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Financial Market Risk and Macroeconomic Variables: Dynamic Interactions and Feedback Effects

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Doctoral Dissertation Paper

Financial Market Risk and Macroeconomic Stability Variables: Dynamic Interactions and Feedback Effects

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Abstract:

This study investigates dynamic interactions and feedback effects between financial market risk proxied by VIX and key macroeconomic stability variables that include the rate of unemployment, headline inflation and market-based inflation expectations reflected by the breakeven inflation. I argue that market risk should play a stronger role in macroeconomic modeling and forecasting than it has been recognized thus far in the literature. I employ vector autoregression with impulse response functions, as well as two-state Markov switching tests to examine these interactions on the longest available US monthly data. The empirical tests show that the association between market risk and macroeconomic fundamentals is predominantly neutral at normal, predictable economic conditions. It becomes however very pronounced at times of financial distress, in the environment of elevated market risk coupled with uncertain expectations for macroeconomic variables. Shocks in VIX have a longer impact on macroeconomic stability than that generally claimed in the prior literature. The Markov switching tests for CPI and breakeven inflation indicate that households and businesses are concerned primarily about episodes of increasing inflation, while bond market participants are worried mainly about declining inflation and deflation.

Keywords: market risk, VIX, unemployment, headline inflation, breakeven inflation, impulse responses, Markov switching process.

JEL classification: C54, E31, G17.

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I. Introduction

There is a growing attention in the macroeconomic literature to the legitimacy and necessity to incorporate financial risk measures in macroeconomic forecasts, particularly in the aftermath of the recent global financial crisis.[1] Inspired by the recent debate pertaining to choices of relevant measures of risk and their impact on macroeconomic variables, I focus on interactions between financial market risk and key macroeconomic policy variables, i.e. unemployment and inflation. Financial market risk is proxied in my exercise by the Chicago Board Options Exchange VIX volatility index based on standard deviation of S&P500 options. I investigate its dynamic interactions with the US civilian unemployment rate and two measures of inflation. I distinguish between *a survey based* CPI headline inflation and *the market-based breakeven inflation* (BEI) that reflects inflation expectations of government bond market investors. BEI has been gradually gaining ground as a viable indicator of inflation expectations for macroeconomic forecasts since it reflects real-time expectations of a very large number of bond market participants (Cunningham, et al., 2010; Stillwagon, 2018; Orlowski and Soper, 2019). In general terms, I argue that the dynamics of market risk should be used in macroeconomic modeling and forecasting more extensively than it has been claimed in the literature thus far.

The initial assumption to be examined in our study is that the relationships between market risk and macroeconomic variables is neutral, subdued at normal periods of financial stability. They become however very pronounced at times of financial instability. The elevated market risk is

[1] See for instance Thorbecke, 1997; Cunningham et al., 2010; Söderlind, 2011; Christensen and Gillan, 2012; Fleckenstein et al., 2017; Orlowski and Soper, 2019.

likely to cause temporary shocks or even a permanent derailment of macroeconomic fundamentals. Therefore, interactions between these variables cannot be ignored in macroeconomic forecasts.

As noted above, market risk is proxied in this study by VIX. The macroeconomic variables include the civilian unemployment rate, the CPI-based year-on-year inflation and the 5-year as well as the 10-year breakeven inflation. I use the longest available monthly series for VIX, unemployment rate and CPI inflation for the March 1990 – December 2018 sample period. The data for breakeven inflation are available as of January 2003. All data are extracted from the Federal Reserve Bank of St. Louis – Federal Reserve Economic Database (FRED). I employ vector autoregression (VAR) optimized for the p-lagged orders by minimizing the Schwartz Information Criterion. The corresponding impulse response functions derived from VAR(p) show response patterns between shocks in market risk and in the selected macroeconomic variables. In order to ascertain varied in time, dynamic interactions between these variables, I employ a two-state Markov switching process. This procedure allows for identifying the episodes of switching between the neutral and the highly significant negative or positive interactions between VIX and macroeconomic variables.

Section II of the study contains a survey of pertinent recent literature. A description of data, empirical methodology and the underlying two-state Markov switching model are presented in Section III. Section IV examines interactions between dynamic changes in VIX and the rate of unemployment. The relationship between VIX and the survey-based CPI inflation is examined in Section V. Interactions between VIX and market-based breakeven inflation are discussed in

Section VI. The concluding Section VII summarizes the key findings and provides suggestions for further investigation that incorporate risk in macroeconomic modeling and forecasting.

