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Adventures at the Zero Lower Bound: A Bayesian Time-Varying Parameter Vector Autoregressive Analysis of Monetary Policy Uncertainty Shocks

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Introduction

The recent events surrounding the financial crisis and ensuing Great Recession have sparked interest in uncertainty and in quantifying and documenting the effect of uncertainty shocks on an economy. A core difficulty in examining this issue is finding an appropriate proxy for uncertainty, a problem which researchers have solved by using a range of measures including stock market volatility indices, the frequency of newspaper articles mentioning uncertainty, and the forecast error on output projections (see Bloom (2009), Bekaert, Hoerova and Lo Duca (2013), and Bachmann, Elstner, and Sims (2010), among others). Previous scholars have also tried to illuminate the transmission channel of uncertainty from a theoretical perspective (see Bernanke (1983), Brennan and Schwartz (1985), McDonald and Siegel (1986), and others). While general macroeconomic uncertainty has attracted much attention, policy uncertainty is only recently beginning to generate interest (see Baker, Bloom, and Davis (2015)). Uncertainty surrounding central bank actions has been largely ignored.

This paper attempts to explore this issue, one that we view as perhaps even more important to economists than that of general uncertainty due to its policy relevance. While general macroeconomic uncertainty may be irreducible, monetary policy uncertainty is responsive to forward guidance. Previous research has shown that forward guidance successfully lowers interest rate uncertainty (Filardo and Hoffman (2014)). The subsequent question is then, how do such fluctuations in monetary policy uncertainty affect real macroeconomic aggregates? The question is currently salient as the U.S. economy begins to exit the zero interest rate regime of the past decade. *Figure 1* shows the relationship between output uncertainty, measured by output forecast dispersion, and monetary policy uncertainty, measured by…. Prior to the financial crisis and zero-lower bound, the two measures roughly tracked each other. However, post-2008, monetary policy uncertainty has stayed at historically low levels, while output uncertainty rose upward (see *Figure 1*). But as the Federal Funds rate begins to creep upward and the media spotlight is directed at upcoming central bank actions, we would expect monetary policy uncertainty to rise, which may prove to impact economic conditions in and of itself.

We examine this issue using a highly flexible framework that allows for a time-varying response of macroeconomic aggregates to shocks to monetary policy uncertainty. By allowing for such temporal shifts, we construct a more dynamic model that allows for significant structural changes to occur at the zero-lower bound. The proposed TVP-VAR also incorporates stochastic volatility, of particular relevance due to the decline in interest rate volatility that accompanies a zero interest rate policy. We estimate the model using panel-level interest rate forecast dispersion, to best capture both fluctuations in the volatility of possible interest rate movements, as well as "Knightian" uncertainty, meaning the rise and fall in forecasters' confidence of the future interest rate path.

Our results suggest that monetary policy uncertainty is of quantitative importance, particularly at the zero-lower bound, and affects macroeconomic conditions via two channels. First, an increase in monetary policy uncertainty leads to an immediate decrease in output, the magnitude of which depends on the dataset used. Second, higher levels of monetary policy uncertainty dampen the transmission of other monetary shocks.

Specifically, at higher levels of interest rate uncertainty, movements in either the Federal Funds rate or shocks to interest rate expectations (forward guidance) have a significantly smaller effect on output.

These results have important implications when taken in the context of the current state of the U.S. economy. As the Federal Reserve begins to exit the zero-lower bound, monetary policy uncertainty is at its' highest levels since pre-2008. Given the impact forward guidance has on controlling uncertainty, the empirical findings show that the Fed has an additional tool with which it can stimulate output. Or, if left unguided, interest rate uncertainty can have direct and detrimental effects on output, or make other policy measures less effective.

The paper is organized as follows: Section 2 introduces the current literature on general macroeconomic uncertainty, Section 3 proposes basic theory through which monetary policy uncertainty can affect the macroeconomy, Sections 4 and 5 discuss the data and estimation procedure used, Section 6 presents the empirical results, Section 7 covers additional robustness checks, and Section 8 concludes.

A Literature Review of Uncertainty

The recent financial crisis and subsequent Great Recession catalyzed interest in quantifying if and how uncertainty affects business cycle dynamics. To date, the concept of uncertainty in economic literature has encompassed a wide range of concepts, reflecting uncertainty about GDP growth, consumer and producer uncertainty, and noneconomic events such as terrorism and war. Several key facts have been established about the behavior of uncertainty, that general "uncertainty" both rises during recessions and falls during expansions, that it likely explains a significant portion of the drop in domestic GDP during the Great Recession, and that shocks to uncertainty affect behavior through multiple channels (Bloom, 2014). These theoretical channels consist of four mechanisms, two that suggest a negative relationship between uncertainty and output and two that suggest a positive relationship.

I. Theory

The first and most prominent theory regarding the effects of uncertainty fluctuations on economic activity is that of real options (Bernanke (1983), Brennan and Schwartz (1985), McDonald and Sigel (1986)). This theory postulates that firms view investment decisions as "options," options which they can postpone to another point in the future. Thus, uncertainty makes firms more hesitant to make large investments, fearing the costs of making a large purchase if the reward is unknown. For example, a firm considering buying a new factory has the option to make the investment today, or to wait for additional information regarding future economic conditions – the potential return on that factory – by delaying the investment until a later date when uncertainty about the future dissipates. Such "real options" mechanisms only come into effect when investments are irreversible, or expensive and difficult to reverse. Firms must not be selling into a perfectly competitive marketplace, where the choice of investment in one period has no effect on profitability in a later one. If both these criteria are satisfied, increased uncertainty is theorized to have an immediate downward effect on real economic activity, incentivizing firms to postpone investment activities, followed by a rebound, as the "pent-up" investments are then simply made at a later date.

The second channel through which overall uncertainty is theorized to have a negative impact on real economic activity is related to risk aversion. Higher levels of uncertainty lead to increasing risk premia, as well as raise the probability of default via increased probability of "black swan" events, ultimately raising borrowing costs. This stifles investment activity and leads to reductions in macroeconomic growth (Arellano, Bai, and Kehoe (2010); Christiano, Motto, and Rostagno (2014); Gilchrist, Sim, and Zakrasjek (2011)). A subset of this channel is that of what Bloom (2014) deems the "confidence effect," whereby individuals have pessimistic beliefs about the future. In such a case, when individuals are highly uncertain about the future, to the point that the distribution of possible outcomes is actually unknown, pessimistic individuals act as though the worst possible scenario will occur, showing an aversion to ambiguity. Finally, aversion to the risk associated with higher uncertainty can lead to precautionary saving on the part of consumers (Bansal and Yaron (2004)), depressing current consumption spending. The potential offsetting increase in investment, however, will only happen if one assumes New Keynesian characteristics (sticky prices) and a closed economy. As shown in Leduc and Liu (2012), Basu and Bundick (2011), and Fernandez-Villaverde, Guerron-Quintana, Kuester, and Rubio-Ramirez (2011), uncertainty shocks can depress output if prices and interest rates do not fall enough after the initial drop in consumption to stimulate investment.

While the real options and risk premium channels point to a negative relationship between economic activity and uncertainty, two other theoretical channels point to a positive one. The first of these, growth options, is based on the idea that uncertainty can stimulate investment by making the potential reward seem even greater. This phenomenon can serve as an explanation for the current tech boom in Silicon Valley – for a "start-up" tech firm, the cost of a poor outcome are relatively small, given the lack of capital requirements for a tech firm, while the potential good outcome (a highly successful company that can be sold for a premium in the current manner equity markets value tech firms) is highly profitable. The theory of growth options has been empirically investigated in Kraft, Schwartz, and Weiss (2013), who show that growth options are particularly important for firms investing heavily in R&D, to the point that higher levels of uncertainty raise their equity value.

The fourth theoretical channel between uncertainty and economic activity is that of Oi-Hartman-Abel effects, named after Oi (1961), Hartman (1972), and Abel (1983). The theory postulates that firms may be risk-loving, not risk averse. Put differently, a firm may expand to take advantage of potential good outcomes, and contract to protect against poor ones. This is exemplified by the recent growth of the tech industry in Silicon Valley. Firms, seeing the potential for excellent financial outcomes, actively take on more risk, in an almost frenzied behavior. As such, an increase in uncertainty, if firms are risk-loving and optimistic, may lead to increased production. However, this theory only holds in the case of little to no adjustment costs, assuming firms can expand and contract relatively easily.

The empirical literature that has tried to quantify the magnitude of these four effects through either estimating responses to historical movements in uncertainty, using structural models, or exploiting natural experiments such as climate disasters, has provided "suggestive but not conclusive evidence" (Bloom (2014)) that negative effects outweigh the positive. A rise in uncertainty tends to be met with decreased short-run output growth, investment, hiring, consumption, and trade. The medium to long-run effects are much less conclusive.

II. Policy Uncertainty

While the literature surrounding output uncertainty has recently expanded into an extensive collection, there have been fewer studies of policy uncertainty, particularly monetary policy uncertainty. Two studies that have narrowed down general uncertainty to policy-based uncertainty are that of Born and Pfeifer (2011), who both theoretically and empirically investigate the effects of broad policy uncertainty, particularly fiscal policy uncertainty, as well as Shelton and Falk (2016), who examine electorally-induced policy uncertainty.

Born and Pfeifer (2011) analyze the role of policy risk in business cycle fluctuations using an estimated New Keynesian model including policy risk, measuring uncertainty from aggregate time series using Sequential Monte Carlo Methods. Their chosen proxy for policy uncertainty includes a mix of uncertainty about labor and capital tax rates, monetary policy, and government spending. Although the authors find significant evidence for the presence of policy risk in the data, they show that the "pure uncertainty" effect of policy risk only plays a very small role in business cycle fluctuations (Born and Pfeifer (2011)). However, the authors acknowledge that this is due to the general equilibrium effects of the monetary authority's strong and swift response that significantly dampens the estimated effects in the DSGE model. Without this response, the effect on output of an uncertainty shock would increase from -0.025% to -

0.075%. However, a monetary authority that would not respond in such a way as it does in their original model would also imply unrealistically extreme business cycle volatility, an unlikely scenario.

Shelton and Falk (2016) empirically examine policy uncertainty from an electoral standpoint, estimating the effect on investment in the manufacturing sector. Given that policies relevant to business investment vary by political party, uncertainty about upcoming governor political affiliation is a source of risk to firms when making investment decisions. The authors use an instrumental variables approach to estimate that the elasticity of manufacturing investment with respect to the vote margin of a gubernatorial election is -0.027.

We provide a novel investigation of the effects of monetary policy uncertainty, differing from the aforementioned literature on uncertainty and general policy uncertainty. This comes at a time in which monetary policy uncertainty is in the spotlight, having experienced an unprecedented truncation by nearly a decade at the zero-lower bound. The policy implications of monetary policy uncertainty are motivated by the findings of Filardo and Hoffman (2014), who find that forward guidance not only effectively changes interest rate expectations, it lowers interest rate uncertainty – the term premia – as well. Doehr and Martinez-Garcia (2015) effectively show the quantitatively substantive effects of shocking interest rate expectations. However, failing to account for the corresponding negative shock to uncertainty from a guidance episode may understate the effectiveness of forward guidance as an alternative monetary policy tool.

The Transmission Channels of Monetary Policy Uncertainty

I. Direct Effects: Real Options

Similar to investment uncertainty, we propose that fluctuations in monetary policy uncertainty directly influence macroeconomic aggregates through the "real options" and channel. We propose that, when faced with increased uncertainty regarding the future path of interest rates, economic agents postpone their investment and hiring decisions, in the hopes of receiving clearer information in the near future about whether they are about to enter a contractionary or expansionary policy period (or neither), which would directly affect a firm's ability to finance an investment decision, by raising or lowering their cost of debt, as well as signaling the state of the economy – the return that investment may yield in the near future.

In this way, an economy characterized by increased uncertainty regarding upcoming central bank actions will witness a period of decreased output and inflation, as firms postpone major investment and production decisions. On the other hand, economies in which central banks use clear forward guidance to illustrate their preferred policy path – or those that are bound by a zero interest rate policy – will eschew this phenomenon, as agents rightly believe that waiting to make investment decisions will produce no better information than that which they currently have on hand.

II. Indirect Effects: Muting Policy Effectiveness Through Risk Aversion

The second channel through which monetary policy uncertainty affects economic conditions indirect: by dampening the ability of the central bank to effectively use both traditional monetary policy as well as unconventional monetary policy, specifically forward guidance. The underlying channel was conceptually developed for general economic uncertainty in Bloom (2009), and expanded here to incorporate monetary policy and monetary policy expectations.

Bloom develops a firm-level production model where each production unit has the following Cobb-Douglas production function:

$$F(\widetilde{A}, K, L, H) = \widetilde{A} K^{\alpha} (LH)^{1-\alpha} \tag{1}$$

in productivity ($\widetilde{A}$), capital (K), labor (L), and hours (H). Hours are included separately from wages to facilitate the determination of wages, which follows the approach in Caballero and Engle (1993), in which wages are determined by undertime and overtime hours around the standard work week. Each firm is faced with the following demand curve:

$$Q = BP^{-\varepsilon} \tag{2}$$

with elasticity ε. Bloom combines these into the revenue function:

$$R(\widetilde{A}, B, K, L, H) = \widetilde{A}^{1-(1/\varepsilon)} B^{1/\varepsilon} K^{\alpha(1-(1/\varepsilon))} (LH)^{(1-\alpha)(1-(1/\varepsilon))} \tag{3}$$

where A combines unit-level productivity and demand into one general index, termed "business conditions" These business conditions are key to the introduction of monetary policy and monetary policy expectations into the model. Bloom assumes business conditions evolve as an augmented geometric random walk, and models them as a multiplicative composite of three separate random walks. These three components include a macro-level component A_t^M, a firm-level component $A_{i,t}^F$, and a unit-level component $A_{i,j,t}^U$, to best model the assumptions that units within a single firm have linked investment behavior due to common firm-level business conditions, and that they still exhibit independent behavior from idiosyncratic unit-level shocks. Bloom models the three components as follows:

$$A_t^M = A_{t-1}^M(1+\sigma_{t-1}W_t^M),\ W_t^M \sim N(0,1) \tag{4}$$

where σ_t is the standard deviation of business conditions, while W_t^M is a macro-level i.i.d normal shock. The second component, the firm-level component, is modelled as:

$$A_{i,t}^F = A_{i,t-1}^F(1+\mu_{i,t}+\sigma_{t-1}W_{i,t}^F), W_{i,t}^R \sim N(0,1) \tag{5}$$

where $\mu_{i,t}$ is a firm-level trend in business conditions, while $W_{i,t}^F$ is a firm-level i.i.d. normal shock. Finally, the unit-level component is modelled as:

$$A_{i,j,t}^U = A_{i,j,t-1}^U(1+\sigma_{t-1}W_{i,j,t}^U), W_{i,j,t}^U \sim N(0,1) \tag{6}$$

where $W_{i,j,t}^U$ is a unit-level i.i.d. normal shock. The stochastic volatility process and trend in demand conditions are assumed to follow two-point Markov chains. Bloom finishes this model by adding adjustment costs including partial irreversibilities, fixed disruption costs, and quadratic adjustment costs.

