment projects are so sensitive with respect to the interest cost, the reduction of $s_{2,t}$ exceeds the amount of the drop in output caused by reduced labor input. Without the change of demand for consumption, the amount of the drop in aggregate demand is greater than the reduction of the aggregate output. Hence, the price level tends to fall. If the price reduction in the goods market is large enough to make the goods cheaper relative to reduced asset prices, households purchase more goods by rearranging their cash position Q_t, even though labor income shrinks. Therefore, the response of c_t to the monetary policy shock moves in the opposite direction of $s_{2,t}$.

The puzzling movement of consumption can be mitigated by increasing the value of the habit formation parameter ζ. When ζ converges to one, the current utility depends more on the consumption habit. In this case, the contractionary monetary policy shock reduces the size of current consumption and increases expected future reference levels of consumption in order to smooth consumption more across time. In the limiting case, the real interest rate only gives us long run directional information on the consumption response. The solid lines with dots in Figure 4.3 clearly show that, when only consumption relative to previous consumption matters, the consumption moves downward along the real interest rate. In this case, the maximum point of consumption is 0.001% one quarter after the policy shock, which corresponds to a maximum increase of 0.09% from its steady state in the baseline model four quarters after the shock, and to a maximum increase of 0.12% in no-habit formation ($\zeta = 0$) one quarter after the shock. The only difference between $\zeta = 0$ and $\zeta = 1$ is the consumption response. It does not affect the behavior of other variables at all.

In summary, a contractionary monetary policy shock increases the financing cost of labor, which induces the downward response of output. Through the term structure of interest rates, the monetary policy shock also affects agents' expectations on future short-rate paths and, therefore, long rates. Increased long rates reduce the demand for long-term investment projects by increasing financing cost, which then reduces future output. A goods price which has become cheaper relative to bond prices causes households to purchase more goods. The amount of net response in aggregate demand together with the amount of the response in aggregate supply determines the dominance of the monetary policy transmission channel. Since overall aggregate demand response, the sum of $\hat{s}_{2,t}$ and $\hat{c}_t$ responses, to the contractionary monetary policy shock is smaller than the reduction of aggregate supply caused by reduced labor input, the output level falls and inflation rises.

The results of the cost channel effect in the model are based on the monopolistically competitive output and labor markets and frictionless financial market assumption. My model leads to the same conclusion as that reported by Chevalier and Scharfstein

(1996). They showed that the output price moves in the counter-cyclical direction and real wages co-move with output under the monopolistically competitive output market and the imperfect capital market assumption. My model contains the imperfection in the asset market rather than in the loan market. But the asset market imperfection does not change the response of aggregate variables because agents consider the shock from the asset market to be a temporary shock (white noise shock). Moreover, the only way that the asset market shock can influence the economy is through the cost channel by raising long-term financing cost in the production sector. But the asset market shock is blocked from being transferred to other sectors, in particular, to the loan market. That is, the positive asset market shock immediately reduces the long-term bond price by the exact same amount of shock, and the long-term bond price returns to the pre-shock level at the very next period. Hence it does not change the agents' expectations as shown in the equation below, which states the term structure of interest rates driven by (4.77) and (4.78).

$$\frac{1}{1+\varepsilon}\hat{\varepsilon}_t + \hat{q}_{2,t} = \hat{q}_{1,t} + E_t\hat{q}_{1,t+1}$$

This reflects the fact that the current and expected future short-rate movements and the asset market shock affect current long rates, but the inverse is not true.[8] By combining (4.42) with the above term structure equation, we obtain the equation for the return on long-term loans which is the sum of current and expected future short-term bond prices.

$$\hat{R}_{A,t} \quad = -\hat{q}_{1,t} - E_t\hat{q}_{1,t+1} \tag{4.93}$$

[8]When ε_t is assumed to have AR(1) process, the asset market shock has an effect on the whole economy. That is, when the positive persistent asset market shock is detected, the market raises current short-term bond prices and expects the short-term bond price to increase in the future.

Since the term structure shock does not disturb current short-term bond price or agents' expectations, the asset market shock has no effect on the whole economy.

4.3.3 Role of Loan Markets

The loan markets play a crucial role in generating the cost channel effect. Without the loan markets, firms are assumed to use the sales revenue to cover factor costs and investment project costs. Therefore, the marginal cost is not a function of nominal interest rates. Hence there is no direct effect of monetary policy on the production sector. Households purchase short- and long-term bonds from financial intermediaries as in the baseline model. The central bank participates in the short-term bond market. Before purchasing bonds, households are assumed to resell pre-matured long-term bonds to financial intermediaries. After observing the shock, households rebalance their portfolios by purchasing short- and long-term bonds from financial intermediaries. If a long-term loan market exists, the optimality condition in the loan market connects the long-term asset prices to the returns on long-term loan contracts, which is a function of marginal costs of investment projects. Therefore, without a long-term loan market, the price change of long-term bonds does not affect other macro variables.

Figure 4.4 displays the IRFs for a version of a model which does not have loan markets. I set the fraction of resources allocated in $s_{1,t}$ as $\varphi_1 = 0.504$[9] and hold other parameters at the same values as in the baseline model. As shown in the third and fourth rows of the first column in the figure, the downward response of inflation and the upward response of real wages to the contractionary monetary policy shock imply that the demand channel prevails in the economy. The initial and maximum fall of inflation is 0.24%, and real wages rise by 0.16% initially. Given the unchanged price level, the contractionary monetary policy shock increases interest rates. Since the consumption

[9] The baseline model is stable when $0.503 \leq \varphi_1 \leq 0.829$, and the results are robust for the change of φ_1.

goods becomes more expensive than bonds, households reduce consumption. Because of the reduction of aggregate demand, production levels also fall by using less labor and capital. The reduced investment projects shift the aggregate demand more to the left. Hence, the price level drops as a result of the contractionary monetary policy shock. Households also reduce labor supply for every level of real wages. Since the decrease in labor supply caused by the demand-side effect is stronger than the drop in labor demand caused by the cost-side effect, real wages rise and equilibrium employment shrinks.

Despite sticky prices and wages, and the time-to-build technology, when firms cannot access loan markets, only interest rates and consumption show staggered responses. Macro variables such as output and inflation are less persistent than those of the baseline model. These results emphasize the role of long-term interest rates and the long-term loan market in generating persistent responses.

4.3.4 Sticky Prices and Wages

In this section, I examine the role of sticky prices and wages. Figure 4.5 displays the IRFs with three different restrictions. The solid lines represent the IRFs from the baseline model, the dashed lines represent the IRFs from the flexible price model in which I impose $\omega_\pi = 0$, the solid lines with dots are the IRFs from the flexible wage model in which the restriction $\omega_n = 0$ is given, and the solid lines with diamonds display the flexible price and wage model in which I set $\omega_\pi = \omega_n = 0$. In each model, I hold the other parameter values unchanged as in the baseline model.

In the flexible price model, the responses of the variables do not show substantial differences from the baseline model. The major influence of the restriction is that it slightly exaggerates the rise in inflation and drop in input factors such as labor and investment projects. The decreased inflation reduces real wages slightly more than in the baseline model. But all variables continue to show that the cost channel is the dominant monetary policy transmission channel. They also display substantial staggered behaviors even though flexible prices are assumed.

The wage stickiness assumption has two major impacts on the economy. Sticky wages increase the persistency of responses in the sense that the variables' maximal impact arrives several quarters after the shock. When nominal wage rigidity is assumed, the reduction in output takes four quarters after the shock to reach its maximal drop of 0.65%, compared to two quarters after the shock in flexible wages. Inflation in the wage stickiness model reaches its maximum rise of 0.77% three quarters after the shock, compared to one quarter after the shock in flexible wages. Capital takes nine quarters to reach a maximum drop of 0.13% from its steady state value in the flexible wage model, whereas twelve quarters are required to reach a maximal fall of 0.18% in the baseline model. Labor takes nine quarters to reach the pre-shock level in the flexible wage model, but it requires twelve quarters to recover its pre-shock level in the baseline model. Nominal wage rigidity is an important factor in driving real wages in the direction that the cost channel effect implies. The positive movement of real wages in the flexible wage assumption indicates that the contractionary monetary policy shock raises the nominal wage beyond the amount of the price increase.

