Monetary Policy in Times of Fiscal Turbulence: A TVP-FAVAR Approach

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Abstract

We analyze how the response of macroeconomic variables to monetary policy in the US economy depends on fiscal policy using a factor augmented vector autoregressive model with drifting coefficients and stochastic volatility. The time varying structure of the model allows us to assess whether expansionary and contractionary fiscal shocks, identified with the narrative approach, affect the transmission of monetary policy shocks. When monetary policy shocks coincide with times of expansions in government spending and temporary transfers, their effects are weakened. Increases in permanent transfers modify less the demand effects of monetary policy shocks; while tax shocks do not alter the propagation of monetary policy shocks.

JEL codes: C32, E52, E62, E63, E65

Key words: fiscal policy shocks, monetary policy shocks, narrative evidence, TVP-FAVAR

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1 Introduction

After almost a decade stop at the zero lower bound, the Federal Reserve is normalizing the conduct of monetary policy and started to lift the interest rate. At the same time, the President announced \$ 1 trillion in investments in a national infrastructure program and more recently the Senate passed the "Tax Cuts and Jobs Acts", a tax reform that aims to cut the corporate tax rates and some income tax rates. Many policymakers are concerned about the effectiveness of monetary policy in these times of fiscal turbulence and understanding the dynamics of monetary policy in times of fiscal policy changes has recently become of great importance.

In this paper we evaluate how fiscal policy shocks determine the time-varying response of the US economy to monetary policy shocks. We define episodes of expansionary and contractionary fiscal policies based on large and exogenous variations in fiscal instruments (taxes, government spending and transfers), taking advantage of information from the narrative evidence developed "outside" the VAR. In these periods we assess the impulse response function of a monetary policy shock using a Time-Varying Parameter Factor Augmented VAR (TVP-FAVAR). When the economy is hit by fiscal shocks, the time-varying coefficients of the model capture the indirect effect of fiscal policy in the monetary transmission, amplifying or dampening the response of macroeconomic variables to monetary policy shocks, which we show are orthogonal to the fiscal policy shocks.

For our methodology to work it is crucial to insulate variations in fiscal variables, which are determined by discretionary and exogenous policy interventions. The action of automatic stabilizers, together with the endogenous and systemic response of fiscal authorities to cyclical conditions (Galí and Perotti (2003)), makes the dynamics of fiscal variables sensitive to economic conditions creating a tight interaction with monetary policy. For instance, contractionary monetary policy, which depresses the economic activity, leads to an expansion of the public deficit without any direct intervention of the fiscal authority by increasing the interest payments on the debt and unemployment benefits and reducing tax revenues. Further, higher interest payments tighten the government's intertemporal budget constraint inducing the fiscal authority to increase the primary balance. In order to address this issue, we rely on the narrative approach, which consists of selecting shifts in fiscal policy variables by reading official documents and other sources reporting not only the timing and the size of fiscal interventions but also their motivation, which allows to discriminate between endogenous and exogenous fiscal actions that are independent to the state of the economy.

We use different sources of narrative fiscal variables: Romer and Romer (2010) for tax shocks, Romer and Romer (2016) for transfers shocks and Ramey (2011) for government spending shocks. Romer and Romer (2010) identify tax shocks distinguishing exogenous tax variations to reduce public deficits (contractionary tax shocks) or spur long-term growth (expansionary tax shocks) from endogenous tax variations that are implemented for countercyclical purposes or to offset a change in government expenditure. In the same vein, Romer and Romer (2016) construct new series of permanent and temporary legislated increases in Social Security benefits excluding changes that extended the coverage, were retroactive and were implemented in response to cyclical fluctuations. Ramey (2011) extends the narrative approach of Ramey and Shapiro (1998) based on the "war dummy" variable, by constructing a defense news variable, which measures changes in the expected present value of government spending associated with military events.

The main contribution of this paper is to show that fiscal shocks can alter the transmission of monetary policy shocks in the US. This is particularly true for disturbances in government spending rather than tax shocks or permanent transfers shocks since the latter have a direct impact on aggregate demand which determines the response of unemployment to monetary policy. We find that the adjustment in labor market takes place not only through labor supply but also labor demand and that when contractionary monetary policy shock takes place in times of expansions of government spending their effects on consumption are less pronounced.

These results cannot be explained by standard real business cycle models which predict that monetary policy works mainly through the intertemporal substitution effect and fiscal policy through wealth effects induced by Ricardian equivalence. New Keynesian models with heterogeneous agents, such as Galí, López-Salido, and Vallés (2007) and Kaplan, Moll, and Violante (2017), can rationalize our results. An expansion in government spending has a positive impact on employment and consumption because of the presence of hand-to-mouth consumers who do not borrow or save. In particular, our findings lend support to the theoretical results of Kaplan, Moll, and Violante (2017) who show the importance of the indirect effect of monetary policy through labor demand and the response of fiscal policy.

Although in our study fiscal policy acts independently from monetary policy some of our findings in the aggregate confirm the predictions of their model. In particular, they show that the impact of monetary policy on consumption is stronger when there is an adjustment in government expenditure rather than in taxes. Similarly, we find that the transmission of monetary policy on industrial production, consumption and employment is not affected by the simultaneous presence tax shocks. We also show that the effect of a contractionary monetary policy shock can eb undone when the government raises surprisingly temporary transfers. Finally, we find that monetary policy strongly reacts to permanent transfers shocks, reconfirming the findings in Romer and Romer (2016), hence such shocks cannot counteract the effects of the tightening of monetary policy.

Most of the empirical studies used to evaluate the consequences of macroeconomic policies are based on structural vector autoregressions (SVARs), which recover orthogonal monetary and fiscal policy shocks to trace out alternately their impact on the economy. A few exceptions analyze the interactions between fiscal and monetary policy, i.e. the possibility that one policy reacts to the other one.[1] Canova and Pappa (2011), use different patterns of sign restrictions to study how the impact of a fiscal policy shock changes when monetary policy is accommodative or strongly reacts to inflation.[2] Gerba and Hauzenberger (2013) use a time-varying parameter VAR (TVP-VAR) model with fiscal and monetary policy shocks to assess how the interactions between fiscal and monetary policies changed over time. They identify different policy regimes and find that the response of fiscal policy variables to a monetary policy shock varies across regimes.

Several papers study how the transmission mechanism of monetary policy evolved over time using TVP-VAR models for the US economy due to structural changes (Cogley and Sargent (2005), Primiceri (2005), Canova and Gambetti (2006), Gambetti, Pappa, and Canova (2008), Benati (2008)). In this paper the time-varying structure of the model is crucial to assess to what extent fiscal policy shocks affect the propagation of monetary policy shocks.[3]

SVAR models including few time series are likely to suffer problems of omitted variables and information sufficiency (Forni and Gambetti (2014)), since monetary authorities have access to a much larger information set than the few variables included in the SVAR. Unobserved factors by summarizing the dynamics of a large number of variables can limit this issue.[4] Bernanke, Boivin, and Eliasz (2005) is the first paper that com-

[1]Leeper (1991) study the interactions between fiscal and monetary policy defining active and passive policy regimes. Traum and Yang (2011) estimate a New Keynesian model allowig for passive and active policy regimes in the US.

[2]On the theoretical side, Christiano, Eichenbaum, and Rebelo (2011) and Woodford (2011) study the impact of fiscal policy when monetary policy is constrained by the zero lower bound.

[3]Our approach can be thought similar to Galí and Gambetti (2015), who using a SVAR with time varying parameters, analyze the impact of a monetary policy shock in the presence of asset bubbles.

[4]Factor models have been increasingly employed in empirical analyses on the effects of monetary policy. See Bernanke and Boivin (2003) Favero and Marcellino (2001), Giannone, Reichlin, and Sala (2002), Giannone, Reichlin, and Sala (2005), Marcellino, Favero, and Neglia (2005),

bines VAR with factor analysis (FAVAR). We increment their model with time-varying parameters[5] and we follow their approach to identify a monetary policy shock based on the distinction between the reaction of slow-moving and fast-moving variables; we exploit the factor structure to assess the impulse response function on several variables, in order to investigate why the transmission mechanism of a monetary policy shock changes when it coincides with exogenous fiscal policy shocks.

The remainder of the paper is organized as follows: Section 2 introduces the TVP-FAVAR model and explains the estimation procedure; Section 3 discusses the joint identification of monetary and fiscal policy shocks; Section 4 describes the empirical results and Section 5 concludes.

2 Methodology

2.1 The Model

The TVP-FAVAR model is composed by a factor equation and a VAR equation. The factor equation is

$$x_t = \lambda^x f_t^x + \lambda^r r_t + u_t \tag{1}$$

where x_t is a (n x 1) vector collecting a large number of variables. This information set is summarized by a (k x 1) vector of unobserved factors f_t^x, which represent forces that affect the variables included in x_t simultaneously ($n >> k$). λ^x and λ^r are matrices of factor loadings of dimensions (n x k) and (n x 1) respectively, relating unobservable factors f_t^x and the federal funds rate r_t to x_t. The errors, u_t, have zero mean and covariance Ω, which is assumed to be diagonal, and are uncorrelated with the unobserved

Boivin, Kiley, and Mishkin (2010).