The process of solving the optimization problem of maximizing the present discounted flow of revenues less the wage bill and adjustment costs is described in full in Bloom (2009).[1]

The key relevant result of the model is that it yields a central region of inaction in the $(A/K, A/L)$ space. As such, units only engage in hiring and investing when business conditions A are sufficiently good, and only engage in firing and disinvestment when business conditions are sufficiently poor. Uncertainty comes into play by making this central region of inaction wider by shifting the thresholds of action outward and upward. This is represented as follows:

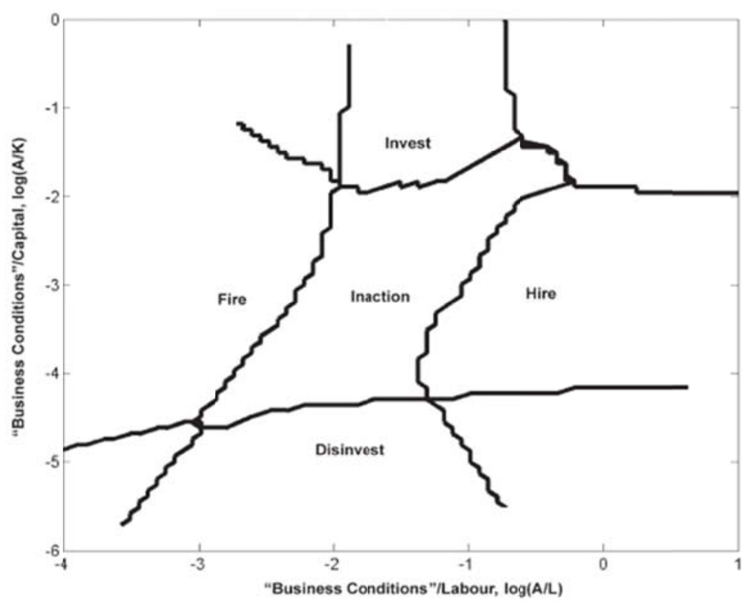


Figure from Bloom (2009).The inner region of inaction is where the real-option value of waiting is more valuable than the returns to investment or hiring

[1] See paper for additional assumptions the author makes that are necessary to derive numerical results and incorporate aggregation into the model, as well as a complete derivation of the various adjustment costs.

The same representation of action versus inaction, when faced with an increase in uncertainty, is depicted as:

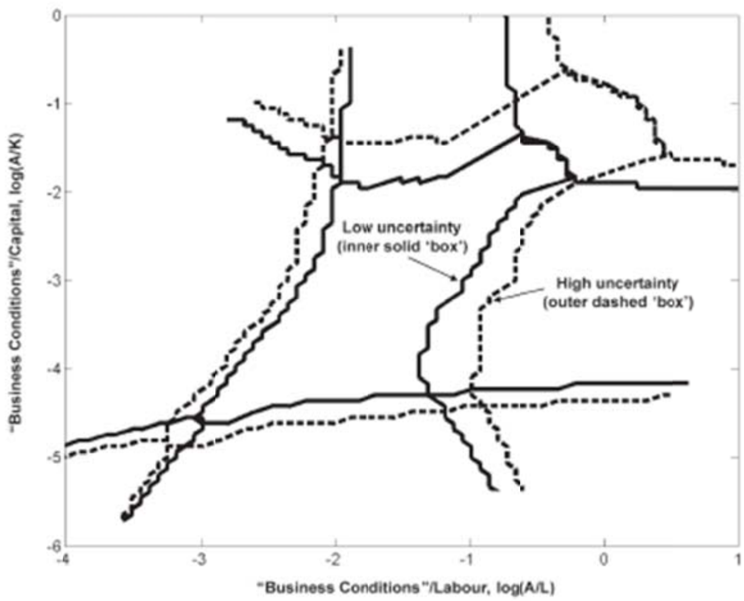


Figure from Bloom (2009).Thresholds at low and high uncertainty. High uncertainty is twice the value of low uncertainty

$$\sigma_H = 2X\sigma_t$$

These show that an increase in uncertainty leads to a more insensitive economy to changes in business conditions, as the uncertainty shock causes the thresholds to shift outward, and as a result, there are no units next to any of the thresholds. Thus, a subsequent shock to business conditions leads to a dampened output response.

While Bloom leaves business conditions defined generally as conditions ultimately affecting firm demand that apply to firms, we more definitively identify what those consist of, focusing in on A_t^M , or macro-level business conditions. Output uncertainty shocks are modelled as time variations in the standard deviation of the driving process of the aforementioned business conditions, σ_t. Bloom choses to model the volatility term as a two-state Markov process for simplicity, assuming it can either take on the value of "low uncertainty" or "high uncertainty," and the probability of being in either state is only dependent on the current state. In reality, uncertainty can take a continuous range of values . In the following, we explore the possible driving process of those values. Currently, as written into the model, change in σ_t affect the uncertainty of unit-level conditions, firm-level conditions, as well as macro-level conditions. Bloom notes that he also evaluated this assumption by simulating an uncertainty shock to only the variance of W_t^M, which led to broadly similar results to those described in full above. Thus, we are on sound footing to differentiate σ_t into the following:

σ_t^W, macro-level uncertainty

σ_t^F, firm-level uncertainty

σ_t^U, unit-level uncertainty

knowing that shocks to σ_t^W lead to nearly the same results above. Macro-level conditions in the model consist of interest rates, prices, and wages. We decompose σ_t^W into these three components as follows:

$$\sigma_t^M = U_t^M = [\alpha_t(\sigma_t^i)^{(1+\theta_t^i)}] + [\beta_t(\sigma_t^P)^{(1+\theta_t^P)}] + [\lambda_t(\sigma_t^w)^{(1+\theta_t^w)}] \quad (7)$$

$$\alpha_t + \beta_t + \lambda_t = 1 \quad (8)$$

$$0 \geq \theta_t^i, \theta_t^P, \theta_t^w \leq 1 \tag{9}$$

Macro-level "business conditions" uncertainty is a blend of interest rate uncertainty, price level uncertainty, and wage uncertainty, where the relative weights of each component are allowed to vary each time period but always sum to one. We also extend the model to incorporate ambiguity aversion, or Knightian uncertainty, by scaling the individual volatilities by a factor θ_t that represents how known the distribution σ_t is. This is also allowed to vary each time period and is unique to each component (Knightian certainty of interest rates, Knightian certainty of prices, and Knightian certainty of wages). In the most extreme scenario of no Knightian uncertainty (the distribution of possible movements is perfectly known to firms), θ_t takes on a value of 0, so the exponential term collapses to 1, and no power effect comes into play to magnify the volatility term. On the other extreme, if there is complete Knightian uncertainty, θ_t takes on a value of 1, so the volatility term is squared before weighting it and combining it with the other components.

In this way, monetary policy (interest rate) uncertainty is reflected in the model through fluctuations in σ_t^i as well as changes in θ_t^i. Put differently, an increase in either the volatility of monetary policy shocks or a decrease in the certainty of firms about the possible distribution of those shocks both lead to an increase in σ_t^M , which Bloom shows shifts the thresholds of inaction outward. Thus, subsequent shocks to economic conditions that affect macro-level demand – such as a monetary policy shock – lead to dampened results of output. Similarly, Doehr and Martinez-Garcia (2015) show that shocks to interest rate expectations are as important as shocks to the immediate interest rate at the moment, moving output in a similar direction. Thus, an increase in monetary policy uncertainty leads to an indirect result of making policy actions, both conventional monetary policy as well as forward guidance, less effective. This highlights the potential importance of forward guidance at the zero-lower bound. If a central bank has engaged in a zero interest rate policy, truncating and lowering interest rate uncertainty, then shocks to interest rate expectations may be even more effective at the zero-lower bound than previously hypothesized.

Putting all the pieces together, monetary policy uncertainty has two different transmission channels with which it affects real economic conditions. First, it has a direct effect through the "wait and see" channel, similar to the idea of postponing investments in the traditional uncertainty literature. Second, monetary policy uncertainty dampens policy actions that affect interest rate shocks and interest rate expectations shocks (forward guidance) through the mechanisms of Knightian uncertainty and volatility that increase the areas of inaction for firms.

Empirical Strategy

I. Data

We use interest rate forecasts from the Blue Chip Economic Indicators (BCEI) survey, a survey of leading business economists, to generate our uncertainty proxies, as well as to gauge monetary policy expectations. The BCEI provides the panel's monthly arithmetic average one quarter, two quarter, three quarter, and four quarter ahead forecasts of fifteen different macroeconomic variables, in addition to the top 90^{th}

percentile forecast and the bottom 10th percentile forecast for each forecast horizon. To extract monetary policy uncertainty from this panel, we use the dispersion of the forecasts of the panel's expectation of the rate on the three month Treasury bill, calculated as the difference between the top 90th percentile and the bottom 10th percentile. Each month, we use the longest consistent forecast horizon available (four quarters ahead) to measure disagreement among forecasters as our primary measure of monetary policy uncertainty. We also use the reported arithmetic mean forecast of the corresponding four quarter ahead interest rate as the measure of interest rate expectations in the TVP-VAR. This panel of forecasts is taken from 1991:M7 through 2015:M11.

We make forecast dispersion our benchmark measure of policy uncertainty, rather than forecast errors or stock market volatility, two commonly used metrics, due to several factors. Measures of forecast error, while undoubtedly capturing some aspects of uncertainty, are also measuring "wrongness," as well as uncertainty – one can be completely certain and still be incorrect about the future, which would be recorded as a large forecast error. Equity and credit market volatilities, other commonly used measures, were not chosen for the benchmark, as equity markets are too far removed from what we are specifically capturing – monetary policy uncertainty – while measures of volatility in credit markets, e.g. the Ted spread or various ARCH measures, confound perceived default risk along with actual interest rate uncertainty, again not reflecting pure monetary policy uncertainty. We choose to tease out and use Knightian uncertainty from the SPF to more clearly distinguish between known default risks and true uncertainty, where the expected distribution of outcomes is unknown (Knight (1921)). The BCEI provides a rich picture of forecaster's immediate interest rate expectations, and a measure of crosssectional disagreement derived from such survey data has been shown to be an accurate portrayal of the corresponding Knightian uncertainty (see Bomberger (1996), Patton and Timmerman (2010)).

As a robustness check, we use a separate measure of monetary policy uncertainty. We also utilize data from the Survey of Professional Forecasters (SPF) from the Federal Reserve Bank of Philadelphia, which surveys a panel of economists and offers individual forecasts for a variety of macroeconomic variables. The dataset contains the entire panel of forecasts for the interest rate on the three month Treasury bill one quarter ahead, two quarters ahead, three quarters ahead, and one year ahead. To construct a measure of uncertainty from this, we take the standard deviation of the forecast for the rate on the three month Treasury one year ahead, for the same reasons described above regarding forecast dispersion. We use the corresponding median forecast of the interest rate each quarter as our measure of the actual interest rate expectations in the TVP-VAR when running the model with SPF data rather than BCEI data.

All other variables used in our analysis – the core inflation rate, the civilian unemployment rate, the Federal Funds rate, oil prices, and monetary base growth – were taken from the St. Louis Federal Reserve database.

A more detailed description of the data and sources can be found in the Appendix. All data is at either a quarterly or monthly frequency from 1991:M7 through 2015:M11 or 1981:Q3 through 2015:Q2, to match the respective BCEI or SPF panel.

II. Methodology

Time-varying parameter VARs (TVP-VARs) are broadly used in economic literature to capture the possible time-varying nature of the macroeconomy, particularly in monetary policy analysis (Nakajima, 2009). After Primiceri (2005) introduced a TVP-VAR model that allows for all parameters to vary over time, several papers followed that analyzed the time-varying structure of the macroeconomy in certain ways (see Benati and Mumtaz (2005), Baumeister et al. (2008), and D'Agostino et al. (2008)). Among these, we highlight Nakajima (2009), who added the possibility of stochastic volatility into the TVP-VAR, as well as the relevant contributions of Franta (2011), who employed an identification scheme based on sign restrictions in the Japanese economy. Given our goal of examining the underlying structural shifts in the U.S. economy at the zero-lower bound, particularly in regards to the transmission of monetary policy with uncertainty and expectations, we chose to utilize the modeling framework proposed by Franta (2011) that allows for both stochastic volatility as well as sign restrictions.

A TVP-VAR that allows for stochastic volatility enables us to capture both temporary and permanent shifts in parameters, including that of the volatility of the disturbances. The idea of stochastic volatility was first proposed by Black (1976), and has been further developed, particularly in the field of financial economics (Nakajima, 2009). When the data generating process has both time-varying coefficients as well as stochastic shocks, then using a model that exclusively allows coefficients to vary and assumes constant volatility may potentially bias estimates. This is of particular relevance when modeling the economy at the zero-lower bound, as we do here. The zero-lower bound truncates possible downward movements in both the Federal Funds rate itself, as well as expectations of the 3-month Treasury bill, significantly reducing potential fluctuations of those two variables. In this way, a TVP-VAR with stochastic volatility allows us to more accurately incorporate the role of the zero-lower bound in the transmission of monetary policy throughout the macroeconomy, rather than assuming the volatility of the disturbances of the interest rate, interest rate expectations, and monetary policy uncertainty are constant at any level of the Federal Funds rate. Similarly, given that our objective is examining the transmission mechanism of monetary policy, it is crucial to distinguish between changes in the size of exogenous innovations—the stochastic volatility—and underlying shifts in the transmission mechanism itself (Mumtaz, 2005).