The only difference between the flexible price and wage model and the flexible wage model is the magnitude of the response of inflation. Persistent responses relative to the flexible wage model are not detected across all variables. But, even if we do not impose the sticky price and wage assumption, the responses of variables take some time to recover the original level. This result implies that the time-to-build technology and long-term financing contracts are critical factors in generating the staggered responses. For example, the negative response of output to a contractionary monetary policy shock takes almost twelve quarters to return to its pre-shock level in all models. As in the flexible wage but sticky price model, real wages in the flexible price and wage model move in the opposite direction to the output response. This indicates that sticky wages ensure that real wages respond in the direction that the cost channel effect of the monetary policy predicts.

4.3.5 Technology Shock and Preference Shock

This section examines the impact of two macroeconomic shocks on the model economy. The main purpose of this section is to investigate whether my model can generate results similar to those in previous studies. The one-standard deviation of technology and preference shocks are given.

Figure 4.6 displays the impulse response functions to a technology shock. A positive technology shock raises output and investment, reduces inflation, and increases interest rates two periods after the shock. The output response comes from an increase in the current marginal productivity of labor, $Y_{N,t}$, and future marginal productivity of capital, $Y_{K,t+i}, i > 2$, as shown in (4.31) and (4.32). The increase in investment projects reflects the fact that firms tend to launch more projects at time t to meet the increased future demand for capital. The initial response of the short rate is due exclusively to the reduced inflation induced by the shock. Monetary policy reduces the nominal short rate in response to the technology shock. The response of output, inflation and interest rates are qualitatively similar to the study by Galí, López-Salido, and Valles (2002, hereafter GLV) for the Volcker-Greenspan period.

A negative response of labor to a positive technology shock is observed in Figure 4.6. Sticky prices and habit formation play an important role in explaining the negative response of labor discussed belows. Standard real business cycle theory indicates that factor inputs should co-move with a technology shock. For example, GLV (2002) reported the insignificant but positive response of labor to a positive technology shock.

But recent studies regarding technology shocks as a source of economic fluctuation, such as Galí and Rabanal (2004), reported the negative response of labor to a positive technology shock. Their results are based on the DSGE model with price and wage stickiness together with habit formation, which is the same as in my model. They reported that output and nominal interest rate rise but inflation falls, and labor moves down first. As Galí and Rabanal (2004) argued, the presence of nominal frictions could generate the negative response of labor to the positive technology shock. For example, when prices are not fully flexible, the increase in aggregate demand cannot compensate for the increase in *ex ante* aggregate output from the positive technology shock. Hence, the equilibrium output is produced at the aggregate demand level, which requires less labor input than the pre-shock level of labor input. More precisely, a technology shock increases output capacity. Given unchanged labor input, firms can produce more output. Therefore, the aggregate supply curve moves out. If price is fixed at the pre-shock level, it generates excess supply in the goods market at that price level. So, firms produce output only to aggregate demand level, given the price level, even if they are able to produce more with the new production capacity. Therefore, firms have to reduce labor input in order to produce the previous output level along the increased output capacity.

There are, however, alternative interpretations of the negative response of labor to a technology shock, such as that of Francis and Ramey (2005). They showed that habit formation in consumption combined with adjustment costs in investment can generate the negative impact of technology on labor input even if the flexible price assumption is adopted. They argued that households prefer to smooth their consumption across time when a positive technology shock is given, and the extra resources are spent on leisure.

A positive technology shock raises real wages because prices are not fully fixed at the pre-shock level. Also, the downward response of labor to a technology shock beyond two periods comes from the cost channel.[10] The short rate response two periods after the shock is close to zero, which implies that the effect of the short rate on the firms' labor decisions is small. But positive short-rate responses beyond three periods after the shock cause firms to use less labor input because of higher interest cost together with higher wage cost. That is, the higher output as a result of the technology shock raises the short-term interest rate through the monetary policy action, and the increased financing cost reduces labor demand. This interpretation of the response of labor to the technology shock is no different from the argument by GLV (2002) that the monetary policy action plays an important role for the transmission of technology shocks.

Figure 4.7 shows the impulse response functions to a positive preference shock. The exogenous positive preference shock stimulates consumption directly by increasing money holdings, Q_t, at the sacrifice of the demand for assets. This, in turn, results in the rise of nominal interest rates. The increased consumption expenditure drives firms to produce more goods by increasing labor input. The change of capital stock arrives two periods after the preference shock because of the time-to-build technology. In contrast to the response of labor, which can be fully explained by the direct effect of demand shock, the decrease in investment projects is due to the increased financing cost.

Even if factor inputs are used in the same production process, their responses to shocks are totally different. In the case of preference shock, the response of labor relies mainly on the demand factor, but the cost channel is more important for the movement of capital. The positive movement of inflation reflects the fact that the demand-side effect is dominant when the preference shock is observed. The impulse responses of output, inflation, and interest rates in Figure 4.7 are directionally the same as those of

[10]Because of the negative co-movements of output and inflation for the first few periods, the response of the short rate as a policy instrument remains around zero.

Evans and Marshall (2002).

4.3.6 Response of the Yield Curve

This section investigates the effect of macro variables on the yield curve and compares their results to the empirical counterparts. Since my DSGE model has only one- and two-period maturity bonds, we can observe only limited results on the yield curve response to macroeconomic shocks. But, even if it has only two different maturity yields, the model gives us enough information on the direction of the yield curve response.

The first row of Figure 4.8 depicts the impulse response functions of the yield curve to a contractionary monetary policy shock in the VAR with quarterly data. The short rate is measured as the federal funds rate and the 5-year rate is used as a long rate. The second to fourth rows in the figure display the model-based impulse response functions of the yield curve to three macroeconomic shocks, respectively: policy shock, technology shock, and preference shock. The level of the yield curve response is calculated as the average of 1- and 20-period (5-year) interest rate responses. The slope of the yield curve response is measured as the long-term interest rate minus short-term interest rate responses. The response of a 20-period rate is calculated from the expectations hypothesis, which is implied by the model.

Empirical results in the first row show that the monetary policy shock raises the level and flattens the slope when the yield curve has positive slope. These results imply that the monetary policy shock affects the long rates in the direction that the expectations hypothesis of the term structure of interest rates predicts. This result is also found in many studies, such as Edelberg and Marshall (1996) and Evans and Marshall (2002).

The model generates the positive response of the level of the yield curve to a contractionary monetary policy shock, as shown in the second row of the figure, and the response of the slope decreases. These results are similar to their empirical counterparts in the previous chapter, which are shown in the first row of Figure 4.8. But the model predicts more persistent response of the slope than the empirical result, which implies that the long-rate response is very small relative to the short-rate response in the model, compared to the empirical long-rate response.

