Three Essays on the Importance of the Liquidity Premium in Monetary Economics

by

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Abstract

To answer the question of whether an interest rate hike causes inflation to increase or decrease, I estimate a liquidity-augmented empirical model of interest rates, inflation, and growth on postwar US data, using three methods: a time-varying structural vector autoregression, a system of latent variables, and a structural vector autoregression with doubtful identifying assumptions. I find that an interest rate hike has a short-run non-positive effect on inflation, regardless of its duration. This result contrasts with the Neo-Fisherian prediction of a positive short-run response of inflation to a permanent shift in interest rates. At the same time, inflation and the nominal interest rate move in the same direction in the long-run, although not one-for-one. I also find that the short- and long-run interactions of macroeconomic variables including inflation and the interest and growth rates have changed across eras from the 1950s to 2016. Finally, the results reinforce the importance of the liquidity premium on near-money assets in macroeconomic analyses.

Keywords: Monetary Policy; Neo-Fisherian Hypothesis; New-Keynesian Models; Structural Vector Autoregression; Bayesian Estimation

Dedication

I dedicate this thesis to my dearest mother and beloved family, whose unwavering support, love, and encouragement have been the guiding light throughout my academic journey. In particular, when the weight of academia threatened to overwhelm me, my beloved sister, Dr. Mina Azizi Rad, was there, ready to lend an empathetic ear and a comforting word. May this dedication serve as a small token of my appreciation, a humble acknowledgment of the immense gratitude I hold in my heart for my family.

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Chapter 1

Introduction

The study of inflation dynamics, along with the determination of its drivers, remains an unsettled question, and a topic of great interest among economists. On the one hand, the one-for-one long-run relationship between expected inflation and the nominal interest rate given by the Fisher equation is one of the most well-known relationships in economics. On the other hand, central banks with inflation-targeting mandates follow the logic of Keynesian models (Old and New) that assert a negative short-run relationship between the two variables, where causality runs from the interest rate to inflation. Recent studies of the Neo-Fisherian hypothesis have suggested that a *permanent* interest rate hike causes inflation to increase, not only in the long-run—as suggested by the Fisher relationship—but even in the short-run. Settling this ongoing debate would provide much needed guidance, and allow central banks to conduct more effective monetary policy.

In the past decade, inflation has been the cause of controversies. During and after the Great Recession, central banks were unable to bring inflation up to the level of their 2% target. Recommendations to remedy such "lowflation" ranged from keeping the interest rate at the zero lower bound for a longer period of time to a permanent and credible hike of the interest rate. These controversies have revealed how much work remains to understand inflation and how it should be managed. It is well-established that inflation is an important signal of the economy's well-being. Understanding the relationship between inflation and the nominal interest rate—the conventional apparatus of central banks to regulate the economy—is a continuing concern.

One challenge regarding the study of inflation is the discrepancy between the theoretical and the empirical studies. Theoretically, most models of nominal interest rates study an asset that is perfectly safe, yet does not have any "monetary" function whatsoever: it does not serve as a medium of exchange or as collateral to relax any liquidity constraints. However, a major problem with this kind of application is that the empirical interest rates usually considered—whether on T-bills, short-term commercial paper, or overnight deposits—are associated with quite liquid, indeed "money-like", assets. These assets provide liquidity, i.e., means of payment or collateral for a loan, should the holder need it. This is shown theoretically by [1], [22], and empirically by [30] among others.

The proxy I use for the liquidity premium is defined by [33]; it is the spread between the three-month general collateral (GC) and the three-month T-bill rate for the period of 1991 and 2016, and the spread between the three-month Banker's Acceptance rate and the three-month T-bill rate for the period between 1954 and 1990. This spread is a reasonable measure of the liquidity premium because the GC is as safe as the T-bill so the yield spread between the two assets does not contain the risk premium. Their difference is in their liquidity; the money lent in a three-month term GC repo agreement is locked in for three months whereas the T-bill can easily be traded in a secondary market. Hence, this is a premium that the economic agents are willing to pay for the liquidity benefits of holding an asset that is liquidable before its maturity date.

By employing three empirical methods, I study the short- and long-run relationships of the macro-aggregates including inflation, GDP, and the Federal Funds Rate (FFR), as well as the liquidity premium. The first empirical approach, studied in chapter (2), is a time-varying parameter structural autoregressive (TVP-SVAR) model following [36] and [18]. This model is well-suited for the examination of the macro-aggregate behaviors, given the non-linearity of the FFR at the zero lower bound as well as aggregation among the economic agents. However, this model is unable to capture the short-run response of inflation to a permanent monetary policy shock due to its recursive identification. In chapter (3) and to capture short-run dynamics between the macro aggregates, I rely on a system of latent variables (SLV) in the spirit of a dynamic stochastic general equilibrium model following [40]. Lastly and in chapter (4), I use a structural vector autoregressive model with a non-recursive identification scheme and doubtful identifying assumptions to further study the relationships in the liquidity-augmented empirical model. I use the results of the first model in the identification of the SLV model and the SVAR model of chapter (4), and the three models combined improve our understanding of the macro-aggregate interrelations.

I show that a proxy of the aggregate liquidity premium is an important variable which our models need to account for; its exclusion results in misspecification of the models which may yield misleading monetary policy recommendations. Moreover, looking at the data and the evolution of the variables suggests that the liquidity premium is particularly important for the period after the Great Recession because its size relative to the FFR is considerable when the FFR is small. The common empirical model of the Fisher equation, hereafter the mainstream model, and the liquidity-augmented model have similar abilities in explaining the data before the Great Recession whereas in the period after, where the FFR is small, the liquidity-augmented model is superior. Furthermore, post-Great Recession is a period in which the Federal Reserve Bank used unconventional monetary policy; for instance, it used the size of its balance sheet to affect the holding of the liquid assets in the economy in order to engineer inflation. Indeed, my results show that an exogenous increase in the liquidity premium, which plausibly reflects scarcity of liquid assets, causes inflation to decrease.

Surprisingly, the macro-aggregate interrelations do not appear to change before and after the Great Recession. However, I do find differences between the interactions of some variables before and after 1992 when the model is time-varying. I report differences in the observed responses before and after 1992, resulted from both transitory and permanent shocks. First, in terms of responses to one-time transitory shocks, I find that in the latter subsample, the growth rate is less responsive to monetary policy and inflation's response to a growth rate change dies out quickly. Moreover, the response of the liquidity premium to a transitory FFR shock becomes significantly smaller after 1992 while remaining positive in the short-run. Second, the responses to the permanent shocks show significant changes around 1992 as well. A one percent permanent increase in inflation has a negative long-run effect on the growth rate after 1992, whether the liquidity premium is included or not. Furthermore, the responsiveness of the central bank to permanent shocks changed significantly after 1992. During the period of 1992 to 2016, the interest rate responses to permanent shifts in both inflation and the growth rate were higher compared to the period before that, with no Taylor-type response of policy to inflation before 1980. Long-run responses of the liquidity premium to permanent shocks to all three variables became smaller after 1992.

The aforementioned result suggests that a non-time-varying empirical model estimated on a dataset covering 1950s to this day will produce results that do not accurately describe the contemporary relationships in the economy.[1] Similarly, in a study of inflation and inflation expectations, [13] find that the expectations were less volatile after the mid-90s despite no clear change in the volatility of inflation itself. In another study, [11] finds that inflation uncertainty for the pre-Volcker period is much larger than that for the post-Volcker era, which may suggest different macro-aggregate interrelations in the two periods.[2] The post-92 period is different from the period before that and the reason lies in how the economic agents perceive the central bank efforts to regulate the economy. This was a period in which the central bank was more open to the public and more aggressive in keeping inflation close to its target. A permanent hike in inflation in this period was recognized as a systematic problem which causes a smaller long-run growth rate as shown by the TVP-SVAR model.

I now discuss the reaction of inflation to different variables' impulses of the TVP-SVAR model in the post-92 period. Impulse response functions indicate that the response of inflation to a transitory FFR shock has remained at a nil level and unchanged.[3] The liquidity-

[1] The FFR data is available starting 1954 and many empirical macroeconomic studies use the entire dataset.

[2] Paul Volcker served as the 12th chairman of the Federal Reserve from 1979 to 1987.

[3] This is true throughout the entire time of study and is not a feature specific to post-92 estimation.

augmented empirical model solves the known price puzzle in the empirical macroeconomic studies.[4] A transitory growth rate shock has a significantly positive effect on inflation that turns negative in the medium run and dies out completely in the long-run, leaving minimal effect on the trend of the price level. A transitory liquidity shock has a significant negative effect on inflation in the short- to medium-run and dies out in the long-run. An increase in the liquidity premium is a sign of scarcity of the liquid assets which can affect inflation negatively via a lower velocity of money.

To identify the SLV model, I rely on the TVP-SVAR empirical results. Particularly, I estimate the SLV model on the data from 1992 to 2016 and I assume a more than one-for-one increase in the FFR for each one percent long-run increase in inflation. The results of this model show that the effect of an FFR hike on inflation in the short-run is negative regardless of the type of the shock, i.e., transitory or permanent. This is different from what [40] finds using the same empirical model but excluding the liquidity premium. Specifically, the result that [40] finds under the Neo-Fisherian hypothesis prediction—positive short-run response of inflation to a permanent increase in the FFR—is not confirmed in the liquidity-augmented model.

In identifying the last empirical model with doubtful identifying assumptions I use the aforementioned results. I assume positive responses of the interest rate to inflation and the growth rate with a smoothing parameter capturing gradual changes in the policy rate. The assumed prior for the response of inflation to an interest rate policy is symmetric and its mode is at zero. The posterior draws and the impulse response function confirm a negative response of inflation to the policy rate.

This thesis is related to three streams of the literature. First, it contributes to the large volume of published studies describing the transmission of the central bank policy to inflation. Traditionally, the effect of an increase in the interest rate is perceived as a means of lowering the inflation rate. In recent years, several attempts to explain the lowflation of the post Financial Crisis have argued that inflation would follow the interest rate in the same direction as long as the change in the interest rate is permanent. Second, it integrates the empirical studies and the growing consensus among the economists about the importance of the liquidity premium in determining the transmission of monetary policy to the economy. Third, it utilizes the state-of-the-art empirical advancements in answering the critical question of how inflation responds to monetary policy.

To date there has been little agreement in the literature on how monetary policy affects inflation in the short-run. On the one hand, the central bank's conventional wisdom, following the New-Keynesian conception, suggests that nominal interest rates should be raised

[4] This puzzle refers to the positive short-run response of inflation to a transitory FFR hike in the empirical models. Consistent with the literature, I find a significant positive short-run response of inflation to a transitory FFR shock in the mainstream empirical model, i.e., the model that does not include the liquidity premium.

to attain a lower inflation ([42], [46], [16], and [20] among others). On the other hand, economists such as [43], [14], and [40] among others find that central banks can increase inflation by increasing their nominal interest rate targets; a result named the Neo-Fisherian hypothesis. For example, [40] finds strong evidence in favor of the Neo-Fisherian hypothesis both empirically and theoretically. Similarly, [14] finds a Neo-Fisherian type result using a model incorporating the fiscal theory of the price level. [4], [17], and [41] find a similar result using different empirical methodologies and observables. I show that the short-run effect of an FFR hike, whether permanent or transitory, on inflation is negative and in the long-run, the two variables move in the same direction.

To add to the disagreement, [3] and [5] find experimental evidence on the economic instability that comes with inactive monetary policy. [5] suggest that the Taylor principle is a necessary condition to ensure convergence to the inflation target whereas [10] argue that once the zero bound on nominal interest rates is taken into account, active interest rate feedback rules can easily lead to unexpected consequences.

A large and growing body of literature has investigated the role of the liquidity premium in giving important insights into the behavior of inflation, the interest rates, and the effects of monetary policy. [2] model the role of all government and central bank liabilities as liquidity in a heterogeneous-agent model and find that the inflation rate will fluctuate if there are fluctuations in factors that make the asset market constraint more or less tight. [44] develops a model with money, government bonds, and private equity to study the effects of both conventional and unconventional monetary policies which improves the understanding of the effects of asset purchases by the central bank. [37] focus on the conventional conduct of monetary policy and show how market structures and liquidity properties of money and bonds matter for understanding its effects. [19] discuss how the spread between the commercial paper and the Treasury bill contains highly significant information about future movements in real income. They discuss how the value placed by the investors on the superior liquidity, i.e., the liquidity premium, changes systematically over the business cycle.

In the same stream, [24] constructs a model where money can be introduced either via helicopter drops or via open-market purchases. He argues that this distinction helps resolve a great number of puzzles associated with the Euler/Fisher equation and points to a better way of understanding how monetary policy affects the economy. I find that a liquidity-augmented empirical model overcomes the price puzzle which is ubiquitous in the mainstream model studies of the economy. [37], in a Neo-Monetarist model which explicitly captures liquidity, find endogenizing liquidity leads to multiple equilibria and the effect of monetary policy via an open market operation depends on the equilibrium. Similarly, [22] find that the real effect of monetary policy depends on the interest rate on the liquid bonds and the distinction between the interest on liquid and illiquid assets is crucial for understanding the role of monetary policy, and for empirical analysis of its effects. [29] discuss the monetary transmission mechanism running through shifts in asset supplies, such as quantitative easing policies. They find that different assets provide different amounts of liquidity services per unit of asset and the supplies of bonds, deposits, and the path of the nominal interest rate all factor in determining bond market liquidity premiums.

Further researchers have shown the importance of the liquidity premium in the studies of monetary policy. [45] considers the public debt as the private liquidity and argues that changes in the public debt lead to different conclusions about the welfare consequences of policy. Additionally, [32] provide empirical evidence of how monetary policy influences financial markets and then how the effects of those interventions on asset prices are transmitted to the rest of the economy to help achieve the ultimate policy objectives. Within the same stream and in an empirical study, [35] quantify the effects of monetary policy shocks on the yield curve through their impact on Treasury liquidity premia. They find that monetary policy affects the term structure through the liquidity premia. When liquidity "dries up" due to the conduct of monetary policy, the liquidity and safety premium increase as shown by [28]. I show that inclusion of the liquidity premium improves the fit of the empirical models to the data, specifically for the period of post-Financial-Crisis.

Several attempts have been made to define an aggregate rate of the liquidity premium. [30] argue that investors value the liquidity and safety of US Treasuries. Further, they discuss that the low yield on Treasuries, due to their extreme safety and liquidity, suggests that Treasuries are similar to money in important respects. Similarly, [33] shows theoretically and empirically that the liquidity premium on Treasury bonds is impacted by monetary policy.

1.1 Theoretical Background

In this section, I use the standard macroeconomic theory to justify the inclusion of the liquidity premium in an empirical model of macro-aggregates. Time is discrete and given by $t = 0, 1, \ldots$. I begin with the standard textbook Euler equation for a nominal, safe, short-term, and illiquid bond,

$$u'(C_t) = \beta(1 + i_t)\mathbb{E}_t\left(u'(C_{t+1})\frac{P_t}{P_{t+1}}\right) \tag{1.1}$$

where C_t is consumption in period t, $u'(.)$ is the marginal utility of consumption, β is the discount factor, i_t is the nominal interest rate on borrowing and lending, and P_t is the price level at time t. Let,

$$u(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma} \tag{1.2}$$

and log-linearize equation (1.1) to get,

$$i_t = \rho + \sigma\mathbb{E}_t(g_{t+1}) + \mathbb{E}_t(\pi_{t+1}) \tag{1.3}$$

where $\mathbb{E}_t$ stands for expectations at time t, g_t is the growth rate of real consumption, π_t is inflation, σ is the inverse elasticity of intertemporal substitution, and $\rho = -\log \beta$. Define the ex-ante real interest rate, r_t, by the Fisher equation,

$$r_t \equiv i_t - \mathbb{E}_t(\pi_{t+1}) \tag{1.4}$$

which gives us,

$$r_t = \rho + \sigma \mathbb{E}_t(g_{t+1}) \tag{1.5}$$

So far, everything is standard in macroeconomics and equation (1.3) has been studied empirically by many authors including [40] and using the concurrent values of the variables. In these studies, the FFR is a proxy for i, the growth rate of either the economy or consumption is a proxy for r assuming fixed ρ and σ, and inflation is either measured by the GDP deflator or personal consumption expenditures price index. The justification for using the concurrent values of the variables is,

$$x_{t+1} = \mathbb{E}_t(x_{t+1}) + \xi^x_{t+1} \tag{1.6}$$

where ξ^x_{t+1} is a zero-mean shock, independent from any of the variables in the information set at time t, since they are expectational errors, and for $x = \{\pi, g\}$. Hence, taking the expected values of the variables into account would result in,

$$i_{t+1} = \rho + \sigma g_{t+1} + \pi_{t+1} - \sigma \xi^g_{t+1} - \xi^\pi_{t+1} \tag{1.7}$$

At the same time, the New-Keynesian macroeconomic models specify a monetary policy rule given by,

$$i_t = i^* + \alpha_\pi(\pi_t - \pi^*) + \alpha_y y_t \tag{1.8}$$

where i_t is the monetary policy interest rate at time t, i^* is the target interest rate, π_t is actual inflation at time t, π^* is the inflation target, α_π captures the central bank response to deviation of inflation from its target level, and y_t is the output gap at time t, i.e., the difference between output if prices were flexible and the actual output. The idea behind equation (1.8) is that the central banks react to deviations of the inflation rate by setting the policy rate away from its target in the short-run. The parameter α_π is greater than zero which means this reaction is in the same direction as inflation deviation based on the logic of a negative effect of the FFR on inflation. By the Taylor principle, this rate must be greater than one and central banks should respond more than one-for-one to inflation deviations.

The empirical studies of the Neo-Classical model and the New-Keynesian models are similar in the variables they include in a time-series empirical study. What I add to the empirical model is a measure of the aggregate liquidity premium to bring the empirical work and predictions closer to those of the theory. Note that i in both the Neo-Classical theory and the New-Keynesian monetary policy is the yield on a nominal asset which is perfectly safe yet completely illiquid, in the sense of being neither a monetary asset nor a substitute to one. In empirical studies, this interest rate is usually proxied for by an interest rate which is the yield on a safe and, to some degree, liquid asset. There are several definitions of the liquidity premium and I use the definition of [23] who define an asset's liquidity as the ease with which an agent can sell it for cash, if needed. This definition can cover a broader range of providing means of payment such as the ease at which and the percentage of an asset that can be collateralized, should the holder of the asset require means of payment. Such an asset will have a lower yield than an asset which should be held to its maturity; the difference between the yields is called the liquidity premium. [37] point out the empirical difficulty of testing the Fisher equation since most assets have some degree of liquidity.

To account for—and correct—the difference between the interest rate in the theoretical models and the observed interest rates, [25] proposes to use,

$$i \equiv i^{FFR} + \ell \tag{1.9}$$

where ℓ is the "aggregate liquidity premium", defined as the spread between a perfectly illiquid safe asset and a perfectly liquid Treasury Bill. In practice, where perfection is absent, this spread must be proxied by the spread between a "less liquid" and a "more liquid" asset; I use the measure proposed by [33] and for details see section (1.2) below. To summarize, the liquidity-augmented empirical model I study in the rest of this thesis is given by,

$$i_t^{FFR} = \rho + \sigma g_{c,t} + \pi_t - \ell_t. \tag{1.10}$$

In section (2.1.4), I show how the inclusion of the liquidity premium improves the specification of the model and how its fit to the data is superior to that of the mainstream empirical models. I also highlight key differences in the dynamics of macro-aggregates with important monetary policy implications.