The second key characteristic of our chosen methodology is that of incorporating sign restrictions in the TVP-VAR, following the framework of Franta (2011). Sign restrictions are a manner in which we can further incorporate the binding effects of the zero-lower bound into the model—as well as avoid encountering puzzles common in macroeconomic VARs (Franta, 2011). The zero-lower bound on the nominal interest rate is implemented during the identification of the shocks rather than during the initial model estimation. Previous attempts in the literature to examine the transmission of monetary policy at the zero-lower bound impose assumptions from the very beginning of the estimation, such as treating the interest rate as a censored variable, using a Markov-switching VAR, or a estimating a censored VAR where the latent variable capture the stance of monetary policy and equals the interest rate if it exceeds zero (see Nakajima (2011), Fujiwara (2006), and Iwata and Wu (2006)). The approach we follow, à la Franta (2011), imposes the zero lower bound at a later stage, when estimating impulse response functions, while estimating the initial reduced-form TVP-VAR without restrictions as it is flexible enough to handle nonlinearities stemming from the floor on interest rates. Similarly, using structural assumptions in the form of sign restrictions lets us relax the oftentimes inappropriate assumptions of the more typical recursive VAR ordering, that shocks to some endogenous variables do not have any simultaneous effects on those that come before them in the recursive ordering. Sign restrictions allow us to base our empirical model in economic theory rather than be tied to the characteristics of the specific dataset itself and a particular recursive ordering, making it easier to interpret the TVP VAR evidence using the standard New-Keynesian model. For those shocks that do not have a robust underlying economic theory – namely, shocks to monetary policy uncertainty and the effects of shocks to other economic variables *on* policy uncertainty – we adapt the model framework to allow for an unspecified response or effect, relaxing any sign restrictions to let the data simply speak for itself. A more detailed description of the exact restrictions chosen can be found in the discussion of the benchmark model.

The following model and estimation approach closely follow Primiceri (2005)[2], a multivariate time series framework with varying coefficients that captures nonlinearities and time-variation in the parameters, while also accounting for possible heteroscedasticity of the disturbances (Arratibel and Michaelis, 2014). We estimate the VAR model in the following manner:

$$y_t = c_t + \beta_{1,t} y_{t-1} \ldots + \beta_{1,t} y_{t-l} + u_t \qquad t = 1,\ldots,T$$

[2] See Primiceri (2005) for a more in depth analysis of the model specification, assumptions, and estimation technique, as well as Nakajima (2009) for a more extensive discussion of the role of stochastic volatility.

where the vector of endogenous variables y_t is of the size n x 1; c_t, the vector of time-varying coefficients that multiply constant terms of of the size n x n; the time-varying coefficients $\beta_{i,t}$ with the lag length t have the size n x n, and u_t, of the size size n x 1, are unknown stochastic shocks with time-variation in the covariance matrix of the error terms.

The matrix capturing simultaneous relations, A_t, is lower triangular, denoted as:

$$A_t = \begin{bmatrix} 1 & 0 & \dots & 0 \\ \alpha_{21,t} & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{M1,t} & \dots & \alpha_{M,M-1,t} & 1 \end{bmatrix}$$

γ_t is an $M(Mp + 1)$ x 1 vector of the effects of lagged endogenous variables on the system, and the matrix of standard deviations of the structural shocks, $\sum_t$, is diagonal:

$$\sum_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{M,t} \end{bmatrix}$$

The reduced form time-varying VAR to be estimated can then be summarized as:

$$y_t = X_t\beta_t + A_t^{-1}\sum_t \varepsilon_t \qquad t = p + 1, \ldots T,$$

The dynamics of the time-varying parameters follow a random walk without drift, while the covariance matrix evolves as a geometric random walk with no drift, shown as:

$$\beta_{i,t} = \beta_{i,t-1} + u_t^1 \qquad i = 1,\ldots M^2p + M,$$

$$\alpha_{i,t} = \alpha_{i,t-1} + v_t^1 \qquad i = 1,\ldots (M^2 - M)/2,$$

$$\log(\sigma_{i,t}) = \log(\sigma_{i,t-1}) + w_t^i \qquad i = 1,\ldots M$$

Using a random walk to model the underlying dynamics provides a highly flexible framework to capture the evolving nature of different parameters coming from potential shifts in the macroeconomy (Arratibel and Michaelis, 2014).

The vector of model innovations [$\varepsilon_t^{'}, u_t^{'}, v_t^{'}, w_t^{'}$] is assumed to be jointly normally distributed, as the following:

$$\begin{bmatrix} \varepsilon_t \\ u_t \\ v_t \\ w_t \end{bmatrix} \sim N\left(0, \begin{bmatrix} I_M & 0 & 0 & 0 \\ 0 & U & 0 & 0 \\ 0 & 0 & V & 0 \\ 0 & 0 & 0 & W \end{bmatrix}\right)$$

where vectors u_t, v_t, and w_t consist of innovations as introduced above, and the matrices U, V and W are positive definite. V is assumed to be block diagonal, implying that the parameters of the contemporaneous effects among variables are independent, uncorrelated across equations.

Consistent with the Bayesian approach, a Gibbs sampler is used to evaluate the posterior distribution of the unobservable states $\alpha_{i,t}$, $\beta_{j,t}$, $\sigma_{k,t}$, and the hyperparameters U, V, and W (see Blake and Mumtaz, 2012, for a detailed explanation of Bayesian estimation of TVP-VARs with stochastic volatility). To perform the estimation of the posteriors, the Gibbs sampler provides draws from the conditional posteriors of the set of parameters. In order to do this, we need to specify the distribution of the priors. *U, V,* and *W* follow the independent inverse Wishart distribution, consistent with the literature, while the priors for the initial states of the other parameters, $\alpha_{i,t}$, $\beta_{j,t}$, and log($\sigma_{k,t}$) are normally distributed. Consistent with Primiceri (2005), we use a small subset of the data set estimated through ordinary least squares (specifically, the first 40 months of the time series) to form estimations used in the specification of the prior distributions.

After initializing the parameters, a draw is taken from the distribution of the vector β, given the other parameters *A*, $\sum$, hyperparameters *U*, and the data. Next, the Gibbs sampler goes over U first, producing a draw, and continues on over the other subsets of the parameter set (*A*, *V*, $\sum$, and *W*). This process is then repeated, ultimately providing posterior numerical evaluations of the parameters. For this estimation, we use the same specification of the priors (k_q, k_s, and k_w) as in Primiceri (2005), which are consistent with the literature, and slightly tighter than those used in Nakajima (2009), attributing more of the time variation to the disturbances (σ) rather than the parameter estimates (β) themselves. Primiceri's tighter priors negate the possibility of erroneously attributing additional time variation to the parameters when they are truly closer to time invariant.[3] This is further confirmed by Stock and Watson (1996), who show that models

[3] We also estimate the model using the code and methodology of Nakajima (2009) as a robustness check. The results show higher parameter instability and less stochastic volatility, while nevertheless confirming the critical importance of monetary policy uncertainty and expectations in the transmission of monetary policy, and the structural shifts that occur at the zero-lower bound. More detailed results are available upon request from the author.

with large a priori time variation do poorly in forecasting, and that allowing for significant time variation in the volatilities is fundamental to improving the model fit.

To recover the impulse-response functions (IRF's) after the initial model estimation, we identify five structural shocks (monetary policy uncertainty, interest rate expectations, inflation, unemployment, and the Federal Funds rate) by using sign restrictions on the contemporaneous reactions of the other variables to the shocks, as in Franta (2011).[4] We base our sign restrictions on assumptions about the behavior of the system, imposing qualitative information requirements on the IRF's. Certain responses are left unidentified, to be determined by the data (see Faust, 1998, Uhlig, 2005) when there is uncertainty surrounding the underlying economic theory, or in the case of our measure of monetary policy uncertainty, where the specific variable itself and its construction is novel in economic literature. We consider four different types of restrictions: positive, negative, zero, or unidentified (see Table 2), and motivate our sign choices by results found in Doehr and Martínez-García (2015), in which the authors estimate a four variable panel VAR that includes interest rate expectations in addition to inflation, unemployment, and the Federal Funds rate. The sign restrictions imposed here on the effects from shocks to "realized" economic variables (inflation, unemployment, and the Federal Funds rate) are consistent with the findings of Doehr and Martínez-García (2015)—as well as economic theory. The restrictions imposed on the effects from shocks to interest rate expectations account for the reversal in the response of output by leaving that response unspecified, while restricting the responses of inflation and the

[4] See Franta (2011) for a detailed explanation of the estimation procedure for impulse response functions using sign restrictions.

Federal Funds rate to nearly zero. Shocks to monetary policy uncertainty or the effect of a shock on monetary policy uncertainty are always left unspecified.

The model estimation and additional procedures were estimated in Matlab[5] using one lag of the endogenous variables. Given the relatively high number of parameters estimated in this five variable VAR, allowing for any more lags leads to convergence issues, as the number of parameters to be estimated rapidly explodes. We use a sample of 10,000 iterations of the Gibbs sampler, with a burn-in of 2,000.

III. Results

Benchmark Model

The specification of our benchmark TVP VAR is motivated by the New Keynesian model, the standard three variable VAR, augmented with both expectations of future monetary policy as well as uncertainty surrounding those expectations. The inclusion of the first of these two channels—expectations of monetary policy—is driven by the results found in Doehr and Martínez-García (2015), that expectations of monetary policy themselves can generate a response in macroeconomic variables even if no policy change takes place. This allows us to explicitly differentiate between innovations to anticipated monetary policy (news shocks) and unexpected monetary policy shocks. The inclusion of monetary policy uncertainty is motivated by the underlying theory of forward guidance: that providing guidance to economic agents not only changes interest rate expectations themselves, but decreases the corresponding uncertainty, particularly

[5] The model used code for a TVP VAR with stochastic volatility and sign restrictions, made publicly available by Haroon Mumtaz (Benati and Mumtaz, 2005).

when traditional policy rates are fixed by the zero-lower bound (Filardo and Hoffman (2014). By including uncertainty in the VAR, we also not only allow for the simulation of shocks to uncertainty itself, but we incorporate any potential indirect, non-linear effects described previously in the transmission mechanism of monetary uncertainty into the econometric model. We use the dispersion of the expectation of the one-year ahead rate on the 3-Month Treasury as the proxy for monetary policy uncertainty in the benchmark, performing robustness checks by using alternative measures (the Survey of Professional Forecasters) in a later model. We find that monetary policy uncertainty plays a significant role in the macroeconomy not only directly, but by indirectly shaping the transmission of other shocks throughout the economy. We focus our analysis on the impulse-response functions, the recovered stochastic volatilities, and an analysis of nonlinearities in the model.

A. <u>Impulse-Response Functions</u>

The impulse response functions from the benchmark model are presented in *Figure 3,* showing the responses over 5 years (60 months) and the time period 2001:M7 – 2015:M11 to one standard deviation shocks to the endogenous variables in the VAR. We can first clearly see what influences monetary policy uncertainty itself, and that, in some cases, the way in which other macroeconomic variables affect monetary policy uncertainty has changed over time. In *Figure 3b*, we find that a shock to interest rate expectations leads to a rise in monetary policy uncertainty. Of important note is the fact that this effect is magnified at the zero-lower bound: after 2008, a rise in forecasts of future short-term rates has nearly twice the initial effect on monetary policy uncertainty.

We theorize that this is due, in part, to the fact that at the zero-lower bound, interest rate expectations are truncated at zero—the possibility of downward revisions to forecasts is eliminated, as the distribution itself can move no farther downward. Thus, an upward shock to interest rate expectations at the zero-lower bound shifts the distribution upward, inducing the possibility of downward revisions to forecasts. This impulse-response function can also be explained by the focus on interest rates when they are bounded by zero. We see in the data in *Figure 2* that over the past 3-4 quarters, as talk of rising rates has begun in earnest, interest rate expectations as well as monetary policy uncertainty have started to tick upward. Even a very small positive movement in rate forecasts, relative to the historical range of interest rates, leads to this spike in policy uncertainty, as the security of the zero-lower bound policy is left behind even though we are still at the zero-lower bound. Shocks to unemployment have also had time-varying effects on monetary policy uncertainty (see *Figure 3d*), as prior to the Great Recession a positive shock to unemployment had very little impact on uncertainty. However, this response has gradually been magnified since 2008, implying increased confidence in the Federal Reserve's response to such an event. We also find that a shock to the Federal Funds rate leads to a spike in uncertainty. This effect is most heightened at the onset of the financial crisis, after which it dies down. Interestingly, the magnitude of the response is in the process of spiking upward again, implying an increased sensitivity to movements in the Federal Funds rate. This may again be due to the loss of the binding zero-lower bound on the potential distribution of rates. After being truncated by zero for so long, an upward movement induces the possibility of downward movements again. Another possible explanation is the increased scrutiny of the Federal Reserve's actions in the past few quarters, as talks of rising rates begin in earnest. Thus, any uptick in rates by the central bank that may signal the end of the zero interest rate policy leads to a heightened response of uncertainty.