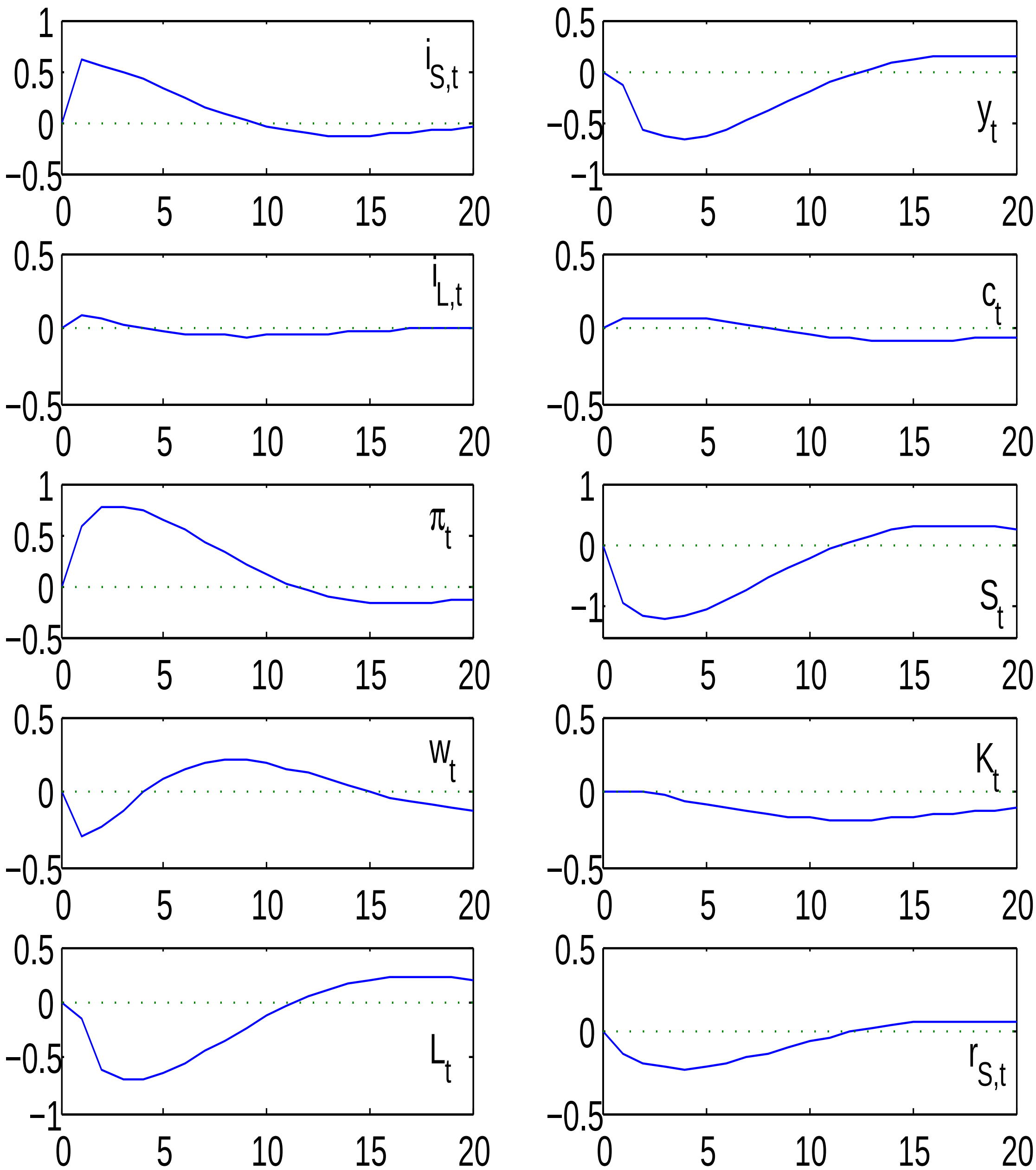
The third row in the figure displays the impulse response functions of the level and slope of the yield to a one standard deviation positive technology shock. The shock raises both the level and slope of the yield curve. The positive response of the slope implies that the technology shock causes the market's expectations of interest rates to rise. That is, market participants expect that the increased output will cause the central bank to raise the short rate to stabilize the output gap. The slope response to the technology shock is similar to the results of Evans and Marshall (2002) with a full information identification strategy.

The impulse response of the level and slope of the yield curve to a one standard deviation preference shock is displayed in the fourth row of Figure 4.8. The positive preference shock raises the level of the yield curve. Both the initial inflation and output responses cause the policy authority to raise the short rate, resulting in the positive response of the level of the yield curve. The negative response of the slope to the preference shock is observed. Even though my model adopts the expectations hypothesis of the term structure, the result of the slope response is the same as Evans and Marshall's (2002) study, in which they relied on the role of the term premium to explain the prolonged negative response of the slope.

Table 4.1: Calibrated parameters

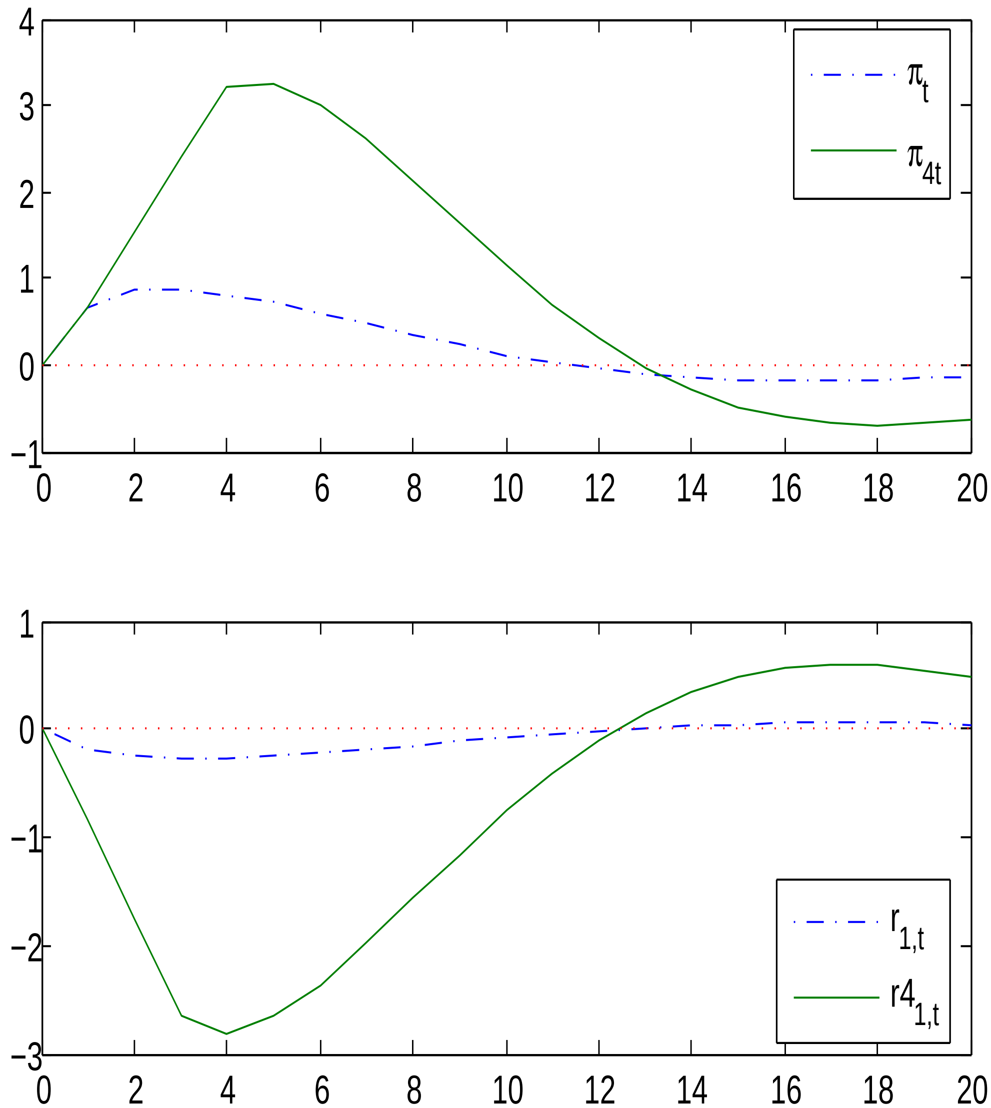
Parameters	Values	Descriptions
β	$1.03^{-1/4}$	Time discount factor
η	0.5	Inverse of wage elasticity of labor supply
α	0.64	Steady state labor share
δ	0.026	Rate of depreciation of capital stock
ψ	0.1087	Scale parameter in the utility function
σ	10.2	Inverse of intertemporal elasticity of consumption
ζ	0.8	Habit persistence
ρ_c	0.6	Weight on the last consumption in the habit formation
φ_1	0.7	Fraction of resource in the 1st stage projects
φ_2	0.3	Fraction of resource in the 2nd stage projects
ρ_ξ	0.96	AR(1) coefficient of technology shock
ρ_ν	0.7	AR(1) coefficient of preference shock
ρ_g	0.56	Interest rate smoothing parameter
a_π	1.15	Coefficient of inflation in the policy rule
a_y	0.7	Coefficient of output gap in the policy rule
a_w	0.03	Coefficient of wage inflation in the policy rule
ω_π	0.3	Probability of firm i re-optimizing the price
ω_n	0.3	Probability of household h re-optimizing the wage
θ_π	1.7	Price elasticity of demand for good i
θ_n	23	Wage elasticity of demand for labor h