1.2 Data

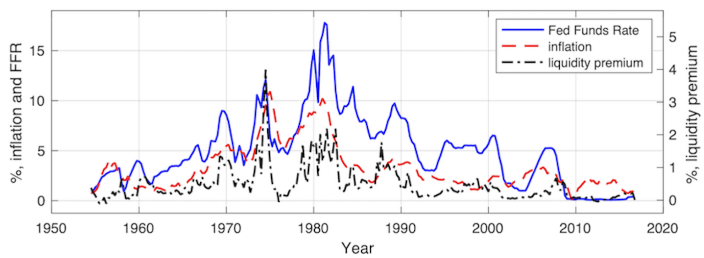
I estimate the model in equation (1.10) using a time-varying parameter structural vector autoregression (TVP-SVAR) following [36] and [18], a system of latent variables (SLV) following [40], and a SVAR with doubtful identifying assumptions following [8] and [9]. The data I use for estimations is quarterly and covers 1954:Q3 to 2016:Q4. In the TVP-SVAR and the SVAR models, I use the FFR for i^{FFR}, year-over-year growth rate of GDP for g, and year-over-year growth rate of GDP deflator for π. GDP is downloaded from the U.S. Bureau of Economic Analysis and the GDP deflator is calculated as the ratio of GDP in current dollars and real GDP.[5] For the liquidity premium, I use the rate introduced by [33] and I obtain it from [29]. The liquidity premium is the spread between the 3-month general collateral (GC) repo rate and the 3-month Treasury bill rate for the period of 1991 to 2016, and the spread between the 3-month general Banker's Acceptance rate and the 3-month Treasury bill rate for the period of 1954 to 1991. The 3-month GC repo rate is only available for the period of 1991 to 2016 and the Banker's Acceptance rate is used for the period of 1954 to 1990 as the rate of a less liquid asset.[6]

This liquidity premium, as [33] puts it, is the cleanest measure of the liquidity premium on near-money assets. The GC repo term loan is illiquid, as the money lent is locked in for three months and the bid-ask spread between lending and borrowing rates are relatively wide compared with T-bills. In contrast, a T-bill investment can easily be liquidated in a deep market with a minuscule bid-ask spread. Hence, this yield spread reflects the premium that market participants are willing to pay for the liquidity benefits provided by T-bills.

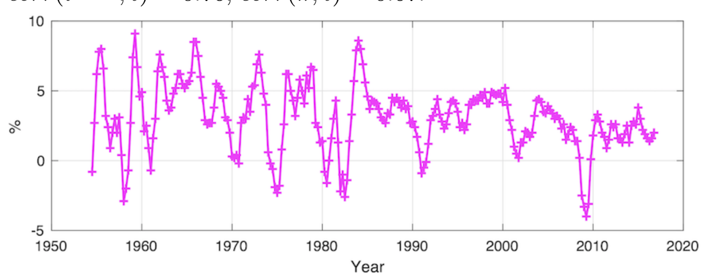
The SLV model takes the GDP as opposed to the growth rate, and the data I use for GDP is the logarithm of real GDP seasonally adjusted in chained dollars of 2012 ([39]). The remaining variables are the same as the ones used for the TVP-SVAR model. Panel (a) of figure (1.1) displays nominal interest rate, inflation, and the liquidity premium used for model estimations. The dataset covers the period of 1954:Q3 to 2016:Q4 and it ends when the GC repo rate is no longer available. The pairs of these variables show correlations of about 70%. Panel (b) of figure (1.1) displays the growth rate of GDP.

[5] Table 1.1.11. Real Gross Domestic Product: Percent Change From Quarter One Year Ago, series GDP from FRED database, and series GDPC1 from FRED database respectively.

[6] I do not do the winsorization of [29] and I use the variable as originally created by [33].



(a) Nominal variables of the model. This figure indicates the evolution of the liquidity premium and its tight connection to the other two nominal variables. $corr(i^{FFR}, \pi) = 0.75$, $corr(i^{FFR}, \ell) = 0.76$, $corr(\pi, \ell) = 0.67$.



(b) Real variable of the model, the growth rate.

Figure 1.1: Variables of the model.

Chapter 2

Empirical Evidence for the Inclusion of the Liquidity Premium in the Studies of Inflation and the Interest Rate

It is well known in empirical macroeconomics that the suitability of estimation methods cannot be established a priori, but clearly depends on the specific problem at hand. Furthermore, each empirical model has its own limitations in the question it answers. As a result, and to get a deeper understanding of the transmission of the central bank policy to the economy, particularly to inflation, I work with three empirical models. Each of the last three chapters introduces one of these empirical models and summarizes its associated results. The results I focus on are mainly impulse response functions as measures of the causal relationships; an innovation to a variable of the model causes reactions by the other variables. I interpret the horizons of 1-5 quarters as short-run, 6-12 quarters as medium-run and horizons greater than 13 quarters as long-run in the empirical models.

2.1 Time-Varying Parameter SVAR Model

The model used in this section is a time-varying parameter structural vector autoregressive (TVP-SVAR) model with stochastic volatility following [36] and [18] with two features that make it preferable for the purpose of this section. First, it has drifting coefficients which capture possible nonlinearities or time variation in the lag structure of the model. This makes the TVP-SVAR model a proper choice; macroeconomic aggregates' features makes them better captured in a time-varying model compared to discrete break models. These features include learning private agents and policymakers as well as aggregation among them. Second, the multivariate stochastic volatility feature finds possible heteroskedasticity of the shocks and nonlinearities in the simultaneous relations among the variables of the model. [36] explains how allowing for time variation both in the coefficients and the variance-covariance matrix leaves it up to the data to determine whether the time variation of the linear structure derives from changes in the size of the shocks (impulse) or from changes in the propagation mechanism (response). This method allows the sources of time variation to be both the coefficients and the variance-covariance matrix of the innovations and it distinguishes the typical size of exogenous innovations and changes in the transmission mechanism.

To introduce the model, let,

$$\mathbf{y}_t = c_t + B_{1,t}\mathbf{y}_{t-1} + \cdots + B_{p,t}\mathbf{y}_{t-p} + u_t, \qquad t = 1, \ldots, T \tag{2.1}$$

where $\mathbf{y}_t$ is an $(n \times 1)$ vector of observed endogenous variables; c_t is an $(n \times 1)$ vector of time-varying intercepts; $B_{i,t}$, for $i = 1, \ldots, p$ are $(n \times n)$ matrices of time varying coefficients with p lags; u_t is an $(n \times 1)$ vector of heteroskedastic unobservable shocks and,

$$\mathbf{y}_t = X_t' B_t + A_t^{-1} \Sigma_t \varepsilon_t, \tag{2.2}$$

$$X_t' = I_n \otimes [1, \mathbf{y}_{t-1}', \ldots, \mathbf{y}_{t-p}'] \tag{2.3}$$

with $V(\varepsilon_t) = I_n$, Σ_t diagonal, and A_t lower triangular. All the time-varying coefficients evolve as random walks, except for the diagonal elements of Σ_t, which behave as geometric random walks.

Before estimating the TVP-SVAR model, I use the Akaike information criterion in a simple VAR(p)-process and I find seven significant lags of the VAR model whether the liquidity premium is included or not. Then I estimate two models using the TVP-SVAR method, a liquidity-augmented empirical model as in equation (1.10) with $\mathbf{y}_t = (\pi_t, g_t, i_t, \ell_t)'$ and a mainstream empirical model of the Fisher equation, i.e., the same model without the liquidity premium. The order of the variables in my models is the common ordering for the first three variables and I order ℓ as the last and the most endogenous variable. This ordering also matches the actual behavior of the central banks in responding to inflation and the growth rates but not to the liquidity premium as defined here. The variables of the model are stationary up to structural breaks, hence I estimate the model in the levels of the variables to study the effects of transitory and permanent shocks to the model.

I again follow [36] for the identification of the parameters in which I rely on the first 10 years of the series to estimate the priors set. This method sets priors which are not flat but diffuse and uninformative, leaving it up to the data to find the likelihood function. [36] uses the term non-systematic monetary policy in referring to policy mistakes as well as interest rate movements that are responses to variables other than inflation and the growth rate.[1]

[1] [36] models three variables; inflation, unemployment and the FFR.

The time varying standard deviation of the identified monetary policy shocks is then used as the measure of non-systematic policy actions which are shown and discussed in section (2.1.4).

2.1.1 Transitory Shocks

Recall the empirical model introduced by equation (2.1),

$$\mathbf{y}_t = c_t + B_{1,t}\mathbf{y}_{t-1} + \cdots + B_{p,t}\mathbf{y}_{t-p} + u_t, \qquad t = 1, \ldots, T$$

which has a Wold moving average representation with the form of,

$$\mathbf{y}_t = u_t + \Phi_1 u_{t-1} + \Phi_2 u_{t-2} + \ldots \tag{2.4}$$

where,

$$\Phi_s = \sum_{j=1}^{s} \Phi_{s-j} A_j, \qquad s = 1, 2, \ldots \tag{2.5}$$

and $\Phi_0 = I_n$.

This model is then represented at the form of equation (2.2),

$$\mathbf{y}_t = X_t' B_t + A_t^{-1} \Sigma_t \varepsilon_t$$

with $V(\varepsilon_t) = I_n$. Since ε_t has a diagonal covariance matrix, a moving average representation of (2.2) based on ε is given by,

$$\mathbf{y}_t = \Xi_0 \varepsilon_t + \Xi_1 \varepsilon_{t-1} + \Xi_2 \varepsilon_{t-2} + \ldots \tag{2.6}$$

where $\Xi_j = \Phi_j A^{-1}$ for $j = 1, 2, \ldots$. The elements of the Ξ_j matrices represent the responses to ε_t shocks and the corresponding impulse responses will be unique.

Due to the time-varying structure of the model, I can study and compare the impulse responses of the variables to shocks at different points in time. I find several significant differences in the impulse responses before and after 1992. The post-92 period is different from the period before that in important aspects. Table (2.1) summarizes the results of transitory shocks in this model and it separates the results for the two periods. The reactions of the variables to different shocks that occur after 1992 are not significantly different and, interestingly, are the same before and after the Great Recession. Most of the responses indicate a significant change around 1992; the responses of pre- and post-92 fall out of the 68% error bands of one another, so I use it as a cutoff for summarizing the results. Later on, I discuss some of the impulse responses in detail. There are three impulse responses which experience significant changes after 1992 and they are shown in red in table (2.1). First, the response of inflation to the growth rate used to be more persistent; second, response of the growth rate to the FFR changed from negative to nil; and third, the response of the liquidity premium became smaller. The results of the mainstream model are presented in appendix (C).[2,3]

impulse / response	inflation pre-92	inflation post-92	growth rate pre-92	growth rate post-92	FFR pre-92	FFR post-92	liquidity premium pre-92	liquidity premium post-92
inflation	+	+	+ persistent	+	nil	nil	-	-
growth rate	nil	nil	+	+	-	nil	-	-
FFR	+	+	+	+	+	+	-	-
liquidity premium	nil then +	nil then +	nil then +	nil then +	+ large	+	+	+

Table 2.1: Comparison of impulse responses, transitory shocks in the TVP-SVAR model.

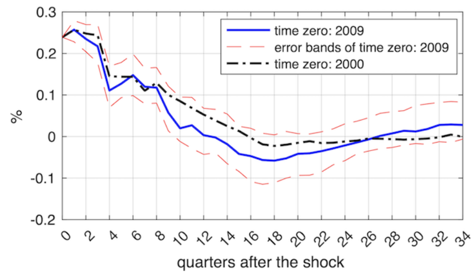
Figure (2.1) displays responses of inflation to transitory shocks to the variables of the model. Each variable is separately shocked at two points in time, 2000:Q1 and 2009:Q1, with the 68% error bands associated with the shocks at 2009:Q1. All panels of this figure indicate that responses of inflation to shocks to different variables are not significantly different before and after the Great Recession. One point to note here is that the inclusion of the liquidity premium solves the price puzzle which is otherwise ubiquitous in empirical studies of macro-aggregates.

Despite solving the price puzzle in the liquidity-augmented empirical model, this is not the main reason to include this variable. [38] demonstrated that the price puzzle largely disappeared if commodity prices were included in a VAR model and he calls it the information variable. I argue that including the liquidity premium is crucial for the model specification and then find that price puzzle is solved. Similar to the literature, the same response associated with the mainstream model indicates a significant positive response of inflation to the FFR shocks; which is presented in appendix (C). Shocks to inflation and the growth rate have significant positive effects on inflation and a transitory higher liquidity premium, i.e., higher shortage of liquid assets in the economy, causes a significant and persistent decline in inflation, which is the largest in the medium-run.

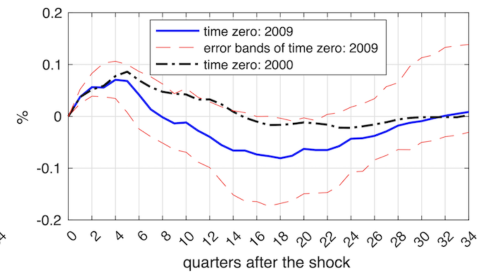
Due to the importance of other variables of the model in determining the transmission mechanism of an FFR shock to inflation, this section contains more impulse responses than those of inflation. Figures (2.2) to (2.4) graphically display the changes in the impulse responses marked by red in table (2.1). They respectively indicate the inflation responses to transitory growth rate shocks, the liquidity premium responses to transitory FFR shocks, and the growth rate responses to transitory FFR shocks. Each variable is shocked at three points in time, 1976:Q1, 2000:Q1, and 2009:Q1. Figure (2.2) confirms the smaller persistence of the inflation response to a growth rate shock after 1992 compared to the period before

[2]Response of the growth rate to an FFR shock changes from negative to nil in the mainstream model as well and it is shown in figure (C.2) in appendix (C).

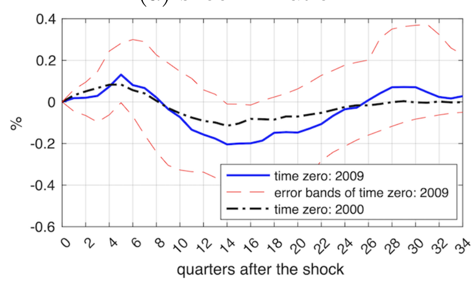
[3]The appendices can be found at this link.



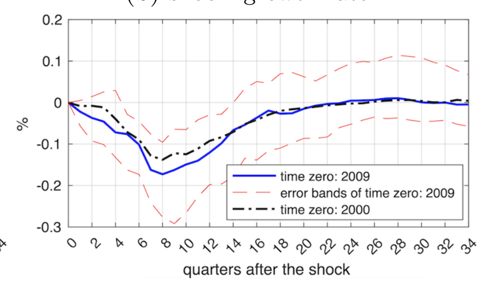
(a) shock: inflation



(b) shock: growth rate



(c) shock: FFR

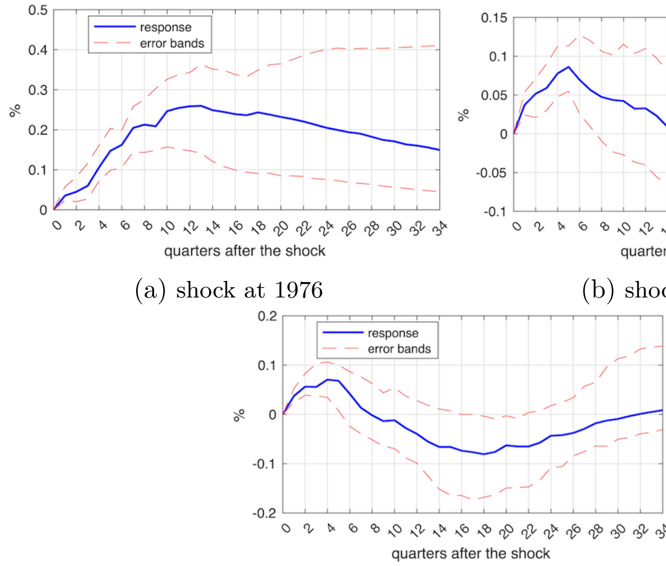


(d) shock: liquidity premium

Figure 2.1: Impulse responses of inflation to transitory shocks to the different variables of the model. Each panel displays the responses to shocks starting at 2000:Q1 and 2009:Q1 with the error bands of the shock at 2009:Q1. These graphs confirm that the responses of inflation to transitory shocks is not significantly different before and after the Great Recession.

that. Figure (2.3) shows the smaller short-run response of the liquidity premium to an FFR shock in the post-92 period.

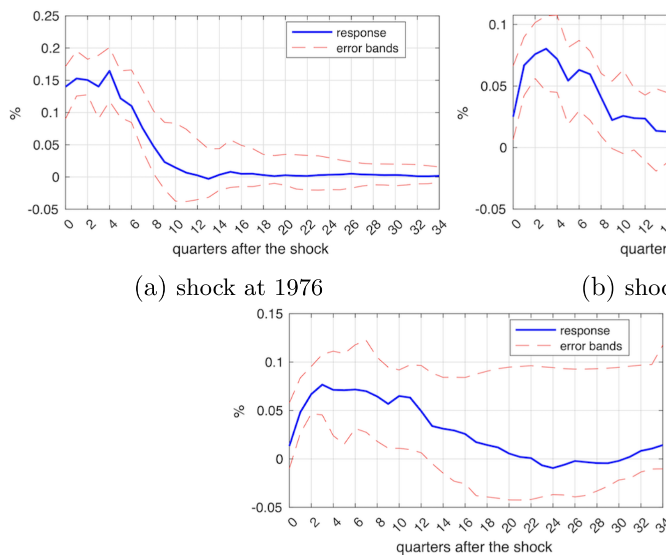
Finally, figure (2.4) indicates the impulse responses of the growth rate to FFR shocks at different points in time. This figure displays that the impulse response of the growth rate to an FFR shock has not been significantly different from zero in the post-2000s. The story was different prior to 1992 and panel (a) shows that in 1976, as an example, an increase in the FFR would cause a recession after two quarters. Additionally, and as shown, before the 2000s, inflation had a significantly larger and more persistent response to the growth rate. These results have an important policy implication. Prior to 1992, the growth rate responded negatively to an FFR shock and inflation responded positively to the changes in the growth rate; hence the FFR was a strong policy apparatus to manage inflation. In the post-2000s, the growth rate response to the FFR is insignificant and the policy rate was not successful in engineering inflation. I interpret this result as the market expectations being anchored by a strong and adamant Federal Reserve using all its power in keeping inflation close to the targeted level.



(a) shock at 1976 (b) shock at 2000

(c) shock at 2009

Figure 2.2: Impulse responses of inflation to transitory growth rate shocks. The impulse response of inflation to the growth rate in 1976 is an example of the responses of inflation before 1992, where the relationship changes significantly. The responses in panels (b) and (c) are not significantly different from one another.



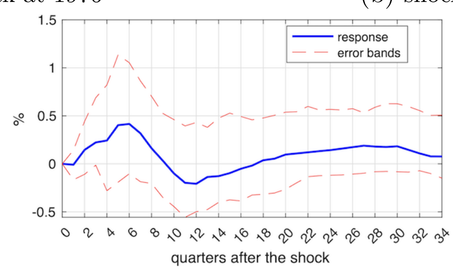
(a) shock at 1976 (b) shock at 2000

(c) shock at 2009

Figure 2.3: Impulse responses of the liquidity premium to transitory FFR shocks in different points in time. In the post-92 period, the liquidity premium was less responsive to the FFR compared to the earlier period.

(a) shock at 1976

(b) shock at 2000



(c) shock at 2009

Figure 2.4: Impulse responses of the growth rate to transitory FFR shocks in different points in time. On the one hand, comparing panels (b) and (c) show that this response in not significantly different from zero in the post-92 period. Panel (a) on the other hand indicates that the response of the growth rate to a transitory FFR shock was significantly negative in 1976 as an example of the period before 1992. This has changed from 1992 (graphs not provided) prior to which this response has been significantly negative in the short- and medium-run with the strongest negative responses between 1967 (the earliest date I can study in this model) and 1984 (similar result in the mainstream model is attained).