[5]See Eickmeier, Lemke, and Marcellino (2011), Korobilis (2013), Liu, Mumtaz, and Theophilopoulou (2011) for other applications of TVP-FAVAR models.

factors and the monetary policy instrument, r_t, at all leads and lags and are mutually uncorrelated at all leads and lags, namely $E[u_{i,t}f_t^x] = E[u_{i,t}r_t] = E[u_{i,t}u_{j,s}] = 0$ for all i, j=1,...,n and t,s=1,..,T with i≠j and t≠s.

Let $y_t' = [f_t^{x'}, r_t]$ a vector of dimension (q x 1) with q = k + 1, the TVP-FAVAR can be expressed as a VAR(p) process with drifting coefficients and stochastic volatilities describing the joint dynamics of y_t :

$$y_t = a_t + b_{1,t}y_{t-1} + ... + b_{p,t}y_{t-p} + v_t \tag{2}$$

where a_t is a (q x 1) vector of time varying intercepts, $b_{i,t}$ for i = 1,...,p is a (q x q) matrix of time-varying coefficients and v_t is a (q x 1) vector of residuals which follows a white noise Gaussian process with mean zero and covariance matrix Σ_t. The time varying intercepts and coefficients can be collected in B_t which follows a driftless random walk

$$B_t = B_{t-1} + \eta_t^B \tag{3}$$

where η_t^B is a Gaussian white noise process with zero mean and constant covariance matrix Γ, which determines the degree of variability of the coefficients. Following Primiceri (2005), we model the time variation of Σ_t as follows

$$\Sigma_t = A_t^{-1}H_tH_t'(A_t')^{-1} \tag{4}$$

We can express $v_t = A_t^{-1}H_t\epsilon_t$, where ϵ_t are the structural shocks with $E[\epsilon_t\epsilon_t'] = I_q$ and $E[\epsilon_t\epsilon_{t-k}'] = 0$. The contemporaneous relations of the shocks and the variables are represented through the matrix A_t of dimension (q x q). From the above triangular reduction it follows that

$$A_t = \begin{bmatrix} 1 & 0 & \dots & 0 \\ \alpha_{21,t} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{q1,t} & \dots & \alpha_{qq-1,t} & 1 \end{bmatrix} \quad ; \quad H_t = \begin{bmatrix} h_{1,t} & 0 & \dots & 0 \\ 0 & h_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & h_{q,t} \end{bmatrix}$$

We collect the non-zero elements $\alpha_{i,t}$ and $h_{i,t}$ into α_t and h_t and assume that they evolve as driftless random walks and geometric random walk, respectively

$$\alpha_t = \alpha_{t-1} + \eta_t^\alpha \tag{5}$$

$$log\ h_t = log\ h_t + \eta_t^h \tag{6}$$

where η_t^α and η_t^h are white noise Gaussian process with zero mean and constant covariance matrices Ξ and Ψ, respectively. We assume that the innovations $\epsilon_t, \eta_t^B, \eta_t^\alpha, \eta_t^h$ are mutually uncorrelated and Ξ is restricted to be block diagonal, where each block corresponds to parameters belonging to separate equations.

2.2 Estimation

The model can be represented in a state-space form in which the measurement equation is the factor equation and the state equation is the VAR equation (see Appendix B).

We estimate the model in two stages. The first stage involves estimating the unobserved factors as first principal components of x_t. The second stage consists of including the estimated principal components in the VAR and estimate the time-varying parameters via Bayesian methods applying the Gibbs sampling algorithm. An alternative one-step procedure consists of estimating equations (1) and (2) simultaneously by Gaussian maximum likelihood (ML) or Quasi ML using the Kalman filter.[6]

[6] Doz, Giannone, and Reichlin (2012) show that ML estimates of the common factors are also

The advantage of the two-step procedure is that, being semiparametric, it requires weaker distributional assumptions and is computationally less cumbersome especially with a high number of parameters and with non linearities. Furthermore, Forni, Hallin, Lippi, and Reichlin (2004) and Stock and Watson (2002) show that principal components are consistent estimators of the common factors for large cross-sectional dimensions and sample size, and Stock and Watson (2009) argue that they are consistent even if there is some time variation in the loadings.

We estimate the first three principal components (k=3) obtained from the singular value decomposition of the data matrix x_t, which collects 124 macroeconomic and financial variables. The series are taken from the FRED-MD Monthly Database provided by the Federal Reserve Bank of St. Louis from 1961 until 2015, including variables for output and income, labor market, consumption, orders and inventories, money and credit, interest rates and exchange rates, prices and stock market.[7] In addition, we include the ratio of deficit-to-GDP and real wages.[8] Data are made stationary using first and second differences in levels and in logarithms. Details of the transformations are reported in Appendix A. We consider the first three principal components in order to avoid the proliferation of parameters and explain enough variation in x_t (see Figure 9 in Appendix C). McCracken and Ng (2015) find that the first three principal components estimated from the FRED-MD Monthly Database explain respectively 0.159,

consistent for large cross-sectional and time dimension.

[7]From the original dataset we discard the following series with missing values: New Orders for Consumer Goods (ACOGNO), New Orders for Non Defense Capital Goods (ANDENOx), Unfilled Orders for Durable Goods (AMDMUOx), Trade Weighted US Dollar Index: Major Currencies (TWEXMMTH), Consumer Sentiment Index (UMCSENTx), VXO index (VXOCLSx). We right censor the sample because some variables end in 2015.

[8]Deficit is computed as the difference between the Federal government total expenditure (W019RCQ027SBEA) and the Federal government total receipts (W018RC1Q027SBEA). The original series is at quarterly frequency and we interpolate it using the first difference of the Gross Federal Debt at monthly frequency from the Federal Reserve of Dallas with the Chow Lin technique. Real wages are computed as the compensation of employees received: wage and salary disbursement (A576RC1) divided by the CPI index for all urban consumers (CPIAUCSL), using the data downloaded from the Federal Reserve Economic Database (FRED).

0.069 and 0.066 of the variation in the data. Furthermore, they show that these are associated with real economic activity (industrial production and employment), interest rate spreads and prices. Finally, including in the model principal components which are not informationally relevant reduces the precision of the estimate which however remains unbiased (Bernanke, Boivin, and Eliasz (2005)).

In line with the literature on TVP models[9] we set the lag order to p=2 to limit the number of parameters. The matrices of parameters and hyperparameters B_t, A_t, H_t, Γ, Ξ, Ψ are estimated sequentially with a Gibbs sampling algorithm with the conditional prior and posterior distributions described in Appendix .

Figure 1 shows the posterior mean of standard deviation of residuals from the equations of principal components and federal funds rate. The volatility of residuals from the equations of the first principal component exhibits a strong reduction after 1980 while the volatilities of residuals from the equation of the second and third principal components mildly increase during the recession of the 1990s and strongly increase during the global financial crisis in 2009, especially for the third principal component. The overall reduction of volatilities during the period of the Great Moderation suggests that the US economy did not experience important economic shocks during this period that we consider for the analysis of the combined effects of monetary and fiscal policy shocks, reducing the issue that other economic shocks different from fiscal policy shocks could have affected the response of macroeconomic variables to monetary policy shocks.[10] Finally, we observe a spike in the volatility of residuals from the interest rate equation in 1980 during the beginning of the Volcker chairmanship, in line with the dynamics of the series of monetary policy shocks constructed by Romer and Romer (2004).

[9]See Cogley and Sargent (2005), Primiceri (2005), Gambetti, Pappa, and Canova (2008), Benati (2008).

[10]See also Primiceri (2005), Canova and Gambetti (2006), Gambetti, Pappa, and Canova (2008), Benati and Mumtaz (2007).

3 Structural analysis

3.1 Identification of Monetary Policy Shocks

Following Bernanke, Boivin, and Eliasz (2005) we identify only a monetary policy shock with recursive ordering, placing unobserved factors before the federal funds rate. The identifying assumption is that unobserved factors do not respond to monetary policy innovations within a month, but we do not impose this assumption on individual variables composing the information set x_t, which are divided in two blocks. Slow-moving variables like output, employment and price indexes are assumed not to respond instantaneously to monetary policy shocks. In contrast, fast-moving variables like yields and monetary aggregates react to unanticipated changes in monetary policy within a period. Appendix A provides a classification of the variables into the two categories.

In order to remove the direct dependence of principal components on the policy instrument r_t, we first estimate the coefficient of r_t from the following regression

$$\hat{PC}_t = b_c \hat{PC}^s_t + b_r r_t + e_t \tag{7}$$

where $\hat{PC}^s_t$ are principal components extracted from the subset of slow-moving variables, which are a proxy for all the common components other than r_t. $\hat{f}^x_t$ in equation (1) is constructed by subtracting $\hat{PC}_t - \hat{b}_r r_t$ in order to control for the part of $\hat{PC}_t$ that corresponds to the federal funds rate.