II. Overview of Pertinent Literature

It has been widely argued in the literature that the nexus between financial market risk and macroeconomic stability indicators is important in predicting financial stability. Among others, Söderlind (2010) and Christensen and Gillan (2012) provide evidence that market-based inflation expectations have a strong positive impact on market risk. However, a more recent literature (Fleckenstein et al., 2017; D'Amico et al. 2017; Stillwagon, 2018; Orlowski and Soper, 2019) demonstrate an opposite causal reaction, whereas changes in market risk rather instantaneously affect real-time inflation expectations of bond market participants. Orlowski (2012), Netšunajev and Winckelmann (2014), as well as Orlowski and Soper (2019) show that these reactions take place mostly in 'tails', i.e. under elevated risk market conditions. These tail reactions are asymmetric - expectations of low inflation or deflation affect market risk more forcefully that the expectations of high inflation do. This finding is also shared by Fleckenstein et al. (2017) who show that deflation risk is exacerbated by declining consumer confidence that exacerbates market risk. Orlowski and Soper (2019) further show that changes in market risk are de-coupled from inflation expectations under normal, tranquil market conditions.

In addition, the dynamics between market risk and macroeconomic indicators spreads seemingly over long-time horizons with pronounced causal reversals and feedback loops (Putnam et al., 2018). In essence, maintaining macroeconomic and financial stability is crucial for a long-term, sustained economic growth and stability. It has been also debated how market risk is determined and under what conditions it affects macroeconomic variables (Fleming and Krishnan, 2012). In order to predict the market good one must rely on the following: the term spread in US Treasuries, the equity market volatility index (VIX) and key inflection points. They offer useful insights about changes in the economy and the long term trends in the markets (Putnam et al., 2018). This is used with monetary policy and real economic indicators to gain a better understanding about when the shifts occur. A prior literature indicates that VIX is predicative of changes in the term spread on US Treasuries (Orlowski and Soper, 2019).

I aim to investigate a nexus between market risk and key macroeconomic indicators a step further. I limit the macroeconomic stability measures to the rate of unemployment and the rate of inflation implied by surveys of households, i.e. CPI inflation and the rate of inflation stemming from real-time inflation expectations of bond market participants. My choice is consistent with the indicators comprising the dual policy target of the Federal Reserve. In essence, I examine positive and negative shocks between financial market risk and macroeconomic stability measures such as the rate of unemployment, headline inflation and market-based inflations expectation reflected by BEI[2].

[2] In consistency with Fleckenstein et al. (2017), Andreasen et al., (2018) and D'Amico et al., (2018), I recognize that BEI does not only reflect real-time inflation expectations. It also contains a liquidity premium of TIPS. They all provide evidence that the liquidity premium of TIPS is sizeable and countercyclical, as investors anticipating economic recovery and higher inflation buy and hold TIPS reducing their availability for trading. Because of their weaker market liquidity, the prices of TIPS are then penalized with a discount known as a liquidity premium that reflects the present value of expected future trading costs as well as compensation for being forced to sell the bond at a discount. Such forced selling increases TIPS yields and complicates inflation expectations inferred from BEI.

III. Description of Data and Empirical Testing Methodology

The selection of data and testing procedures in this paper stem directly from its key objective to ascertain the role of financial market risk as a driver of macroeconomic stability variables. My analysis focuses on the macro variables that stem directly from the Federal Reserve's 'dual mandate' to ensure low unemployment and price stability. Hence, I choose to relate dynamic changes in market risk to the patterns of civilian unemployment and inflation. I further distinguish between the survey-based CPI inflation and the breakeven inflation (BEI) that reflects inflation expectations of government bond market participants.

My empirical exercise is therefore based on the available monthly US data on VIX, civilian unemployment rate, CPI year-on-year inflation rate and 5-year as well as 10-year BEI. The data is obtained from the Federal Reserve Bank of St. Louis – Federal Reserve Economic Data (FRED) on the longest available series. The VIX series start from January 1990 and end December 2018. Its starting point is matched with the unemployment rate and the CPI inflation data. The BEI data are only available as of January 2003, since its prior estimations suffered from serious liquidity constraints of TIPS (Zeng, 2013; D'Amico et al., 2018, Kim et al., 2019).

The empirical analysis begins from the assessment of transmission of shocks and interaction lags between the tested variables. For this purpose I employ asymptotic vector autoregression (VAR) in the order of p optimized by minimizing the Schwartz information criterion (SIC).

I subsequently devise a two-state Markov switching process on changes in each of the selected macroeconomic variables as a function of log changes in VIX. This specification accounts for uniform stationarity of the selected variables and allows for focusing on transmission of their dynamic changes.[3]

The two-state Markov Switching Process is specified as follows:

State 1 is prescribed by:

$$Y_{t/St=1}=c_1+\gamma_1 X_t+\varepsilon_{1t} \qquad \varepsilon_{1t}\rightarrow N(0,1) \qquad (1)$$

State 2 is specified as:

$$Y_{t/St=2}=c_2+\gamma_2 X_t+\varepsilon_{2t} \qquad \varepsilon_{2t}\rightarrow N(0,1) \qquad (2)$$

The corresponding transition probability matrix for the two-state Markov process is specified as:

$$P=\begin{bmatrix} p_{11}p_{21} \\ p_{12}p_{22} \end{bmatrix} \qquad (3)$$

The 'State' that has a longer expected duration and a higher probability of remaining in it on a given month is termed as 'dominant'. Adversely, the 'State' with a shorter duration and a lower probability of remaining in it on a given month is defined as 'subordinate'.