2.1.2 Permanent Shocks

Due to the recursive form of the model and the ordering of the variables, I can study the permanent effects determined by the lower triangle of matrix A. Even though this model does not allow us to study the neo-Fisherian hypothesis prediction, the responses to the feasible permanent shocks give valuable insights into how the economy was working between 1967 and 2016. Matrix A can be summarized as,

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \alpha_{g\pi} & 1 & 0 & 0 \\ \alpha_{i\pi} & \alpha_{ig} & 1 & 0 \\ \alpha_{\ell\pi} & \alpha_{\ell g} & \alpha_{\ell i} & 1 \end{bmatrix} \tag{2.7}$$

where α_{qp} is the effect of variable p on variable q for $p, q \in \{\pi, g, i, \ell\}$.

Recall the reduced form of the model given in equation (2.1) and rewrite it in the following form,

$$\theta_t(L)\mathbf{y}_t = e_t \tag{2.8}$$

where for a VAR of order p,

$$\theta_t(L) = I - \theta_{1t}L - \cdots - \theta_{pt}L^p \tag{2.9}$$

and $V(e_t) = A_t\Sigma_t A_t'$, for matrices A_t and Σ_t given in equation (2.2). Following [27], I assume that the e_t innovations are time-varying transformations of the underlying structural shocks that satisfy $V(\varepsilon_t) = I_n$, thus,

$$e_t = \varphi_t\varepsilon_t, \quad \forall t$$

and φ_t is a non-singular matrix that satisfies $\varphi_t\varphi_t' = V(e_t)$. Given this normalization scheme, φ_t captures changes in the contributions of different structural shocks to the volatility in the innovations to the variables. Reform equation (2.8) to get,

$$\mathbf{X}_t = \Theta_t\mathbf{X}_{t-1} + De_t \tag{2.10}$$

where $\mathbf{X}_t = (x_t', x_{t-1}', \ldots, x_{t-p+1}')'$ and $D = (I, 0, \ldots, 0)'$ which have the same dimensions. Θ_t is the companion-form matrix derived from the autoregressive coefficients in equation (2.8). A standard local projection of equation (2.10) yields,

$$\frac{\partial x_{t+h}}{\partial e_t} = s_{n,n}(\Theta_t^h), \quad \forall t, h = 0, 1, 2, \ldots \tag{2.11}$$

where $s_{i,j}(.)$ is a selector function defined by [21] and it selects the first i rows and j columns of a matrix and h is the horizon of the impulse response. Application of the chain rule yields the impulse responses at some arbitrary horizon h given by,

$$\frac{\partial x_{t+h}}{\partial \varepsilon_t} = \frac{\partial x_{t+h}}{\partial e_t}\frac{\partial e_t}{\partial \varepsilon_t} = s_{n,n}(\Theta_t^h)\varphi_t, \quad \forall t, h = 0, 1, 2, \ldots \tag{2.12}$$

The level effects, i.e., the permanent changes and their effects, require cumulative impulse responses which are obtained as follows. First, define $\bar{\Theta}_t^h = \sum_{j=0}^{h} \Theta_t^j$. The level response of each variable to each shock after h periods is the cumulative response of the differenced series from period zero to period h. Then, based on equation (2.12) the cumulative responses are given by,

$$M_{t,h} \equiv \sum_{j=0}^{h} s_{n,n}(\Theta_t^j)\varphi_t.$$

From the properties of the selector function, $M_{t,h} = s_{n,n}(\bar{\Theta}_t^h)\varphi_t$. Furthermore, letting $h \to \infty$,

$$M_t \equiv s_{n,n}(\bar{\Theta}_t^\infty)\varphi_t$$

is defined as time-varying matrix of long-run cumulative multipliers that measures the long-run effect of each shock on the corresponding variable. Let P stand for permanent and T stand for transitory, then the underlying structural shocks, $\varepsilon_t = (\varepsilon_t^P \varepsilon_t^T)'$, are identified by the assumption that a transitory shock does not affect the level of the shocked variable in the long run. This implies that the matrix of cumulative long-run multipliers is lower triangular. Thus, from the definition of M_t,

$$M_t M_t' = s_{n,n}(\bar{\Theta}_t^\infty)\varphi_t\varphi_t'[s_{n,n}(\bar{\Theta}_t^\infty)]' \tag{2.13}$$

and M_t is obtained as the Cholesky factor of the right-hand side of equation (2.13). Given M_t, one can solve for φ_t as a function of the parameters in the VAR model and obtain the structural impulse responses of each shock occurring at time t,

$$\frac{\partial x_{t+h}}{\partial \varepsilon_t} = s_{n,n}(\Theta_t^h)[s_{n,n}(\bar{\Theta}_t^\infty)]^{-1}M_t, \quad \forall t, h = 0, 1, 2, \ldots \tag{2.14}$$

Finally, the cumulative effects of the differenced variables gives the dynamic responses of each variable to each shock,

$$\frac{\partial(\pi_{t+h}, g_{t+h}, i_{t+h}, \ell_{t+h})}{\partial \varepsilon_t} = s_{n,n}(\bar{\Theta}_t^h)[s_{n,n}(\bar{\Theta}_t^\infty)]^{-1}M_t, \quad \forall t, h = 0, 1, 2, \ldots \tag{2.15}$$

Before showing the graphs, I summarize the long-run responses of the variables to permanent changes in the variables of the model in table (2.2). All the long-run relationships are changed either in size or significance for the post-92 period compared to the period before that. Tables (2.1) and (2.2) suggest that with a model that is not time-varying we need to study the period after the Great Recession separately from the 1970s and 1980s.

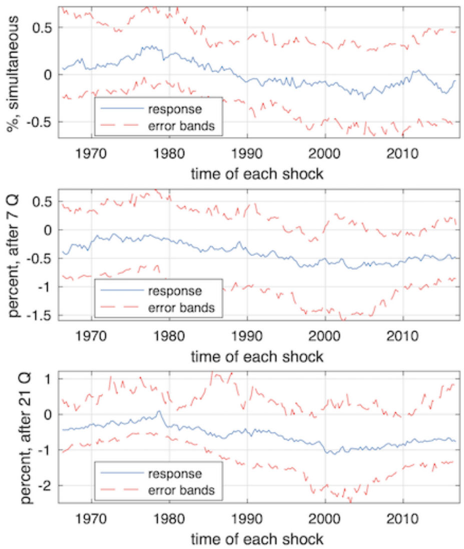
The third row of table (2.2) indicates that the Federal Reserve policy has been more actively responding to permanent changes in inflation and the growth rate. One fact shown by both the augmented and the mainstream empirical models is the long-run responses of the growth rate to permanent changes in inflation; a permanent high inflation affects the long-run growth rate negatively.[4] This has an important implication for the policymakers, both monetary and fiscal, that keeping inflation under control is important for well-being of the economy. Liquidity premium responses to the permanent shocks to the other variables of the model became smaller in both the short- and the long-run during the period of study as summarized in the last row of table (2.2).

impulse	inflation		growth rate		FFR		liquidity premium	
response	pre-92	post-92	pre-92	post-92	pre-92	post-92	pre-92	post-92
inflation	...	...	...	...	...	...	...	...
growth rate	nil	-	...	...	...	...	...	...
FFR	+ small	+	+ small	+	...	...	...	...
liquidity premium	- large	-	-	nil	+ large	+	...	...

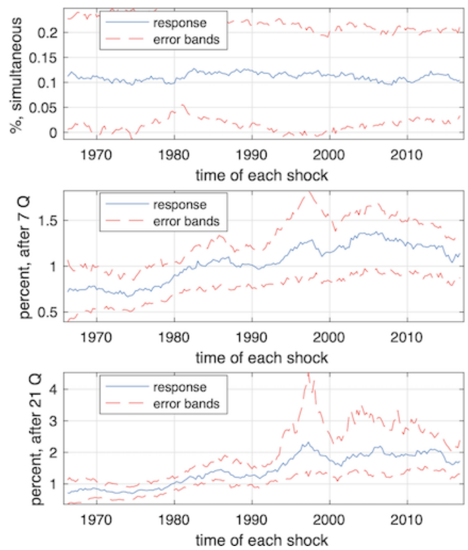
Table 2.2: Comparison of long-run responses, permanent shocks in the TVP-SVAR model.

Figures (2.5) and (2.6) display the responses of the variables of the model to permanent shocks. The simultaneous responses as well as the responses after 7 and 21 periods are presented here as examples of the short-, medium-, and long-run responses. This means each specified variable is permanently shocked at each point in time and the graphs in each panel show the simultaneous, the medium- and long-run responses of the respondent variable. Panel (a) of figure (2.5) shows the responses of the growth rate to permanent inflation shocks at different points in time. This panel suggests that the medium- and long-run behavior of the real side of the economy was getting more responsive to permanent changes in inflation until 2010. To make this claim clearer, figure (2.7) displays the responses of the growth rate to permanent inflation shocks at 1976:Q1 and 2009:Q1. This figure indicates that the medium- and long-run responses of the growth rate were not significantly different from zero in the pre-1992 period but in 2009, as an example of the post-92 era, they have been arguably negative. This is another important result in favor of the Federal Reserve's mandate to keep inflation under control and avoid letting it experience permanent hikes. The negative long-run response of the growth rate to a permanent inflation shock is confirmed in the mainstream model as well.

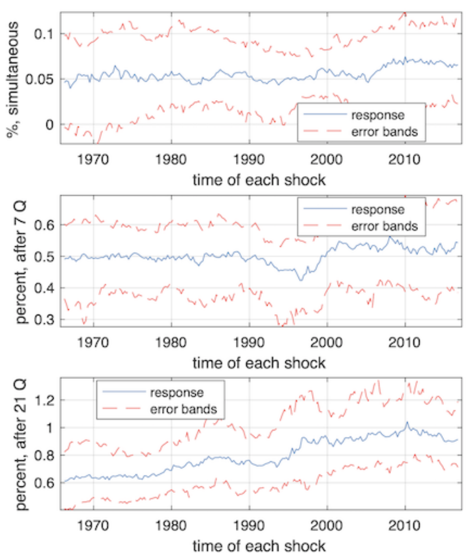
[4]Graphs of the mainstream model are presented in appendix (C).



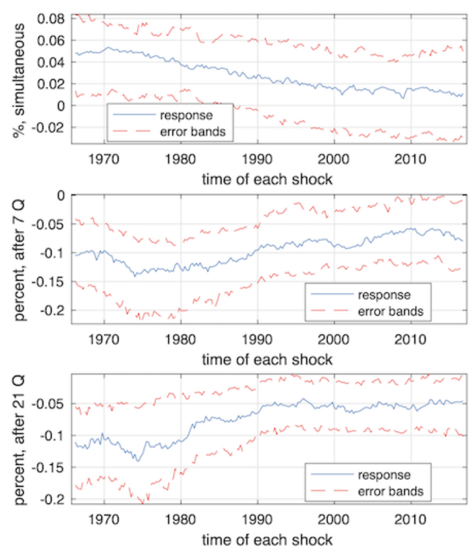
(a) shock: π; response: g



(b) shock: π; response: i

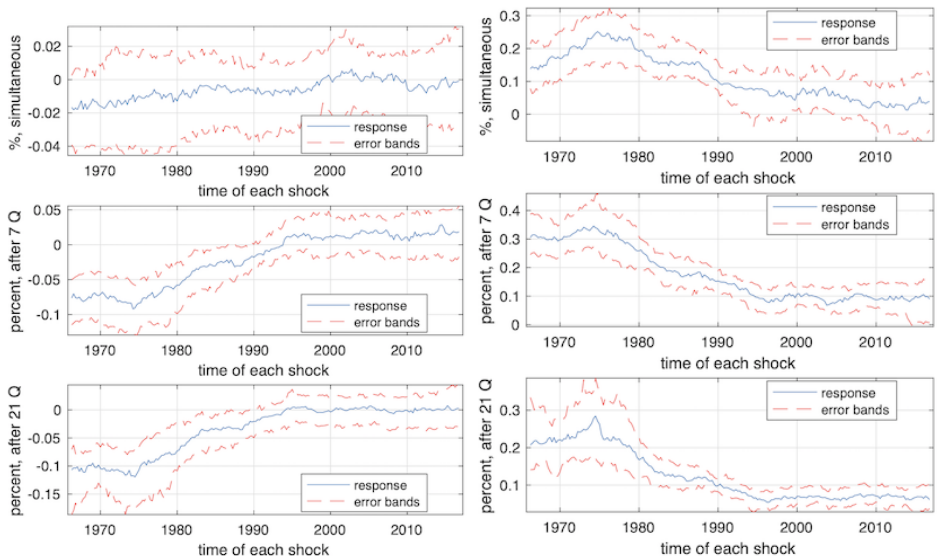


(c) shock: g; response: i



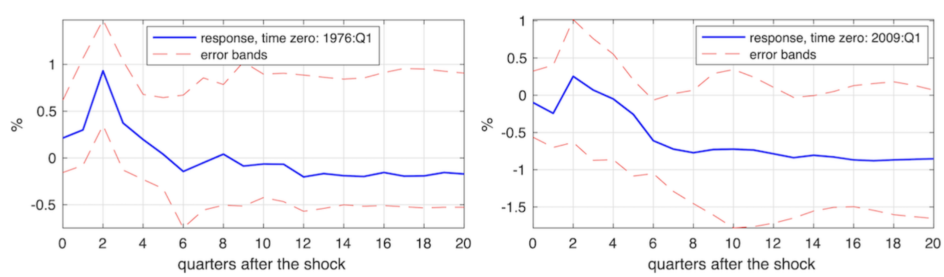
(d) shock: π; response: ℓ

Figure 2.5: Responses to permanent shocks. Each panel shows the responses of a variable to a permanent shock in another variable. The simultaneous, after 7 quarters, and after 21 quarters responses are presented here as examples of the short-, medium-, and long-run responses; they do not change after 21 quarters.



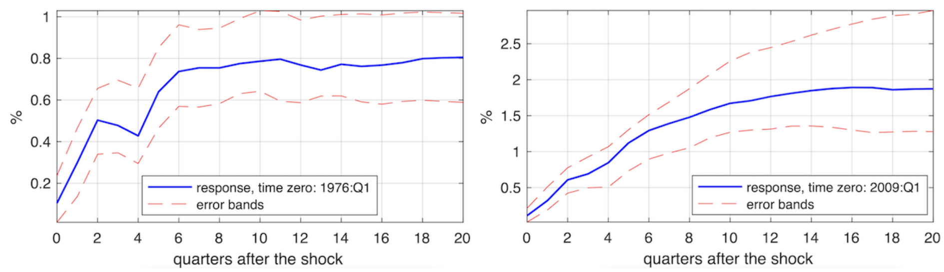
(a) shock: g; response: ℓ (b) shock: i; response: ℓ

Figure 2.6: Figure (2.5) continued.



(a) shock at 1976 (b) shock at 2009

Figure 2.7: Responses of the growth rate to permanent inflation shocks in 1976:Q1 and 2009:Q1.



(a) shock at 1976 (b) shock at 2009

Figure 2.8: Responses of the FFR to permanent inflation shocks in 1976:Q1 and 2009:Q1. These graphs confirm the more aggressive central bank responses to permanent inflation changes in 2009 compared to 1976. This result does not hold in the mainstream model shown in figure (C.4).

Panels (b) and (c) of figure (2.5) suggest that the monetary policy has been more reactive to the permanent changes in both inflation and the growth rate. Figure (2.8) displays the responses of inflation to permanent FFR shocks at 1976:Q1 and 2009:Q1 as examples of the two eras. This observation arguably supports the claim that the Federal Reserve has been intensely using its power to avoid high and volatile rates of inflation. Many authors including [36] have emphasized this fact. However, [36] finds that the 1960s and 1970s are not characterized by a violation of the Taylor principle, whereas I find that the long-run reaction of the central bank to permanent shifts in inflation were below one.

This result is consistent with a large part of the literature that has found an interest rate reaction to inflation lower than one before the beginning of the 1980s, for example, [26], [12], [15]. At the post-92 period, higher inflation is perceived as a systematic sign of economic disruption. This perception in turn affects the real side of the economy negatively and permanently in response to a permanently higher inflation. This discussion is different in the mainstream empirical model. The mainstream model indicates a one-for-one long-run response of the FFR to the permanent inflation shocks which has been constant throughout time.[5] Both the mainstream and the liquidity-augmented models show a more aggressive response of policy to the permanent growth rate shocks. Finally, the response of the liquidity premium to all the variables is smaller after mid-90s compared to the period before it.

[5]These different results of the two models are confirmed with the SLV model with details in section (3.1).

2.1.3 Comparing the Results from the Liquidity-Augmented Model and the Mainstream Empirical Model

This section summarizes the different results from estimating the liquidity-augmented and the mainstream models using the TVP-SVAR method. The figures related to the mainstream model results are illustrated in appendix (C). The transitory impulse responses show more volatile inflation in the mainstream model. In the mainstream model, the response of inflation to a transitory growth rate shock is significantly positive in the short- and medium-run. In the liquidity-augmented model this response is only positive in the short-run, dies out quickly and turns negative in the medium-run; leaving minimal effect on the path of the price level. One important feature of the liquidity-augmented model is solving the price puzzle in empirical macroeconomics. In an estimated mainstream model, the impulse response of inflation to a transitory FFR shock is significantly positive in the short- to medium-run; as is ubiquitous in the literature. This response is significantly larger in the pre-1992 period compared to the period after that. Conversely, the same function for the estimated liquidity-augmented model shows a nil response in the short-run that turns negative in the medium-run.

Interestingly and in terms of the long-run relationships, both the liquidity-augmented and the mainstream models show negative long-run responses of the growth rate to permanent inflation changes after 1992. This confirms that inflation has been an important signal of the stance of the economy in the post-92 period. This was not the case in the 1970s and 1980s with high and volatile inflation rates. The long-run response of the FFR to permanent inflation shocks in the mainstream model remains constant and not significantly different from one. In the liquidity-augmented model this response changes significantly. It is less than one in the pre-1992 period and it is significantly larger than one in the period after that.[6] Finally, the long-run response of the interest rate to a permanent growth rate shock is larger than one in the mainstream model with a slight increase throughout time. In the liquidity-augmented model, this response is significantly below one in the pre-1992 period and is close to one after that.

To summarize, comparing the results of the liquidity-augmented model and the mainstream empirical model indicates that the responses from a TVP-SVAR model in the liquidity-augmented model are consistent with our understanding of the economy as well as the changes in the behavior of the Federal Reserve Bank throughout time. The mainstream empirical model produces results that are harder to understand and likely associated with underlying misspecification.

[6] This is important in identification of the SLV model that follows. [40] assumes that inflation and the FFR move one-for-one in the long-run and the posterior supports the assumption. In the liquidity-augmented model I allow for a long-run relationship between the interest rate and the inflation rate that is not necessarily one-for-one; the result suggests that the posterior value is significantly different from one.

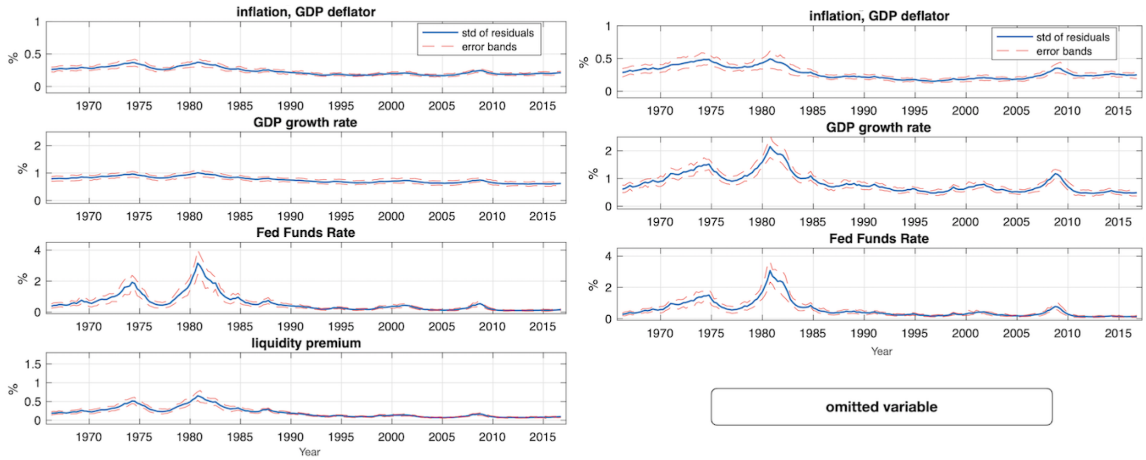
2.1.4 Empirical Evidence for the Importance of Including the Liquidity Premium

I use the TVP-SVAR model introduced in section (2.1) to show that the liquidity-augmented model captures the behavior of the macro-aggregates better than the mainstream models. A systematic behavior of a variable is defined as the value of that variable explained by the estimated parameters of a model. Hence, a non-systematic behavior is the part of the variable summarized in the error term. I show that inclusion of the liquidity premium makes the interactions of the variables more systematic than non-systematic. Furthermore, with nowcast drawings of the two models I show the liquidity-augmented model has improved the fit of the model to the data compared to the mainstream empirical models.