The inclusion of unobserved factors is a key element for the identification of the monetary policy shock and to study its propagation jointly with fiscal policy shocks. One limit of SVARs is that they include a small number of economic variables that cannot contain all the information available to policymakers and agents. As a result, the shocks can be non-fundamental and the impulse response functions can be biased. As shown by Forni and Gambetti (2014), adding principal components in the SVAR can solve the problem of information deficiency. In order to evaluate the role of information for the identification of a monetary policy shock we perform the following exercise in the time-varying framework. We first estimate a TVP-VAR including inflation, unemployment and the federal funds rate such as Primiceri (2005) and Cogley and Sargent (2005). Then we extend the model with the first three principal components extracted from the information set. Figure 10 in Appendix C compares the standard deviation of residuals for the two models. The volatility of the monetary policy innovations reduces substantially when the model includes principal components not only in the period preceding the Volcker chairmanship but also during the Great Moderation, when a Taylor-type rule, as the policy rate equation in a small-scale VARs, is supposed to describe adequately the evolution of the federal funds rate. This result suggests that US monetary authority bases its decision about the policy rate on a large range of economic indicators and therefore a small set of variables in the monetary policy rule cannot identify correctly the monetary policy shock.

In addition, for monetary VARs the problem of omitted variables has been indicated as the cause of the price puzzle, the positive response of inflation to a monetary tightening, when the model does not contain information about future inflation used by the monetary authority (Sims (1992)). Our information set x_t includes expectations variables such as a commodity price index, new orders and the term structure of Treasury yields.[11]

Further, Giannone, Lenza, and Reichlin (2008) find that small-scale VARs tend to overestimate the variance of the shocks and understate the importance of their transmission mechanism compared to large-scale VARs, concluding that the distinction between

[11] However the role of expectations for monetary policy has been questioned. Castelnuovo and Surico (2010) argue that the price puzzle as consequence of the VAR mis-specification and lack of a measure of expected inflation arises only before the Volcker chairmanship when the regime of monetary policy was passive. Canova and Gambetti (2010) show that the variance of time-varying monetary policy innovations does not change when the model includes or not expectations.

shocks and propagation depends crucially on the conditioning information set. Therefore, the inclusion of unobserved factors allows to lower differences in the variance of monetary policy shocks over time and magnify the changes in their transmission mechanism that we will show in the next Section are caused by fiscal policy shocks. Gerba and Hauzenberger (2013) estimates a TVP-VAR close to Primiceri (2005) and Cogley and Sargent (2005), except that their model also embeds government spending and net taxes,[12] and show a significant time variation in the impulse responses of monetary policy shocks, in contrast to the other studies that find most of time variation in the variance of residuals but not in the coefficients.

Finally, since the information set includes the deficit-to-GDP as measure of fiscal policy we also assume that monetary policy reacts with one period of lag to fiscal policy, but can affect it instantaneously. Rossi and Zubairy (2011) show the importance of analyzing jointly fiscal and monetary policy in a SVAR with time invariant parameters, since the inclusion of a fiscal policy shock affects the impulse response function and forecast error variance decomposition of a monetary policy shock, which is therefore not properly identified excluding fiscal policy variables.

3.2 Identification of Fiscal Policy Shocks

In order to select episodes of expansionary and contractionary fiscal policies we use the narrative fiscal variables of Romer and Romer (2010) for tax shocks, Romer and Romer (2016) for permanent and temporary transfers shocks and Ramey (2011) for government spending shocks. For permanent transfers shocks we also consider the extension of permanent increases in Social Security benefits constructed by Parraga-Rodriguez (2016). Government spending shocks and tax shocks are reported at quarterly frequency, while transfers shocks are at monthly frequency. Thus, for tax shocks we consider the month

[12] Other differences are the time sample and the inclusion of GDP instead of unemployment.

when the legislated tax change was signed and for government spending shock we select the month when the relevant news used by Ramey (2011) to construct the defense news variable appears in the newspapers, by consulting the online Appendix of her paper.

The time needed to implement fiscal policy raises the problem that fiscal policy shocks can be anticipated. For tax shocks we focus on tax surprises, following the classification of Mertens and Ravn (2012) who differentiate the Romer and Romer (2010) narrative variable into anticipated and unanticipated tax variations based on the implementation lag of tax liability changes, i.e. the time between the announcement of a tax change and its implementation.

Romer and Romer (2016) distinguish between the date of passage of legislation of Social Security benefit increases and the date of when benefit checks were received and show that consumption responds more strongly to benefit increases dated when checks arrived. In addition, they do not find that this measure is anticipated by regressing consumption on benefit increases at different leads which they find to be not significant. Accordingly, we consider transfers shocks at the time when the benefit checks were received.[13]

Ramey (2011) directly addresses the problem of the anticipation of a government spending shock which motivates the construction of the defense news variable since she shows that VAR shocks are Granger-caused by the war dummy variable and professional forecasts.[14]

A main assumption of our empirical strategy is that monetary and fiscal policy shocks are independent. The orthogonality of fiscal policy shocks to monetary policy

[13] Parraga-Rodriguez (2016) also considers anticipation effects for the extension of transfers shocks excluding those changes with an implementation lag of more than 90 days consistent with the Mertens and Ravn (2012) approach.

[14] An important property of the defense news variables is that affects economic activity both at business cycle and medium cycle frequencies, while government spending shocks identified in a SVAR with recursive ordering stabilize output only at medium frequency (see Rossi and Zubairy (2011)). Since monetary policy contributes mostly to short-run fluctuations of economic activity, the defense news can alter the transmission of monetary policy.

shocks is the identifying assumption of Romer and Romer (2010), Ramey (2011) and Romer and Romer (2016) in the construction of the narrative variables that are meant to be exogenous to the state of the economy including monetary policy. However, we cannot exclude a priori that the monetary policy shock contains not only the exogenous shock but also the endogenous response to fiscal policy shocks. In order to evaluate this possibility we test whether the monetary policy shock can be predicted by fiscal policy shocks with a Granger-causality test and orthogonality F-test. Table 1 reports the results of the tests and shows that government spending shocks, unanticipated tax shocks and temporary and permanent transfers shocks cannot predict the monetary policy shocks.

Furthermore, in order to make the impulse response functions estimated in different periods more comparable we apply the following criteria to select episodes of fiscal policy shocks: We consider only shocks taking place during phases of economic growth and not in recessions as defined by NBER; we exclude fiscal policy shocks that were counteracted by other fiscal policy shocks with the opposite sign; we select only fiscal policy shocks that took place during the Great Moderation (1984 - 2007); for permanent and temporary transfers shocks we consider only benefit increases bigger than 0.15% of personal income.[15]

Bianchi and Melosi (2017) using a Markov-Switching VAR model show that during all this period the fiscal policy regime was passive and the monetary policy regime was active. Hence our findings cannot be attributed to a mixture of changes in fiscal and monetary policy regimes. Boivin, Kiley, and Mishkin (2010) using a FAVAR model find for the US a change in the transmission of monetary policy before and after 1984. As a result, focusing on the interaction of shocks during 1984 to 2007 implies that differences in results are not driven by different regimes between monetary and fiscal interventions, neither due to change in the transmission of monetary policy.

[15] Romer and Romer (2016) note that these fiscal interventions are smaller than tax shocks and changes in government spending associated with wars.

4 Results

4.1 The impact of a monetary policy shock in a FAVAR model

We start by assessing the impact of a monetary policy shock in a FAVAR model with time invariant parameters. The model is the same one presented in Section 2, but with constant coefficients and volatilities, therefore it is close to Bernanke, Boivin, and Eliasz (2005), hereafter BBE (2005). The estimation is implemented with 10,000 draws of the Gibbs sampling, after having discarded the first 2,000 as burn-in to minimize the effects of initial conditions.

Figure 2 shows the impulse responses of macroeconomic and financial variables to a contractionary monetary policy shock. The impact on industrial production is negative and persistent and, to a lesser extent, real personal consumption expenditure and real personal income also decrease. The response of unemployment is positive and long-lasting and average weekly hours and employment reduce significantly with a lag, while the response of the labor force participation rate slightly increases. Inflation declines significantly. The response of the federal funds rate is positive and persistent and is inherited by yields of the the 10-year Treasury rate and AAA corporate bonds. Monetary policy also affects the credit market, commercial and industrial loans and real estate loans reduce significantly with a lag.[16] The response of the ratio of deficit-to-GDP is positive with a lag and significant because of the automatic and direct effect of the interest payments.