[3] The Augmented Dickey Fuller unit root tests indicate stationarity of all tested variables at their levels, except for the CPI inflation. The estimated ADF τ-statistics are: -4.27 for VIX, -2.98 for the unemployment rate, -2.84 for CPI year-on-year inflation rate, -4.04 for 5-year BEI and -3.94 for 10-year BEI. The McKinnon critical values at 5% are between -2.87 and -2.88 for the examined sample periods.

IV. Dynamic Interactions between VIX and Unemployment Rate

Interactions between VIX and the civilian unemployment rate are intuitively not straightforward; they are subject to a rather long, complex transmission with hard-to-specify monthly lags. My initial hypothesis is that higher financial market risk will likely result in gradually rising unemployment. In the high risk environment, companies face difficulties to raise capital in equity markets and to formulate robust fixed capital investment expansion plans. In spite of ambiguous and long transmission effects, market risk observed patterns and future projections cannot be ignored in business expansion strategies.

I begin examination of interactions between VIX and unemployment rate with the asymptotic VAR(p) tests and the corresponding impulse response functions. The SIC suggests the optimized VAR specification with two lagged terms. The corresponding impulse responses to the VAR(2) test are shown in Figure 1.

….. insert Figure 1 around here …..

The bi-variate impulse responses shown in Figure 1 indicate that there is a very pronounced, long-lasting positive transmission of one-standard-deviation shocks in VIX into the unemployment rate. Specifically, a one-standard deviation positive shock in market risk entails a growing pattern of unemployment for at least ten months ahead. The reverse reaction is indiscernible. There is a mild, positive response of market risk to shocks in the unemployment rate for the time horizon not exceeding two-to-four months. This reaction tends to dissipate in a longer time frame.

Considering the above impulse responses, I devise a two-state Markov switching process for changes in the unemployment rate as a function of percent (log) changes in VIX, following Equations 1-3. The process is optimized with higher-order autoregressive (AR) terms that account for a dispersion of lagged terms and correct for autocorrelation in the examined series. The estimation results are shown in Table 1.

….. insert Table 1 around here …..

The estimation of the two States in the Markov process shown in Table 1 identifies a discernible strong, positive relationship between VIX and unemployment rate reflected by State 1 and a mild, negative relationship between these two variables implied by State 2. The positive estimated γ coefficient in State 1 is high, indicating a strong positive interaction between VIX and unemployment at time intervals when such relationship becomes prevalent. The subdued, negative interaction between these variables is implied by a low absolute value of γ coefficient in State 2. Nonetheless, this rather insignificant negative interaction is prevalent since State 2 clearly dominates the Markov process – its expected duration exceeds 85 months and the probability of remaining in this State on any given month is 99 percent. State 1 is evidently subordinate, its expected duration is only 2 months and the probability of remaining in it on any given month is 52 percent. I therefore conclude that the relationship between VIX and unemployment is predominantly weak at normal periods of predictable risk and sustained economic growth conditions.

….. insert Figure 2 around here …..

There are however sporadic episodes of switching form the weak, normal relationship to strong, positive interactions between these variables. In order to identify these switching episodes, I show in Figure 2 the time pattern of Markov switching filtered regime probabilities of remaining in the dominant State 2. The relationship between VIX and unemployment follows a weak association pattern reflected by State 2 for the entire sample period, except for the three discernible switching episodes. The strongest switch occurs in December 2010 in the immediate aftermath of the peak of the recent financial crisis at the time of strong proliferation of market risk coupled with concerns about recession and rising unemployment. In addition, there are two, somewhat weaker switching episodes in August 1996 and in April 2014. The first breaking point coincides with serious concerns about the growing private and public sector debt in the US economy. The second one seems to match market expectations of an exit from the quantitative easing policy of the Federal Reserve.

In sum, I conclude that there is a pronounced transmission of positive shocks in market risk into unemployment. The transmission is long-lasting and rather gradual. The co-movement between VIX and the unemployment rate is neutral and indiscernible under normal risk conditions. However, it tends to be strong and positive at times of financial distress and expected major policy changes.

V. VIX and Survey-Based CPI Inflation

As argued by Stillwagon (2018) as well as Orlowski and Soper (2019), interactions between VIX and survey-based CPI Inflation indicate that households and business are concerned primary about episodes of increasing inflation, while bond market participants are worried mainly about declining inflation and deflation. The measures of long-term inflation compensation reflects investors' underlying long-term expectations as well as premiums for risk and market liquidity. Monetary policy carefully monitor long-term inflation expectations to assess whether households and business view changes in inflation as permanent or transitory.