Figure (2.9) compares standard deviations of the residuals of equations of the two models. The right panel displays the posterior means, 16th and 84th percentiles of the residuals of equations for the mainstream model, and the left panel displays them for the augmented model including the liquidity premium. Both the right and left panels of the third graph, the FFR, indicate the non-systematic monetary policy around 1980 but the augmented model confirms a smaller volatility in this period. Similarly, they both confirm non-systematic monetary policy around the Great Recession.[7] Furthermore, figure (2.9) is consistent with an overall higher non-systematic behavior in the economy of 1970s and 1980s compared to the Great Recession period. It is also consistent with the finding of [36] in larger share of non-systematic policy (volatile residuals) in the first part of the sample. Comparing the residuals volatility of the two models for the growth rate and inflation is an observation in support of the liquidity-augmented model. The behaviors of these two variables show less non-systematic component throughout the sample compared to those of the mainstream model.

So far the discussion about non-systematic behaviors confirmed that the augmented model captures the economic turmoil of the 1970s and 1980s better than the mainstream model; the standard deviation of the residuals of the liquidity-augmented model are smaller and show fewer fluctuations. Furthermore, figure (2.10) shows the superiority of the augmented model in capturing the systematic behaviors during and after the Great Recession. In this figure, I calculate the average of the parameters from the estimated posteriors between 2007:Q1 and 2016:Q4 and impose this average as the model nowcast to compare the model outcomes and the actual data. The blue lines are the nowcast drawings and the red dashed lines depict the 86% confidence intervals of the these drawings. The red ellipses display how often the data, displayed in dash-dotted black lines, fall out of the confidence

[7] Apart from the non-systematic monetary policy, the other variables in the model show non-systematic behavior at the same time as monetary policy. This fact confirms that factors out of this model affect the economy. Coinciding these behaviors with the high crude oil prices might be one plausible explanation that I leave for future studies.

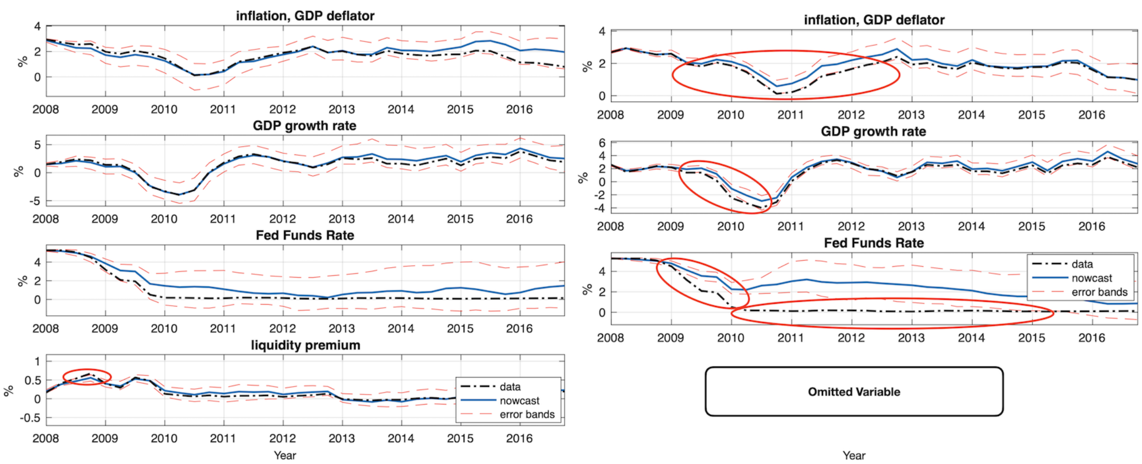


(a) Augmented model

(b) Mainstream empirical model

Figure 2.9: Posterior mean, 16th and 84th percentiles of the standard deviations of residuals of the equations, for the models with and without the liquidity premium. Comparing these graphs confirms non-systematic behavior of all the variables in late 1970s and early 1980s as well as during the Great Recession. Additionally, this comparison indicates that the augmented model captures more of the variables behaviors and finds less non-systematic behaviors, particularly for inflation and the growth rate. Variables of this figure contain year-over-year growth rate of GDP deflator and GDP, the FFR and the liquidity premium.

intervals of the nowcast drawings. This figure indicates that the augmented model is superior to the mainstream model in fitting the data of the post-Great-Recession. Appendix (C) contains drawings of figure (2.10) for different periods of time and with parameters from different eras.



(a) Augmented model (b) Mainstream empirical model

Figure 2.10: Nowcastings of the models using the average parameters from their respective posteriors between 2007:Q1–2016:Q4 to compare the data to the models and their 68% error bands. Red ellipses show where data falls out of 68% confidence intervals and it confirms that the augmented model does better in explaining the data. Robustness checks, taking posteriors from different time periods, indicate the superior fit to the data of the augmented model compared to the mainstream model, specifically for the post-Great-Recession era. Variables of this figure contain year-over-year growth rate of GDP deflator and GDP, the FFR and the liquidity premium.

Chapter 3

Short-run and Long-run Responses of Inflation to the Interest Rate Policy in a System of Latent Variables

3.1 System of Latent Variables

To study the effects of both transitory and permanent shocks, I use a system of latent variables (SLV) in the spirit of dynamic stochastic general equilibrium models following [40]. This also allows for more identified shocks than observable time series, and thereby has more flexibility than SVAR systems. I assume the variables of the model are driven by two nonstationary and three stationary shocks; X_t^m and X_t are the monetary and real nonstationary shocks; z_t^m, z_t and z_t^ℓ are the monetary, real, and liquidity stationary shocks. Several stationarity tests including [34], [31], and [47] confirm the stationarity of inflation and the FFR up to structural breaks. Presence and coincidence of these structural breaks allow me to follow [40] in finding a common nonstationary exogenous shock, up to a multiplying factor, driving inflation and the FFR, i.e., X_t^m. As mentioned, I use the results of the TVP-SVAR model in identifying this model. For the long-run movement of inflation and the interest rate, [40] assumes a one-for-one long-run comovement. He finds that the estimated value of the comovement is close to one which can be seen in a mainstream empirical model estimated using TVP-SVAR as well. However, a liquidity-augmented model estimates this movement significantly different from one as illustrated by figure (2.5). Accordingly, an identifying assumption in the estimation of the SLV model is that a one percent increase in the long-run component of inflation is accompanied by a 1.5 percent increase in the long-run component of the FFR.

I start the model with defining the vector of stationary variables as,

$$\mathbf{\hat{y}_t} = \begin{bmatrix} \hat{y}_t \\ \hat{\pi}_t \\ \hat{i}_t \\ \hat{\ell}_t \end{bmatrix} = \begin{bmatrix} y_t - X_t \\ \pi_t - \alpha X_t^m \\ i_t - X_t^m \\ \ell_t \end{bmatrix} \tag{3.1}$$

and it takes an autoregressive law of motion given by,

$$\begin{bmatrix} \hat{y}_t \\ \hat{\pi}_t \\ \hat{i}_t \\ \hat{\ell}_t \end{bmatrix} = \sum_{i=1}^{4} B_i \begin{bmatrix} \hat{y}_{t-1} \\ \hat{\pi}_{t-1} \\ \hat{i}_{t-1} \\ \hat{\ell}_{t-1} \end{bmatrix} + C \begin{bmatrix} \Delta X_t^m \\ z_t^m \\ \Delta X_t \\ z_t \\ z_t^\ell \end{bmatrix} \tag{3.2}$$

where $\Delta X_t^m \equiv X_t^m - X_{t-1}^m$, $\Delta X_t \equiv X_t - X_{t-1}$, and B_i and C are matrices of coefficients to be estimated. The laws of motion of driving forces are assumed to follow a univariate autoregressive form of order one,

$$\begin{bmatrix} \Delta X_{t+1}^m \\ z_{t+1}^m \\ \Delta X_{t+1} \\ z_{t+1} \\ z_{t+1}^\ell \end{bmatrix} = \rho \begin{bmatrix} \Delta X_t^m \\ z_t^m \\ \Delta X_t \\ z_t \\ z_t^\ell \end{bmatrix} + \psi \begin{bmatrix} \epsilon_{t+1}^1 \\ \epsilon_{t+1}^2 \\ \epsilon_{t+1}^3 \\ \epsilon_{t+1}^4 \\ \epsilon_{t+1}^5 \end{bmatrix} \tag{3.3}$$

where ρ and ψ are diagonal matrices of coefficients to be estimated and ϵ_t^i, $i = 1, \ldots, 5$ are i.i.d. disturbances distributed $N(\mathbf{0}, 1)$. This model is different from an SVAR so for the choice of the lags of the model to be included for estimation I follow [40] in including four lags.

I follow [40] in the identification assumptions; I assume a trend for output, X_t, a trend for the FFR, X_t^m which is scaled down by $\alpha = 0.67$ for the trend of inflation, as well as nonpositive effect of transitory shocks to the FFR on both inflation and the growth rate, $C_{12}, C_{22} \leq 0$. All the variables introduced in this model, except the liquidity premium, are unobservable and to estimate the model the vector of observable variables are defined by,

$$o_t = \begin{bmatrix} \Delta y_t \\ \Delta \pi_t \\ \Delta i_t \\ \hat{\ell}_t \end{bmatrix} + \mu_t \tag{3.4}$$

where,

$$\begin{aligned}\Delta y_t &= \hat{y}_t - \hat{y}_{t-1} + \Delta X_t \\ \Delta \pi_t &= \hat{\pi}_t - \hat{\pi}_{t-1} + \alpha \Delta X_t^m \\ \Delta i_t &= \hat{i}_t - \hat{i}_{t-1} + \Delta X_t^m\end{aligned} \tag{3.5}$$

and μ_t is a vector of measurement errors distributed i.i.d. $N(\mathbf{0}, R)$ and restricted to explain no more than 10 percent of the variance of the observables and R is a diagonal variance-covariance matrix. Notice that ℓ is a stationary spread and the assumption is that $\hat{\ell} = \ell$. The model is estimated using the Bayesian techniques and it uses Kalman filter to evaluate likelihood.[1] The prior distributions of the estimated parameters are summarized in table (3.1).

Parameter	Distribution	Mean	Standard Deviation
α	Normal	0.67	0.15
Diagonal elements of B_1	Normal	0.95	0.5
All other elements of B_i, $i = 1, \ldots, 4$	Normal	0	0.25
C_{21}, C_{31}	Normal	-1	1
$-C_{12}$, $-C_{22}$	Gamma	1	1
All other estimated elements of C	Normal	0	1
ψ_{ii}, $i = 1, \ldots, 5$	Gamma	1	1
ρ_{ii}, $i = 1, 2, 3$	Beta	0.3	0.2
ρ_{44}	Beta	0.7	0.2
ρ_{55}	Beta	0.2	0.2
R_{ii}, $i = 1, \ldots, 4$	Uniform $(0, \frac{var(o_t)}{10})$	$\frac{var(o_t)}{10 \times 2}$	$\frac{var(o_t)}{10 \times \sqrt{12}}$

Table 3.1: Prior distributions for the SLV model.

The prior for α is different from the identifying assumption of [40]'s model and I used the result of the previous section to set the prior mean of α different from one. The rest of the identifying assumptions in this section follow [40]. The prior distributions of all elements of B_i, $i = 1, \ldots, 4$, are assumed to be normal with nonzero values for the diagonal elements of B_1 and nil values for all other elements. The assumption here is that the elements of $\hat{\mathbf{y}}_\mathbf{t}$ follow univariate autoregressive processes at the mean of the prior distribution. A prior standard deviation of 0.5 to the diagonal elements of B_1 is imposed, which implies a coefficient of variation close to one half (0.5/0.95). As in the Minnesota prior, lower prior standard deviations on all other elements of the matrices B_i for $i = 1, \ldots, 4$ is imposed and set to 0.25.

[1] More details on the state space representation of the model and its exposition is presented in appendix (D).

A prior belief that the impact effect of a permanent interest rate shock on inflation, given by $1+C_{21}$ can be positive or negative with equal probability is imposed by $C_{21} \sim N(-1,1)$. The assumption for the effect of a permanent shock to inflation on interest rate is similarly imposed, i.e., $C_{31} \sim N(-1,1)$. The effects of transitory shocks are assumed to be nonpositive given by gamma prior distributions with mean and standard deviations of 1 for $-C_{12}$ and $-C_{22}$. In matrix C, elements C_{32}, C_{14}, and C_{45} are normalized to be unity and all other elements are assigned $N \sim (0,1)$. This set of normalization guarantees the transitory shocks each have an initial size of one percent.

The standard deviations of the five exogenous innovations in the AR(1) process in equation (3.3) given by elements of ψ_{ii}, $i = 1, \ldots, 5$, are all assigned gamma prior distributions with mean and standard deviation equal to 1. The serial correlations of the driving processes, ρ_{ii}, $i = 1, \ldots, 5$, have beta prior distributions with standard deviations of 0.2. The prior serial correlations of the two monetary shocks and the nonmonetary nonstationary shock have relatively small means of 0.3 and the stationary nonmonetary shock has a relatively high mean of 0.7. These last assumptions reflect the fact that the monetary shocks are serially uncorrelated and the growth rate of the stochastic trend of output has a small serial correlation whereas a stationary nonmonetary shock is persistent. The liquidity stationary shock is assumed to have a beta distribution with mean and standard deviation of 0.2 and this assumption uses the result of the impulse responses of the TVP-SVAR model. Finally, the variances of all measurement errors are assumed to have uniform prior distributions. They all are assumed to have lower bounds equal to zero and each of them has an upper bounds equal to 10 percent of the sample variance of the corresponding observable indicator.

The model is estimated with the Metropolis-Hastings sampler to construct a Monte Carlo Markov Chain (MCMC) of one million draws after burning the initial 100,000 draws, again following the procedure of [40]. Posterior means and error bands around the impulse responses shown in later sections are constructed from a random subsample of the MCMC chain of length 100,000 with replacement. Since in the TVP-SVAR model of section (2.1) I showed several relationships change after 1992, I estimate this model on the post-1992 data. Presence of the structural breaks in early 2000s as well as after the Great Recession make this subsample an appropriate choice for the SLV model while eliminating the pre-1992 period in which the economy was behaving differently. Allowing one structural break in each series using [7] method shows that the FFR and the liquidity premium each have a structural break at 2001:Q1, inflation has a structural break at 2004:Q1, and output has a structural break at 2008:Q2. Different specifications of the model as well as their estimations using the entire dataset, along with their details and results, are presented in appendix (E).

Before looking at the impulse responses, it is worth discussing the permanent component of inflation in the estimated model depicted in figure (3.1). This figure confirms that in the post-1992 period the permanent component of inflation was around 2% (which was the target of the Federal Reserve Bank after 2012). The nearly constant permanent component

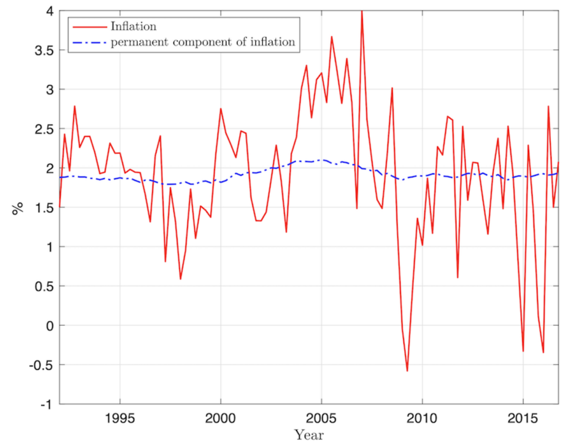


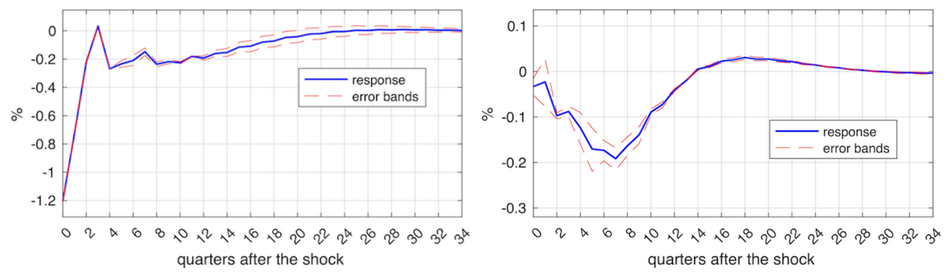
Figure 3.1: Inflation and its permanent component in the SLV model. The path of the permanent component of inflation is computed by Kalman smoothing and evaluating the empirical model at the posterior mean of the estimated parameter vector. The initial value of this component is normalized to make its average value equal to the average rate of inflation over the sample.

of inflation is the feature of the estimated model embodying the liquidity premium and the liquidity shock, as well as allowing the long-run relationship of the FFR and inflation to take a value other than one. I build up the estimated liquidity-augmented model from the mainstream model step-by-step to estimate four different models, as described in appendix (E). I call the mainstream model, the Base Case. Then the next model contains the liquidity premium as an added variable which I call the ℓ-Base Case. In the third model, I add a stationary liquidity shock, i.e., z^{ℓ}, and I call it the ℓ-Shock Case. Finally, the full model including the liquidity and the liquidity shock which allows α to take a value different from one is called the Full Case and this is the model I study in this section.[2] The Base, the ℓ-Base, and the ℓ-Shock Cases all show similar permanent components of inflation. These permanent components, shown in figure (E.1), are different from the one in figure (3.1). This means that the estimated liquidity-augmented model of this section is the only one that identifies inflation as a stationary variable around 2% after 1992.

3.1.1 Transitory Shocks

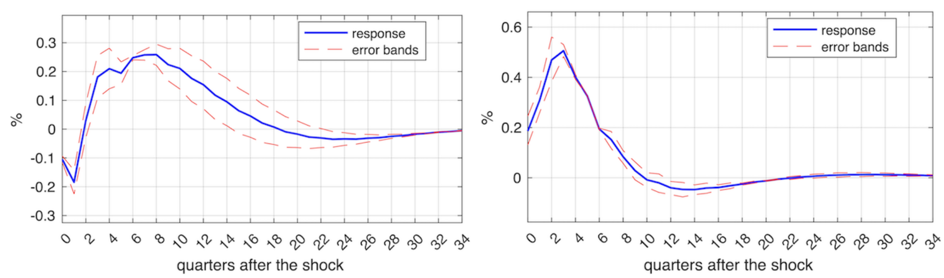
In this section, I focus on the effects of the transitory monetary and liquidity shocks on inflation and output. Recall that the transitory monetary and liquidity shocks in this model, i.e., z^m and z^{ℓ}, are normalized to cause an initial one percent increase in the interest rate and the liquidity premium respectively. Figure (3.2) displays mean posterior estimates of the responses of inflation to these two shocks, with 68% confidence intervals. Consistent

[2] All these models are estimated on the entire sample as well as the post-92 subsample for comparison.