Similarly with other empirical studies, we find a small role for the wealth effect

[16] We do not find a significant response of the external finance premium measured by the spread of the BAA-AAA corporate bond yields. Hence, the impact of monetary policy to credit does not seem to operate through higher agency costs typical of models with asymmetric information and costly state verification.

and intertemporal substitution in the transmission mechanism of monetary policy in US.[17] According to standard real business cycle models a contractionary monetary policy shock reduces consumption through the Euler equation and increases labor supply. Figure 2 confirms the fall in consumption. It depicts a significant and persistent fall in real personal income consumption expenditure that reduces demand. Yet, the responses of the labor market shows only a marginal increase in the labor supply, since real wages hardly move and most of the labor market dynamics are driven by the fall in labor demand. Hence the response in Figure 2 can be better rationalized by New Keynesian models with labor market imperfections because of search and matching frictions (Mortensen and Pissarides (1994)) or staggered wage setting (Galí (2011)). More recently, models with hand-to-mouth consumers predict that the direct effect of monetary policy through intertemporal substitution is quantitatively less important than the indirect effect through labor demand (Kaplan, Moll, and Violante (2017) Debortoli and Galí (2017)).[18]

4.2 The impact of a monetary policy shock combined with fiscal policy shocks

In Figure 2 we present responses of the variables of interest to a monetary policy contraction on average in our sample. However, given the time-varying parameter structure of our exercise we can investigate the responses of the aggregate economy to the monetary policy shock at specific points in time. In particular, we are interested to investigate the impulse responses to monetary policy contractions at times in which the shocks to monetary policy coincide with episodes of exogenous changes in fiscal policy, which are

[17] See Boivin, Kiley, and Mishkin (2010) for a survey.

[18] We do not find a portfolio rebalance effect in the asset portfolio of households as suggested by the Kaplan, Moll, and Violante (2017) model since the returns on more liquid Treasuries and less liquid corporate bonds are equally affected by monetary policy.

reported in Table 2.

In order to understand the impulse responses in the time varying framework presented in the following sections we first show the individual impulse response functions of monetary policy shocks with respect to the episodes described in Table 2.

Figures 3, 4 and 5 display the response of unemployment and inflation to a contractionary monetary policy shock in periods with different fiscal policy shocks (government spending, tax and transfers shocks).[19] Impulse responses of unemployment are very sparse, suggesting a high degree of time variation in the coefficients. The lagged effect of a monetary policy shock on unemployment is different when combined with expansionary and contractionary fiscal policy shocks, although inflation responses are similar. In particular, the responses of unemployment to the monetary contraction are amplified and their persistence increases when they occur in times of ex the persistence of their negative effects. On the other hand, the adverse effect of the monetary contraction on unemployment is reduced significantly in times of fiscal expansions in spending or temporary transfers. her hand, increases in temporary transfers and expansionary government spending shocks reduce the adverse effect of the monetary contraction on unemployment. On the contrary, the effect of monetary policy shocks on unemployment do not differ significantly in episodes of tax cuts or tax increases. In what follows, we analyze average responses of all variables of interest for the combination of monetary policy with fiscal policy shocks, weighted by the size of the fiscal intervention.

4.2.1 Government spending shocks

Figure 6 shows the impulse responses of macroeconomic variables to contractionary monetary policy shocks occurring in times of expansions (continuous lines) and contractions (dashed lines) of government spending.

[19]Each impulse response function is the median of 20,000 draws after having discarded the first 10,000 draws as burn-in.

Overall, we observe a large heterogeneity in the reaction of most of the variables to monetary policy conditional on government spending shocks with different signs, especially variables related to economic activity. Industrial production falls less and less persistently with an expansion of government spending and the difference is remarkable for the production of non-durable consumption goods and retail and food services sales that increase in times of a positive government spending shock and decline in times of a negative government spending shock.

The presence of expansionary government spending shocks has a substantial impact on the reaction of labor market variables to monetary policy: labor force participation rate increases and average weekly hours and employment decline less than on average. This result is in line with Ramey (2011), who finds a positive impact of the defense news variable on total hours. However, she also finds that all components of consumption, except services consumption, decrease as predicted by neoclassical models. We also observe a rightward shift in labor supply because of the negative wealth effect, however we find that labor demand increases and consumption falls less after a positive government spending shock, tracking closely the response of real personal income. Galí, López-Salido, and Vallés (2007) shows that a New Keynesian model with hand-to-mouth consumers can generate a positive response of consumption to an expansionary government spending shock through the aggregate demand channel and the expansion in employment. Hence, by stimulating demand the expansionary fiscal shock in the aggregate undoes to a larger extent the effect of the monetary contraction on production and consumption and unemployment, affecting marginally the credit market and inflation. In addition, the real interest rate is not affected by the different combinations of monetary policy and government spending shocks, therefore the different reactions of consumption cannot be based on the Euler equation and the intertemporal substitution effect.[20]

[20]A possible explanation of why the response of inflation to a monetary policy shock is not affected by government spending shocks is that they do not result in a higher public deficit, which

Concerning the credit market, we observe a different reaction of commercial and industrial loans and real estate loans to the tightening of monetary policy combined with different fiscal policies. The presence of expansionary government spending shocks dampens substantially the drop in commercial and industrial loans, but not in real estate loans, which suggests a different response of credit demand for firms and households. The positive impact of the fiscal stimulus on aggregate demand and labor demand leads to a smaller reduction of credit to firms. By contrast, the limited decline of real personal income does not translate into a smaller decline in mortgages. This can be explained by the presence of hand-to-mouth agents who do not borrow, or because the demand for mortgages is mostly driven by the value of the real estate used as collateral, more than personal income, in line with the model of Kiyotaki and Moore (1997).

In sum, the transmission of contractionary monetary policy shocks differs substantially when it is combined with positive or negative government spending shocks. The differences in the responses seem to stem from the ability of government spending to stimulate demand and counteract the contractionary effects of the shock through the labor market.

4.2.2 Tax shocks

Figure 7 shows the combined effects of monetary policy and tax shocks. In our sample tax shocks are evenly distributed between tax changes on personal and corporate income as defined by Mertens and Ravn (2013). Continuous lines represent the average of the impulse responses of monetary policy shocks in periods with contractionary tax shocks

according to the fiscal theorem of price level is a key mechanism through which an expansion in fiscal policy can generate higher inflation. The empirical literature finds mixed results about the impact of a government spending shock on inflation. Ramey (2011) does not assess the impact of the defense news variables on inflation, while Parraga-Rodriguez (2016) using a proxy-SVAR with the defense news variable as instrument for the structural shocks to public expenditure finds that the response of inflation to a government spending shock is not significant. Mountford and Uhlig (2009) using sign restrictions find that the impact of a fiscal stimulus deficit-financed or with a balanced budget on the GDP deflator is negative.

and dashed lines the respective responses in the presence of expansionary tax shocks. Compared with government spending shocks, there is almost no difference between tax cuts and tax hikes on the impact of monetary policy on economic activity.

Expansionary tax shocks through the substitution effect should increase the labor supply and should result to a smaller fall in output and employment and a moderate increase in the unemployment rate, whereas contractionary tax shock should imply the opposite movement. In Figure 7 we do not observe differences.[21] Those responses are difficult to justify with standard representative agent models. Possibly, heterogeneous agent models have a better chance for explaining our empirical findings. For example, in the model of Kaplan, Moll, and Violante (2017) a tax cut is less expansionary than an increase in government spending and positive transfers: higher government expenditure leads to a direct increase in aggregate spending and output, and transfers are more redistributive and addressed to agents with a higher marginal propensity to consume compared with tax cuts recipients.

4.2.3 Transfers shocks

Figure 8 shows the impulse responses of macroeconomic variables to monetary policy shocks combined with permanent and temporary increases in Social Security benefits. Continuous (dashed) lines depict the average impulse responses to a monetary policy shock in periods with temporary (permanent) transfers shocks.[22] Since transfers shocks are all expansionary we compare them with the cases of expansionary government spending shocks (green lines) and tax shocks (black lines).

The two types of expansionary transfers shocks affect similarly the reaction of indus-

[21] Following the classification of Mertens and Ravn (2013) all the tax shocks that we consider are changes in personal income taxes except the "Jobs and Growth Tax Relief Reconciliation Act" of 2003 which entailed changes in both personal and corporate income taxes.

[22] On average temporary and permanent transfers shocks that we consider have the same magnitude, being respectively 0.1873% and 0.1863% of personal income.

trial production to a monetary shock, but temporary transfers shocks lead to an increase in industrial production of durable consumption goods and non durable consumption goods, while permanent transfers shocks mitigate their reduction. Consumption falls less after a monetary contraction in the presence of temporary benefits increases. Romer and Romer (2010) show that permanent transfers shocks raise consumption more than temporary transfers shocks. Our results indicate that when transfers shocks occur simultaneously with a monetary policy contraction, temporary benefit increases undo to a large extent the negative effects of monetary policy. Furthermore, Parraga-Rodriguez (2016) compares the impact of government spending shocks and transfers shocks using a Proxy-SVAR using the Ramey (2011) and Romer and Romer (2016) narrative variables and finds that a government spending shock has a stronger impact on consumption because of its effect on aggregate demand, which is in line with our results.

Temporary transfers shocks seem to counterbalance the fall in labor demand induced by the monetary contraction leading to an increase in wages that translates to a smaller fall in consumption and a smaller increase in unemployment. Further, the positive response of consumption is in favor of the presence of hand-to-mouth agents whose consumption depends more strongly on current income, which declines less with temporary transfers shocks, and have a larger marginal propensity to consume.