I begin examination of interactions between VIX and CPI Inflation with asymptotic VAR(p) tests and the corresponding impulse functions. The SIC suggests the optimized VAR specification with two lagged terms. The corresponding impulse responses to VAR(2) test are shown in Figure 3.

….. insert Figure 3 around here …..

The bi-variate impulse responses shown in Figure 3 indicate that there is a mild, long-lasting negative transmission of one-standard-deviation shocks in VIX into inflation. There is a reverse, positive response of market risk pattern in inflation. This reaction tends to hold for a long time frame.

Considering the above impulse responses, I devise a two-state Markov switching process for changes in CPI inflation as a function of percent (log) changes in VIX, following Equations 1-3. The process is optimized with higher-order autoregressive (AR) term that account for a dispersion of lagged terms and correct for autocorrelation in the examined series. The estimation results are shown in Table 2.

The estimation of the two States in the Markov process shown in Table 2 identifies a discernible strong, positive relationship between VIX and CPI inflation reflected by State 1 and a positive relationship between the two variables implied by State 2. The positive estimated γ coefficient in State 1is high, indicating a strong positive interaction between VIX and CPI inflation at time intervals when such relationship becomes prevalent. The positive interaction between these variables is implied by the low absolute value of γ coefficient in State 2. This rather positive interaction is prevalent since State 2 clearly dominates the Markov process- its expected duration exceeds 169 months and the probability of remaining in this State on any given month is 99 percent. State 1 is evidently subordinate its expected duration is only 1.5 months and the probability of remaining in it on any given month is 33 percent.

….. insert Figure 4 around here …..

In order to identify these switching episodes, I show in Figure 4 the time pattern of Markov switching filtered regime probabilities of remaining in the dominant State 2. The relationship between VIX and CPI inflation follows State 2 for the entire sample period, except for two discernible switching episodes. One strong switch occurred in 2006, which was the first phase of expansion. The growth was positive, with healthy 2% inflation. The second strong switch occurred in 2008. As the economy expanded beyond 3% growth, it created asset bubbles. This created the second phase, when expansion ended and contraction began.

VI. VIX and Market-Based Breakeven Inflation

Interactions between VIX and 5-year and 10-year BEI have been investigated in the literature only recently (D'Amico et al., 2018; Orlowski and Soper, 2019) . The largest source of variations in BEI has been attributed not to changes in inflation expectations, inflation uncertainty, or liquidity itself, but rather to financial market fear (Güler et al., 2017). VIX is the one variable that captures about 60% of the variation in BEI (Güler et al., 2017; D'Amico, 2018).

I begin examination of interaction between VIX and 5-year BEI with the asymptotic VAR(p) tests and the corresponding impulse response functions. The SIC suggests the optimized VAR specifications with two lagged terms. The corresponding impulse response to VAR(2) test are shown in Figure 5. In the 10-year BEI the corresponding impulse response to VAR(3) test are shown in Figure 7.

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The bi-variate impulse responses shown in Figure 5 indicate that there is very interesting negative to positive transmission of one-standard deviation shock in VIX into 5-year BEI rate. The reverse reaction is less pronounced. There is a mild, slightly negative response of market risk shocks in the 5-year BEI rate for the time horizon not exceeding two to four months. This reaction tends to become more visible and positive in a longer time frame.

Considering the above impulse responses, I devise a two-state Markov switching process for changes in the 5-year BEI rate as a function of percent (log) changes in VIX, following Equations 1-3. The process is optimized with higher-order autoregressive (AR) terms that account for dispersion of lagged terms and correct for autocorrelation in the examined series. The estimation results are shown in Table 3.

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The estimation of the two States in the Markov process shown in Table 3 identifies a evident strong, negative relationship between VIX and 5-year BEI rate reflected by State 1 and mild, negative relationship between these two variable implied by State 2. The negative estimated γ coefficient in State 1 is low, indicating a weak negative interaction between VIX and 5-year BEI at time intervals when such relationship becomes prevalent. The subdued, negative interaction between these variables is implied by a low absolute value of γ coefficient in State 2. Nonetheless, this rather insignificant negative interaction is prevalent since State 2 clearly dominates the Markov process – its expected duration exceed 129 months and the probability of remaining in this state on any given month is 99 percent. State 1 is evidently subordinate, its expected duration is only 8 months and the probability of remaining in it on any given month is 88 percent.

….. insert Figure 6 around here …..