(a) monetary shock (b) liquidity shock

Figure 3.2: Mean posteriors of the responses of inflation to transitory monetary and liquidity shocks.



(a) monetary shock (b) liquidity shock

Figure 3.3: Mean posteriors of the responses of output to transitory monetary and liquidity shocks.

with our understanding, one-time transitory shocks to the interest rate and the liquidity premium cause inflation to respond negatively, with a larger response to the interest rate compared to the liquidity premium.

Similarly, figure (3.3) shows the effect of a one percent shock to z^m and z^ℓ on output. The result of z^m is as expected; a transitory monetary shock has a short-run negative effect on output. The effect of z^ℓ might seem controversial since it is different from what the SVAR model predicts. The identification schemes of the TVP-SVAR and the SLV models are different with respect to the real side of the economy. The former model starts with the growth rate which is a stationary variable and the latter starts with the GDP and finds its nonstationary and stationary components using a Kalman filter. Furthermore, table (3.2) shows that the effect of a liquidity premium shock on output, despite its sign, is minuscule and only the nonmonetary shocks have sizeable effects on output.

3.1.2 Permanent Shocks

The permanent monetary shock in this model is imposed with an increase in X^m. The size of the permanent monetary shock is set to ensure that, on average, it leads to a one percent increase in the nominal interest rate in the long run. Recall that the long-run increase in

Figure 3.4: Mean posterior of the response of inflation to a permanent monetary shock.

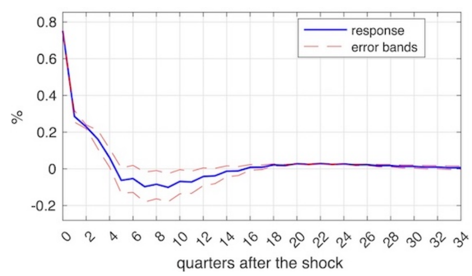


Figure 3.5: Mean posterior of the response of output to a permanent monetary shock.

inflation accompanied by a one percent increase in X^m has the size α and the estimated posterior value for α is 0.64. This is the value to which the response of inflation in figure (3.4) converges. Even-though the negative response of inflation to the permanent monetary shock dies out quickly and changes to positive, it is shown that the simultaneous response of inflation to a monetary shock regardless of the duration of the shock is negative. The short-run response of output to a permanent monetary shock is positive, but I will show that the effect of both types of the monetary shocks on the fluctuations of output are negligible in the following subsection.

3.1.3 Variance Decompositions

Where the Neo-Fisherian hypothesis and the conventional monetary understanding diverge is not only in the direction of the response of inflation to a permanent monetary policy shock, but also in the variance decomposition. Table (3.2) summarizes the effects of different shocks on the cyclical movements of each variable and figure (3.6) illustrates the forecast error variance decompositions. The cyclical movement of inflation is mostly explained by the changes in the permanent nonmonetary shock. The table shows that the nonstationary nonmonetary shock, X_t, explains about 84% of the fluctuations in inflation and the transitory monetary shock, z_t^m, explains about 10% of it. The effects of the nonstationary monetary and the stationary liquidity shocks, i.e., X_t^m and z_t^ℓ respectively, on inflation are minuscule. Inclusion of the liquidity premium and the transitory liquidity shock to the model is critical to conclude that the Neo-Fisherian hypothesis prediction does not hold in the US economy of the post-92 era. This brings us back to the conventional wisdom; a shock to the interest rate affects inflation negatively in the short-run and the two variables move in the same direction in the long-run, but not one-for-one.

As mentioned, appendix (E) summarizes the different versions of the SLV model estimated on the entire sample as well as the post-92 subsample. Comparing the results of these estimations allows us to conclude that the effect of the permanent monetary shock on inflation is smaller in the latter subsample. This result is consistent with the observations of the variables in post-92 and the stationarity of the variables in this period compared to the entire sample. With having this fact in mind, it is worth noting that minuscule effect of X_t^m on inflation is a feature of the liquidity-augmented model; estimating none of the other versions on the latter subsample changes the effect of the permanent monetary policy shock on inflation fluctuations to a negligible quantity. In one of the robustness checks presented in appendix (E), I show that the Neo-Fisherian hypothesis is not supported by the liquidity-augmented model estimated on the entire dataset and the sign of the response is not a result of truncating the data. Furthermore, I find that the effect of a change in the permanent component of the interest rate has a minuscule effect on the short-run variation in inflation at 0.7%, while [40] estimates it to be 45%.

	Δy_t	$\Delta \pi_t$	Δi_t	$\hat{\ell}_t$
Permanent monetary shock, ΔX_t^m	2.63	0.71	1.67	2.46
Transitory monetary shock, z_t^m	1.90	10.19	36.30	4.92
Permanent nonmonetary shock, ΔX_t	56.70	84.11	35.11	17.31
Transitory nonmonetary shock, z_t	36.74	4.19	22.20	13.41
Transitory liquidity shock, z_t^l	2.03	0.80	4.72	61.90

Table 3.2: Posterior mean, variance decompositions.

3.1.4 Comparing the Results from the Liquidity-Augmented Model and the Mainstream Empirical Model

In this section, I briefly discuss the differences between the results of the liquidity-augmented model and the mainstream model estimated using the SLV method.[3] Both the liquidity-augmented and the mainstream empirical models estimated on data from 1992 to 2016 show a negative short-run response of inflation to a transitory FFR shock with a larger

[3] The estimated mainstream model of this section is the replication of the [40] results with slight differences. First, the data I use cover 1992 to 2016 whereas [40] estimates the model on the data spanning from 1954 to 2018. I have estimated the model on the data from 1954 to 2016 too and the result is illustrated in appendix (E); this is similar to the result of [40]. Second, [40] uses per capita GDP and I use the aggregate GDP to be consistent with the TVP-SVAR model. I have shown that the result is not affected by using either measure.

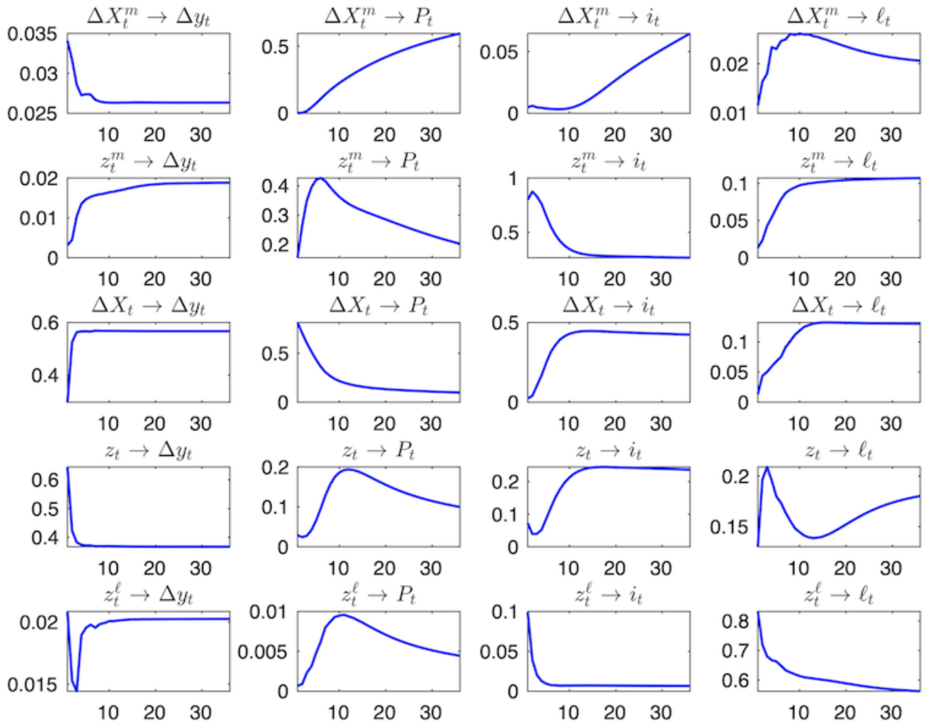


Figure 3.6: Forecast error variance decompositions.

response in the liquidity-augmented model. The major difference between the results is in the short-run response of inflation to permanent FFR shocks; the mainstream model shows a positive response of 0.47% and the liquidity-augmented model shows a negative response of -0.34%. These show that the inclusion of the liquidity premium invalidates the Neo-Fisherian hypothesis prediction of a positive short-run response of inflation to a permanent monetary policy shock.

Chapter 4

Identifying the Identifying Assumptions in a Liquidity-Augmented Fisher Equation

Recall the empirical method of section 2.1 with Cholesky identification in which the matrix of contemporaneous effects is lower triangular. [8] and [9] discuss how this identification scheme may be considered as dogmatic where certain elements of matrix $\mathbf{A}$ are known with certainty to be zero. This can be generalized with an informative prior that those elements of $\mathbf{A}$ are likely to be close to zero, though we are not completely certain they are exactly zero. The method I use in this chapter is based on [9] which follows this generalized identification scheme and once more I study short- and long-run responses of inflation policy shocks.

I begin with a dynamic structural VAR model of the form

$$\mathbf{A}\mathbf{y_t} = \mathbf{B}\mathbf{x_{t-1}} + \mathbf{u_t} \tag{4.1}$$

where $\mathbf{y_t}$ is an $(n \times 1)$ vector of observed variables, $\mathbf{A}$ is an $(n \times n)$ matrix of contemporaneous structural relations among the elements of $\mathbf{y_t}$, $\mathbf{x_{t-1}}$ is a $(k \times 1)$ vector of a constant and m lags of $\mathbf{y}$ with $k = mn + 1$, and $\mathbf{u_t}$ is an $(n \times 1)$ vector of structural disturbances. $\mathbf{D}$ is the diagonal variance matrix of $\mathbf{u_t}$.

Let $\mathbf{Y}_T = (\mathbf{y}_1', \mathbf{y}_2', \ldots, \mathbf{y}_T')'$ denote the vector of observed data. Given a distributional assumption for the structural shocks in equation (4.1), the likelihood function $p(\mathbf{Y}_T|\theta)$ can be calculated. For example, if $\mathbf{u}_t \sim N(\mathbf{0}, \mathbf{D})$,

$$\begin{aligned} p(\mathbf{Y}_T|\theta) =& (2\pi)^{-Tn/2} |\det(\mathbf{A}(\theta))|^T |\mathbf{D}(\theta)|^{-T/2} \times \\ & \exp\Big[-(1/2)\sum_{t=1}^{T}(\mathbf{A}(\theta)\mathbf{y}_t - \mathbf{B}(\theta)\mathbf{x}_{t-1})'\mathbf{D}(\theta)^{-1}(\mathbf{A}(\theta)\mathbf{y}_t - \mathbf{B}(\theta)\mathbf{x}_{t-1})\Big] \end{aligned}$$

where $|\det(\mathbf{A})|$ denotes the absolute value of the determinant of $\mathbf{A}$. Given a prior distribution $p(\theta)$, the Bayesian posterior distribution is

$$p(\theta|\mathbf{Y}_T) = \frac{p(\mathbf{Y}_T|\theta)p(\theta)}{\int p(\mathbf{Y}_T|\theta)p(\theta)d\theta}.$$

A suggested class of priors $p(\theta)$ and algorithm for generating draws $\{\mathbf{A}^{(\ell)}, \mathbf{D}^{(\ell)}, \mathbf{B}^{(\ell)}\}_{\ell=1}^{N}$ from the posterior distribution $p(\theta|\mathbf{Y}_T)$ that can handle most applications of interest is described and used as follows in this chapter.

Define the reduced form of equation (4.1) as,

$$\mathbf{y}_t = \mathbf{\Phi}\mathbf{x}_{t-1} + \varepsilon_t \tag{4.2}$$

where $\mathbf{\Phi} = \mathbf{A}^{-1}\mathbf{B}$ and $\varepsilon_t = \mathbf{A}^{-1}\mathbf{u}_t$ which is used to define the non-orthogonalized impulse response function at horizon s,

$$\mathbf{\Psi}_s = \frac{\partial \mathbf{y}_{t+s}}{\partial \varepsilon_t'} \tag{4.3}$$

where $\mathbf{\Psi}_0 = I_n$ and $\mathbf{\Psi}_1$ is given by the first n rows and n columns of $\mathbf{A}^{-1}\mathbf{B}$.

As pointed out in the theory, I study the dynamics of,

$$i = \rho + \sigma g_c + \pi - \ell. \tag{4.4}$$

The model is a long-run one in which ρ and σ are constants and hence $\mathbf{y_t}$ in equation (4.1) is given by $\mathbf{y_t} = (\pi, g, i, \ell)'$.[1] The structural quarterly model will consist of:

$$\pi_t = \alpha_{\pi g} g_t + \alpha_{\pi i} i_t + \alpha_{\pi \ell} \ell_t + \mathbf{b}_1' \mathbf{x}_{t-1} + u_{1t} \tag{4.5}$$

$$g_t = \alpha_{g\pi} \pi_t + \alpha_{gi} i_t + \alpha_{g\ell} \ell_t + \mathbf{b}_2' \mathbf{x}_{t-1} + u_{2t} \tag{4.6}$$

$$i_t = \alpha_{i\pi} \pi_t + \alpha_{ig} g_t + \alpha_{i\ell} \ell_t + \mathbf{b}_3' \mathbf{x}_{t-1} + u_{3t} \tag{4.7}$$

$$\ell_t = \alpha_{\ell\pi} \pi_t + \alpha_{\ell g} g_t + \alpha_{\ell i} i_t + \mathbf{b}_4' \mathbf{x}_{t-1} + u_{4t} \tag{4.8}$$

and the contemporaneous structural coefficients are summarized in matrix $\mathbf{A}$,

$$\mathbf{A} = \begin{bmatrix} 1 & -\alpha_{\pi g} & -\alpha_{\pi i} & -\alpha_{\pi \ell} \\ -\alpha_{g\pi} & 1 & -\alpha_{gi} & -\alpha_{g\ell} \\ -\alpha_{i\pi} & -\alpha_{ig} & 1 & -\alpha_{i\ell} \\ -\alpha_{\ell\pi} & -\alpha_{\ell g} & -\alpha_{\ell i} & 1 \end{bmatrix}$$

[1] The identification scheme is not recursive and the ordering of the variables does not matter.

Finding the elements of matrix **A** requires additional information otherwise the model remains unidentified and there would be no basis for drawing conclusions. I follow the method of [8] and [9] in the identification of parameters claiming that we do know something about plausible values for these parameters, but do not know any of the values with certainty. I also use the results of the time-varying parameter structural vector autoregression (TVP-SVAR) model of [6] in assigning prior modes. Since this TVP-SVAR model has a recursive identification scheme, I put a relatively low confidence on these assumptions. In writing the prior, $p(\theta) = p(\mathbf{A})p(\mathbf{D}|\mathbf{A})p(\mathbf{B}|\mathbf{A},\mathbf{D})$, [8] assume an unrestricted functional form for $p(\mathbf{A})$ but those of $p(\mathbf{D}|\mathbf{A})$ and $p(\mathbf{B}|\mathbf{A},\mathbf{D})$ take the natural conjugate families form.

4.1 Prior Information about Contemporaneous Structural Effects

Following the prior assumption of [9] and the empirical result of [6], let,

$$i_t - i^* = (1-\rho)\psi^g(g_t - g^*) + (1-\rho)\psi^\pi(\pi_t - \pi^*) + \rho(i_{t-1} - i^*) + u_t^m \tag{4.9}$$

which also captures the desire of the Federal Reserve Bank in implementing changes gradually over time. I let the prior model of ψ^g to be 0.5 and that of ψ^π to be 1.5 with scale parameters of 0.4 and $\nu_\psi = 3$ degrees of freedom. This choice of the degrees of freedom for the t-student distribution allows for bigger tail probability compared to a normal distribution ($\nu_\psi \to \infty$). Both of these distributions are truncated to be positive. The smoothing parameter, ρ, is drawn from a Beta distribution prior with mean 0.5 and standard deviation 0.2. Table (4.1) summarizes the assumed prior distributions. Lastly, let $\alpha_{i\pi} = (1-\rho)\psi^\pi$ and $\alpha_{ig} = (1-\rho)\psi^g$ which make,

$$\mathbf{A} = \begin{bmatrix} 1 & -\alpha_{\pi g} & -\alpha_{\pi i} & -\alpha_{\pi \ell} \\ -\alpha_{g\pi} & 1 & -\alpha_{gi} & 0 \\ -(1-\rho)\psi^\pi & -(1-\rho)\psi^g & 1 & 0 \\ 0 & -\alpha_{\ell g} & -\alpha_{\ell i} & 1 \end{bmatrix}$$

As explained in [6], the data is truncated and covers 1992 to 2016. With this and with the nil effect of the interest rate on the growth rate driven from the TVP-SVAR, I let the prior mode of α_{gi} to be zero and assume no sign restriction. The same reason is behind the prior assumption for $\alpha_{g\pi}$. The Fed's responses to inflation and the growth rates are both standard in the literature and empirically shown in [6]. The choices of the priors for $\alpha_{\ell g}$ and $\alpha_{\ell i}$ follow the way the liquidity premium is defined and the empirical results of [6].

Parameter	Meaning	Prior mode	prior scale	sign restriction
		Student t distribution with 3 degrees of freedom		
$\alpha_{\pi g}$	effect of growth on inflation	0.5	0.4	$\alpha_{\pi g} \geq 0$
$\alpha_{\pi i}$	effect of interest on inflation	0	0.4	none
$\alpha_{\pi \ell}$	effect of liquidity premium on inflation	0.1	0.4	$\alpha_{\pi \ell} \geq 0$
$\alpha_{g\pi}$	effect of inflation on growth	-0.5	0.4	$\alpha_{g\pi} \leq 0$
α_{gi}	effect of interest on growth	-0.5	0.4	$\alpha_{gi} \leq 0$
ψ^{π}	Fed's response to inflation	1.5	0.4	$\psi^{\pi} \geq 0$
ψ^{g}	Fed's response to growth	0.5	0.4	$\psi^{g} \geq 0$
$\alpha_{\ell g}$	effect of growth on liquidity premium	0	0.4	none
$\alpha_{\ell i}$	effect of interest on liquidity premium	-1	0.4	$\alpha_{\ell i} \leq 0$
		Beta distribution with $\alpha = 2.6$ and $\beta = 2.6$		
ρ	interest rate smoothing	0.5	0.2	$0 \leq \rho \leq 1$

Table 4.1: Priors for contemporaneous effects.

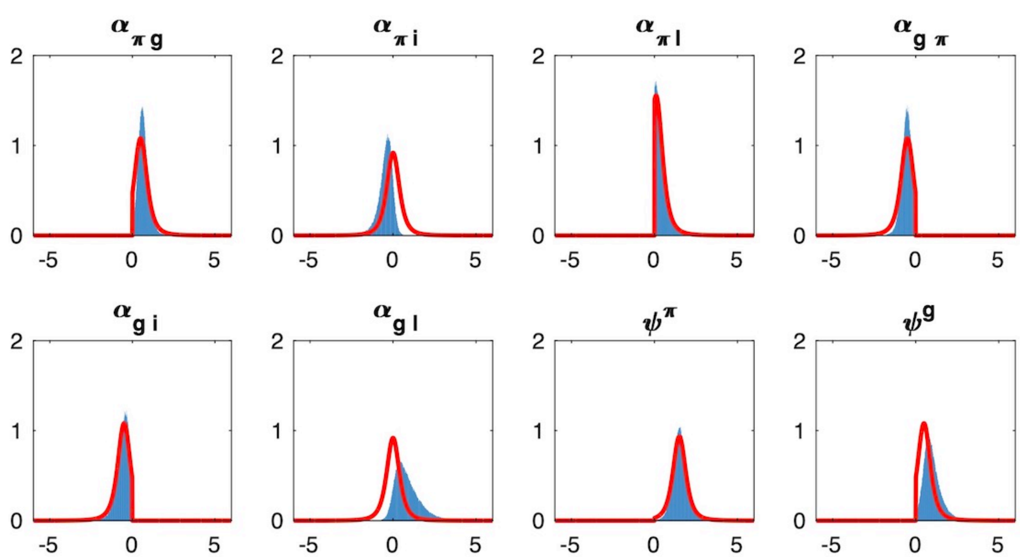


Figure 4.1: Prior distributions (red line) and posterior distributions (blue histogram) for contemporaneous coefficients.