Figure 4.1: Impulse responses to monetary policy shock: Baseline model



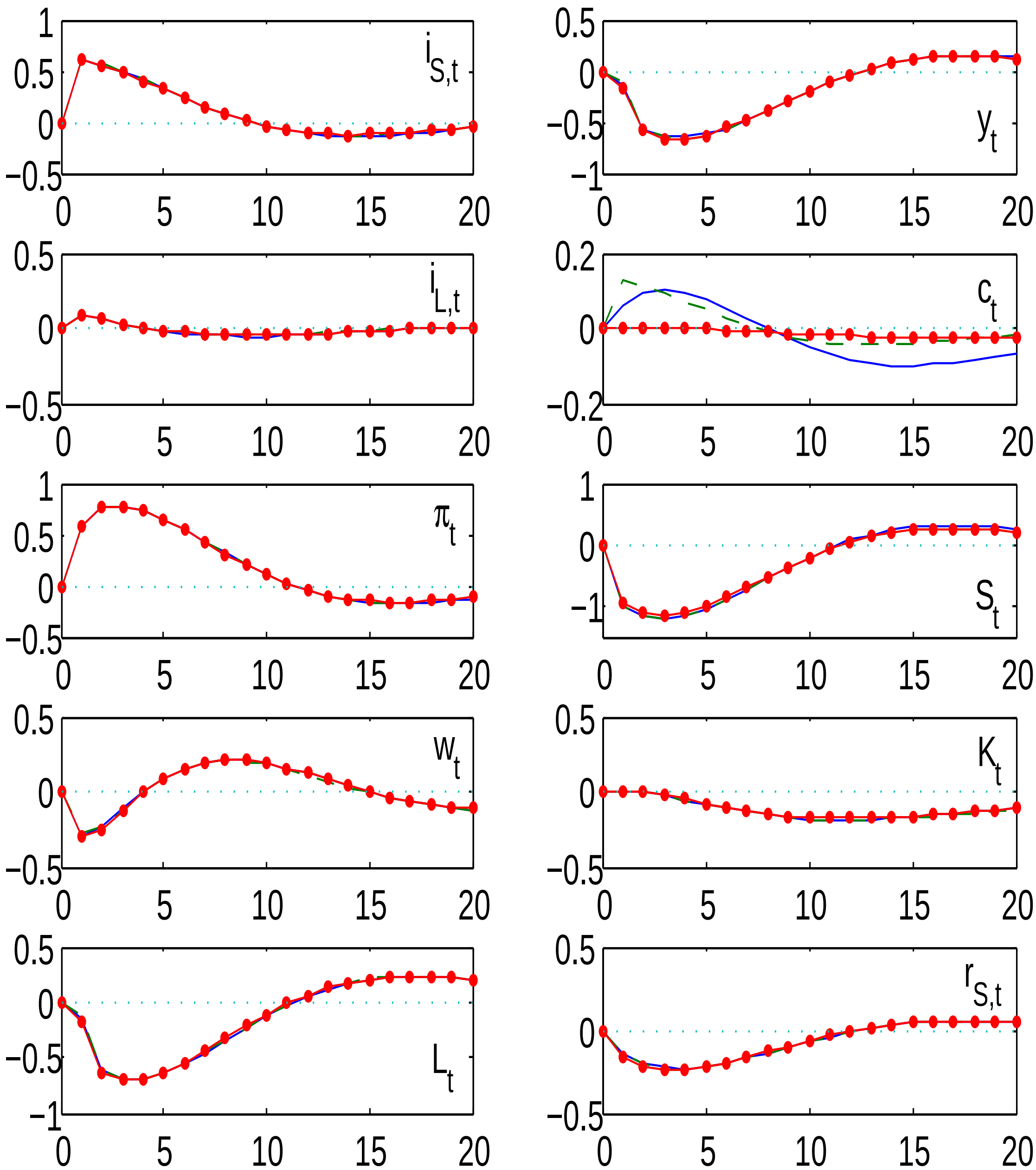
A contractionary monetary policy shock which generates 60 basis points' initial rise in the short rate is given. $i_{S,t}$, $i_{L,t}$, π_t, w_t, L_t, y_t, c_t, S_t, K_t, and $r_{S,t}$ represent short rate, long rate, inflation, real wages, labor, output, consumption, investment projects, capital, and real short rate, respectively. The baseline model contains sticky prices and wages, and habit formation. The 5-year rate impulse response, $i_{L,t}$, is calculated from the expectations hypothesis, which is implied in the model.

Figure 4.2: Two different inflation performances



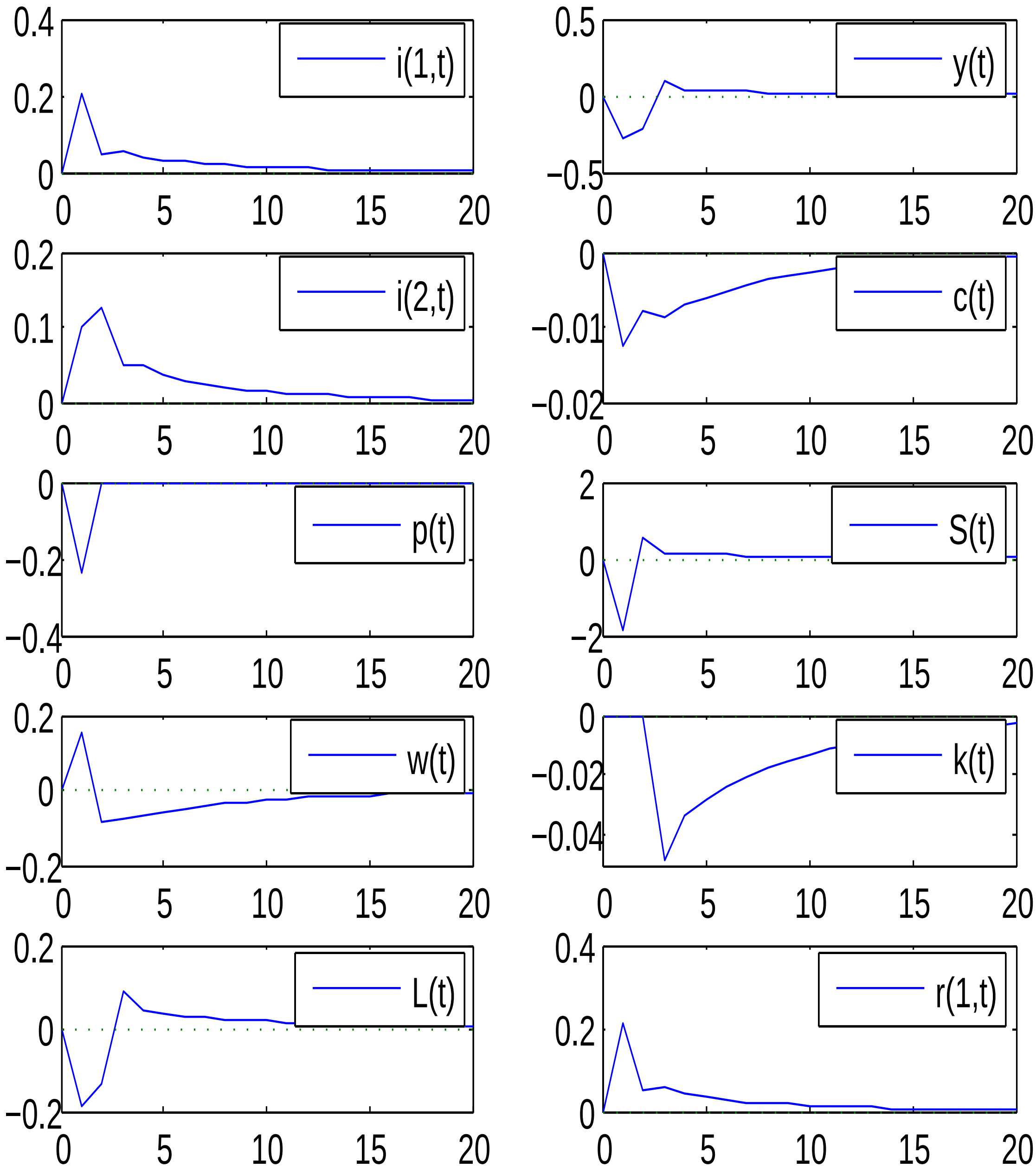
In the top panel, the dash-dotted line represents the inflation measured as $\hat{\pi}_t = \hat{P}_t - \hat{P}_{t-1}$, and the solid line displays $\hat{\pi}_{4t} = \hat{P}_t - \hat{P}_{t-4}$, which is used in the empirical analysis. The dash-dotted line in the bottom panel represents the real short rate defined as $\hat{r}_{1,t} = \hat{i}_{1,t} - \hat{\pi}_{t+1}$, and the solid line is defined as $\hat{r4}_{1,t} = \hat{i}_{1,t} - \hat{\pi}_{4t+1}$.