We also highlight several other key impulse-response functions in the benchmark model. In *Figure 3b*, we see that even when including monetary policy uncertainty in the model, the effect on the unemployment rate from a shock to interest rate expectations still displays the extreme parameter instability found in Doehr and Martínez-García (2015), where the response of output entirely reverses at the zero lower bound: a rise in expected monetary policy leads to an increase in unemployment, in sharp contrast to the decrease in unemployment found prior to 2007. In *Figure 3e*, we show that a tightening of the policy instrument itself, the Federal Funds rate, leads to an immediate decrease in inflation. Using core inflation rather than headline inflation in conjunction with including monetary policy expectations as an additional variable successfully mitigates the price puzzle found in many such VARs, providing corroborating evidence for Sims (1992) and Giordani (2004)'s theory that price puzzles arise from un-modelled inflationary pressures that lead to price increases only captured by including commodity prices such as oil to resolve the puzzle. Given that core inflation excludes such un-modelled pressures, this impulse-response function demonstrates the effectiveness of unexpected monetary policy in bringing down non-commodity prices.

Finally, we consider the direct effects of a shock to monetary policy uncertainty itself on other macroeconomic indicators (see *Figure 3a*). As postulated in the "wait and see" theory, the responses of output and inflation are immediate and imply a depressed economic state, with an increase in unemployment and decrease in inflation. These also display parameter instability, with the responses heightened at the zero-lower bound. It is important, however, to gauge the magnitude of these responses relative to, say, a traditional monetary policy shock. The equivalent positive one standard deviation shock to the Federal Funds rate leads to a maximum response of unemployment of nearly 3.0%, while the uncertainty shock alone only leads to an increase on the order of 0.3%, or 10% the size of the former response. This is a relatively small direct effect when considered in the context of traditional monetary policy, though nevertheless a conclusive and long lasting effect. These impulse-response functions show that when traditional monetary policy becomes constrained by the zero-lower bound, forward guidance shocks that decrease monetary policy uncertainty can indeed have direct effects on stimulating output, albeit not of the magnitude of traditional policy. However, it is also important to consider the possible non-linear effects of uncertainty that are not immediately reflected in these impulse-response functions but nevertheless may shape how forward guidance ripples through the economy.

B. *Modeling Non-Linearities in Uncertainty*

While it has been shown that interest rate expectations play a significant and direct role in shaping the macroeconomy, monetary policy uncertainty may play a more nuanced role, though just as important. Monetary policy uncertainty is akin to the 'second moment' of interest rate expectations, capturing the steadfastness with which economic agents hold their beliefs about the future path of policy. Simply shocking the certainty with which people hold their beliefs is not enough to generate significant economic responses; however, the propagation of other shocks throughout the economy is dependent on the level of certainty in the future policy path at that time. As stated in the discussion of the transmission channel of monetary policy uncertainty, higher levels of uncertainty may dampen the ultimate effect of expected monetary policy shocks by causing agents to place more weight on the current interest rate environment when faced with a series of unknown movements in future interest rates. We examine this empirically by calculating the cumulative response of other variables to shocks to unexpected and expected monetary policy at each horizon in the impulse-response function (s=1…s=20), and regress these cumulative impacts against the level of monetary policy uncertainty measured at that time, while simultaneously controlling for other potential confounding variables. Results are shown in *Figure 4*.

Our results show that the level of monetary policy uncertainty plays a formidable role in the dynamics of the macroeconomy, particularly in regards to the effectiveness of unconventional monetary policy, forward guidance. In *Figure 4*, we can see that a one unit increase in monetary policy uncertainty – roughly equivalent to a one standard deviation increase - is associated with a decrease in the maximum impulse-response function of unemployment of -0.063%. Considering that the average maximum response of unemployment is 0.28%, this represents a 23% decrease in the typical response of unemployment to an expectations shock, a significant amount, statistically significant at the 99% confidence level. As theorized, higher levels of uncertainty significantly dampen the propagation of unconventional monetary policy actions taken by the Federal Reserve. Similarly, we find that a one unit increase in monetary policy uncertainty is associated with a decrease in the cumulative response of unemployment from s=1 to s=20 of -1.20, or of 42% of the average cumulative response, 2.81, again significant at the 99% confidence level. Finally, we consider the shape of the response, the slope of the response function. We find that a one unit increase in uncertainty is associated with a decrease in the slope of -0.06, significant at the 5% level, implying that not only does uncertainty cause less of a cumulative total response in output, but makes that response more gradual.

Robustness Checks[6]

I. Survey of Professional Forecasters

To consider the robustness of the results to other measures of uncertainty, we also utilize data from the Survey of Professional Forecasters (see Appendix for additional detail). Given that the SPF reports the entire panel, rather than simply the median forecast and select percentiles, we construct our measure of interest rate uncertainty as the standard deviation of the one year ahead forecasts of the 3-month Treasury bill each quarter. The other, "real" variables – core inflation, unemployment, and the Federal Funds rate – are kept the same in the TVP-VAR. Results from the corresponding impulse-response functions and multivariate regressions are reported in *Figures 5* and *6* in the Appendix.

Overall, we find that the same themes emerge that were found in the Blue Chip data. Monetary policy uncertainty has a direct and detrimental effect on output, and higher levels of uncertainty dampen the ultimate effect of monetary policy actions (shocks to anticipated and unanticipated monetary policy). The key differences of the SPF results lie

[6] Although omitted here for the sake of brevity, we also run robustness checks using different lengths of the forecast horizon, of both the Blue Chip and SPF data, and find confirmatory results in shorter forecast horizons. Results are available upon request from the authors.

in the relative magnitude of these effects. The SPF data yields smaller direct effects, and larger indirect effects (non-linearities). Beginning with the former, we see that a direct shock to monetary policy uncertainty leads to a significantly smaller and less conclusive negative response of output than we find in the Blue Chip data – and one that recovers quicker. However, higher levels of monetary policy uncertainty have indirect effects on the transmission of monetary policy shocks to both output and inflation, by dampening the effect on output (as found in the Blue Chip data), as well as strengthening the response of inflation, something not seen in the Blue Chip data. Put differently, higher levels of monetary policy uncertainty actually make an interest rate hike *more* effective at pulling inflation down. This could be due to forecasters, in times of high monetary policy uncertainty, grabbing onto whatever guidance is provided to them by the central bank when they form their inflation expectations, and ultimately propagating those into actual inflation. In times of lower uncertainty, guidance is simply less impactful, as forecasters already have their own information sets they are relatively confident in, making additional news less effective.

Concluding Remarks

The dual effects of monetary policy uncertainty on the economy, directly depressing output as well as indirectly stifling the effectiveness of both conventional and non-conventional monetary policy actions, illuminates the complexities of an expectations-driven business cycle. It also provides evidence for the importance of managing interest rate uncertainty as a policy tool in and of itself. In this paper we empirically investigate both channels with a TVP-VAR that allows for stochastic volatility, augmenting the traditional three-variable New-Keynesian model with both interest rate expectations and interest rate uncertainty. We find that short term interest rate uncertainty plays a moderate role in its immediate effect on current output, while playing a highly significant role in the propagation of monetary policy shocks through the economy. These effects are seen just as strongly at the zero-lower bound as in "normal" policy times. As such, we find strong evidence that downward pressure on monetary policy uncertainty can be an important policy tool in stimulating output and assuring the proper transmission of other policy shocks. This provides a case for the use of forward guidance when traditional monetary policy has become bounded by zero. While the immediate effects are not as quantitatively substantial as direct shocks to the Federal Funds Rate itself, when moving the Federal Funds Rate is no longer a viable option for policymakers, guidance can provide another means of steering the economy. Managing policy expectations, as shown in Doehr and Martinez-Garcia (2015), in conjunction with managing policy uncertainty, can together make a significant opportunity for guiding an economy when traditional monetary policy measures are no longer realistic options.

Appendix

Table 1 - Data

	Description	Source	Comments
$\mathbf{i^e_{3m,t+4lt}(j)}$	Expected short-term rate (SPF)	FRB.P	Forecasts 4 quarters ahead of the 3-month T-bill (annualized rates, %) for a varying sample of *j* forecasters in each quarter
$\mathbf{UC^c_{MP}}$	Monetary policy uncertainty – dispersion (SPF)	FRB.P	Standard deviation of $i^e_{3m,t+4lt}$ for each quarter for a varying sample of *j* forecasters in each quarter
$\mathbf{i^e_{3m,t+4lt}(j)}$	Expected short-term rate (BC)	BCEI	Forecasts 4 quarters ahead of the 3-month T-bill (annualized rates, %) for a varying sample of *j* forecasters in each quarter. Dataset reports arithmetic average of panel *j*.
$\mathbf{UC^c_{MP}}$	Monetary policy uncertainty – dispersion (BC)	BCEI	Difference between top 90^{th} and bottom 10^{th} decile of $i^e_{3m,t+4lt}$ for each month for a varying sample of *j* forecasters in each month
$\boldsymbol{\pi^c_t}$	Inflation rate (core CPI)	FRED	Seasonally-adjusted, month-over-month (%)
$\mathbf{u_t}$	Unemployment rate	FRED	Seasonally-adjusted (%)
$\mathbf{y_t}$	Real GDP growth	FRED	Seasonally-adjusted, month-over-month (%)
$\mathbf{i_t}$	Fed Funds rate	FRED	Annualized rate (%)
$\mathbf{M_G}$	Monetary Base	FRED	St. Louis Adjusted Monetary Base, month-over-month (%)
$\mathbf{O_G}$	Oil Price	FRED	West Texas Intermediate Crude Oil Price, month-over-month (%)

Note: All data calculated by the authors are available upon request. The acronym SPF stands for the Survey of Professional Forecasters; BCEI stands for Blue Chip Economic Indicators; FRED stands for Federal Reserve Economic Database of the Federal Reserve Bank of St. Louis; FRB.P stands for Federal Reserve Bank of Philadelphia; and FRB.A stands for Federal Reserve Bank of Atlanta.

Table 2 – Sign Restrictions

Shock	Monetary Policy Uncertainty	Interest Rate Expectations	Core Inflation	Unemployment Rate	Federal Funds Rate
Monetary Policy Uncertainty	+	None	None	None	None
Interest Rate Expectations	None	+	-	None	+
Core Inflation	None	0	+	None	+
Unemployment Rate	None	None	-	+	-
Federal Funds Rate	None	0	-	+	+

Figure 1 – Uncertainty Measures

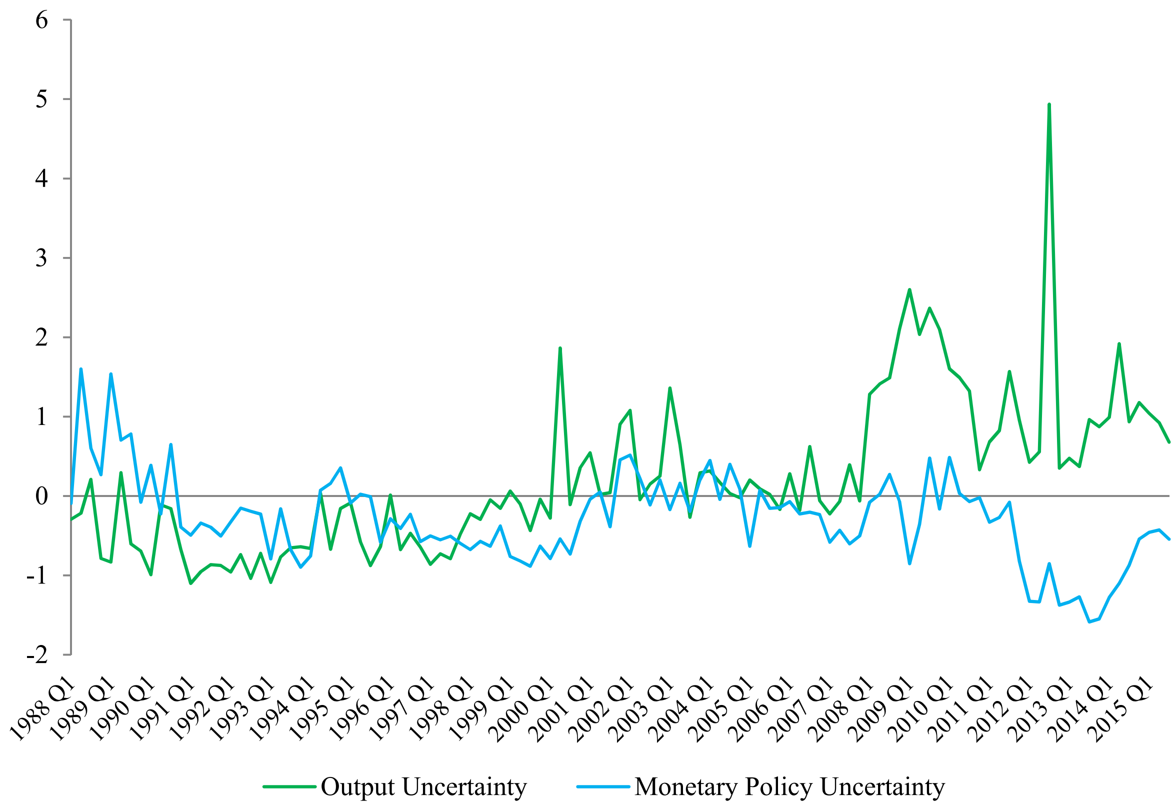
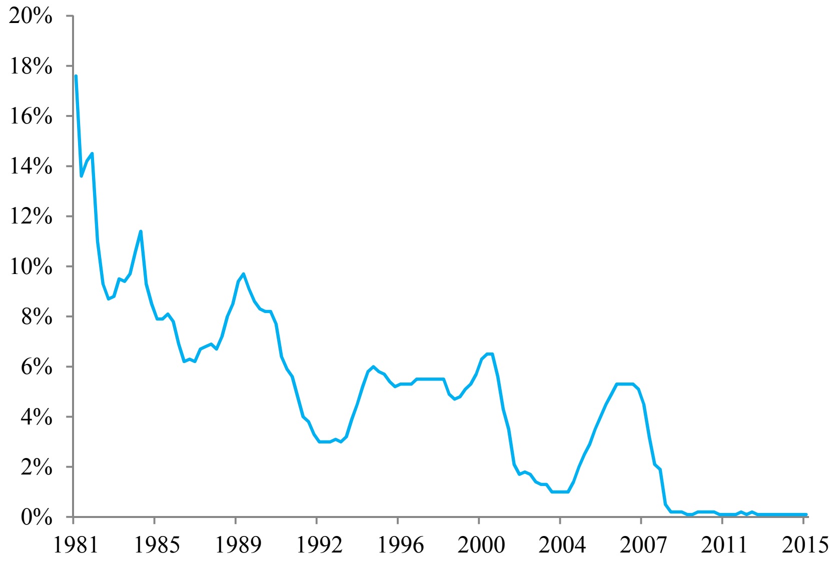
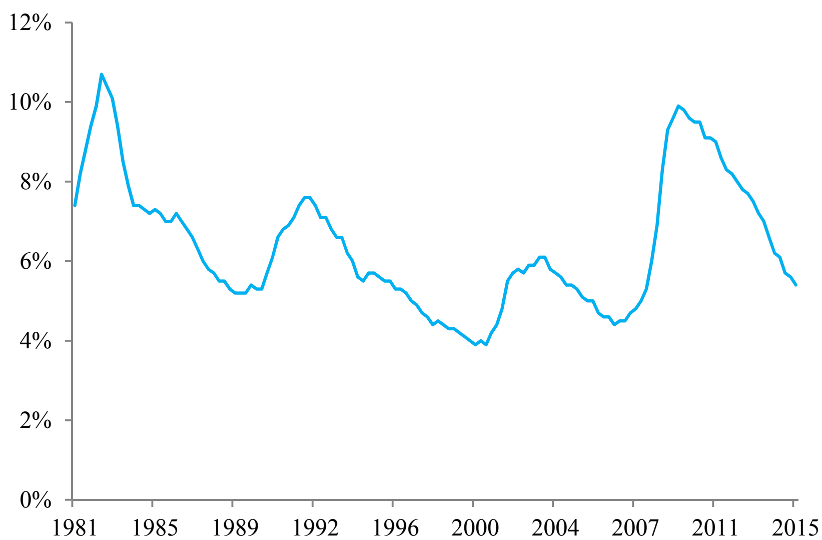