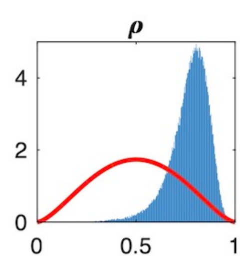


Figure 4.2: Prior distributions (red line) and posterior distributions (blue histogram) for ρ.

Figure (4.1) shows prior distributions (red line) and posterior distributions (blue histogram) for contemporaneous coefficients and figure (4.2) shows the same ones for ρ. The posterior effect of inflation on the liquidity premium (not shown here) is almost zero. The data turn out to be quite informative about the value of ρ but cause modest revisions in the prior beliefs of the other parameters. I started with a symmetric prior distribution with a mode of zero for the contemporaneous effect of the interest rate policy on inflation and the posterior, as expected, shows negative a response. The effect of the liquidity premium on the growth rate with a zero mode prior shows mostly positive posterior values. The smoothing parameter, ρ, has larger values than 0.5 which is similar to the results of [9]. The remaining parameters' posteriors are similar to the assumed priors.

Posterior impulse responses of inflation are depicted in figure (4.3). As expected, response of inflation to a one percent growth rate shock is positive and dies out in the medium run. The liquidity-augmented empirical model does not show a price puzzle in this empirical method either. Inflation falls after a one percent increase in the interest rate and reverts back to its original level in the short-run. A higher liquidity premium drives inflation up for a short period of time and then its effect changes to negative.

The impulse responses of the growth rate, the interest rate, and the liquidity premium are shown in figures (F.1) to (F.3). The response of the growth rate to an inflation shock is negative, to an interest rate hike is almost nil, and to the liquidity premium first nil and then negative in short- to medium-run. The result of the TVP-SVAR model of chapter (2.1) shows a nil response of the growth rate to the policy as well. Once the liquidity premium goes up, i.e., in a less liquid economy, the growth rate responds negatively in a less than a year.

The interest rate responds positively to all the shocks in the short-run. Its response to the liquidity premium dies out very quickly and becomes slightly negative in the medium-run. The liquidity premium has long-lasting responses. Its response to inflation is negative and its responses to the growth and interest rates are positive. A higher rate of inflation diverts individuals' preferences from holding on the liquid assets and it drives the liquidity premium down. Higher growth rates is associated with higher needs for the liquid assets and a higher rate of the nominal interest is associated with a larger spread between liquid and illiquid assets, hence a higher liquidity premium.

Figure (4.4) displays the historical decompositions of inflation in terms of the contributions of the separate shocks to the variables of the model. The red dashed line is the

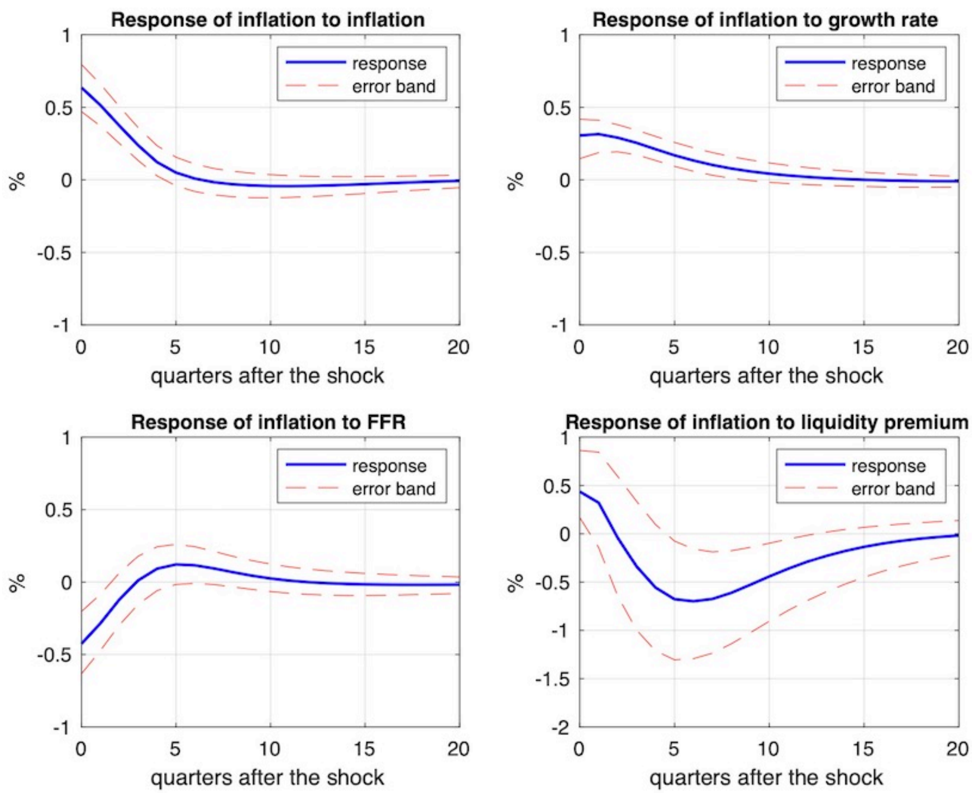


Figure 4.3: Posterior impulse responses of inflation to different shocks, median response and 68% confidence intervals.

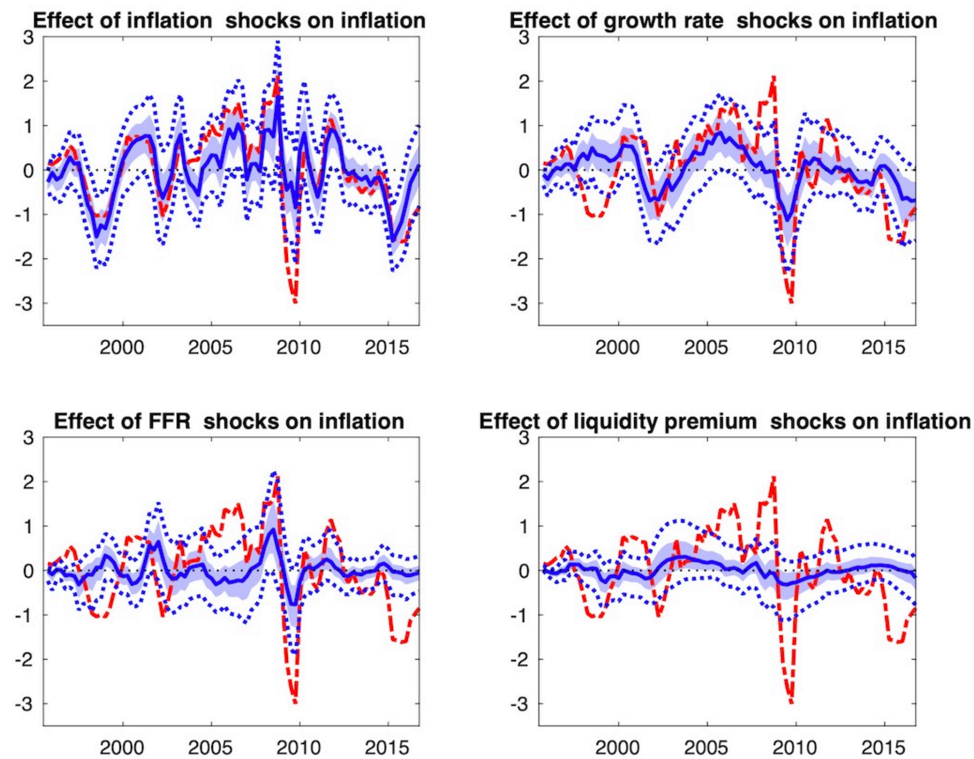


Figure 4.4: Portion of historical variation in inflation attributed to the shocks to each of the variables in the model. Dashed red line is the actual value of inflation deviation from its mean. Solid blue line is the portion attributed to the indicated shock. Shaded region is the 68% and the dotted blue lines are the the 95% posterior credibility sets.

observed value for inflation in deviation from the sample mean. The solid blue lines are the posterior median contribution of each shock over the 10 years prior to the indicated date. The shaded region and the dashed lines denote 68% and 95% posterior credibility regions, respectively.

Inflation and the growth rate shocks have the largest effects on the variations of inflation and the liquidity premium has the smallest effect in the period on 1992 to 2016. One observation is the direction of the effect of the interest rate shocks on inflation before and after the Great Recession. Before 2008, the deviation of inflation from its mean value and the interest rate shock move in the opposite direction. In the period of 2008 to 2010 these changes are mostly in the same direction and after that the effect of the interest shocks on inflation becomes almost nil.

Figure (4.5) shows the historical decompositions of the growth rate variation attributed to different shocks and its details are similar to figure (4.4). The growth rate is mostly affected by its own as well as inflation's variations and the effect of the monetary policy on its variations is mostly nil. Similar graphs for the interest rate and the liquidity premium are shown in figures (F.4) and (F.5). These figures show that the monetary policy has been responsive to the growth rate and inflation and not the liquidity premium as is specified in the mandate of the Fed. Lastly, the liquidity premium has been responsive to all three variables but its response to the interest rate has been mostly nil in the post Financial Crisis period.

To summarize the average contribution of different shocks using variance decompositions, table (4.2) reports the contribution of each of the shocks to the mean-squared error (MSE) of a one-year-ahead forecast of each variable. Estimated contribution of each shock to the 4-quarter-ahead MSE of each variable is shown in bold with its ratio to the total MSE in brackets. Numbers in parentheses indicate the 68% confidence intervals. Consistent with the results of the SLV model, inflation is mostly affected by inflation and growth rate shocks. The interest rate shock has a 7.4% of the total MSE of inflation.

	inflation shock	growth rate shock	interest rate shock	liquidity premium shock
inflation	**0.39** [62.31%]	**0.17** [27.61%]	**0.05** [7.4%]	**0.02** [2.67%]
	(0.27,0.55)	(0.07,0.32)	(0.02,0.13)	(0.01,0.04)
growth rate	**0.51** [42.17%]	**0.60** [49.45%]	**0.06** [4.68%]	**0.04** [3.7%]
	(0.26,0.82)	(0.37,0.89)	(0.02,0.13)	(0.01,0.12)
Fed Funds Rate	**0.03** [4.33%]	**0.26** [33.47%]	**0.48** [60.92%]	**0.01** [1.29%]
	(0.01,0.09)	(0.13,0.45)	(0.31,0.66)	(0,0.03)
liquidity premium	**0** [3.12%]	**0** [3.34%]	**0** [4.74%]	**0.02** [88.79%]
	(0,0)	(0,0)	(0,0)	(0.01,0.02)

Table 4.2: Decompositions of variance of 4-quarter-ahead forecast errors.

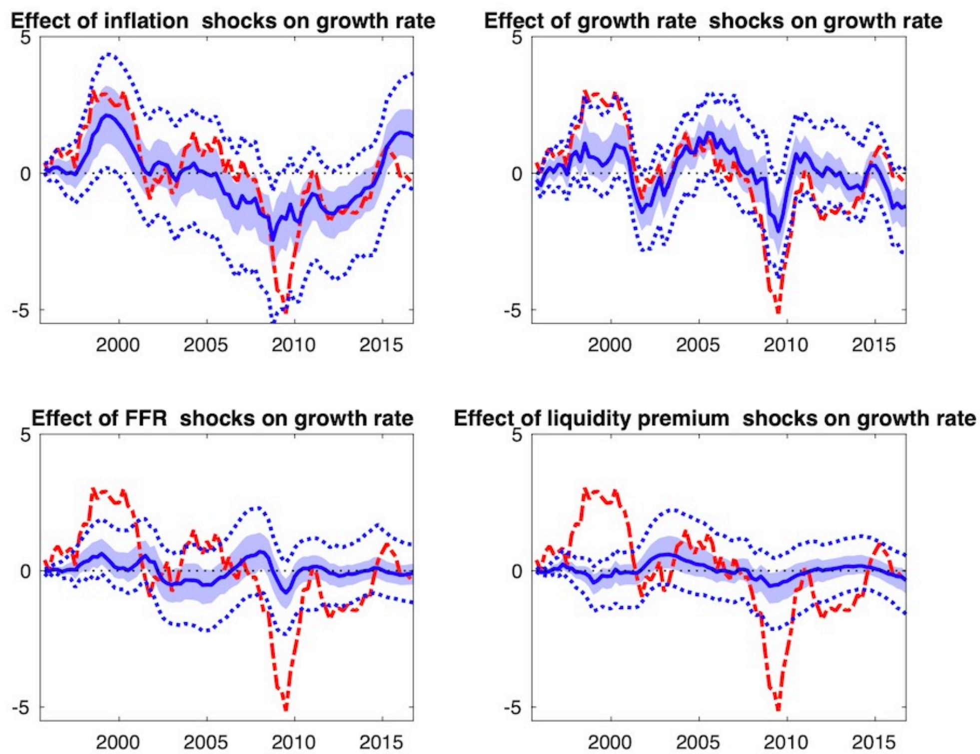


Figure 4.5: Portion of historical variation in the growth rate attributed to the shocks to each of the variables in the model. Dashed red line is the actual value of growth rate deviation from its mean. Solid blue line is the portion attributed to the indicated shock. Shaded region is the 68% and the dotted blue lines are the the 95% posterior credibility sets.

4.2 Conclusion

In this thesis, I study a liquidity-augmented model in the US economy of 1954 to 2016 using three empirical methods; a time-varying parameter vector autoregression, a system of latent variables, and a structural vector autoregressive model with doubtful identifying assumptions. The main focus here is to explain the short- and long-run behavior of inflation caused by changes in the Federal Funds Rate, i.e., the conventional monetary policy instrument. The results vary across eras with a main change in several impulse responses occurring in 1992. I find that the short-run response of inflation to an interest rate hike is negative to zero. In the long-run, inflation and the interest rate move in the same direction but not necessarily one-for-one.

The results lead to implications for policymakers, looking to maintain a stable path of inflation. In the post-Great-Recession period, monetary policy seemed incapable of increasing inflation to its 2% targeted level. The conventional wisdom explains it using the binding zero lower bound; because the interest rate was bound below at the 0% rate, it could not go lower to boost the economy and raise inflation. The Neo-Fisherian hypothesis suggests that a credible announcement of a gradual increase of the nominal interest rate from its zero lower bound would cause an immediate increase in inflation. In this study I showed that the Neo-Fisherian prediction is not supported by the US data of 1992 to 2016. The results suggest that the short-run response of inflation to an FFR hike is zero to negative regardless of the duration of the shock. However, because the two variables move in the same direction in the medium- to long-run, a permanent increase in the interest rate results in a higher rate of inflation after the short-run effect dies out.

The results also indicate that a central bank seeking to affect inflation via the interest rate required a more aggressive policy in the period of 1992 to 2016 compared to the period prior to 1992. The reason is that in the latter period, the inflation response to a transitory growth rate shock is less persistent and the response of the growth rate to a transitory FFR shock is nil. Furthermore, the response of the liquidity premium to a transitory FFR shock becomes significantly smaller after 1992 while remaining significantly positive in the short-run. An increase in the FFR through the open market operation reduces the availability of liquid assets in the economy and this is the time for economic agents to be willing to pay more for the liquidity benefits of the more liquid assets, hence a higher liquidity premium.

I do not find a Taylor type response of the interest rate to inflation in the period prior to 1980. Post 1980, the long-run response of the FFR to a one percent permanent increase in inflation has been greater than one. Hence, a Taylor type response of the policy is confirmed for the period after 1980 with an increase in its size around 1992.

One surprising result, regardless of inclusion of the liquidity premium in the empirical models, is the long-run response of the growth rate to a permanent change in inflation. A one percent permanent increase in inflation has a negative long-run effect on the growth rate after 1992. This means in the post-92 period inflation was not perceived as only a monetary phenomenon but also a signal to the economic agents for their long-run investment decisions. High and volatile inflation rates of the 1970s and 1980s were less of a signal about the status of the economy but that changed when a stable low inflation became the mandate of the Federal Reserve Bank.

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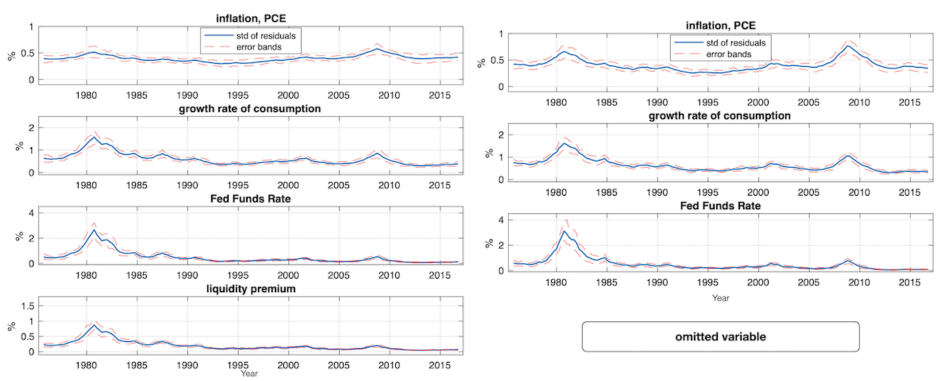
Appendix A

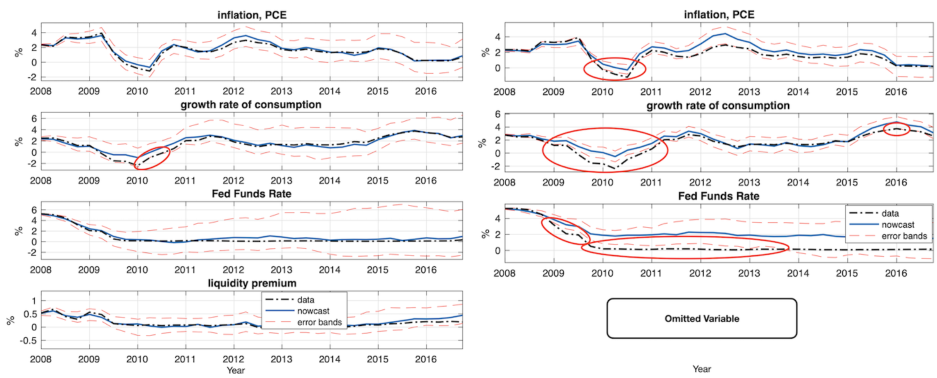
Liquidity Premium in a Model with PCE and PCE Price Index

To confirm the validity of the discussion in section (2.1.4) for a model containing Personal Consumption Expenditures and its related price index, this section provides the equivalent of the figures (2.9) and (2.10) for the new set of variables.



(a) Augmented model (b) Mainstream empirical model

Figure A.1: Posterior mean, 16th and 84th percentiles of the standard deviation of residuals of the equations in the models with and without the liquidity premium. Comparing these graphs confirms non-systematic behavior of all the variables in late 1970s and early 1980s as well as during the Great Recession. The third graph of the two panels show that the augmented model captures more of the monetary policy behavior and finds less non-systematic policy behavior.