Figure 4.3: Limiting case of habit formation: $\zeta = 0$ vs. $\zeta = 1$



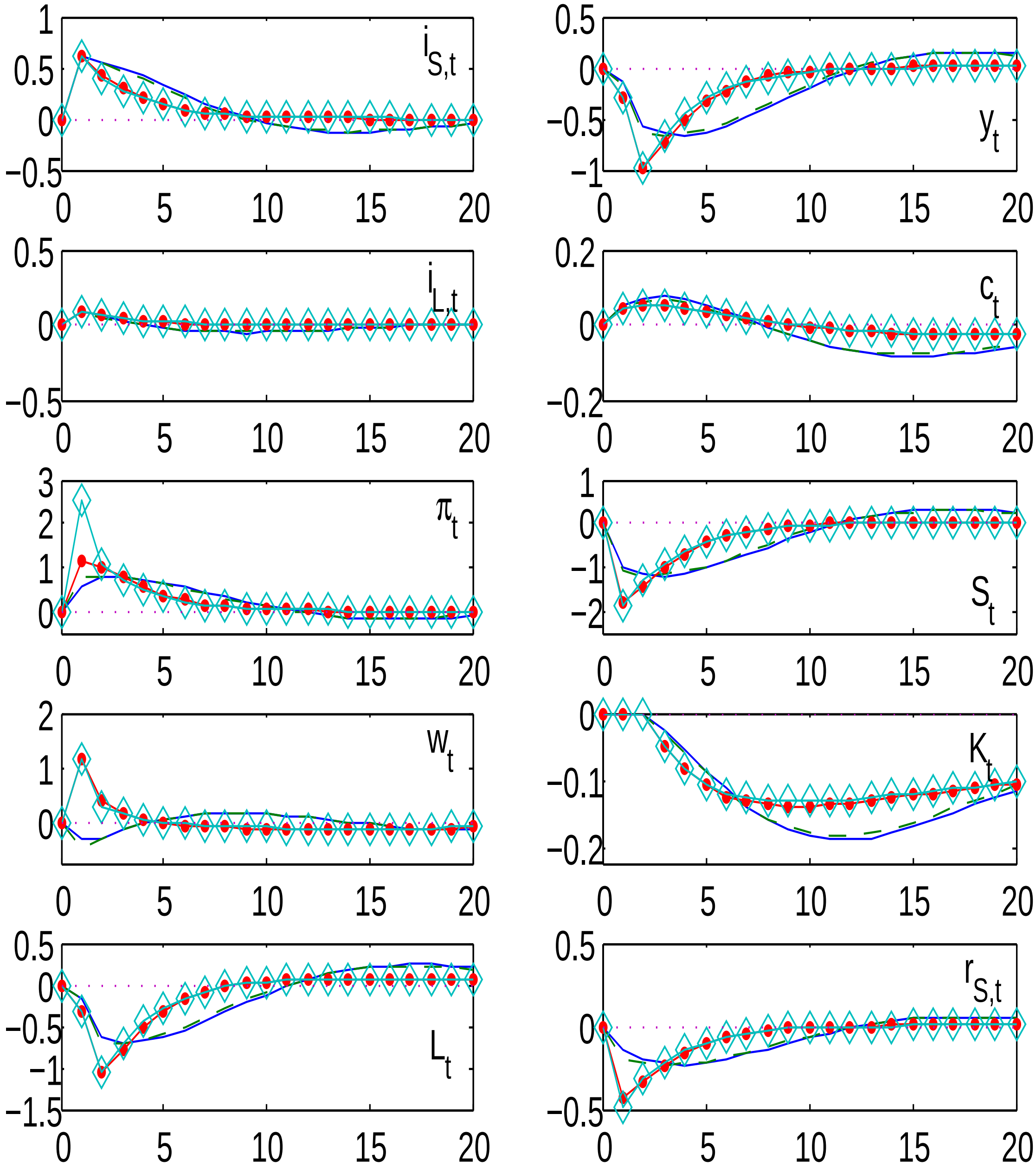
A contractionary monetary policy shock which generates 60 basis points; initial rise in the short rate is given. $i_{S,t}$, $i_{L,t}$, π_t, w_t, L_t, y_t, c_t, S_t, K_t, and $r_{S,t}$ represent short rate, long rate, inflation, real wages, labor, output, consumption, investment projects, capital, and real short rate, respectively. The solid lines represent the impulse response functions of the baseline model. The solid lines with dots plot the impulse response functions when $\zeta = 1$. The dashed lines depict the impulse response functions when $\zeta = 0$.

Figure 4.4: Without loan markets



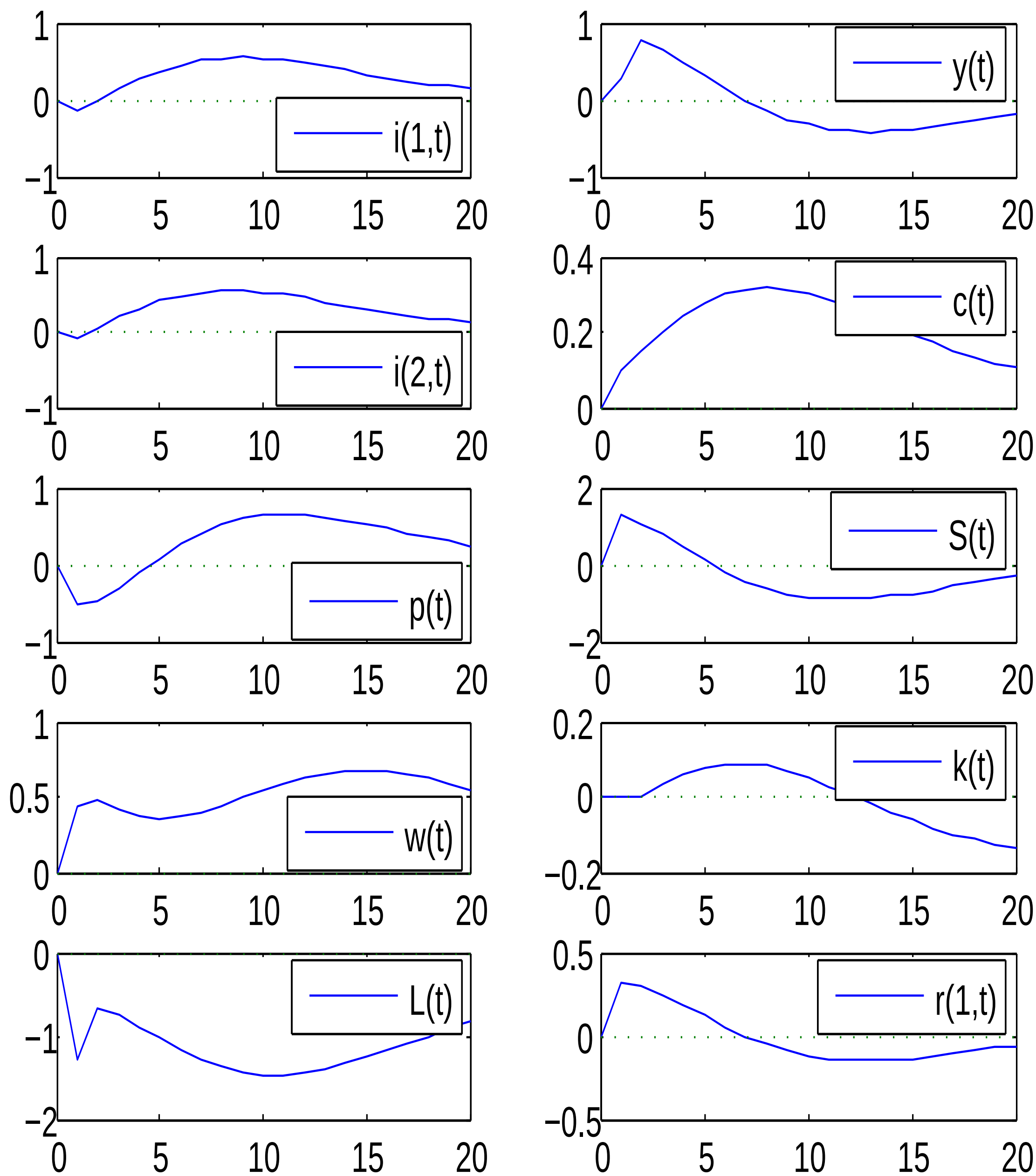
Firms are assumed not to use loan markets. $\varphi_1 = 0.504$ is used. A contractionary monetary policy shock which generates 60 basis points' initial rise in the short rate is given. $i(1,t)$, $i(2,t)$, $p(t)$, $w(t)$, $L(t)$, $y(t)$, $c(t)$, $S(t)$, $K(t)$, and $r(1,t)$ represent one-period rate, two-period rate, inflation, real wages, labor, output, consumption, investment projects, capital, and one-period real rate, respectively.