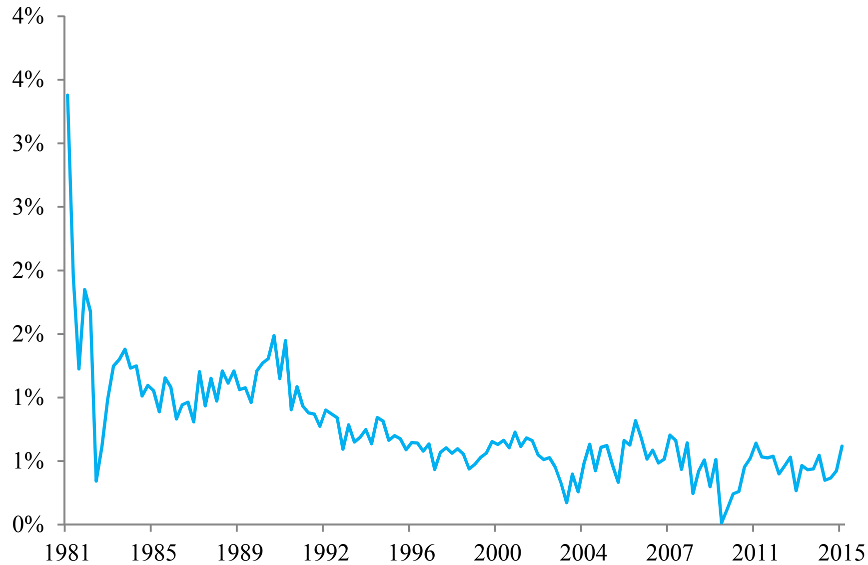
Figure 2 – TVP-VAR Model Inputs



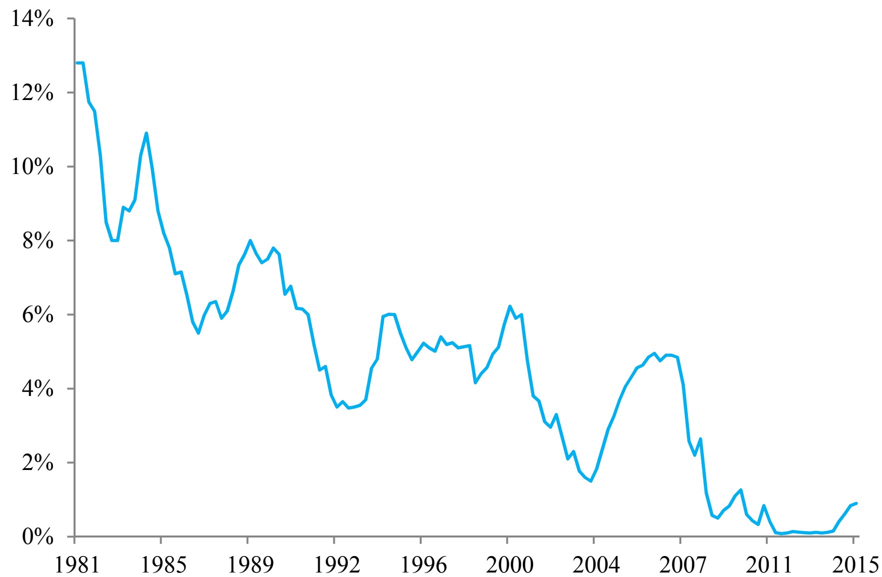
Effective Federal Funds Rate



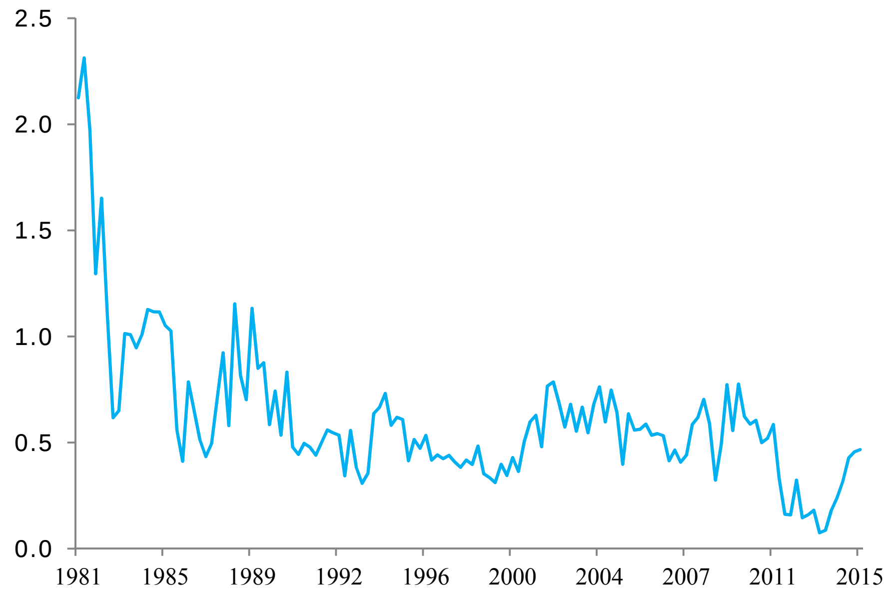
Civilian Unemployment Rate



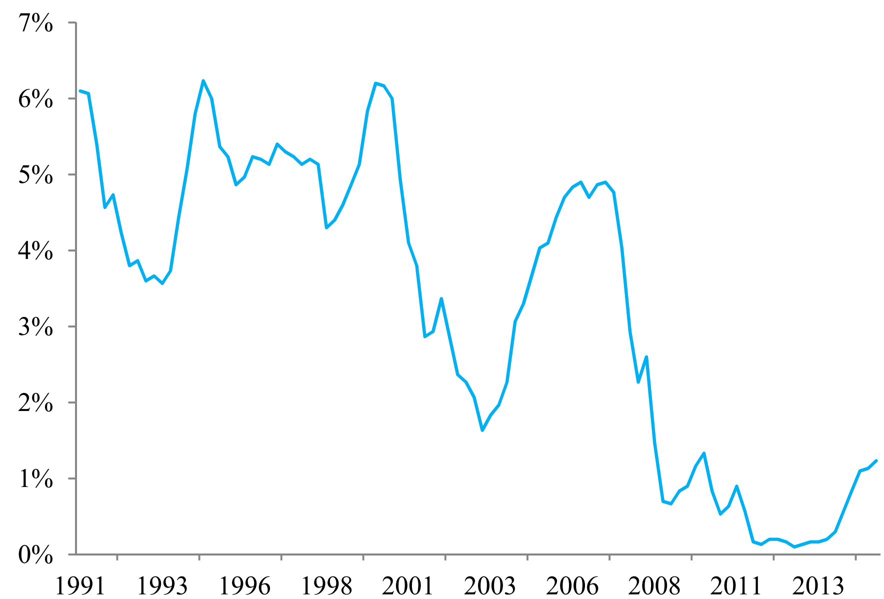
Core Inflation Rate



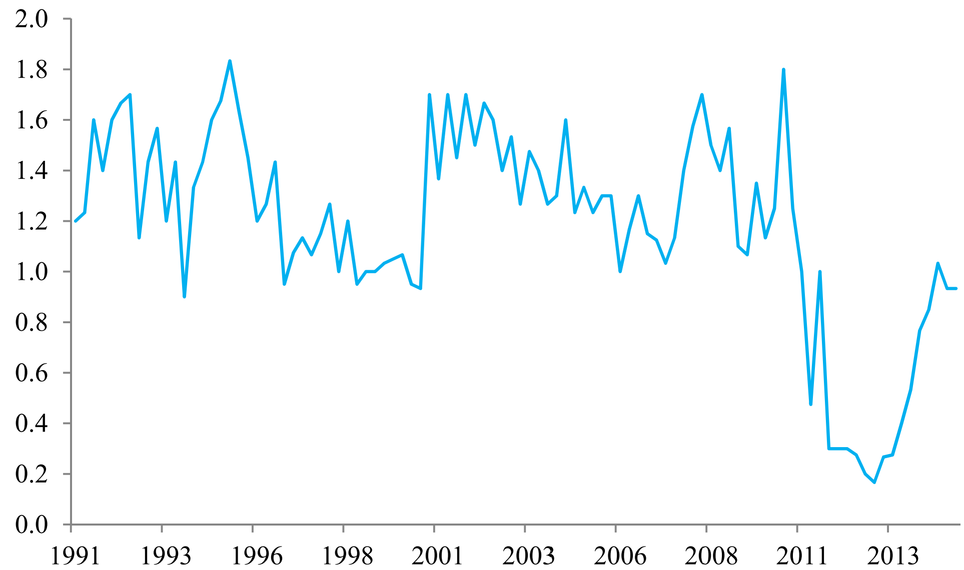
Interest Rate Expectation on 3-Month Treasury Bill, SPF



Monetary Policy Uncertainty (Dispersion of Interest Rate Expectations, SPF)



Interest Rate Expectation on 3-Month Treasury Bill, BCEI



Monetary Policy Uncertainty (Dispersion of Interest Rate Expectations, BCEI)