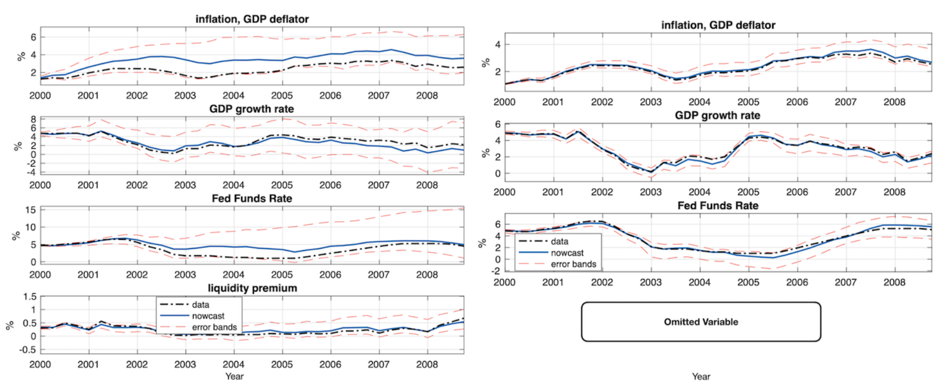
(a) Augmented model (b) Mainstream empirical model

Figure A.2: Nowcastings of the models using the average parameters from their respective posteriors between 2007:Q1–2016:Q4; comparing the data to the models and their 68% error bands. Red ellipses show where data falls out of 68% confidence intervals and it confirms that the augmented model does better in explaining the data of the post-Great-Recession era.

Appendix B

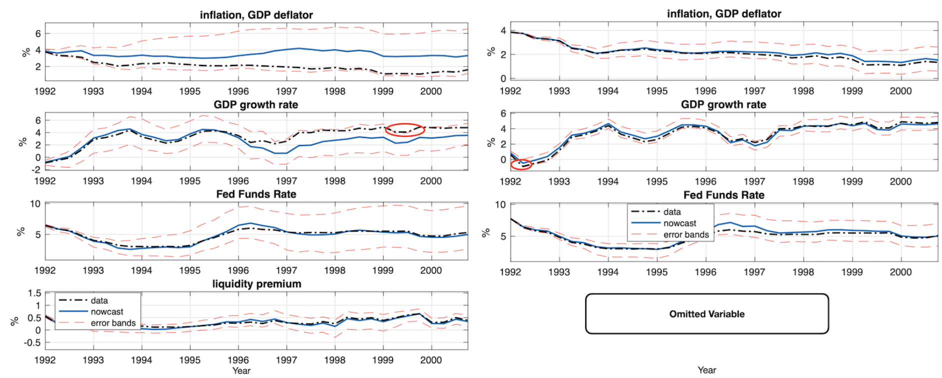
Robustness Check, Nowcasting of the Liquidity-Augmented and the Mainstream Models

This appendix contains the comparisons of the mainstream and the liquidity-augmented models in explaining the data using nowcasting. All graphs confirm that the liquidity-augmented model performs at least as well as the mainstream models with its absolute superiority in the post-Great-Recession period.



(a) Augmented model (b) Mainstream empirical model

Figure B.1: Nowcastings of the models using the average parameters from their respective posteriors between 2000:Q1–2008:Q4; comparing the data to the models and their 68% error bands.



(a) Augmented model (b) Mainstream empirical model

Figure B.2: Nowcastings of the models using the average parameters from their respective posteriors between 1992:Q1–2000:Q4; comparing the data to the models and their 68% error bands.

Appendix C

The TVP-SVAR Model Results for the Mainstream Model

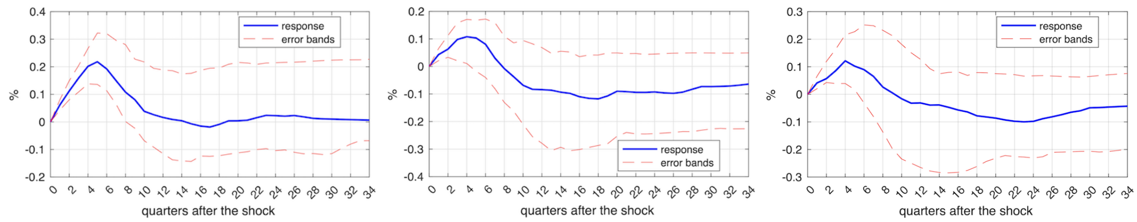
This appendix contains the graphs of an estimated mainstream model for the sake of comparing its results to those of the liquidity-augmented model. The summary of impulse responses to transitory and permanent shocks are presented in tables (C.1) and (C.2). Similar to the liquidity-augmented model, the red entries of these tables indicate where this model results in significant changes in the impulse responses in 1992. Figures (C.1) and (C.2) show the impulse responses for the cases in which there is a difference before and after 1992. Figure (C.3) shows the impulse responses of inflation to all three variables of the model for before and after the Great Recession. Finally, figure (C.4) shows the simultaneous, after 7 quarters, and after 21 quarters responses of the variables of the model to permanent shocks.

impulse	inflation		growth rate		FFR	
response	pre-92	post-92	pre-92	post-92	pre-92	post-92
inflation	+	+	+	+	+ large	+
growth rate	nil	nil	+	+	-	nil
FFR	+ persistent	+ persistent	+ persistent	+ persistent	+	+

Table C.1: Comparison of impulse responses, transitory shocks in TVP-SVAR.

impulse	inflation		growth rate		FFR	
response	pre-92	post-92	pre-92	post-92	pre-92	post-92
inflation	...	...	...	...	...	...
growth rate	nil	-	...	...	...	...
FFR	+	+	+	+	...	...

Table C.2: Comparison of long-run responses, permanent shocks in TVP-SVAR.

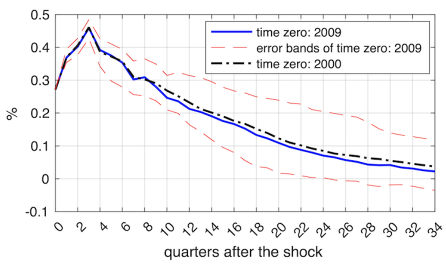


(a) shock at 1976 (b) shock at 2000 (c) shock at 2009

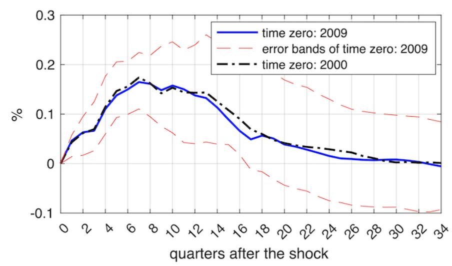
Figure C.1: Impulse responses of inflation to transitory FFR shocks at different points in time in the mainstream model. They all show the price puzzle with a larger response in the period before 1992.

(a) shock at 1976 (b) shock at 2000 (c) shock at 2009

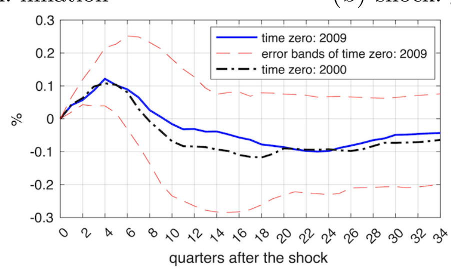
Figure C.2: Impulse responses of the growth rate to transitory FFR shocks at different points in time in the mainstream model. On the one hand, comparing panels (b) and (c) show that this response in not significantly different from zero in the post-92 period. Panel (a) on the other hand indicates that the response of the growth rate to a transitory FFR shock was significantly negative in 1976 as an example of the period before 1992. This has changed from 1992 (graphs not provided) prior to which this response has been significantly negative in the short- and medium-run with the strongest negative responses between 1967 (the earliest date I can study in this model) and 1984. This result holds in both the mainstream and the liquidity-augmented models.



(a) shock: inflation

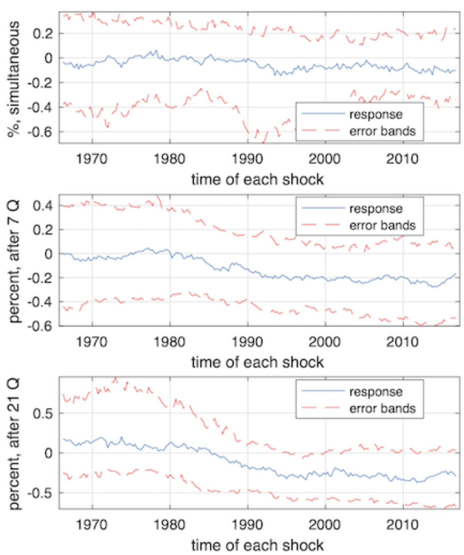


(b) shock: growth rate

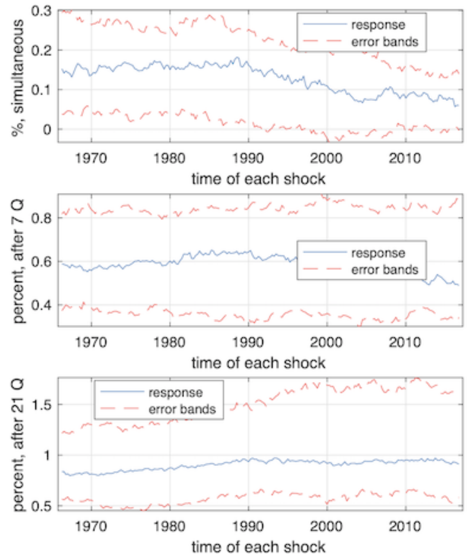


(c) shock: FFR

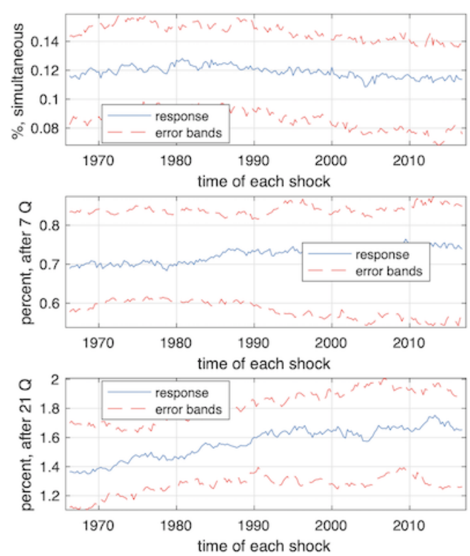
Figure C.3: Impulse responses of inflation to transitory shocks to the different variables of the model. Each panel shows the responses to shocks starting at 2000:Q1 and 2009:Q1 with the error bands of the shock at 2009:Q1. These graphs confirm that the responses of inflation to transitory shocks is not significantly different before and after the Great Recession.



(a) shock: π; response: g



(b) shock: π; response: i



(c) shock: g; response: i

Figure C.4: Responses to permanent shocks. The responses after 7 quarters is an example of the medium-run responses and responses after 21 quarters do not change, hence this one shows the long-run responses.

Appendix D

Detailed Exposition of the SLV Model

This part follows [40] and modifies the model and assumptions based on the number of variables and shocks in the model. Let Y_t be a vector collecting the model variables,

$$Y_t \equiv \begin{bmatrix} y_t \\ \pi_t \\ i_t \\ \ell_t \end{bmatrix}$$

where y_t denotes the logarithm of real output per capita, π_t denotes the inflation rate expressed in percent per year, and i_t denotes the nominal interest rate expressed in percent per year. Define $\tilde{Y}_t$

$$\tilde{Y}_t \equiv \begin{bmatrix} (y_t - X_t) \times 100 \\ \pi_t - \alpha X_t^m \\ i_t - X_t^m \\ l_t \end{bmatrix}$$

where X_t^m is a permanent monetary shock, α is scaling the effect of a one percent permanent change in the FFR to an α percent permanent change in inflation, z_t^m is a transitory monetary shock, X_t is a nonstationary nonmonetary shock, and z_t is a stationary nonmonetary shock. Let $\hat{Y}_t$ denote the deviation of $\tilde{Y}_t$ from its unconditional mean, that is,

$$\hat{Y}_t \equiv \begin{bmatrix} \hat{y}_t \\ \hat{\pi}_t \\ \hat{i}_t \\ \hat{\ell}_t \end{bmatrix} \equiv \tilde{Y}_t - \mathbb{E}\tilde{Y}_t$$

where $\mathbb{E}$ denotes the unconditional expectations operator.

The law of motion of $\hat{y}_t$ takes the autoregressive form,

$$\hat{y}_t = \sum_{i=1}^{L} B_i \hat{Y}_{t-1} + C u_t \tag{D.1}$$

where,

$$u_t \equiv \begin{bmatrix} x_t^m \\ z_t^m \\ x_t \\ z_t \\ z_t^\ell \end{bmatrix},$$

$$x_t^m \equiv \Delta X_t^m - \Delta X^m$$

and

$$x_t \equiv (\Delta X_t - \Delta X) \times 100$$

with Δ denoting the time-difference operator, $\Delta X^m \equiv \mathbb{E}\Delta X_t^m$ and $\Delta X \equiv \mathbb{E}\Delta X_t$. The variables x_t^m and x_t denote demeaned changes in the nonstationary shocks. The objects B_i, for $i = 1, \ldots, L$, are 4-by-4 matrices of coefficients, C is a 4-by-5 matrix of coefficients, and L is a scalar denoting the lag length of the model. The vector u_t is assumed to follow an AR(1) law of motion of the form,

$$u_{t+1} = \rho u_t + \psi \epsilon_{t+1}, \tag{D.2}$$

where ρ and ψ are 5-by-5 diagonal matrices of coefficients, and ϵ_t is a 5-by-1 i.i.d. disturbance distributed $N(\mathbf{0}, I)$.

The observable variables used in the estimation of the SLV model are output growth expressed in percent per quarter, the change in the nominal interest rate and the change in inflation. The following equations link the observables to the variables included in the unobservable system given by equations (D.1) and (D.2);

$$\begin{aligned} 100 \times \Delta y_t &= 100 \times \Delta X + \hat{y}_t - \hat{y}_{t-1} + x_t \\ \Delta \pi_t &= \alpha \Delta X^m + \hat{\pi}_t - \hat{\pi}_{t-1} + \alpha x_t^m \\ \Delta i_t &= \Delta X^m + \hat{i}_t - \hat{i}_{t-1} + x_t^m \end{aligned} \tag{D.3}$$

The variables Δy_t, $\Delta \pi_t$, and Δi_t are assumed to be observed with measurement error. Let o_t be the vector of variables observed in quarter t. Then,

$$o_t = \begin{bmatrix} 100 \times \Delta y_t \\ \Delta \pi_t \\ \Delta i_t \\ \hat{\ell}_t \end{bmatrix} + \mu_t \tag{D.4}$$

where μ_t is a 4-by-1 vector of measurement errors distributed i.i.d. $N(\mathbf{0}, R)$, and R is a diagonal variance-covariance matrix.

The state-space representation of the system composed of equations (D.1) to (D.4) can be written as follows:

$$\xi_{t+1} = F\xi_t + P\epsilon_{t+1}$$

and,

$$o_t = A' + H'\xi_t + \mu_t,$$

where,

$$\xi_t \equiv \begin{bmatrix} \hat{Y}_t \\ \hat{Y}_{t-1} \\ \vdots \\ \hat{Y}_{t-L-1} \\ u_t \end{bmatrix}.$$

The matrices F, P, A, and H are known functions of B_i for $i = 1, \ldots, L$, C, ρ, ψ, ΔX, and ΔX^m. Specifically, let,

$$B \equiv [B_1 \ldots B_L],$$

and let I_j denote an identity matrix of order j, 0_j denote a square matrix of order j with all entries equal to zero, and $0_{i,j}$ denote a matrix of order i-by-j with all entries equal to zero. Also let L, S, and V denote, respectively, the number of lags, the number of shocks, and the number of endogenous variables included in the model. Then, for $L \geq 2$ we have,

$$F = \begin{bmatrix} B & C\rho \\ \begin{bmatrix} I_{V(L-1)} & 0_{V(L-1),V} \end{bmatrix} & 0_{V(L-1),S} \\ 0_{S,VL} & \rho \end{bmatrix},$$

$$P = \begin{bmatrix} C\psi \\ 0_{V(L-1),S} \\ \psi \end{bmatrix},$$

$$A' = \begin{bmatrix} 100 \times \Delta X \\ \alpha \Delta X^m \\ \Delta X^m \\ 0 \end{bmatrix},$$

$$H' = \begin{bmatrix} M_\xi & 0_{V,V(L-2)} & M_u \end{bmatrix}$$

where, for S=5, V=4, and for the details of the SLV model considered here, matrices M_ξ and M_u are given by,

$$M_\xi = \begin{bmatrix} 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$M_u = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

and following [40] I let $L = 4$.

Appendix E

Different Versions of the SLV Model

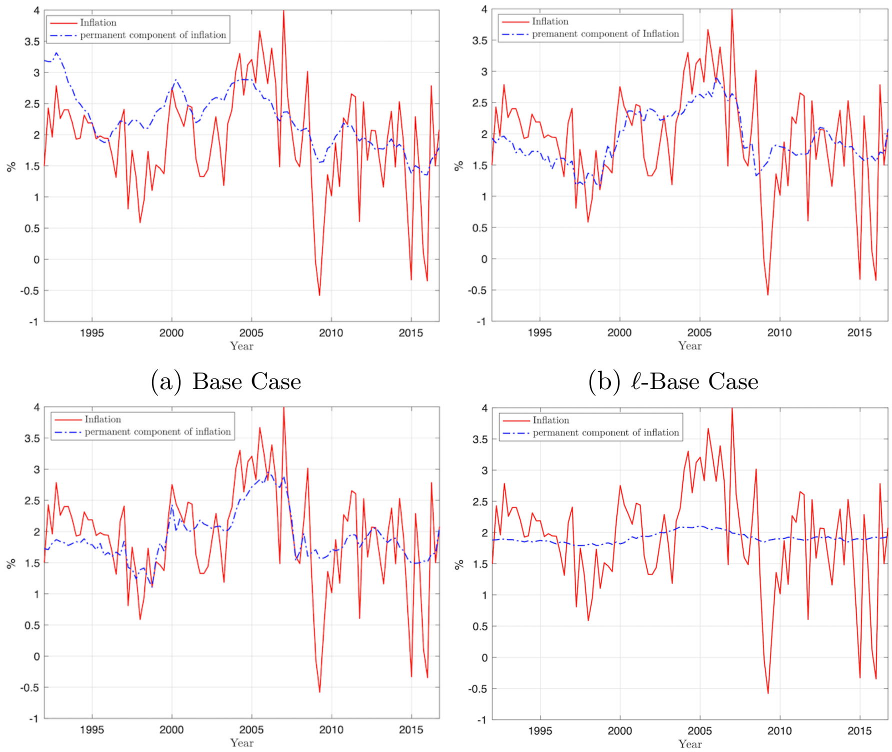
In order to evaluate the performance of the SLV specification of the liquidity-augmented model compared to the mainstream models, I estimate four version of the model; Base Case is the replication of [40]'s model; ℓ-Base Case extends the model to contain an extra variable; ℓ-Shock Case extends the base case to contain both the liquidity premium and the liquidity shock; and finally, Full Case is the SLV model introduced here which embodies both the liquidity premium and the liquidity shock and allows α to take a value different from one. This appendix briefly explains these specifications of the model and their results. In summary, the list of the cases is as follows:

- Base Case: [40]'s model;
- ℓ-Base Case: $\hat{\ell}$ is added;
- ℓ-Shock Case: $\hat{\ell}$ and z^{ℓ} are added;
- Full Case: $\hat{\ell}$, z^{ℓ} and α are added.

M_ξ and M_u matrices vary depending on the case. These matrices for the Full Case are defined in appendix (D). For the Base Case they are given as,

$$M_\xi = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \end{bmatrix},$$

$$M_u = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$



(a) Base Case (b) ℓ-Base Case

(c) ℓ-Shock Case (d) Full Case

Figure E.1: Inflation and its permanent component in different versions of the SLV model.