Ricardian equivalence can explain why permanent benefit increases fail to dampen the fall in consumption following a contractionary monetary policy shock. Agents anticipate the higher present discount value of taxes used to finance transfers working more and consuming less because of the negative wealth effect, which is stronger in the case of permanent increases. However, this result can be explained by another mechanism which hinges upon the impact of transfers on monetary policy. Romer and Romer (2016) and Parraga-Rodriguez (2016) provide empirical evidence that a positive permanent transfer shock increases significantly the federal funds rate.[23] Similarly, we find that the impact of a monetary policy shock on the federal funds rate is more persistent in periods of a permanent rather than a temporary transfer shock. The quick and short-lived impact of a monetary policy shock combined with temporary transfers shocks on the nominal interest rate is reflected on the credit market and we observe a smaller decline of commercial and industrial loans and even a positive impact on real estate loans. Furthermore, in our sample an increase in temporary transfers is the only fiscal policy shock which is not counteracted by other fiscal instruments which keep the public budget balanced.

Fiscal policy shocks are not evenly distributed over time. Contractionary government spending shocks and temporary transfers shocks occur in the first half of the sample; expansionary government spending shocks and permanent transfers shock in the second half. However, the different impact of these fiscal shocks in combination with a monetary policy shock cannot be attributed to their different distribution over time and a possible change in the transmission mechanism of monetary policy within the period of the Great Moderation since fiscal policy shocks which are found to be more stimulative are distributed over the entire sample: expansionary government spending shocks are in the last part of the sample, while temporary transfers shocks are in the first part.

5 Conclusions

This paper studies how fiscal policy affects the monetary policy transmission in the US economy using a Time-Varying Parameter Factor Augmented VAR (TVP-FAVAR) model. The time varying structure allows to estimate the impulse response function of a monetary policy shock in the same periods of different fiscal policy shocks (government spending, tax and transfers shocks) identified with the narrative approach. We find that

[23] Romer and Romer (2016) also provide narrative evidence that monetary authority explicitly took into account benefit increases to set the policy rate.

government spending shocks and temporary transfers shocks undo the contractionary effects of a tightening of monetary policy, while tax shocks and permanent transfers are less effective in dampening the fall in economic activity and consumption following a monetary policy contraction. The labor market plays a key role in explaining the different response of the US economy to a combination of monetary policy shock with government spending shocks mainly through an adjustment in labor demand.

Our findings on the effects of different combinations of a monetary policy shocks with fiscal policy shocks lend support to models with hand-to-mouth consumers and in particular the Heterogeneous Agents New Keynesian (HANK) model of Kaplan, Moll, and Violante (2017), which emphasizes the quantitative importance of the indirect effect of monetary policy on consumption through labor demand and the response of fiscal policy, especially with government spending.

Our results are also relevant for policymakers which aim to understand the implications of different policy mix, suggesting than an increase in the federal funds rate can be counteracted by expansionary government spending or an increase in temporary transfers.

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Table 1: Predictability of monetary policy shock

Fiscal policy shocks	Granger-causality, F-statistics	BIC Critical value	Orthogonality, 2 lags p-value
Defense news shock	1.58	3.89	0.25
Tax shock	1.88	3.89	0.30
Permanent transfers shock	1.64	3.86	0.52
Temporary transfers shock	0.36	3.86	0.49

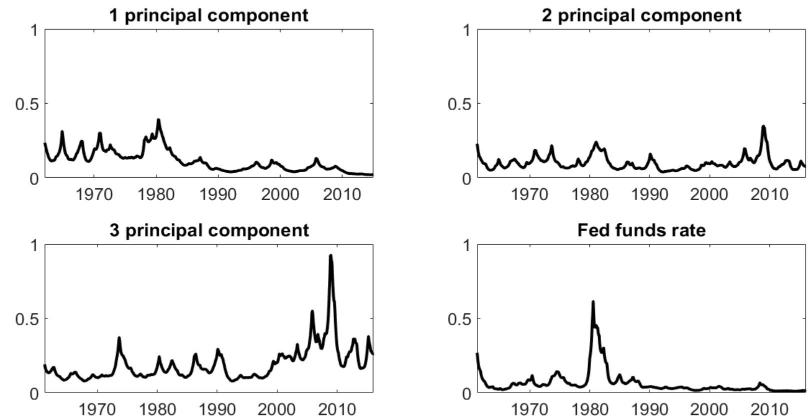
Note: This table report the Granger-causality test and orthogonality F-test of fiscal policy shocks on monetary policy shock. The number of lags for the Granger-causality test is selected with the BIC with a maximum of 10 lags and the significance level is 0.05. Since the defense news variable and tax shocks are at quarterly frequency we transform the monthly series into quarterly series taking the average. When the F-statistics is larger than the critical value we reject the null hypothesis that fiscal shocks do not Granger cause the MP shock. For the orthogonality test a p-value smaller than 0.10 indicates that In order to make results comparable for different fiscal policy shocks the sample size is 1961-2007, except for temporary transfers shocks for which the sample size is 1961-2001.

Table 2: Episodes of fiscal policy shocks

Fiscal policy shocks		
	Expansionary	Contractionary
Defense news shocks	Jan. 1999, Feb. 2002, Aug. 2002, Feb. 2003, Sep. 2003, May 2004, Jan. 2005, Apr. 2006	Mar. 1988, Oct. 1989, Oct. 1991
Tax shocks	Jul. 1984, Aug. 1993	Dec. 1987, May 2003
	Permanent	Temporary
Transfers shocks	Jan. 1990, Jan. 1992, Jan. 1993, Jan. 1997, Jan. 2001, Jan. 2006	Dec. 1984, Jul. 1985, Jul. 1986, May 1987

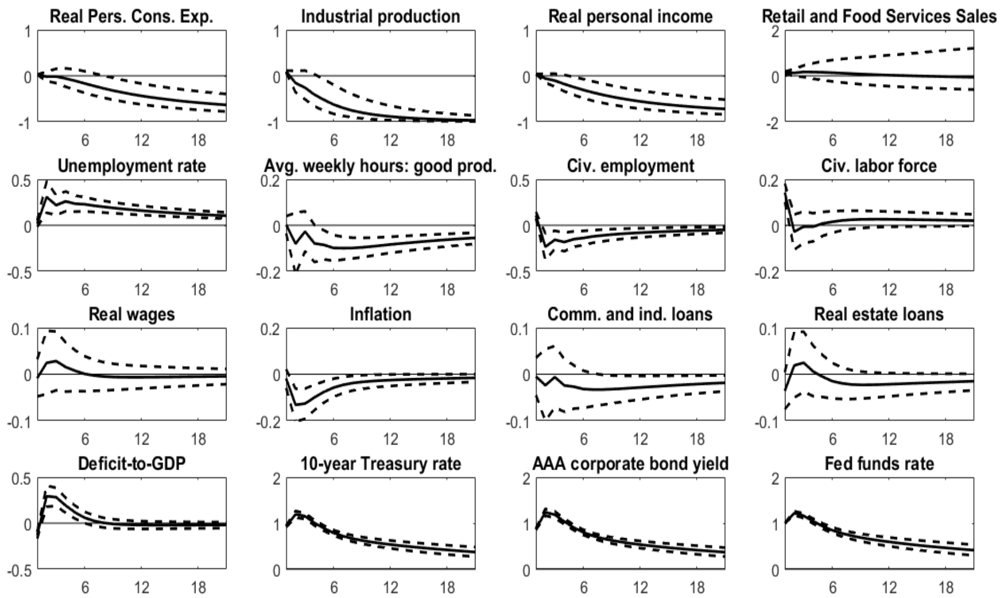
Note: This table reports the episodes of fiscal policy shocks that we consider for the analysis.

Figure 1: Time-varying volatilities of residuals



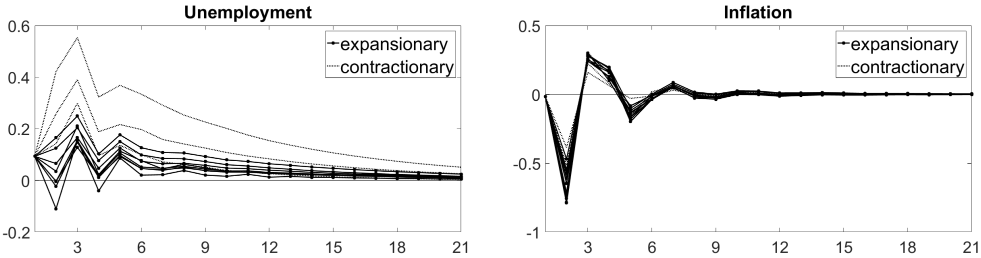
Note: This figure plots the posterior mean of the standard deviation of residuals of the equations of unobserved factors and the federal funds rate.

Figure 2: Impulse responses of a monetary policy shock generated from a FAVAR



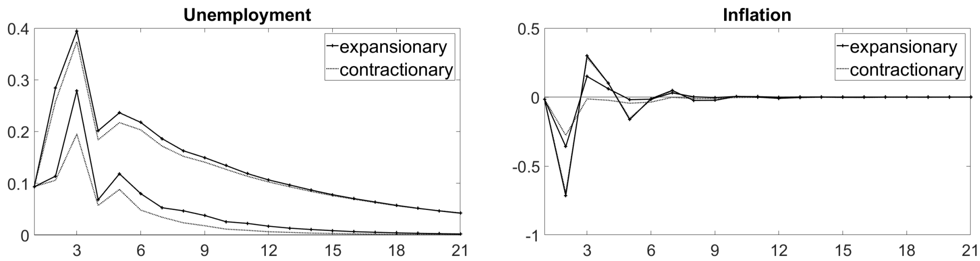
Note: This figure shows the impulse responses to a contractionary monetary policy shock. The dashed lines are the 16^{th} and 84^{th} percentiles and the solid lines the median of 10,000 draws.