Figure 3a – Shock to Monetary Policy Uncertainty

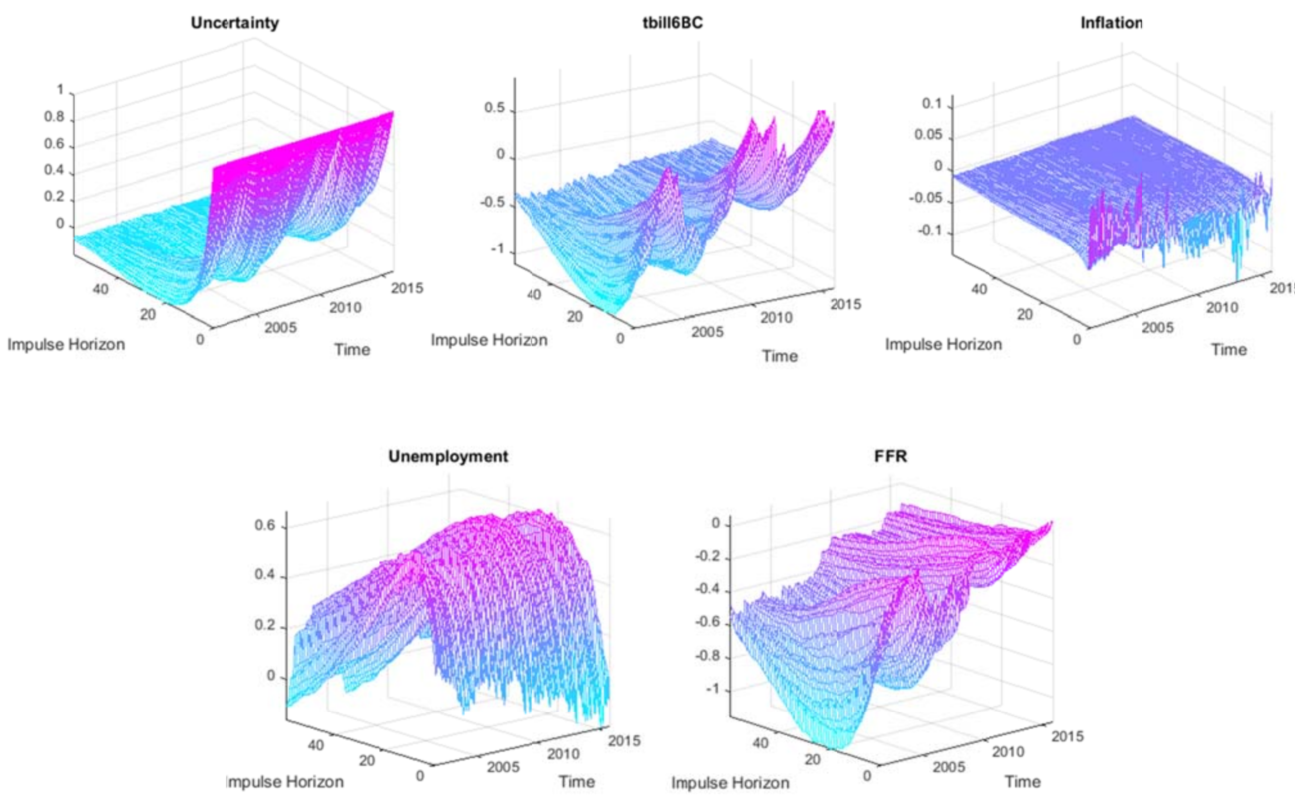


Figure 3b – Shock to Interest Rate Expectations

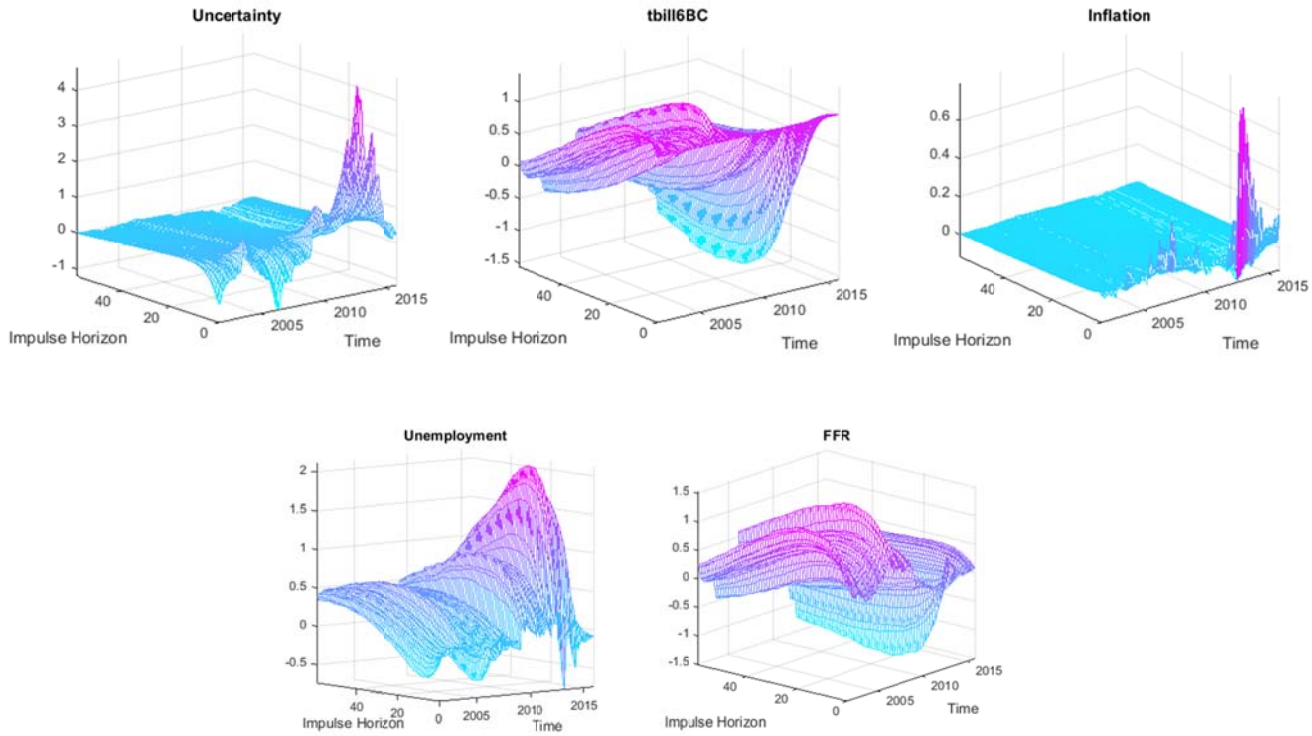


Figure 3c – Shock to Core Inflation

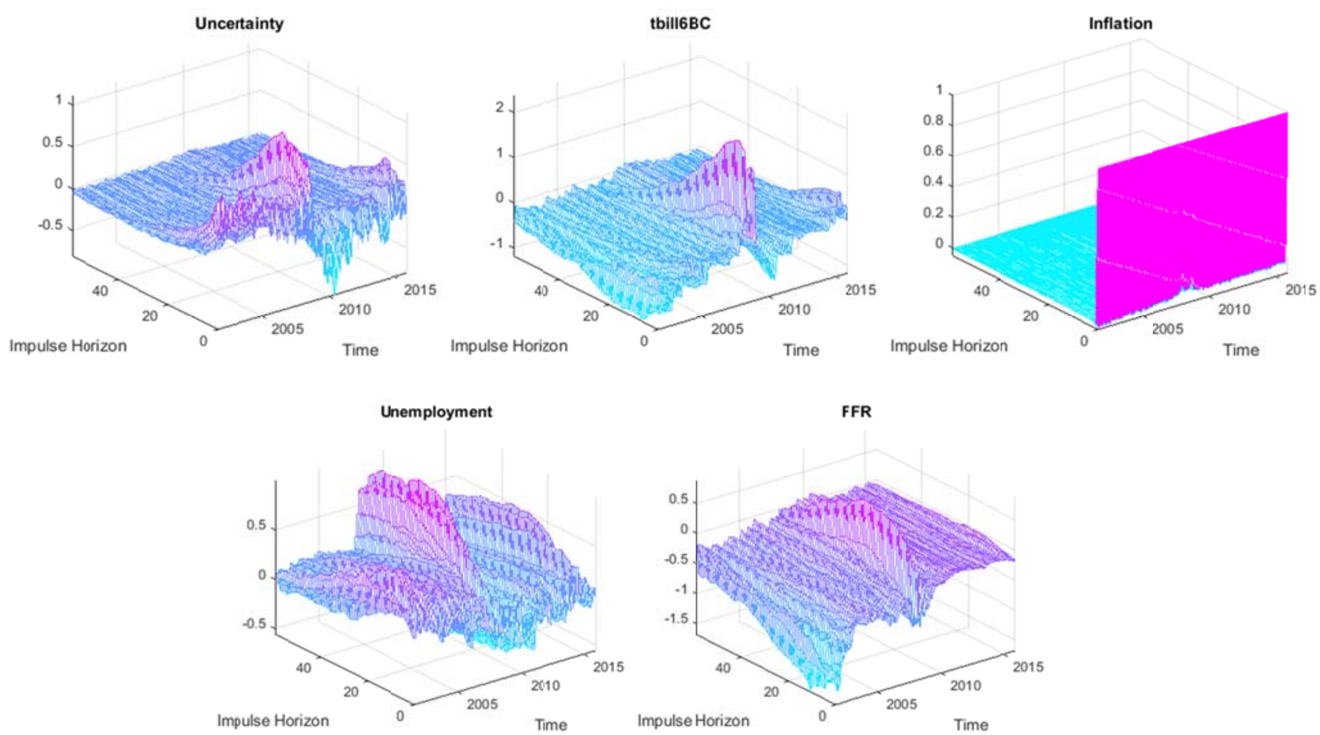


Figure 3d – Shock to Unemployment

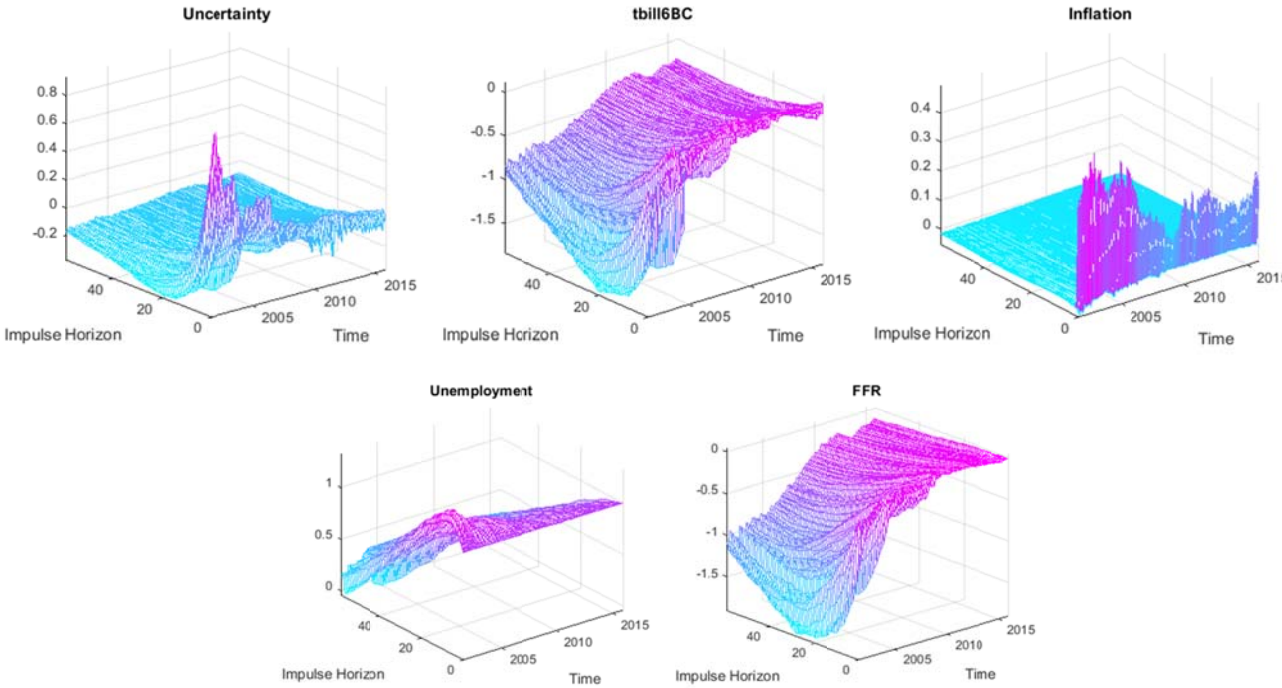


Figure 3e – Shock to Federal Funds Rate

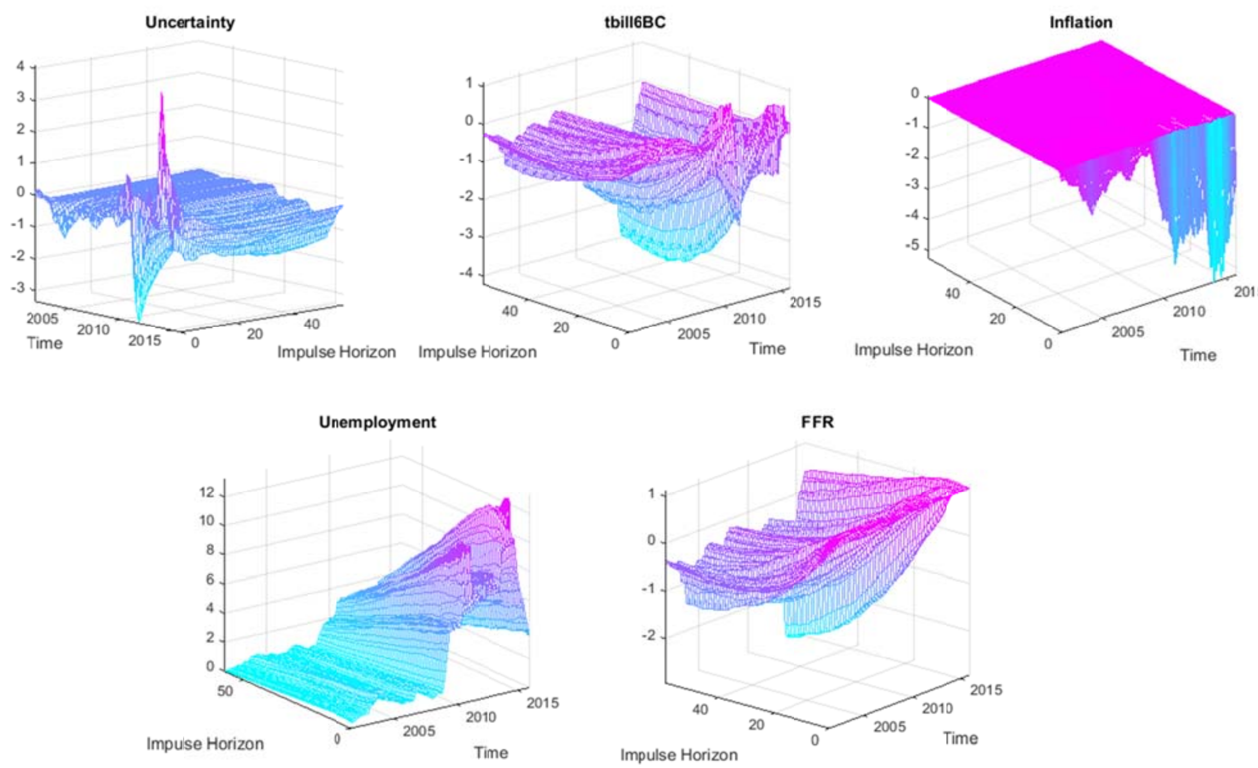


Figure 4a – Nonlinearities

VARIABLES	(1) Maximum IRF - Shock: FFR; Response: Unemployment	(2) Maximum IRF - Shock: FFR; Response: Inflation	(3) Maximum IRF - Shock: Tbill6; Response: Unemployment	(4) Maximum IRF - Shock: Tbill6; Response: Inflation
Uncertainty	**-2.634*** **	**-0.0157*** **	**-0.373*** **	**-0.200*** **
	(0.449)	(0.00408)	(0.0539)	(0.0290)
Tbill6	**-1.582*** **	0.00942**	-0.0942*	-0.0498*
	(0.416)	(0.00378)	(0.0500)	(0.0269)
Inflation	-0.986	-0.00957	0.128	-0.134
	(1.819)	(0.0165)	(0.218)	(0.118)
Unemployment	0.311**	**0.00663*** **	**0.0814*** **	-0.0139*
	(0.125)	(0.00113)	(0.0150)	(0.00808)
Fed Funds Rate	0.439	**-0.00803*** **	0.0494	**0.0437** **
	(0.315)	(0.00287)	(0.0379)	(0.0204)
Monetary Base	-0.0834**	-0.000620*	-0.00518	0.00302
	(0.0400)	(0.000363)	(0.00480)	(0.00259)
Oil Price	-0.0261	3.92e-05	0.000392	0.000365
	(0.0162)	(0.000147)	(0.00194)	(0.00105)
Constant	7.902***	0.00598	0.682***	0.505***
	(1.056)	(0.00960)	(0.127)	(0.0684)
Observations	173	173	173	173
R-squared	0.774	0.420	0.708	0.506