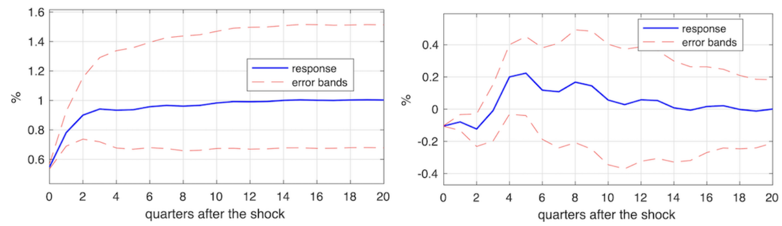
In ℓ-Base Case they are,

$$M_\xi = \begin{bmatrix} 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$M_u = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

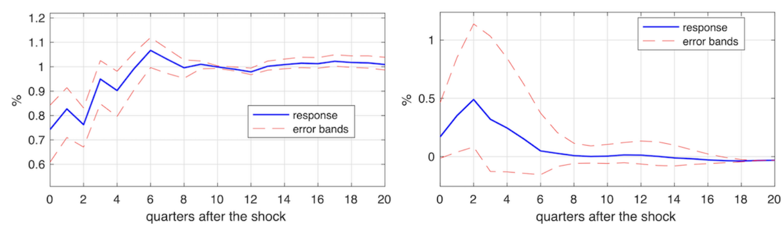
In ℓ-Shock Case M_ξ is the same as the one in ℓ-Base Case and M_u is given by,

$$M_u = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$



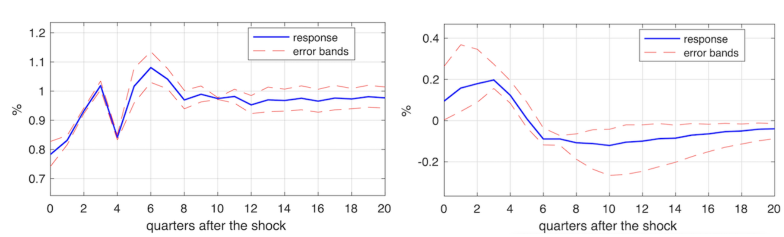
(a) permanent monetary shock (b) transitory monetary shock

Figure E.2: Mean posteriors of the inflation responses to permanent and transitory monetary shocks in the Base Case model estimated on the post-92 subsample.



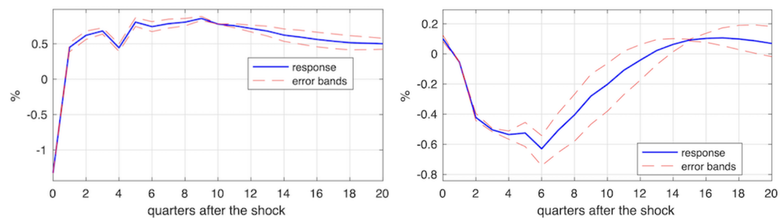
(a) permanent monetary shock (b) transitory monetary shock

Figure E.3: Mean posteriors of the inflation responses to permanent and transitory monetary shocks in the ℓ-Base Case model estimated on the post-92 subsample.



(a) permanent monetary shock (b) transitory monetary shock

Figure E.4: Mean posteriors of the inflation responses to permanent and transitory monetary shocks in the ℓ-Shock Case model estimated on the post-92 subsample.



(a) permanent monetary shock (b) transitory monetary shock

Figure E.5: Mean posteriors of the inflation responses to permanent and transitory monetary shocks in the Full Case model estimated on the entire sample. The instant response of inflation to a permanent monetary shock is negative and the fact that the findings do not support the prediction of the Neo-Fisherian hypothesis is not the result of truncating the data from 1992.

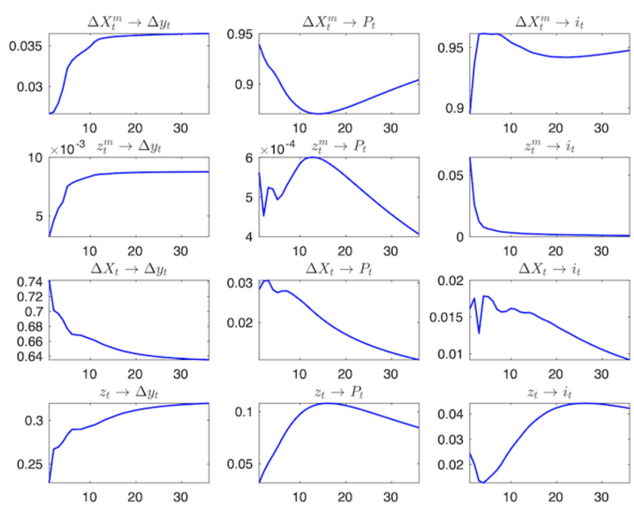


Figure E.6: Forecast error variance decompositions, Base Case estimated on the post-92 subsample.

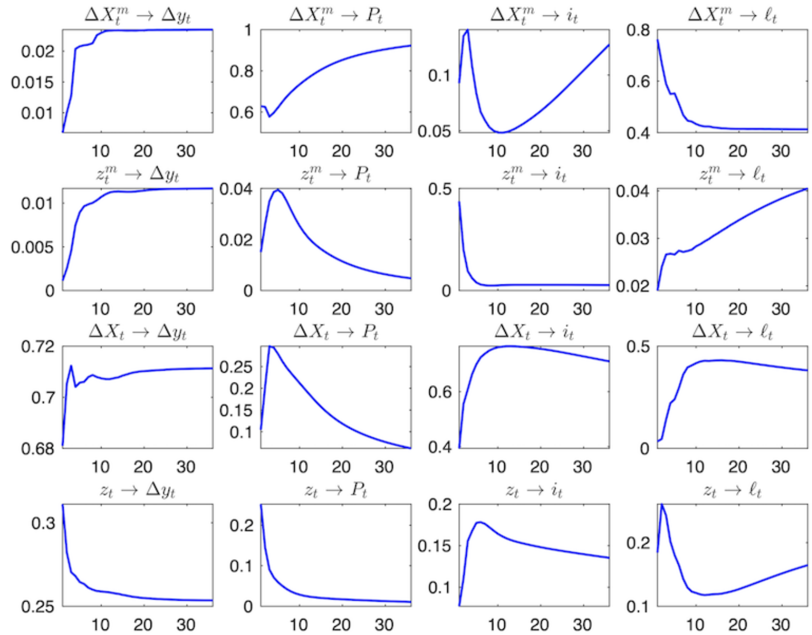


Figure E.7: Forecast error variance decompositions, ℓ-Base Case estimated on the post-92 subsample.

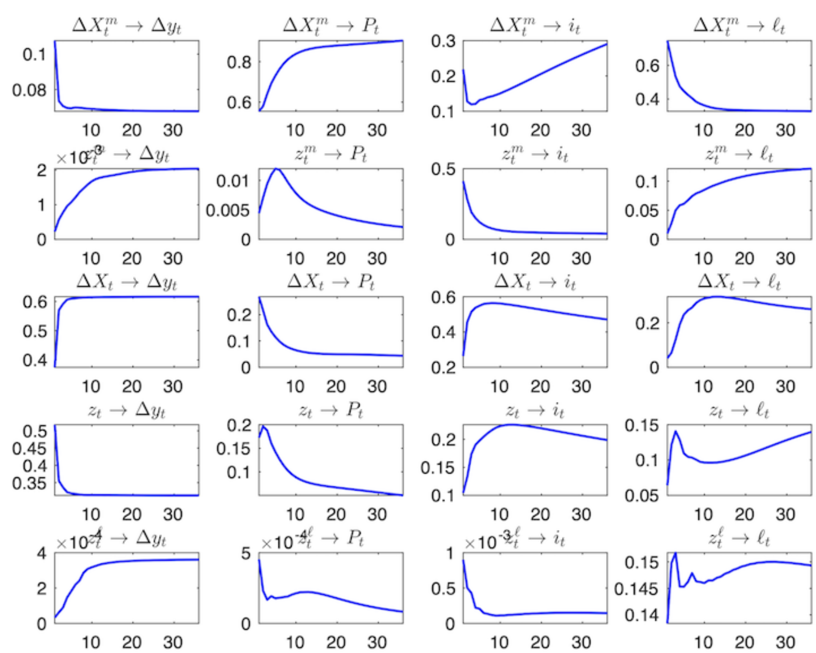


Figure E.8: Forecast error variance decompositions, ℓ-Shock Case estimated on the post-92 subsample.

Appendix F

Further Graphs of chapter 4

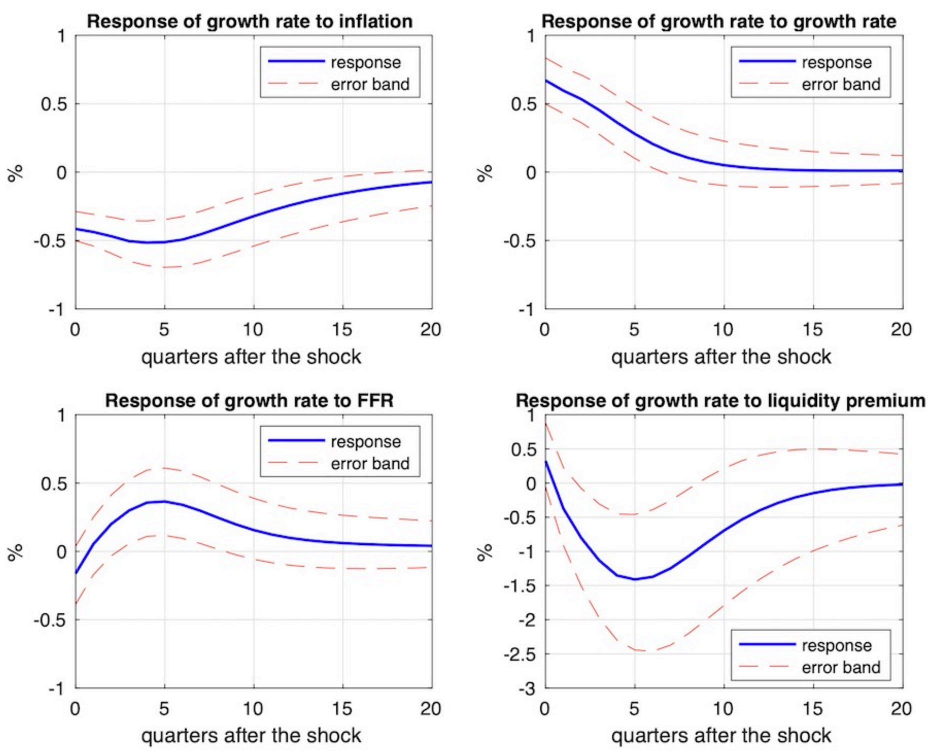


Figure F.1: Posterior impulse responses of the growth rate, median and 68% confidence intervals.

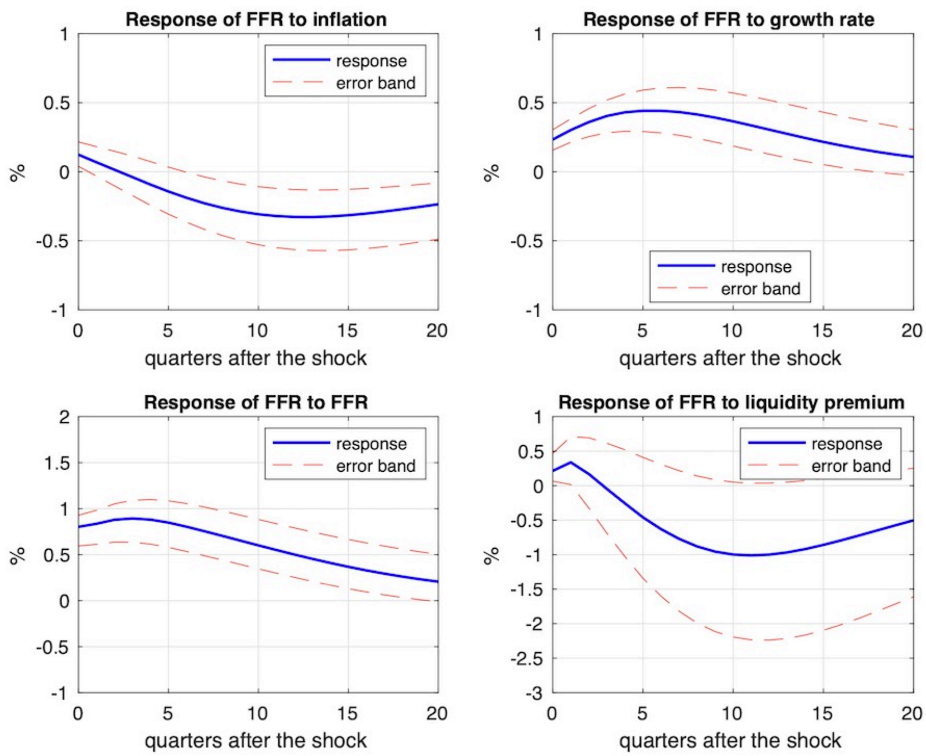


Figure F.2: Posterior impulse responses of the interest rate, median and 68% confidence intervals.

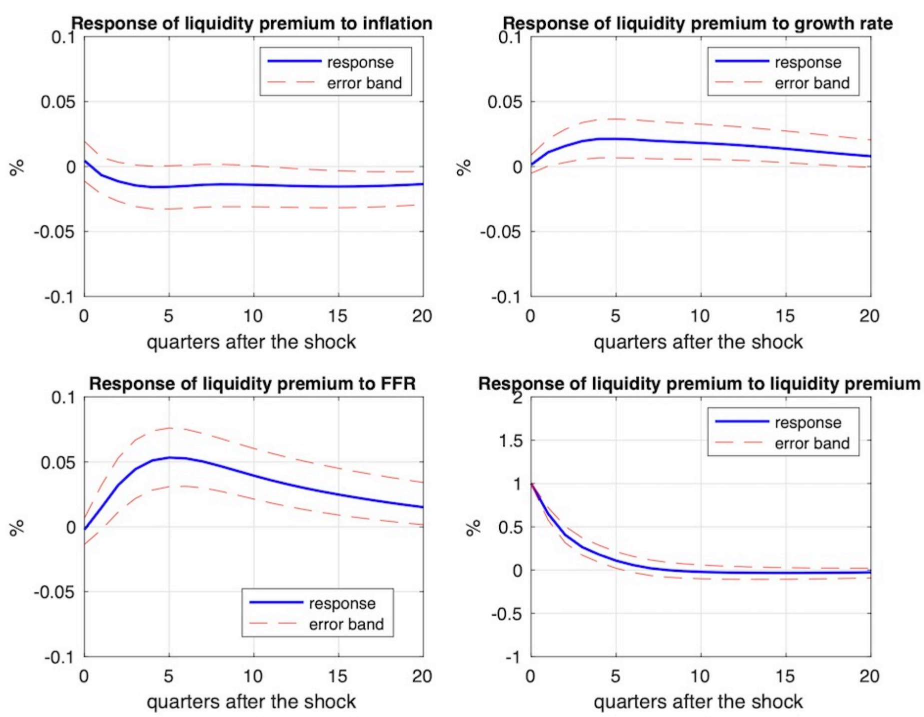


Figure F.3: Posterior impulse responses of the liquidity premium, median and 68% confidence intervals.

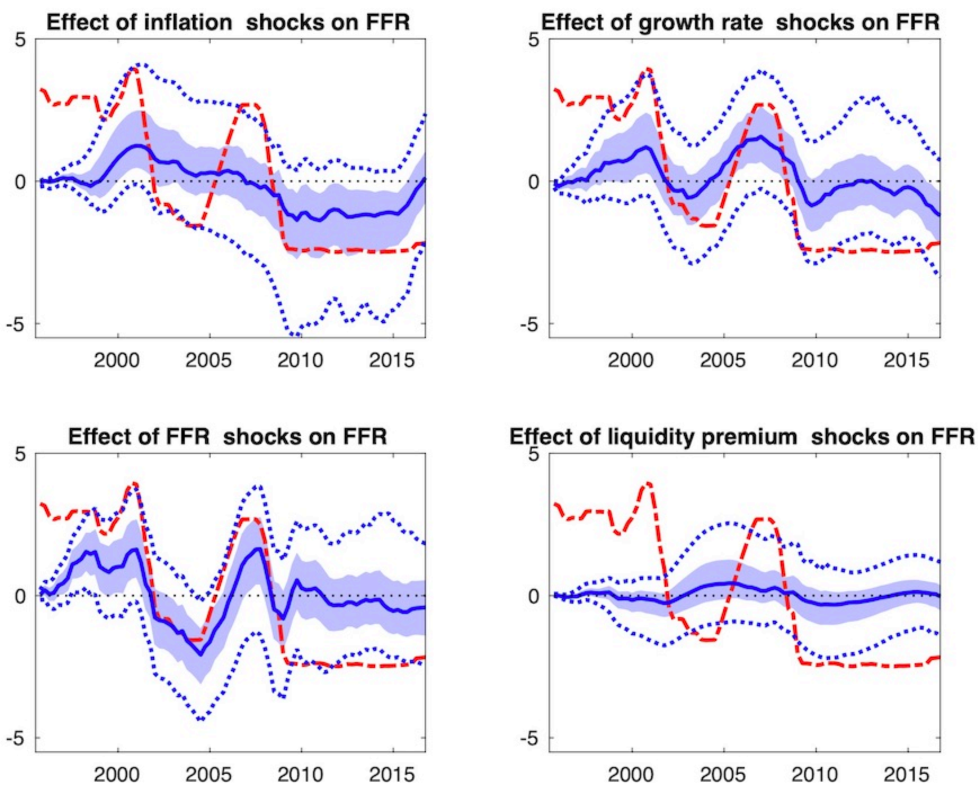


Figure F.4: Portion of historical variation in the interest rate attributed to the shocks to each of the variables in the model. Dashed red line is the actual value of interest rate deviation from its mean. Solid blue line is the portion attributed to the indicated shock. Shaded region is the 68% and the dotted blue lines are the the 95% posterior credibility sets.

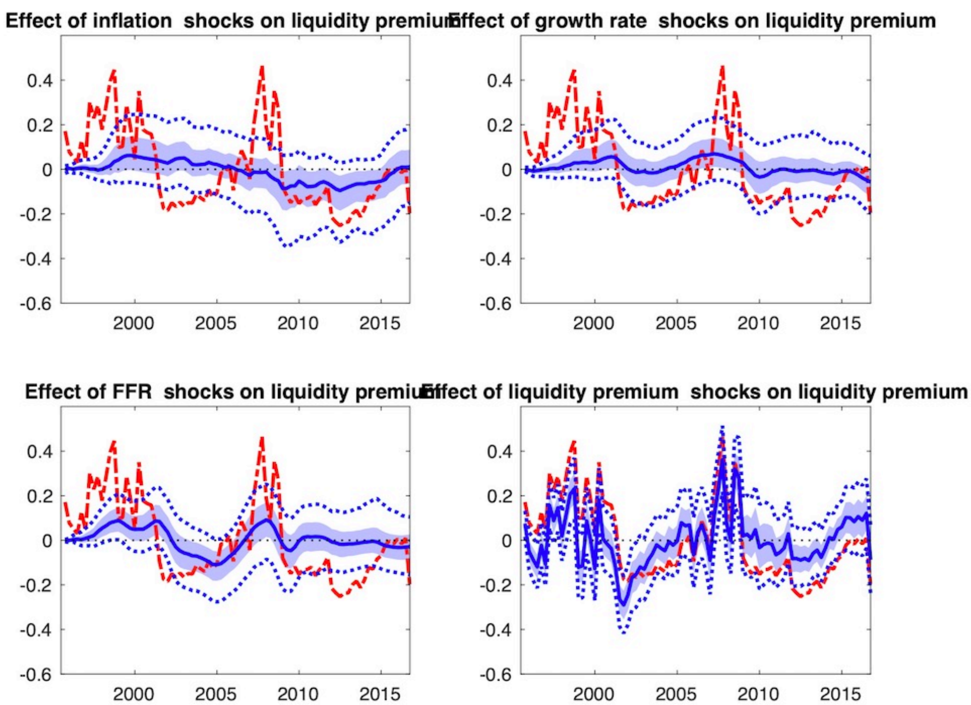


Figure F.5: Portion of historical variation in the liquidity premium attributed to the shocks to each of the variables in the model. Dashed red line is the actual value of liquidity premium deviation from its mean. Solid blue line is the portion attributed to the indicated shock. Shaded region is the 68% and the dotted blue lines are the the 95% posterior credibility sets.