In order to identify these switching episodes, I show in Figure 6 the time pattern of Markov switching filtered regime probabilities of remaining in the dominant State 2. The relationship between VIX and 5-year BEI follows State 2 for the entire sample period, except for the three discernible switching episodes. The strongest switch occurs in 2008, when the economy faced financial crisis, most of the effect emanated from the changes in the variance premium. In addition, this was the beginning of the major spike in the VIX and plunge in BEI following Lehman Brothers bankruptcy. Most of the variation during this period was driven by the variance premium, as conditional volatility was relatively placid. In 2009 there an economic slowdown and global growth was flat around (-0.5%). After the stimulus package the economy started getting better and expansive Monetary Policy tried everything they could. By September 2010 the Great Recession finally ended.

I begin examination of interaction between VIX and 10-year BEI with the asymptotic VAR(p) tests and the corresponding impulse response functions. The SIC suggests the optimized VAR specifications with two lagged terms. The corresponding impulse response to VAR (3) test are shown in Figure 7.

….. insert Figure 7 around here …..

The bi-variate impulse responses shown in Figure 7 indicate that there is very interesting negative to positive transmission of one-standard deviation shock in VIX into 10-year BEI rate. The reverse reaction is less pronounced. There is a mild, slightly negative response of market risk shocks in the 10-year BEI rate for the time horizon not exceeding two to four months. This reaction tends to become more visible and positive in a longer time frame.

Considering the above impulse responses, I devise a two-state Markov switching process for changes in the 10-year BEI rate as a function of percent (log) changes in VIX, following Equations 1-3. The process is optimized with higher-order autoregressive (AR) terms that account for dispersion of lagged terms and correct for autocorrelation in the examined series. The estimation results are shown in Table 4.

….. insert Table 4 around here …..

The estimation of the two States in the Markov process shown in Table 4 identifies a mild, negative relationship between VIX and 10-year BEI rate reflected by State 1 and mild, negative relationship between these two variable implied by State 2. The negative estimated γ coefficient in State 1 is low, indicating a weak negative interaction between VIX and 10-year BEI at time intervals when such relationship becomes prevalent. The subdued, negative interaction between these variables is implied by a low absolute value of γ coefficient in State 2. Nonetheless, this rather insignificant negative interaction is prevalent since State 2 clearly dominates the Markov process – its expected duration exceed 8 months and the probability of remaining in this state on any given month is 88 percent. State 1 is evidently subordinate, its expected duration is only 1 month and the probability of remaining in it on any given month is 16 percent.

….. insert Figure 8 around here …..

In order to identify these switching episodes, I show in Figure 8 the time pattern of Markov switching filtered regime probabilities of remaining in the dominant State 2. The relationship between VIX and 10-year BEI follows State 2 for the entire sample period, with a number of shocks during the switching episodes. The strongest switch occurs in 2008, when the economy faced financial crisis followed by heavy borrowing by the government at the end of 2015 aimed at catching up after the last debt ceiling showdown and another round of borrowing in advance of another possible debit ceiling standoff looming in the early 2017.

VII. Conclusions

Several key results encapsulate my empirical analysis. The relationship between VIX and the rate of civilian unemployment is subject to long-term effects. As shown by the VAR(2) estimation and the corresponding impulse response functions, the unemployment rate increases gradually in response to positive shocks in VIX. This can be explained in two ways. First, market shocks evidently respond to expectations of economic slowdown and rising unemployment in the future. Also, expectations of a sustained economic growth contribute to stability of financial markets. The obtained response pattern underpins a notion that financial stability is associated with a sustained economic growth and low unemployment in the predictable future.

As implied by the two-state Markov switching test, the association between VIX and the rate of unemployment is rather weak and statistically insignificant during tranquil market periods. However, it becomes strong and positive at times of financial distress. Rising unemployment is clearly associated with higher market risk, albeit these reactions are quite sporadic. The filtered regime switching probabilities identify only three episodes of such positive reactions in 1996, 2010 and 2014.

The impulse responses between changes in VIX and in the headline CPI inflation rate imply that positive shocks in market risk are normally associated with concerns about declining inflation and deflation. Market risk becomes exacerbated by fears of decreasing prices and declining profitability of firms. The two-state Markov switching test ascertaining the interplay between these two variables over time indicates that their patterns are rather de-coupled over time, as prescribed by the dominant State 2. There are two sporadic episodes of positive interactions between market risk and inflation expectations in 2006 and 2008 (Figure 4).

Interactions between changes in VIX and changes in both 5-year and 10-year breakeven inflation are quite different. The impulse responses (Figures 5 and 7) suggest that a positive shock in market risk is associated with declining patterns of both BEI rates for up to three months. The two-state Markov switching exercise for these variables (Tables 3 and 4) imply that the association between market risk and BEI is predominantly weak at normal market periods. It becomes strong and negative at stressful market periods. VIX increased significantly in response to fears of deflation embedded in 5-year BEI at the peak of the financial crisis in 2008 (Figure 6). The switching episodes between VIX and 10-year BEI are more pronounced and more frequent (Figure 8).