Figure 4.5: Without nominal rigidities



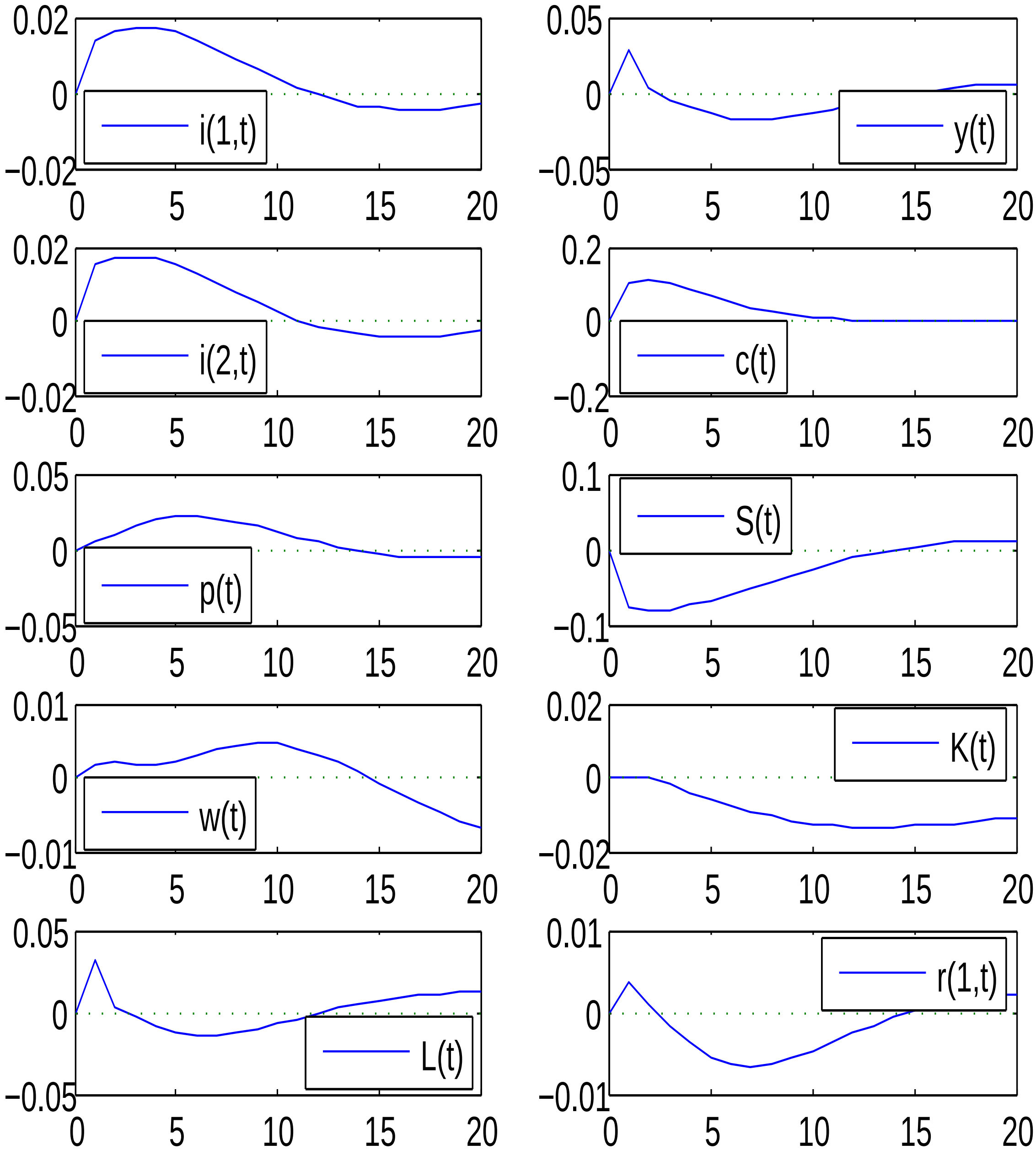
$i_{S,t}$, $i_{L,t}$, π_t, w_t, L_t, y_t, c_t, S_t, K_t, and $r_{S,t}$ represent short rate, long rate, inflation, real wages, labor, output, consumption, investment projects, capital, and real short rate, respectively. The solid lines represent the baseline model, the dashed lines represent the flexible price model set by $\omega_\pi = 0$, the solid lines with dots represent the flexible wage model set by $\omega_n = 0$, and the solid lines with diamonds are the flexible price and wage model set by $\omega_\pi = \omega_n = 0$. Contractionary monetary policy shocks which generate an initial rise of 60 basis points in the short rate are given.

Figure 4.6: Technology shock: $\hat{\xi}_t = \rho_\xi \hat{\xi}_{t-1} + \epsilon_{\xi,t}$



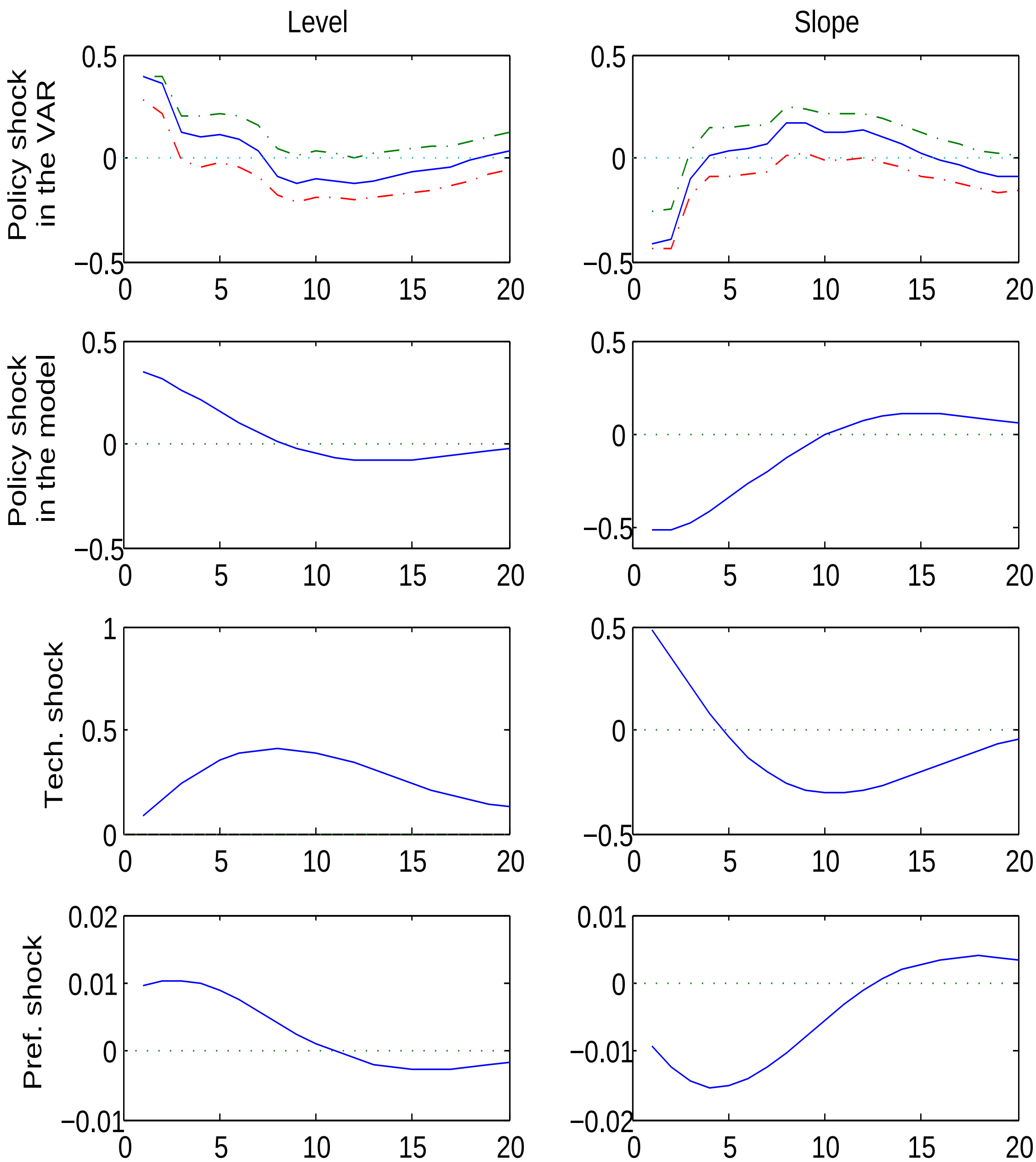
$i(1,t)$, $i(2,t)$, $p(t)$, $w(t)$, $L(t)$, $y(t)$, $c(t)$, $S(t)$, $K(t)$, and $r(1,t)$ represent one-period rate, two-period rate, inflation, real wage, labor, output, consumption, investment projects, capital, and one-period real rate, respectively. A one standard deviation positive technology shock ($\epsilon_{\xi,t}$) is given.