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 4b – Nonlinearities

VARIABLES	(1) Cumulative Response at s=60: Unemployment; Shock: FFR	(2) Cumulative Response at s=60: Inflation; Shock: FFR	(3) Cumulative Response at s=60: Unemployment; Shock: Tbill6	(4) Cumulative Response at s=60: Inflation; Shock: Tbill6
Uncertainty	**-1.658*** **	-0.00950	**-0.202*** **	0.00461
	(0.406)	(0.0359)	(0.0714)	(0.00672)
Tbill6	-0.902**	-0.00965	-0.0985	0.00315
	(0.377)	(0.0333)	(0.0662)	(0.00624)
Inflation	-2.199	-0.188	0.183	-0.00706
	(1.646)	(0.146)	(0.289)	(0.0272)
Unemployment	0.189*	0.00712	0.0515**	-0.00294
	(0.113)	(0.00999)	(0.0198)	(0.00187)
Fed Funds Rate	0.294	0.0126	0.0115	-0.000576
	(0.285)	(0.0253)	(0.0502)	(0.00472)
Monetary Base	-0.0284	7.99e-05	-0.000374	-0.000142
	(0.0362)	(0.00320)	(0.00636)	(0.000599)
Oil Price	0.00191	-0.000856	0.00246	-6.84e-05
	(0.0146)	(0.00130)	(0.00257)	(0.000242)
Constant	4.829***	-0.0164	0.519***	0.0167
	(0.956)	(0.0846)	(0.168)	(0.0158)
Observations	173	173	173	173
R-squared	0.587	0.026	0.501	0.126

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 4c – Nonlinearities

VARIABLES	(1) IRF Slope Through s=30; Shock: FFR, Response: Unemployment	(2) IRF Slope Through s=30; Shock: FFR, Response: Inflation	(3) IRF Slope Through s=30; Shock: Tbill6, Response: Unemployment	(4) IRF Slope Through s=30; Shock: Tbill6, Response: Inflation
Uncertainty	**-0.0553*** **	-0.000317	**-0.00675*** **	0.000154
	(0.0135)	(0.00120)	(0.00238)	(0.000224)
Tbill6	-0.0301**	-0.000322	-0.00328	0.000105
	(0.0126)	(0.00111)	(0.00221)	(0.000208)
Inflation	-0.0733	-0.00627	0.00609	-0.000235
	(0.0549)	(0.00486)	(0.00964)	(0.000908)
Unemployment	0.00629*	0.000237	0.00172**	-9.79e-05
	(0.00376)	(0.000333)	(0.000662)	(6.23e-05)
Fed Funds Rate	0.00980	0.000420	0.000383	-1.92e-05
	(0.00951)	(0.000842)	(0.00167)	(0.000157)
Monetary Base	-0.000948	2.66e-06	-1.25e-05	-4.74e-06
	(0.00121)	(0.000107)	(0.000212)	(2.00e-05)
Oil Price	6.37e-05	-2.85e-05	8.22e-05	-2.28e-06
	(0.000488)	(4.32e-05)	(8.58e-05)	(8.08e-06)
Constant	0.161***	-0.000547	0.0173***	0.000558
	(0.0319)	(0.00282)	(0.00560)	(0.000527)
Observations	173	173	173	173
R-squared	0.587	0.026	0.501	0.126

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 5a – Shock to Monetary Policy Uncertainty (SPF)

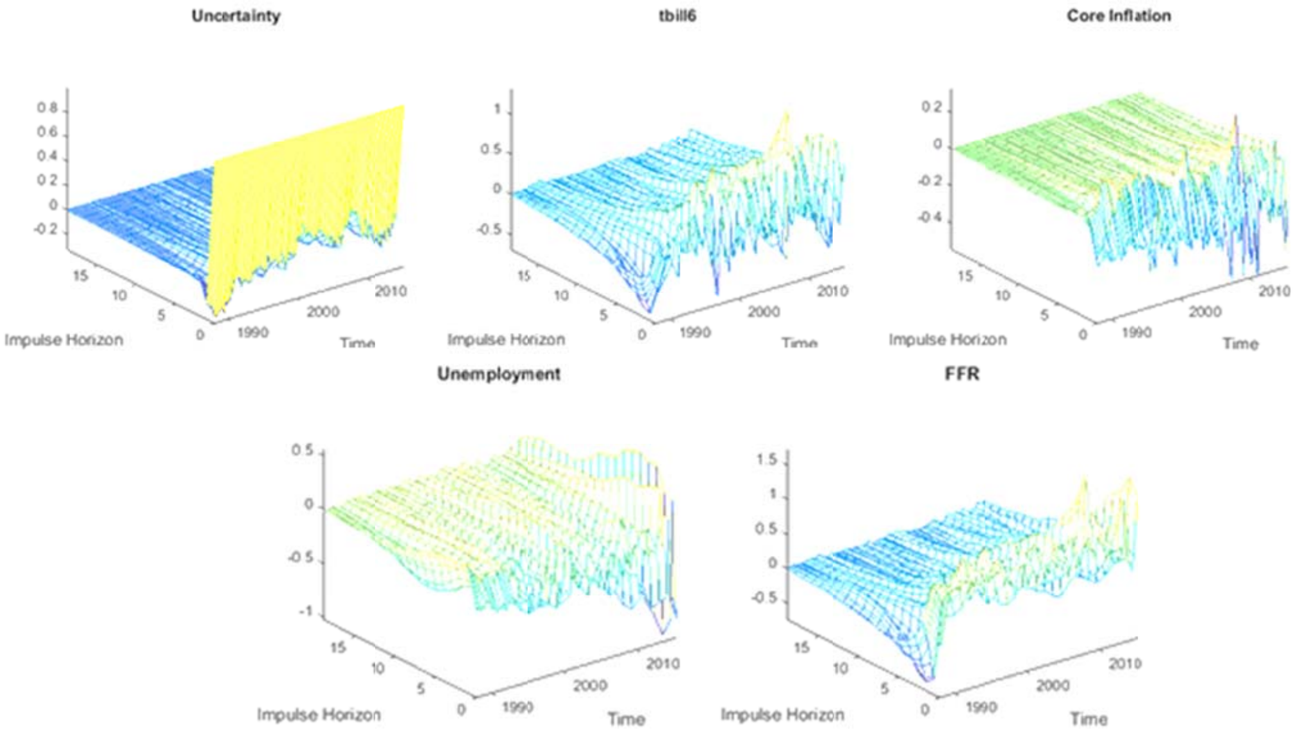


Figure 5b – Shock to Interest Rate Expectations (SPF)

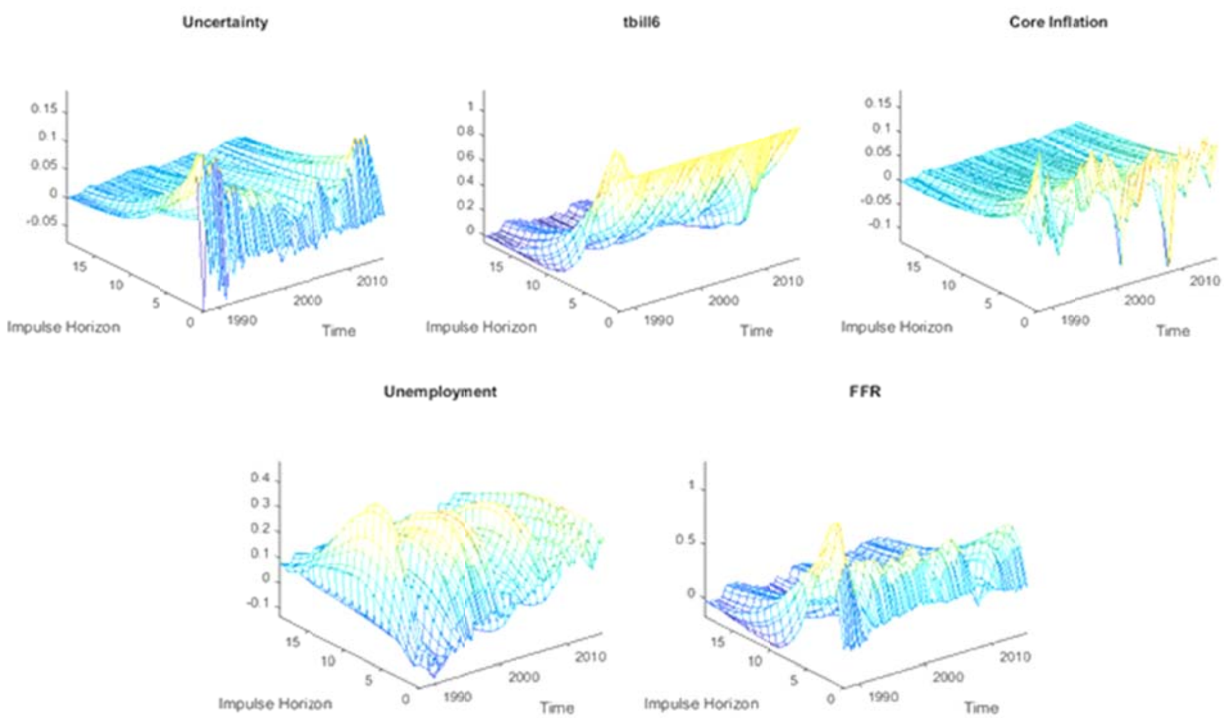


Figure 5c – Shock to Core Inflation (SPF)

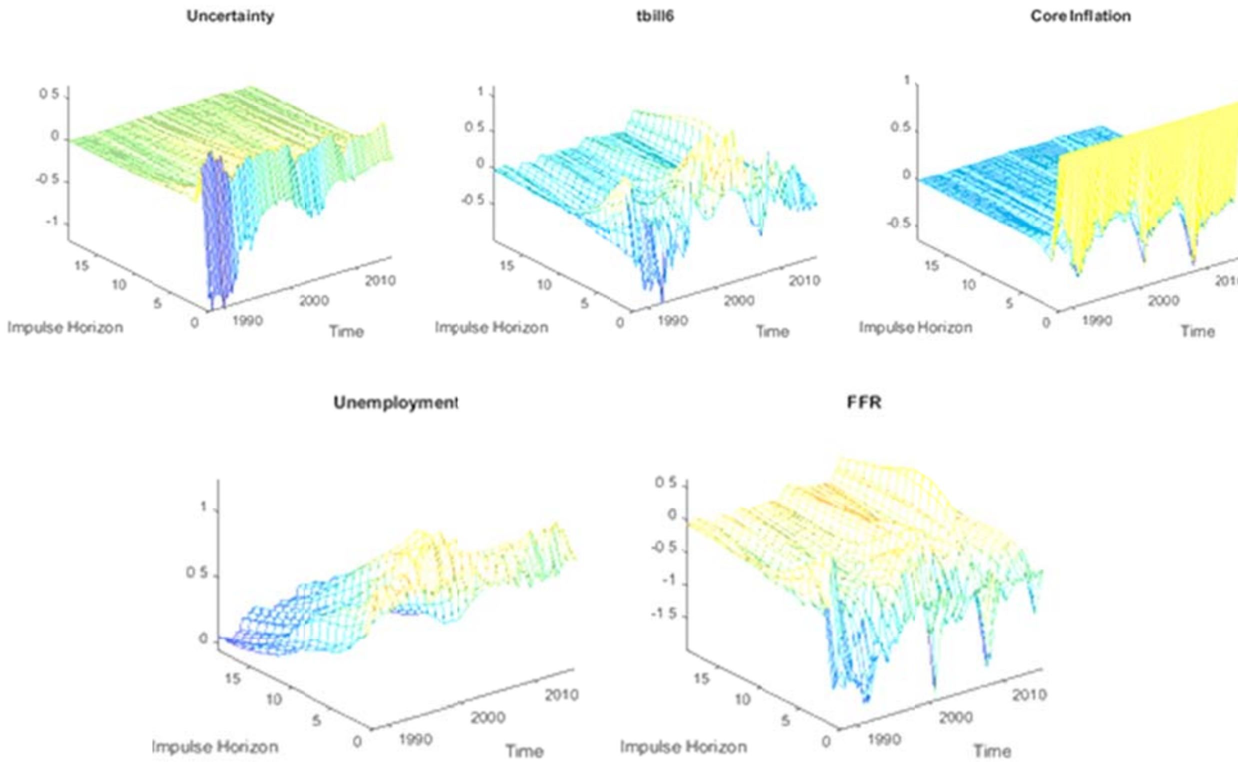


Figure 5d – Shock to Unemployment Rate

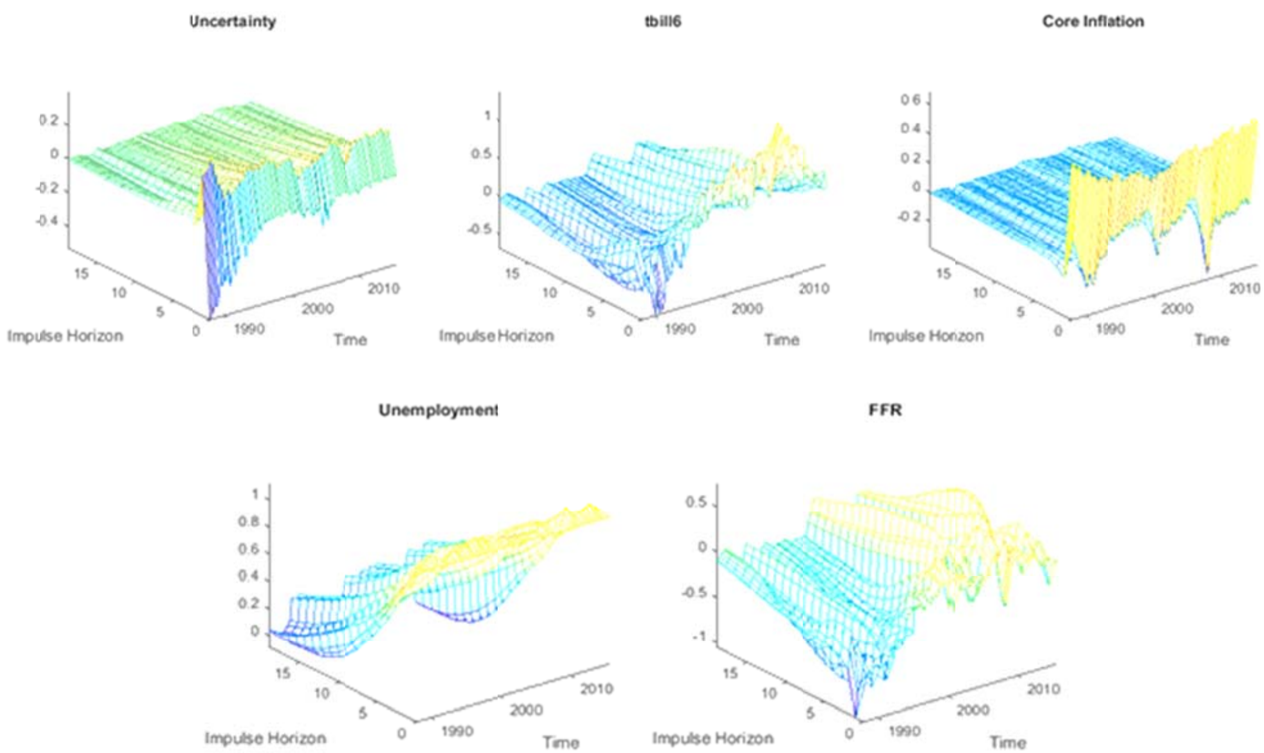


Figure 5e – Shock to Federal Funds Rate (SPF)