In hindsight, this study finds that market risk is mostly exacerbated by fears of economic slowdown, i.e. higher unemployment, and declining inflation, based mostly on market-implied BEI. It remains to be seen if the interactions empirically found in my paper will hold in the future, under a scenario of late stages of the global business cycle.

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Tables:

Table 1: Estimation of Two-State Markov Switching for Changes in the Civilian Unemployment Rate in Relation to log changes in VIX (Equations 1, 2 and 3).

	Changes in Unemployment Rate as a Function of Log Changes in VIX
State I	$\hat{c}_1$ = - 0.168** (-2.11) **$\hat{\gamma}_1$ = 2.080** (2.25)**
State II	$\hat{c}_2$ = 0.001 (0.01) $\hat{\gamma}_2$ = -0.066 (-1.39)
Common terms:	AR(1) = 0.009 AR(2)= 0.145*** AR(3)= 0.212*** AR(4)= 0.138*** AR(5)= 0.148*** log σ = -1.997 *** (-47.64)
Diagnostic tests:	Log likelihood = 185.3 Schwartz Info. Criterion = -0.879 Durbin Watson stats. = 2.100
Constant transition probabilities, Probability of staying (switching): State I State II	 0.52 (0.48) 0.99 (0.01)
Constant expected durations: State I State II	 2.1 months 85.1 months

Notes: Adjusted sample period July 1990 – December 2018 (342 included observations), *** denotes significance at 1%, ** at 5%, * at 10%, z-statistics in parentheses.

Source: Author's own estimation based on the Federal Reserve Bank of St. Louis – Federal Reserve Economic Data (FRED).

Table 2: Estimation of Two-State Markov Switching for Changes in the CPI Year-On-Year Inflation Rate in Relation to log changes in VIX (Equations 1, 2 and 3).

	Changes in CPI Inflation Rate as a Function of Log Changes in VIX
State I	**$\hat{c}_1$ = -1.809*** (-7.74)** **$\hat{\gamma}_1$ = 1.105*** (2.34)**
State II	$\hat{c}_2$ = 0.007 (0.31) $\hat{\gamma}_2$ = 0.166 (1.45)
Common terms:	AR(1)=0.376*** AR(2)= - 0.201*** AR(3)=0.031 log σ = -1.119 *** (-28.84)
Diagnostic tests:	Log likelihood = -116.89 Schwartz Info. Criterion = 0.852 Durbin Watson stats. = 1.846
Constant transition probabilities, Probability of staying (switching): State I State II	 0.33 (0.67) 0.99 (0.01)
Constant expected durations: State I State II	 1.5 months 169.8 months

Notes: Adjusted sample period February 1990 – December 2018 (346 included observations), *** denotes significance at 1%, ** at 5%, * at 10%z-statistics in parentheses.

Source: as in Table 1.

Table 3: Estimation of Two-State Markov Switching for Changes in the 5-Year Breakeven Inflation Rate in Relation to log changes in VIX (Equations 1, 2 and 3).

	Changes in 5-Year BEI Rate as a Function of Log Changes in VIX
State I	$\hat{c}_1$ = -0.011 (-0.20) **$\hat{\gamma}_1$ = -2.153*** (-8.47)**
State II	$\hat{c}_2$ = 0.001 (0.12) **$\hat{\gamma}_2$ = - 0.169** (-2.01)**
Common terms:	AR(1)=-0.045 AR(2)= 0.183** AR(3)= -0.192*** AR(4)= -0.115 log σ = -1.765 *** (-32.59)
Diagnostic tests:	Log likelihood = 59.96 Schwartz Info. Criterion = - 0.301 Durbin Watson stats. = 1.542
Constant transition probabilities, Probability of staying (switching): State I State II	 0.88 (0.12) 0.99 (0.01)
Constant expected durations: State I State II	 8.1 months 129.3 months

Notes: Adjusted sample period June 2003 – December 2018 (187 included observations), *** denotes significance at 1%, ** at 5%, * at 10%z-statistics in parentheses.

Source: as in Table 1.

Table 4: Estimation of Two-State Markov Switching for Changes in the 10-Year Breakeven Inflation Rate in Relation to log changes in VIX (Equations 1, 2 and 3).