Figure 4.7: Preference shock: $\hat{\nu}_t = \rho_\nu \hat{\nu}_{t-1} + \epsilon_{\nu,t}$



$i(1,t)$, $i(2,t)$, $p(t)$, $w(t)$, $L(t)$, $y(t)$, $c(t)$, $S(t)$, $K(t)$, and $r(1,t)$ represent one-period rate, two-period rate, inflation, real wages, labor, output, consumption, investment projects, capital, and one-period real rate, respectively. A one standard deviation positive preference shock ($\epsilon_{\nu,t}$) is given.

Figure 4.8: Yield curve responses to the three macroeconomic shocks



The first row represents the response of the level and slope of the yield curve to the contractionary monetary policy shock from the U.S. data. Three-month averages of the federal funds rate and 5-year yields are used for short and long rates. The level is defined as $\frac{1}{2}(i_{1,t} + i_{n,t})$, and the slope is $i_{n,t} - i_{1,t}$. Dash-dotted lines display 95% confidence intervals in the first row. The second row represents the response of the yield curve to the monetary policy shock in the baseline model. The impulse response of the 5-year rate which is implied by the model is used for calculating the level and slope responses. The third and fourth rows represent the response of the yield curve to the technology shock and preference shock, respectively.

Chapter 5

Conclusion

This paper has built a DSGE model which generates the cost channel effect of monetary policy. In this model, the price movement influenced by the monetary policy shock no longer is a puzzling response but a natural movement when we take into account the cost channel as well as the demand channel. When the cost channel is dominant, counter-cyclical price movements and pro-cyclical real wage responses are observed.

The big difference of my model from previous cost channel-related studies is that the change of long rates has a direct effect on firms' decisions on long-term investments by changing firms' future marginal costs. This feature takes into consideration the fact in the general equilibrium framework that the change of macro variables such as investment or output has a closer relation to long rates than to short rates. In addition to financing labor cost in the short-term loan market, firms finance their long-term investment projects through the use of the long-term loan market. Hence, the change of long-term rates induced by the policy shock is translated to the higher long-term financing costs. It prolongs the time required for IRFs to recover from the shock. Moreover, without sticky prices and wages, the existence of time-to-build lags and of the multi-period financing contracts ensures that output and price responses are more persistent.

The term structure of interest rates plays a critical role as a policy transmission channel. The changes in short rates have an effect on firms' future economic activity through the term structure of interest rates. This implies that, contrary to previous studies on the term structure, long rates have a bilateral relationship with macro variables. The long rates are determined from the market's expectations on short rates, and the change of long rates, in turn, affects the future marginal cost of firms by changing financing costs.

Standard new Keynesian models put an emphasis on the existence of nominal rigidities to explain the persistence in the response of macro variables to the monetary policy shock. Despite the limited role of sticky prices in generating the persistent responses, sticky wages amplify the staggered responses and help explain the response of real wages observed in the data. My model also finds that, even if flexible prices and wages are assumed, the economy takes some time to return to its pre-shock levels. This is ascribed to the existence of time-to-build lags and long term loan markets. The policy shock changes current investment projects which will be used in the future production process because of the higher long-term borrowing cost to finance the projects.

Bibliography

Abel, Andrew B., "Dynamic behavior of capital accumulation in a cash-in-advance model," *Journal of Monetary Economics* Vol. 16-1, 55-71, 1985.

Amato, Jeffery D., Thomas Laubach, "Implications of habit formation for optimal monetary policy," *Journal of Monetary Economics* Vol. 51-2, 305-325, 2004.

Andrés, Javier, J. David López-Salido, Edward Nelson, "Tobin's imperfect asset substitution in optimizing general equilibrium," *Journal of Money, Credit, and Banking* Vol. 36-4, 665-690, 2004.

Ang, Andrew, Monika Piazzesi, "A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables," *Journal of Monetary Economics* Vol. 50-4, 745-787, 2003.

Ang, Andrew, Monika Piazzesi, Min Wei, "What does the yield curve tell us about GDP growth?" *NBER Working Paper* No. 10672. 2004.

Bagliano, Fabio C., Carlo A. Favero, "Measuring monetary policy with VAR models: An evaluation," *European Economic Review* Vol. 42-6, 1069-1112, 1998.

Barclay, Michael J., Clifford W. Smith. Jr., "The maturity structure of corporate debt," *Journal of Finance* Vol. 50-2, 609-631, 1995.

Barth, Marvin J., Valerie A. Ramey, "The cost channel of monetary transmission," *NBER Macroeconomics Annual* Vol. 16-1, 199-240, 2001.

Beechey, Meredith, "Excess sensitivity and volatility of long interest rates: The role of limited information in bond markets," *Sveriges Riksbank Working Paper Series* No. 173, 2004.

Benhabib, Jess, Stephanie Schmitt-Grohé, Martín Uribe, "Monetary policy and multiple equilibria," *American Economic Review* Vol. 91-1, 167-186, 2001.

Bils, Mark, Peter J. Klenow, Oleksiy Kryvtsov, "Sticky prices and monetary policy shocks," *Federal Reserve Bank of Minneapolis Quarterly Review* Vol. 27-1, 2-9, 2003.

Chevalier, Judith A., David S. Scharfstein, "Capital-market imperfections and counter-cyclical markups: Theory and evidence," *American Economic Review* Vol. 86-4, 703-725, 1996.

Choi, Jae-young, Ronald A. Ratti, "The predictive power of alternative indicators of monetary policy," *Journal of Macroeconomics* Vol. 22-4, 581-610, 2000.

Christiano, Lawrence J., Martin Eichenbaum, "Liquidity effects and the monetary transmission mechanism," *American Economic Review* Vol. 82-2, 346-353, 1992a.

Christiano, Lawrence J., Martin Eichenbaum, "Current real-business-cycle theories and aggregate labor-market fluctuations," *American Economic Review* Vol. 82-3, 430-450, 1992b.

Christiano, Lawrence J., Martin Eichenbaum, "Liquidity effects, monetary policy, and the business cycle," *Journal of Money, Credit and Banking* Vol. 27-4, Part 1, 1113-1136, 1995.

Christiano, Lawrence J., Martin Eichenbaum, Charles Evans, "The effects of monetary policy shocks: evidence from the flow of funds," *Review of Economics and Statistics* Vol. 78-1, 16-34, 1996.

________________________, "Sticky price and limited participation models of money: A comparison," *European Economic Review* Vol. 41-6, 1201-1249, 1997.

________________________, "Modeling money," *NBER Working Paper* No. 6371, 1998.

________________________, "Monetary policy shocks: What have we learned and to what end?" *Handbook of Macroeconomics* Vol. 1A, 65-148, 1999.

________________________, "Nominal rigidities and the dynamic effects of a shock to monetary policy," *Journal of Political Economy* Vol. 113-1, 1-45, 2005.

________________________, "Notes on a model with Calvo-sticky prices, wages and portfolios," *mimeo.*

Clarida, Richard, Jordi Gali, Mark Gertler, "The science of monetary policy: A new Keynesian perspective," *Journal of Economic Literature* Vol. 37-4, 1661-1707, 1999.

———————————, "Monetary policy rules and macroeconomic stability: Evidence and some theory," *Quarterly Journal of Economics* Vol. 115-1, 147-180, 2000.

Cook, Timothy, Thomas Hahn, "The effect of changes in the federal funds rate target on market interest rates in the 1970s," *Journal of Monetary Economics* Vol. 24-3, 331-51, 1989.

Cooley, Thomas F., Gary D. Hansen, "The inflation tax in a real business cycle model," *American Economic Review* Vol. 79-4, 733-748, 1989.

Dai, Qiang, Kennth J. Singleton, "Specification analysis of affine term structure models," *Journal of Finance* Vol. 55-5, 1943-1978, 2000.

Davidson, Russell, James G. MacKinnon, *Estimation and Inference in Econometrics*, Oxford University Press, 1993.

Demirgüç-Kunt, Asli, Vojislav Maksimovic, "Institutions, financial markets, and firm debt maturity," *Journal of Financial Economics* Vol. 54-3, 295-336, 1999.

Dotsey, Michael, Peter Ireland, "Liquidity effects and transactions technologies," *Journal of Money, Credit and Banking* Vol. 27-4, Part 2, 1441-1457, 1995.

Edelberg, Wendy, David Marshall, "Monetary policy shocks and long-term interest rates," *Federal Reserve Bank of Chicago Economic Perspective* Vol. 20-2, 1996.