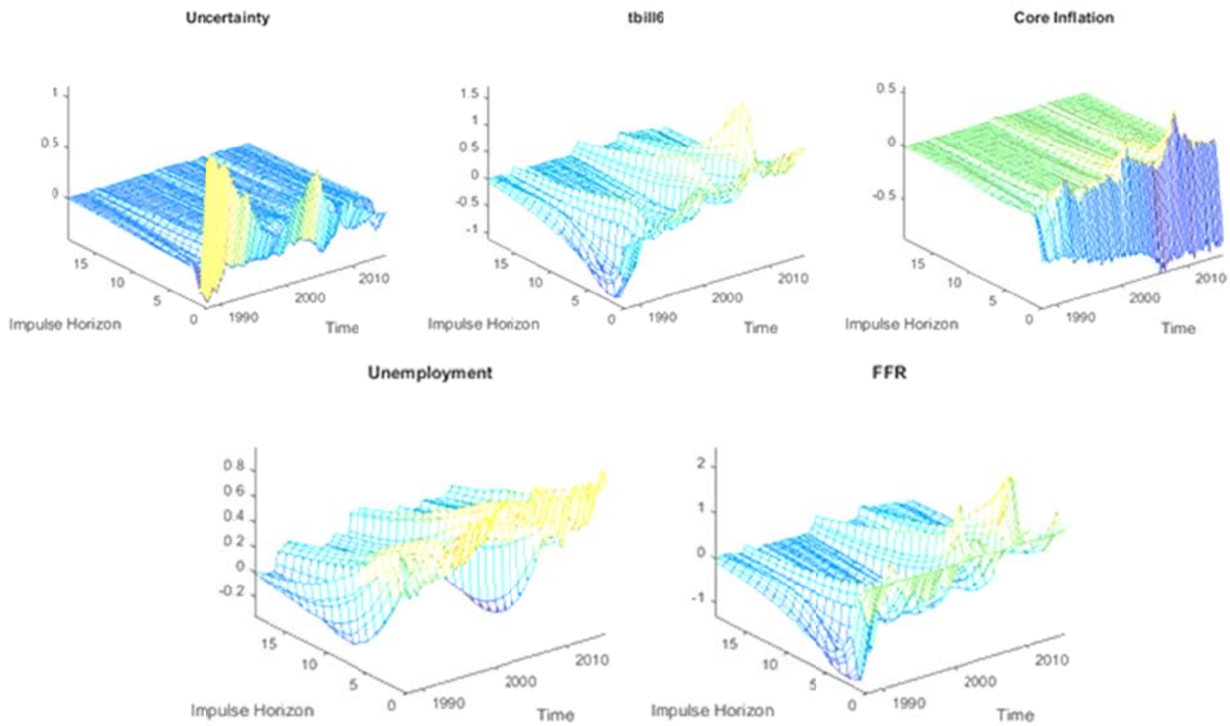


Figure 6a – Nonlinearities (SPF)

	(1)	(2)	(3)	(4)
VARIABLES	Maximum IRF -- Shock: FFR; Response: Unemployment	Maximum IRF -- Shock: FFR; Response: Inflation	Maximum IRF -- Shock: Tbill6; Response: Unemployment	Maximum IRF -- Shock: Tbill6; Response: Inflation
Uncertainty	-0.260***	-0.331***	0.0653	-0.00831
	(0.0629)	(0.0544)	(0.0627)	(0.0173)
Tbill6	0.00250	0.00977	-0.00583	0.00304
	(0.0234)	(0.0203)	(0.0233)	(0.00644)
Inflation	0.112*	0.0911*	0.0108	-0.00106
	(0.0627)	(0.0542)	(0.0624)	(0.0172)
Unemployment	-0.0184*	-0.0144	-0.0159	-0.00251
	(0.0102)	*(0.00884)*	*(0.0102)*	*(0.00281)*
Fed Funds Rate	-0.0112	-0.0140	-0.00434	-0.00330
	(0.0193)	(0.0167)	(0.0192)	(0.00531)
Monetary Base	0.000179	0.00574***	-0.00143	-0.000161
	(0.00177)	(0.00153)	(0.00177)	(0.000487)
Oil Price	4.13e-05	0.000701	0.000441	0.000298
	(0.000781)	(0.000676)	(0.000778)	(0.000215)
Constant	0.993***	0.352***	0.336***	0.128***
	(0.0748)	(0.0647)	(0.0745)	(0.0206)
Observations	110	110	110	110
R-squared	0.203	0.397	0.040	0.041

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 6b – Nonlinearities (SPF)

VARIABLES	(1) Cumulative Response at s=20: Unemployment; Shock: FFR	(2) Cumulative Response at s=20: Inflation; Shock: FFR	(3) Cumulative Response at s=20: Unemployment; Shock: Tbill6	(4) Cumulative Response at s=20: Inflation; Shock: Tbill6
Uncertainty	-3.103**	-1.419***	1.291	0.128
	(1.454)	(0.233)	(0.970)	(0.0938)
Tbill6	-0.157	0.0534	-0.276	-0.0362
	(0.541)	(0.0866)	(0.361)	(0.0349)
Inflation	0.928	0.276	0.101	-0.0342
	(1.448)	(0.232)	(0.966)	(0.0934)
Unemployment	-0.104	-0.0314	-0.286*	-0.0110
	(0.236)	(0.0378)	(0.157)	(0.0152)
Fed Funds Rate	0.110	-0.0468	0.0640	0.0251
	(0.447)	(0.0714)	(0.298)	(0.0288)
Monetary Base	-0.0728*	0.0207***	-0.0656**	-0.00738***
	(0.0410)	(0.00656)	(0.0273)	(0.00264)
Oil Price	-0.0195	0.000756	0.00173	-0.000967
	(0.0181)	(0.00289)	(0.0120)	(0.00117)
Constant	8.204***	0.444	5.009***	0.650***
	(1.729)	(0.277)	(1.153)	(0.112)
Observations	110	110	110	110
R-squared	0.079	0.360	0.093	0.091

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 6c – Nonlinearities (SPF)

VARIABLES	(1) IRF Slope Through s=4; Shock: FFR, Response: Unemployment	(2) IRF Slope Through s=8; Shock: FFR, Response: Unemployment	(3) IRF Slope Through s=12; Shock: FFR, Response: Unemployment	(4) IRF Slope Through s=20; Shock: FFR, Response: Unemployment
Uncertainty	-0.207***	-0.176**	-0.168**	-0.155**
	(0.0620)	(0.0758)	(0.0814)	(0.0727)
Tbill6	0.0103	-0.00306	-0.00913	-0.00785
	(0.0231)	(0.0282)	(0.0303)	(0.0271)
Inflation	0.109*	0.0842	0.0621	0.0464
	(0.0618)	(0.0755)	(0.0810)	(0.0724)
Unemployment	-0.00495	-0.00463	-0.00476	-0.00522
	(0.0101)	(0.0123)	(0.0132)	(0.0118)
Fed Funds Rate	-0.0141	-0.00112	0.00571	0.00549
	(0.0190)	(0.0233)	(0.0250)	(0.0223)
Monetary Base	-0.00130	-0.00300	-0.00370	-0.00364*
	(0.00175)	(0.00214)	(0.00229)	(0.00205)
Oil Price	-0.000230	-0.000827	-0.00108	-0.000973
	(0.000770)	(0.000941)	(0.00101)	(0.000903)
Constant	0.708***	0.604***	0.527***	0.410***
	(0.0737)	(0.0901)	(0.0967)	(0.0865)
Observations	110	110	110	110
R-squared	0.130	0.081	0.073	0.079

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 6d – Nonlinearities (SPF)

	(1)	(2)	(3)	(4)
VARIABLES	IRF Slope Through s=4; Shock: FFR, Response: Inflation	IRF Slope Through s=8; Shock: FFR, Response: Inflation	IRF Slope Through s=12; Shock: FFR, Response: Inflation	IRF Slope Through s=20; Shock: FFR, Response: Inflation
Uncertainty	-0.112***	-0.117***	-0.101***	-0.0710***
	(0.0290)	(0.0214)	(0.0170)	(0.0116)
Tbill6	0.00403	0.00379	0.00332	0.00267
	(0.0108)	(0.00798)	(0.00632)	(0.00433)
Inflation	0.0229	0.0226	0.0195	0.0138
	(0.0289)	(0.0213)	(0.0169)	(0.0116)
Unemployment	0.00172	-0.00126	-0.00177	-0.00157
	(0.00472)	(0.00348)	(0.00276)	(0.00189)
Fed Funds Rate	-0.00181	-0.00285	-0.00281	-0.00234
	(0.00892)	(0.00658)	(0.00521)	(0.00357)
Monetary Base	0.00223***	0.00183***	0.00150***	0.00103***
	(0.000818)	(0.000604)	(0.000478)	(0.000328)
Oil Price	5.23e-05	8.01e-05	6.37e-05	3.78e-05
	(0.000361)	(0.000266)	(0.000211)	(0.000144)
Constant	-0.0736**	0.00944	0.0237	0.0222
	(0.0345)	(0.0255)	(0.0202)	(0.0138)
Observations	110	110	110	110
R-squared	0.200	0.311	0.348	0.360

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 6e – Nonlinearities (SPF)

	(1)	(2)	(3)	(4)
VARIABLES	IRF Slope Through s=4; Shock: Tbill6, Response: Unemployment	IRF Slope Through s=8; Shock: Tbill6, Response: Unemployment	IRF Slope Through s=12; Shock: Tbill6, Response: Unemployment	IRF Slope Through s=20; Shock: Tbill6, Response: Unemployment
Uncertainty	-0.157***	-0.0307	0.0360	0.0646
	(0.0520)	(0.0580)	(0.0583)	(0.0485)
Tbill6	-0.0156	-0.0145	-0.0138	-0.0138
	(0.0194)	(0.0216)	(0.0217)	(0.0181)
Inflation	0.0327	0.0148	0.00812	0.00507
	(0.0518)	(0.0577)	(0.0580)	(0.0483)
Unemployment	-0.0266***	-0.0218**	-0.0185*	-0.0143*
	(0.00844)	(0.00941)	(0.00947)	(0.00787)
Fed Funds Rate	0.00297	0.00243	0.00210	0.00320
	(0.0160)	(0.0178)	(0.0179)	(0.0149)
Monetary Base	-0.000678	-0.00267	-0.00337**	-0.00328**
	(0.00146)	(0.00163)	(0.00164)	(0.00137)
Oil Price	0.000107	0.000146	0.000151	8.66e-05
	(0.000646)	(0.000720)	(0.000724)	(0.000602)
Constant	0.404***	0.359***	0.317***	0.250***
	(0.0618)	(0.0689)	(0.0693)	(0.0577)
Observations	110	110	110	110
R-squared	0.210	0.085	0.076	0.093

Standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Figure 6f – Nonlinearities (SPF)

	(1)	(2)	(3)	(4)
VARIABLES	IRF Slope Through s=4; Shock: Tbill6, Response: Inflation	IRF Slope Through s=8; Shock: Tbill6, Response: Inflation	IRF Slope Through s=12; Shock: Tbill6, Response: Inflation	IRF Slope Through s=20; Shock: Tbill6, Response: Inflation
Uncertainty	**0.0305****	**0.0210****	0.0138*	0.00642
	(0.0148)	(0.00964)	(0.00717)	(0.00469)
Tbill6	-0.00329	-0.00262	-0.00240	-0.00181
	(0.00549)	(0.00359)	(0.00267)	(0.00175)
Inflation	-0.0102	-0.00612	-0.00379	-0.00171
	(0.0147)	(0.00960)	(0.00714)	(0.00467)
Unemployment	-0.000612	-0.000243	-0.000391	-0.000548
	(0.00239)	(0.00157)	(0.00116)	(0.000762)
Fed Funds Rate	0.00263	0.00206	0.00180	0.00126
	(0.00453)	(0.00296)	(0.00220)	(0.00144)
Monetary Base	**-0.00107****	**-0.000724*****	**-0.000555*****	**-0.000369*****
	(0.000416)	(0.000272)	(0.000202)	(0.000132)
Oil Price	-6.77e-06	-3.81e-05	-5.19e-05	-4.84e-05
	(0.000183)	(0.000120)	(8.91e-05)	(5.83e-05)
Constant	0.0649***	0.0517***	0.0437***	0.0325***
	(0.0175)	(0.0115)	(0.00853)	(0.00558)
Observations	110	110	110	110
R-squared	0.107	0.113	0.105	0.091

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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