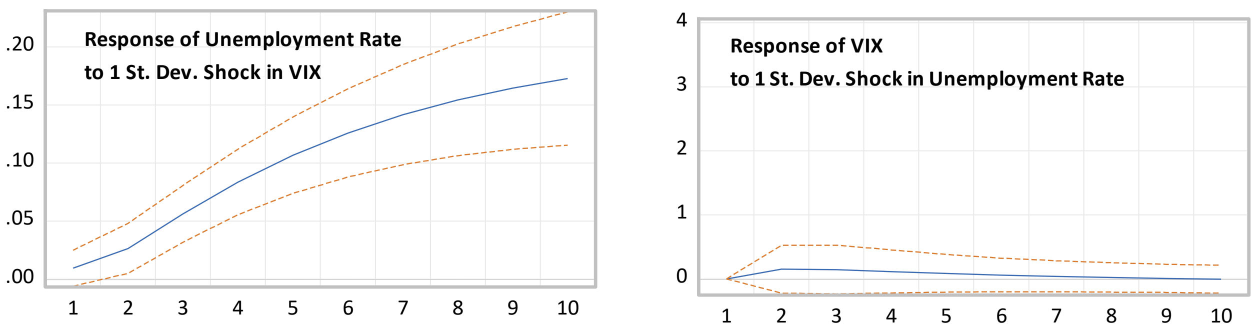
	Changes in 10-Year BEI Rate as a Function of Log Changes in VIX
State I	$\hat{c}_1$= 0.114*** (3.28) **$\hat{\gamma}_1$= -0.859*** (-7.71)**
State II	$\hat{c}_2$ = - 0.012 (-1.05) **$\hat{\gamma}_2$= - 0.099** (-2.30)**
Common terms:	AR(1)=0.651*** AR(2)= -0.475*** AR(3)= 0.363*** AR(4)= - 0.261*** log σ = -2.377 *** (-33.73)
Diagnostic tests:	Log likelihood = 148.36 Schwartz Info. Criterion = - 1.279 Durbin Watson stats. = 1.877
Constant transition probabilities, Probability of staying (switching): State I State II	 0.16 (0.84) 0.88 (0.12)
Constant expected durations: State I State II	 1.2 months 8.6 months

Notes: Adjusted sample period June 2003 – December 2018 (187 included observations), *** denotes significance at 1%, ** at 5%, * at 10%z-statistics in parentheses.

Source: as in Table 1.

Figures:

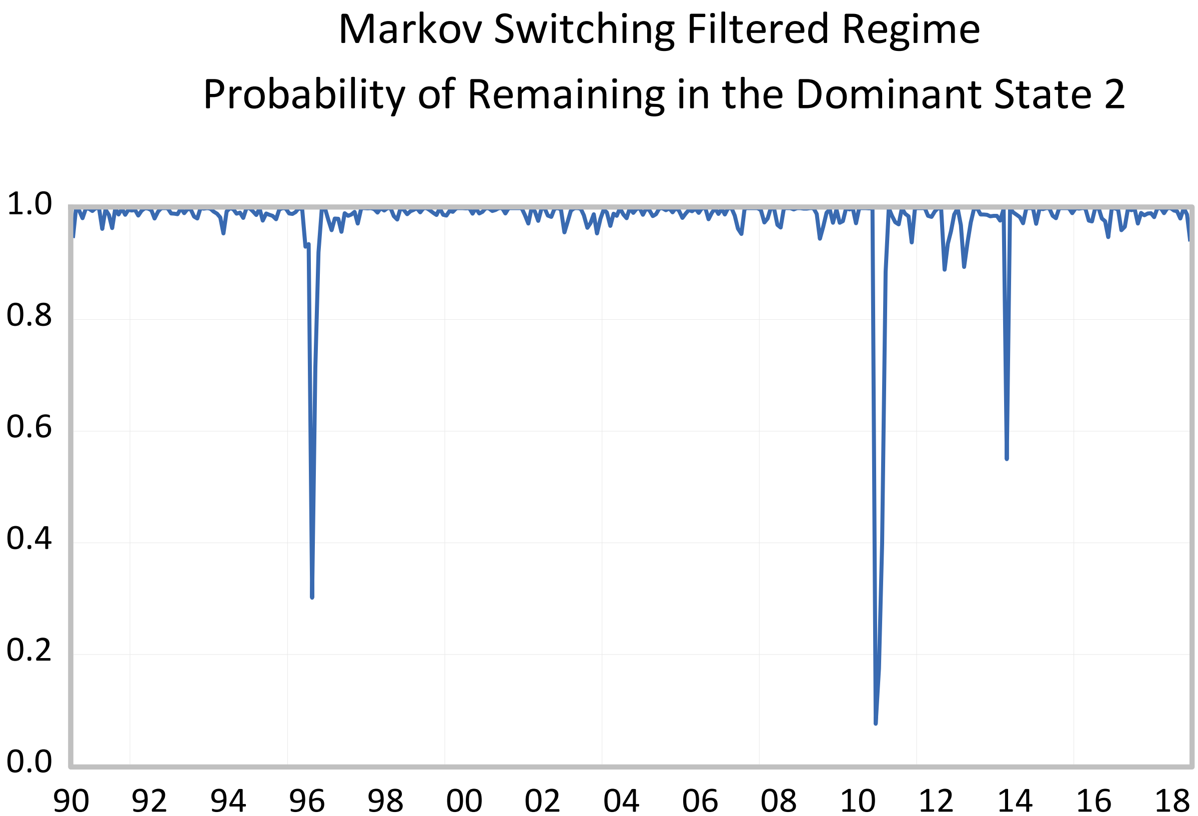
Figure 1: Impulse Responses between VIX and the Civilian Rate of Unemployment.