Figure 3: Impulse responses to monetary policy shocks with expansionary and contractionary government spending shocks



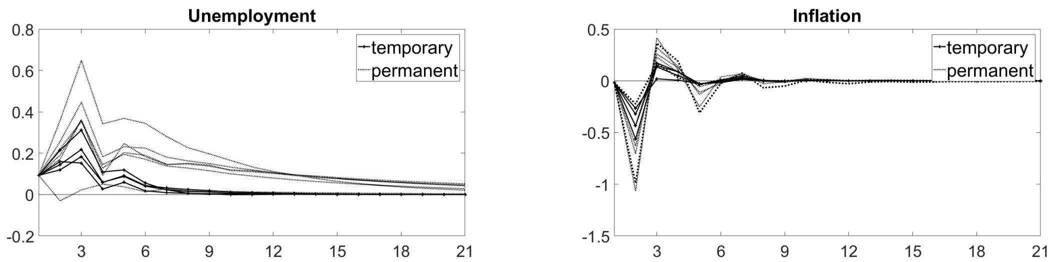
Note: The dashed blue lines represent the impulse response functions of monetary policy shocks in periods with expansionary government spending shocks. The dashed red lines represent the impulse response functions of monetary policy shocks in periods with contractionary government spending shocks.

Figure 4: Impulse responses to monetary policy shocks with expansionary and contractionary tax shocks



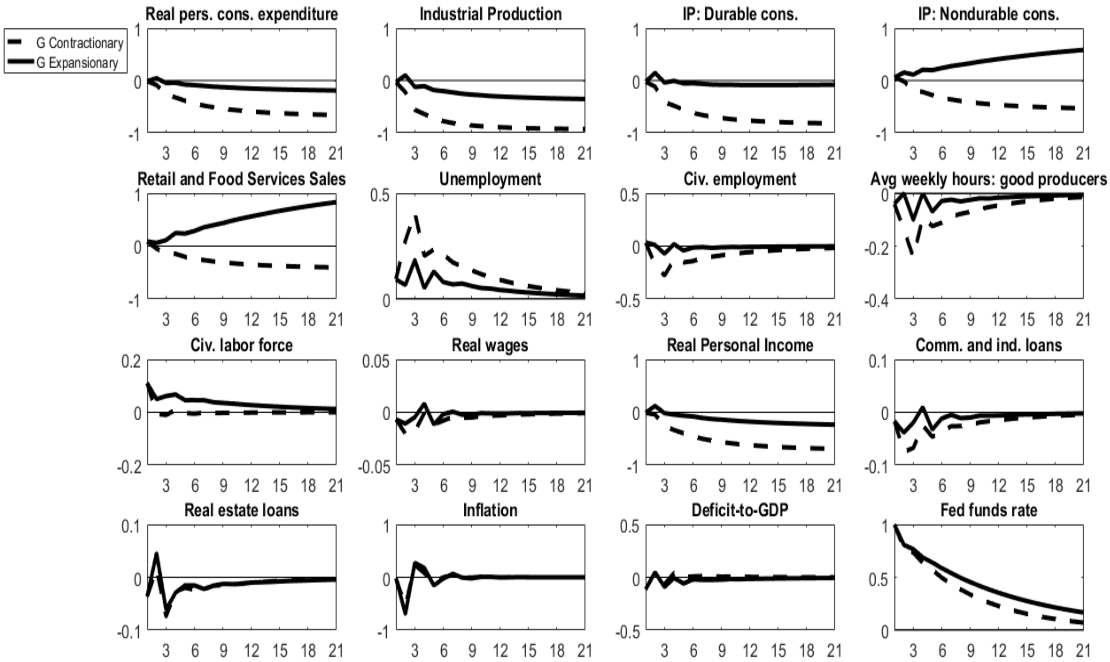
Note: The dashed blue lines represent the impulse response functions of monetary policy shocks in periods with expansionary tax shocks. The dashed red lines represent the impulse response functions of monetary policy shocks in periods with contractionary tax shocks.

Figure 5: Impulse responses to monetary policy shocks with permanent and temporary transfers shocks



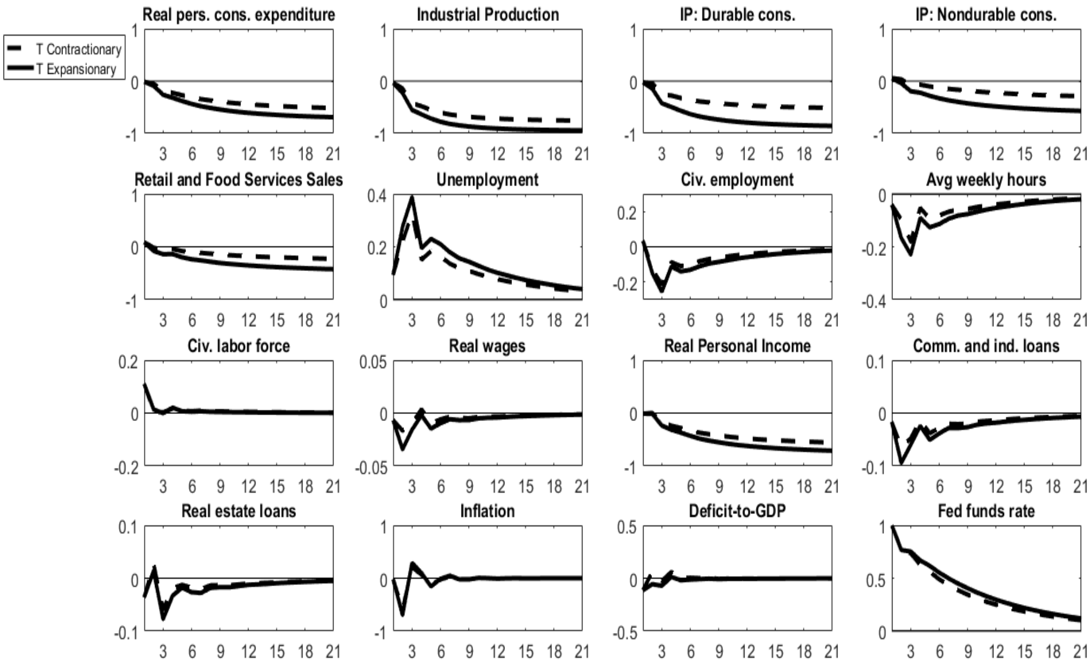
Note: The dashed blue lines represent the impulse response functions of monetary policy shocks in periods with temporary transfers shocks. The dashed red lines represent the impulse response functions of monetary policy shocks in periods with permanent transfers shocks.

Figure 6: Impulse responses to monetary policy shocks joint with government expenditure shocks



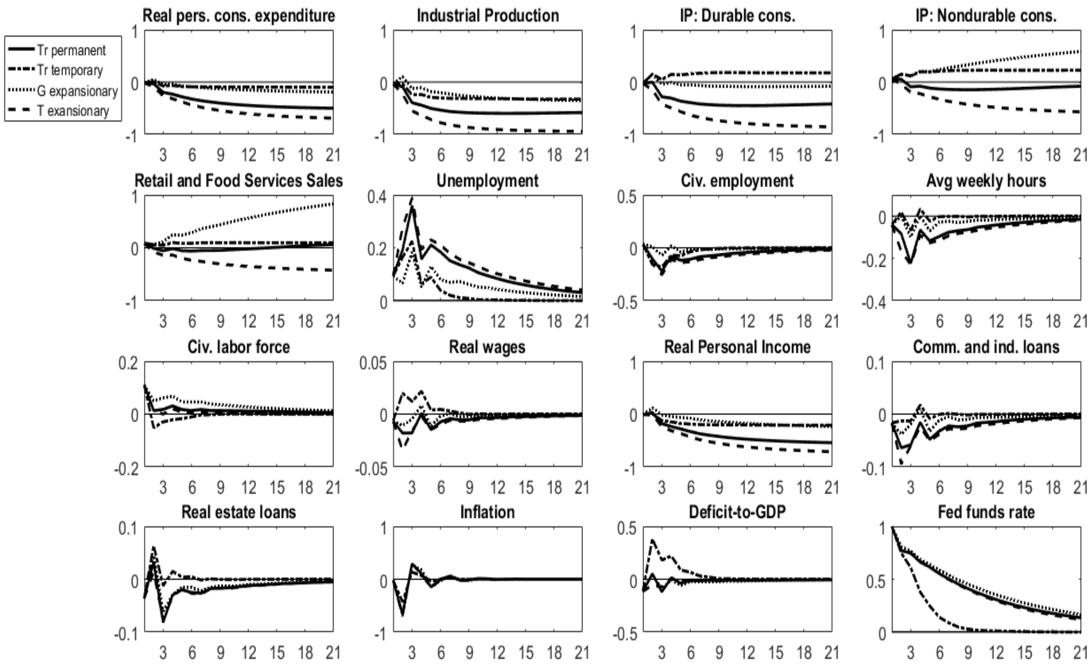
Note: The red dashed line and blue continuous lines are the averages of impulse response functions of monetary policy shocks in periods with contractionary and expansionary government spending shocks weighted by the size of fiscal interventions. The black lines are the impulse responses of the linear model.