Ellingsen, Tore, Ulf Söderström, "Monetary policy and market interest rates," *American Economic Review* Vol. 91-5, 1594-1607, 2001.

———————————, "Why are long rates sensitive to monetary policy?" *Sveriges Riksbank Working Paper Series* No. 160, 2004.

Emery, Gary W., "Cyclical demand and the choice of debt maturity," *Journal of Business* Vol. 74-4, 557-590, 2001.

Erceg, Christopher J., Dale W. Henderson, Andrew T. Levin, "Optimal monetary policy with staggered wage and price contracts," *Journal of Monetary Economics* Vol. 46-2, 281-313, 2000.

Evans, Charles L., David A. Marshall, "Monetary policy and the term structure of nominal interest rates: Evidence and theory," *Carnegie-Rochester Conference Series on Public Policy* Vol. 49, 53-111, 1998.

________________________, "Economic determinants of the nominal treasury yield curve," *Federal Reserve Bank of Chicago Working Paper* No. 2001-16, 2002.

Favero, Carlo A., "Taylor rules and the term structure," *Journal of Monetary Economics* Vol. 53-7, 1377-1393, 2005.

Francis, Neville, Valerie A. Ramey, "Is the technology-driven real business cycle hypothesis dead? Shocks and aggregate fluctuations revisited," *Journal of Monetary Economics*, Vol. 52-8, 1379-1399, 2005.

Fuhrer, Jeffrey C., "Habit formation in consumption and its implications for monetary-policy models," *American Economic Review* Vol. 90-3, 367-390, 2000.

Fuhrer, Jeffrey C., George R. Moore, "Monetary policy trade-offs and the correlation between nominal interest rates and real output," *American Economic Review* Vol. 85-1, 219-239, 1995.

Fuhrer, Jeffrey C., Glenn D. Rudebusch, "Estimating the Euler equation for output," *Journal of Monetary Economics* Vol. 51-6, 1133-53, 2004.

Galí, Jordi, J. David López-Salido, and Javier Valles, "Technology shocks and monetary policy: Assessing the Fed's performance," *NBER Working Paper* No. 8768, 2002.

Galí, Jordi, Pau Rabanal, "Technology shocks and aggregate fluctuations: How well does the real business cycle model fit postwar U.S. data?" *NBER Macroeconomics Annual* Vol. 19, 225-288, 2004.

Gorden H. Sellon, Jr., "Expectations and the monetary policy transmission mechanism," *Federal Reserve Bank of Kansas City Economic Review* 4th Quarter, 2004.

Gould J.P., "Adjustment costs in the theory of investment of the firm," *Review of Economic Studies* Vol. 35-1, 47-55, 1968.

Gürkaynak, Refet S., Brian Sack, Eric Swanson, "The sensitivity of long-term interest rates to economic news: Evidence and implications for macroeconomic models," *American Economic Review* Vol. 95-1, 425-436, 2005.

Hanson, Michael S., "The 'price puzzle' reconsidered," *Journal of Monetary Economics* Vol. 51-7, 1385-1413, 2004.

Hayashi, Fumio, "Tobin's marginal q and average q: A neoclassical interpretation," *Econometrica* Vol. 50-1, 213-224, 1982.

Jung, Yongseung, "Catching up with the Joneses in a sticky price model," *Journal of Money, Credit, and Banking* Vol. 36-1, 73-93, 2004.

Khan, Aubhik, Julia K. Thomas, "Modeling inventories over the business cycle," *Federal Reserve Bank of Philadelphia Working Paper* No. 04-13, 2004.

____________________, "Inventories and the business cycle: An equilibrium analysis of (S,s) policies," *Federal Reserve Bank of Philadelphia Working Paper* No. 04-11, 2004.

Kim, Jinill, Sunghyun Henry Kim, "Spurious welfare reversals in international business cycle models," *Journal of International Economics* Vol. 60-2, 471-500, 2003.

Klein, Paul, "Using the generalized Schur form to solve a multivariate linear rational expectations model," *Journal of Economic Dynamics & Control* Vol. 24-10, 1405-1423, 2000.

Kozicki, Sharon, P.A. Tinsley, "Shifting endpoints in the term structure of interest rates," *Journal of Monetary Economics* Vol.47-3, 613-652, 2001.

Kozicki, Sharon, P.A. Tinsley, "Dynamic specifications in optimizing trend-deviation macro models," *Journal of Economic Dynamics & Control* Vol. 26, Iss. 9-10, 1585-1611, 2002.

Kydland, Finn E., Edward C. Prescott, "Time to build and aggregate fluctuations," *Econometrica* Vol. 50-6, 1345-1370, 1982.

Leeper, Eric M., Christopher A. Sims, Tao Zha, "What does monetary policy do?" *Brookings Papers on Economic Activity* No. 1996-2, 1-63, 1996.

Li, Victor E., Chia-Ying Chang, "The cyclical behavior of household and business investment in a cash-in-advance economy," *Journal of Economic Dynamics & Control* Vol. 28-4, 691-706, 2004.

Lucas, Robert E., Jr., "Optimal investment policy and the flexible accelerator," *International Economic Review* Vol. 8-1, 78-85, 1967.

Lucas, Robert E., Jr., Nancy L. Stokey, "Money and interest in a cash-in-advance economy," *Econometrica* Vol. 55-3, 491-513, 1987.

Morgado, Artur, Julio Pindado, "The underinvestment and overinvestment hypotheses: An analysis using panel data," *European Financial Management* Vol. 9-2, 163-177, 2003.

Orphanides, Athanasios, "Monetary policy rules, macroeconomic stability, and inflation: A view from the trenches," *Journal of Money, Credit, and Banking* Vol. 36-2, 151-175, 2004.

Ozkan, Aydin, "The determinants of corporate debt maturity: Evidence from UK firms," *Applied Financial Economics* Vol. 12-1, 19-24, 2002.

Ravenna, Federico, Carl E. Walsh, "Optimal monetary policy with the cost channel," *Journal of Monetary Economics* Vol. 53-2, 199-216, 2006.

Salyer, Kevin D., "The timing of markets and monetary transfers in cash-in-advance economies," *Economic Inquiry* Vol. 29-4, 762-773, 1991.

Sargent, Thomas J., *Dynamic Macroeconomic Theory*, Harvard University Press, 1987.

Schmitt-Grohé, Stephanie, Martín Uribe, "Price level determinacy and monetary policy under a balanced-budget requirement," *Journal of Monetary Economics* Vol. 45-1, 211-246, 2000.

Sims, Christopher A., "Interpreting the macroeconomic time series facts: The effects of monetary policy," *European Economic Review* Vol. 36-5, 975-1000, 1992.

Sims, Christopher A., James H. Stock, Mark W. Watson, "Inference in linear time series models with some unit roots," *Econometrica* Vol. 58-1, 113-144, 1990.

Stockman, Alan C., "Anticipated inflation and the capital stock in a cash-in-advance economy," *Journal of Monetary Economics* Vol. 8-3, 387-393, 1981.

Stohs, Mark Hoven, David C. Mauer, "The determinants of corporate debt maturity structure." *Journal of Business* Vol. 69-3, 1996.

Strauss, Jack, "Capital adjustment costs, time-to-build effects, and inflation nonneutrality," *Atlantic Economic Journal* Vol. 22-4, 13-25, 1994.

Svensson, Lars E.O., "Money and asset prices in a cash-in-advance economy," *Journal of Political Economy* Vol. 95-5, 919-944, 1985.

Svensson, Lars E.O., Michael Woodford, "Indicator variables for optimal policy," *Journal of Monetary Economics* Vol. 50-3, 691-720, 2003.

Uhlig, Harald, "A toolkit for analyzing nonlinear dynamic stochastic models easily," *mimeo*, 1997.

Verbeek, Marno, *A Guide to Modern Econometrics*, John Wiley and Sons, LTD, 2000.

Walsh, Carl E., *Monetary Theory and Policy*, The MIT Press, 2003.

Woodford, Michael, "Monetary policy and price level determinacy in a cash-in-advance economy," *Economic Theory* Vol. 4-3, 345-380, 1994.

Woodford, Michael, "Optimal monetary policy inertia," *NBER Working Paper* No. 7261, 1999.

Woodford, Michael, *Interest and Prices*, Princeton University Press, 2003.

Yun, Tack, "Nominal price rigidity, money supply endogeneity, and business cycles," *Journal of Monetary Economics* Vol. 37-2, 345-370, 1996.