Figure 7: Impulse responses to monetary policy shocks joint with tax shocks



Note: The red dashed line and blue continuous lines are the averages of impulse response functions of monetary policy shocks in periods with contractionary and expansionary tax shocks weighted by the size of fiscal interventions. The black lines are the impulse responses of the linear model.

Figure 8: Impulse responses to monetary policy shocks joint with transfers shocks



Note: The dashed and solid blue lines are the averages of impulse response functions of monetary policy shocks in periods with permanent and temporary transfers shocks weighted by the size of fiscal interventions. The green and black lines are the averages of the impulse response functions of monetary policy shocks in periods with expansionary government spending shocks and tax shocks weighted by the size of fiscal interventions.

A Data

The dataset contains 124 macroeconomic variables spanning from January 1961 to December 2015. The table below shows the series downloaded from the St. Louis' database with the mnemonics. All variables are transformed to be approximate stationary. The transformation codes are: (1) no transformation; (2) Δx_t; (3) $\Delta^2 x_t$; (4) $log(x_t)$; (5) $\Delta log(x_t)$; (6) $\Delta^2 log(x_t)$ (7) $\Delta(\frac{x_t}{x_{t-1}} - 1.0)$. Slow = 1 indicates that a variable is slow-moving, otherwise is a fast-moving variable. All variable descriptions and mnemonics are from the original source. From this database we added the ratio of deficit-to-GDP and real wages.

Table 3: Information set

No.serie	Transformation	Slow-moving	Mnemonic	Description
1	5	1	RPI	Real Personal Income
2	5	1	W875RX1	Real personal income ex transfer receipts
3	5	1	DPCERA3M086SBEA	Real personal consumption expenditures
4	5	1	CMRMTSPLx	Real Manu. and Trade Industries Sales
5	5	1	RETAILx	Retail and Food Services Sales
6	5	1	INDPRO	IP Index
7	5	1	IPFPNSS	IP: Final Products and Nonindustrial Supplies
8	5	1	IPFINAL	IP: Final Products (Market Group)
9	5	1	IPCONGD	IP: Consumer Goods
10	5	1	IPDCONGD	IP: Durable Consumer Goods
11	5	1	IPNCONGD	IP: Nondurable Consumer Goods
12	5	1	IPBUSEQ	IP: Business Equipment
13	5	1	IPMAT	IP: Materials
14	5	1	IPDMAT	IP: Durable Materials
15	5	1	IPNMAT	IP: Nondurable Materials
16	5	1	IPMANSICS	IP: Manufacturing (SIC)
17	5	1	IPB51222S	IP: Residential Utilities
18	5	1	IPFUELS	IP: Fuels
19	2	1	CUMFNS	Capacity Utilization: Manufacturing
20	2	1	HWI	Help-Wanted Index for United States
21	2	1	HWIURATIO	Ratio of Help Wanted/No. Unemployed
22	2	1	CIVPART	Civilian Labor Force Participation rate
23	2	1	EMRATIO	Civilian Employment-Population ratio
24	2	1	UNRATE	Civilian Unemployment Rate
25	2	1	UEMPMEAN	Average Duration of Unemployment (Weeks)
26	5	1	UEMPLT5	Civilians Unemployed - Less Than 5 Weeks
27	5	1	UEMP5TO14	Civilians Unemployed for 5-14 Weeks
28	5	1	UEMP15OV	Civilians Unemployed - 15 Weeks & Over
29	5	1	UEMP15T26	Civilians Unemployed for 15-26 Weeks
30	5	1	UEMP27OV	Civilians Unemployed for 27 Weeks and Over
31	5	1	CLAIMSx	Initial Claims
32	5	1	PAYEMS	All Employees: Total nonfarm
33	5	1	USGOOD	All Employees: Goods-Producing Industries
34	5	1	CES1021000001	All Employees: Mining and Logging: Mining
35	5	1	USCONS	All Employees: Construction
36	5	1	MANEMP	All Employees: Manufacturing
37	5	1	DMANEMP	All Employees: Durable goods
38	5	1	NDMANEMP	All Employees: Nondurable goods
39	5	1	SRVPRD	All Employees: Service-Providing Industries
40	5	1	USTPU	All Employees: Trade Transport
41	5	1	USWTRADE	All Employees: Wholesale Trade
42	5	1	USTRADE	All Employees: Retail Trade
43	5	1	USFIRE	All Employees: Financial Activities
44	5	1	USGOVT	All Employees: Government
45	2	1	CES0600000007	Avg Weekly Hours : Goods-Producing

46	2	1	AWOTMAN	Avg Weekly Overtime Hours : Manufacturing
47	1	1	AWHMAN	Avg Weekly Hours : Manufacturing
48	4	0	HOUST	Housing Starts: Total New Privately Owned
49	4	0	HOUSTNE	Housing Starts Northeast
50	4	0	HOUSTMW	Housing Starts Midwest
51	4	0	HOUSTS	Housing Starts South
52	4	0	HOUSTW	Housing Starts West
53	4	0	PERMIT	New Private Housing Permits (SAAR)
54	4	0	PERMITNE	New Private Housing Permits Northeast (SAAR)
55	4	0	PERMITMW	New Private Housing Permits Midwest (SAAR)
56	4	0	PERMITS	New Private Housing Permits South (SAAR)
57	4	0	PERMITW	New Private Housing Permits West (SAAR)
58	5	0	AMDMNOx	New Orders for Durable Goods
59	5	0	BUSINVx	Total Business Inventories
60	2	0	ISRATIOx	Total Business: Inventories to Sales Ratio
61	6	0	M1SL	M1 Money Stock
62	6	0	M2SL	M2 Money Stock
63	5	0	M2REAL	Real M2 Money Stock
64	6	0	AMBSL	St. Louis Adjusted Monetary Base
65	6	0	TOTRESNS	Total Reserves of Depository Institutions
66	7	0	NONBORRES	Reserves Of Depository Institutions
67	6	0	BUSLOANS	Commercial and Industrial Loans
68	6	0	REALLN	Real Estate Loans at All Commercial Banks
69	6	0	NONREVSL	Total Nonrevolving Credit
70	2	0	CONSPI	Nonrevolving consumer credit to Personal Income
71	5	0	S&P 500	S&Ps Common Stock Price Index: Composite
72	5	0	S&P: indust	S&Ps Common Stock Price Index: Industrials
73	2	0	S&P div yield	S&Ps Composite Common Stock: Dividend Yield
74	5	0	S&P PE ratio	S&Ps Composite Common Stock: Price-Earnings Ratio
75	2	0	FEDFUNDS	Effective Federal Funds Rate
76	1	0	CP3Mx	3-Month AA Financial Commercial Paper Rate
77	1	0	TB3MS	3-Month Treasury Bill:
78	1	0	TB6MS	6-Month Treasury Bill:
79	1	0	GS1	1-Year Treasury Rate
80	1	0	GS5	5-Year Treasury Rate
81	1	0	GS10	10-Year Treasury Rate
82	1	0	AAA	Moodys Seasoned Aaa Corporate Bond Yield
83	1	0	BAA	Moodys Seasoned Baa Corporate Bond Yield
84	1	0	COMPAPFFx	3-Month Commercial Paper Minus FEDFUNDS
85	1	0	TB3SMFFM	3-Month Treasury C Minus FEDFUNDS
86	1	0	TB6SMFFM	6-Month Treasury C Minus FEDFUNDS
87	1	0	T1YFFM	1-Year Treasury C Minus FEDFUNDS
88	1	0	T5YFFM	5-Year Treasury C Minus FEDFUNDS
89	1	0	T10YFFM	10-Year Treasury C Minus FEDFUNDS
90	1	0	AAAFFM	Moodys Aaa Corporate Bond Minus FEDFUNDS
91	1	0	BAAFFM	Moodys Baa Corporate Bond Minus FEDFUNDS
92	5	0	EXSZUSx	Switzerland / U.S. Foreign Exchange Rate
93	5	0	EXJPUSx	Japan / U.S. Foreign Exchange Rate
94	5	0	EXUSUKx	U.S. / U.K. Foreign Exchange Rate
95	5	0	EXCAUSx	Canada / U.S. Foreign Exchange Rate
96	6	1	WPSFD49207	Producer Price Index by Commodity for Final Demand: Finished Goods
97	6	1	WPSFD49502	Producer Price Index by Commodity for Final Demand: Personal Consumption Goods
98	6	1	WPSID61	Producer Price Index by Commodity for Interm. Demand : Processed Goods for Intermediate Demand
99	6	1	WPSID62	Producer Price Index by Commodity for Interm. Demand : Unprocessed Goods for Intermediate Demand
100	6	1	OILPRICEx	Crude Oil spliced WTI and Cushing
101	6	1	PPICMM	PPI: Metals and metal products:
102	6	1	CPIAUCSL	CPI : All Items
103	6	1	CPIAPPSL	CPI : Apparel
104	6	1	CPITRNSL	CPI : Transportation
105	6	1	CPIMEDSL	CPI : Medical Care
106	6	1	CUSR0000SAC	CPI : Commodities
107	6	1	CUUR0000SAD	CPI : Durables
108	6	1	CUSR0000SAS	CPI : Services
109	6	1	CPIULFSL	CPI : All Items Less Food
110	6	1	CUUR0000SA0L2	CPI : All items less shelter
111	6	1	CUSR0000SA0L5	CPI : All items less medical care
112	6	1	PCEPI	Personal Cons. Expend.: Chain Index
113	6	1	DDURRG3M086SBEA	Personal Cons. Exp: Durable goods
114	6	1	DNDGRG3M086SBEA	Personal Cons. Exp: Nondurable goods
115	6	1	DSERRG3M086SBEA	Personal Cons. Exp: Services
116	6	1	CES0600000008	Avg Hourly Earnings : Goods-Producing
117	6	1	CES2000000008	Avg Hourly Earnings : Construction
118	6	1	CES3000000008	Avg Hourly Earnings : Manufacturing
119	6	0	MZMSL	MZM Money Stock
120	6	0	DTCOLNVHFNM	Consumer Motor Vehicle Loans Outstanding
121	6	0	DTCTHFNM	Total Consumer Loans and Leases Outstanding
122	6	0	INVEST	Securities in Bank Credit at All Commercial Banks
123	1	1		Deficit-to-GDP
124	6	1		Real wages

B Priors and Posteriors

B.1 Prior distributions and initial values

The factor equation and VAR equation can be written in the following state-space form:

$$\tilde{x}_t = L y_t + u_t \tag{8}$$

$$y_t = a_t + \Phi(L) y_{t-1} + v_t \tag{9}$$

where $\Phi(L)$ is the lag polynomial of order p, $\tilde{x}_t = [x_t, r_t]$, and $L = \begin{bmatrix} \lambda^x & \lambda^r \\ 0 & 1 \end{bmatrix}$ is a block matrix of factor loadings.

We use Normal and inverse Gamma distributions for the loadings L and the diagonal elements of Ω with non-informative initial conditions:

$$L_0 \sim N(0\ ,\ 4\ I)$$

$$\Omega_0 \sim G^{-1}(a_0\ ,\ b_0)$$

where $a_0 = 0.01$ and $b_0 = 0.01$ denote the scale parameter and the shape parameter respectively of the inverse Gamma distribution (G^{-1}). The priors in the VAR equation take the following forms:

$$B_0 \sim N(0\ ,\ 4\ I)$$

$$A_0 \sim N(0\ ,\ 4\ I)$$

$$log\sigma_0 \sim N(0\ ,\ 4\ I)$$

$$\Gamma \sim W^{-1}(k_\Gamma^2 \cdot (1 + n_\Gamma) \cdot I)\ ,\ 1 + n_\Gamma)$$

$$\Psi \sim W^{-1}(k_\Psi^2 \cdot (1 + n_\Psi) \cdot I)\ ,\ 1 + n_\Psi)$$

$$\Xi \sim W^{-1}(k_\Xi^2 \cdot (1 + n_\Xi) \cdot I)\ ,\ 1 + n_\Xi)$$

For B_t and A_t we use Normal priors and for elements of H_t a log Normal distribution. The priors for the hyperparameters Γ, Ξ and Ψ are assumed to be distributed as independent inverse-Wishart. For the initial conditions we consider non-informative values. n_θ denotes the number of elements on each state vector $\theta = \Gamma, \Phi, \Xi$; k_θ are tuning constant: $k_\Gamma = 0.07; k_\Psi = 0.01; k_\Xi = 0.1$. We also implement a sensitive analysis using priors based on a training data sample, following Primiceri (2005).

B.2 Posterior distributions and Gibbs sampling

The factor loadings are sampled from the following Normal distribution:

$$L_i \sim N(L^*\ ,\ M^*)$$

where $M^* = L_0^{-1} + \Omega^{-1} \cdot y_t' \cdot y_t$ and $L^* = M^* \cdot \Omega^{-1} \cdot y_t' \cdot \tilde{x}_t$.

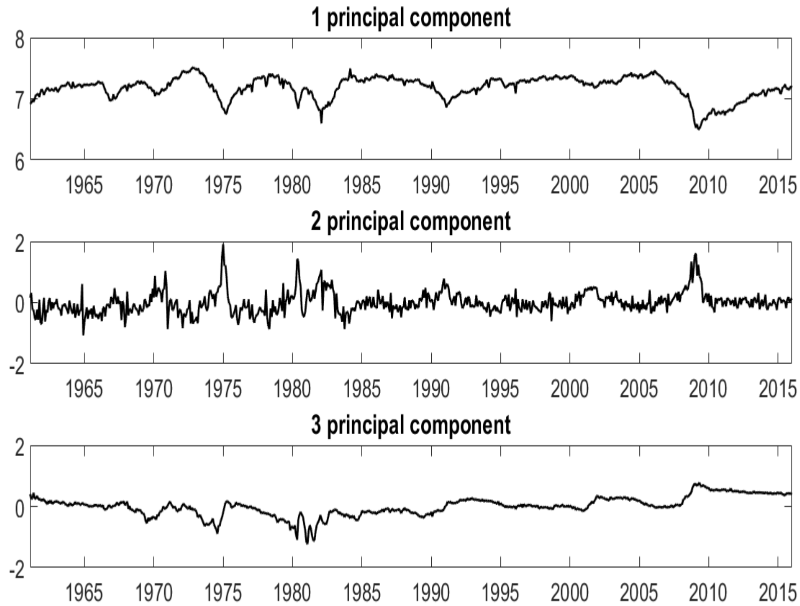
$$\Omega_{i,i} \sim G^{-1}(a^*\ ,\ b^*)$$

where $a^* = \frac{a_0}{2} + \frac{T}{2}$ and $b^* = \frac{b_0}{2} + \frac{\hat{u}_i{}'\hat{u}_i}{2}$, where T is the sample size.

For the VAR equation a Gibbs sampling procedure is applied drawing sequentially time varying coefficients (B_t), simultaneous relations (A_t), volatilities (H_t) and hyperparameters $V = \Gamma, \Xi, \Psi$, conditional on $\tilde{y}_t$ and all other parameters. In the first block B_t is drawn conditional on $\tilde{y}_t, A_t, H_t, V$ hyperparameters. In the second block A_t is drawn conditional on $\tilde{y}_t, B_t, H_t, V$ and hyperparameters. In the third block H_t is drawn conditional on $\tilde{y}_t, B_t, A_t, V$ Finally, the hyperparameters Γ, Ψ and the diagonal blocks in Ξ are drawn from inverse Wishart posterior distributions independent each other conditional on and y_t, B_t, A_t and H_t. Del Negro and Primiceri (2015) provides a detailed description of the algorithm.

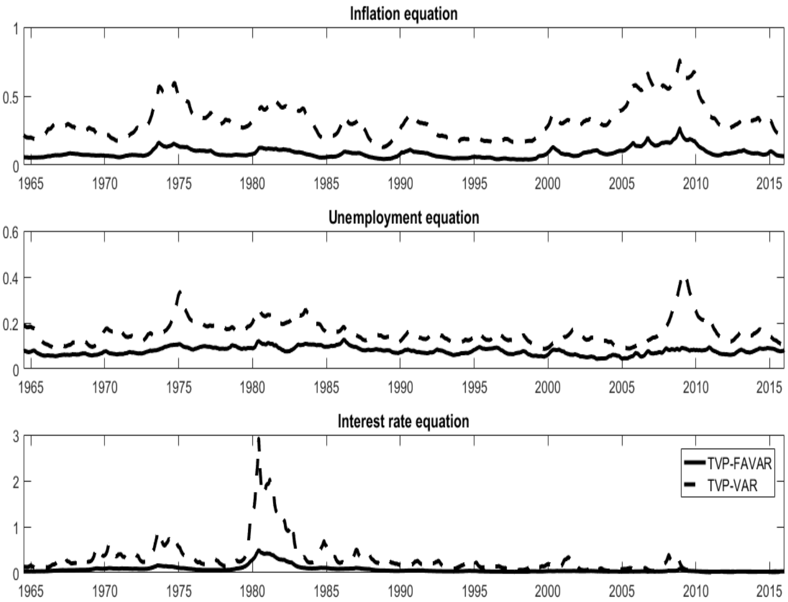
C Additional Figures

Figure 9: Principal components



Note: This figure plots the first three principal components estimated from the information set.

Figure 10: Time-varying volatilities of residuals of inflation, unemployment and federal funds rate



Note: This figure plots the posterior mean of the standard deviation of residuals of unemployment, inflation and the federal funds rate in a TVP-VAR model and a TVP-FAVAR model.