Notes: Un-accumulated impulse response functions derived from VAR(2), optimized for lagged terms by minimizing the Schwartz Information Criterion. Monthly data for the March 1990 – December 2018 sample period (346 observations).

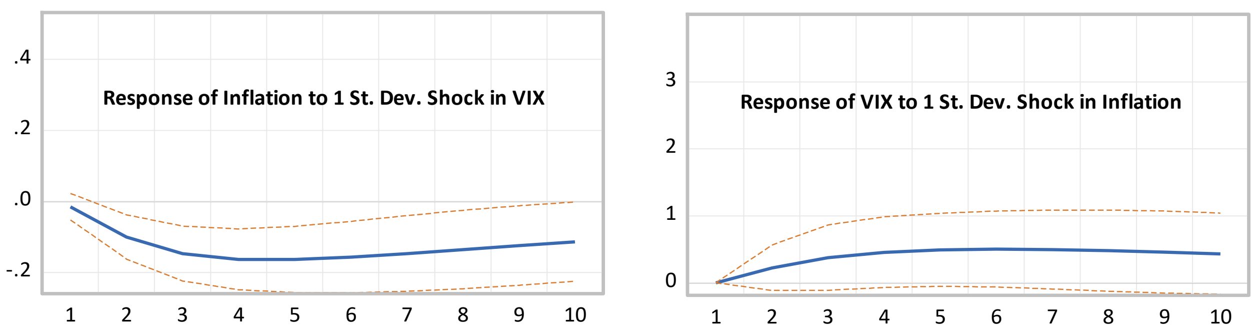
Source: Author's own estimation based on the Federal Reserve Bank of St. Louis – Federal Reserve Economic Database (FRED).

Figure 2: Markov Switching Estimation of VIX and Civilian Unemployment Rate:



Source: as in Figure 1.

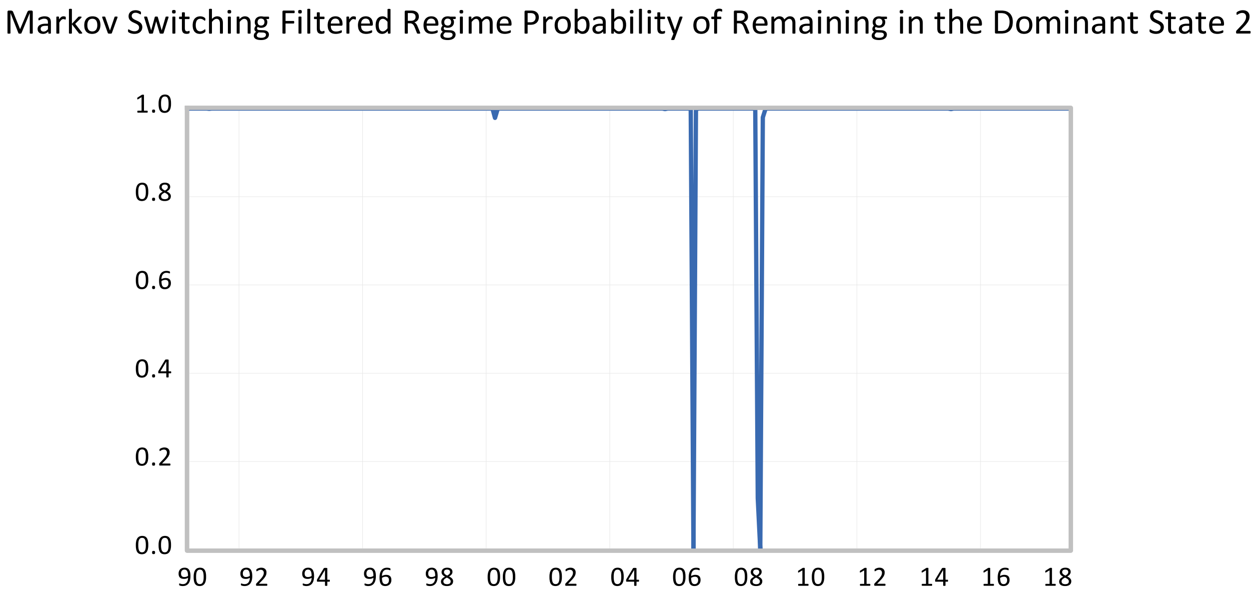
Figure 3: Impulse Responses between VIX and CPI Year-on-Year Inflation Rate.



Notes: Un-accumulated impulse response functions derived from VAR(2), optimized for lagged terms by minimizing the Schwartz Information Criterion. Monthly data for the March 1990 – December 2018 sample period (346 observations).

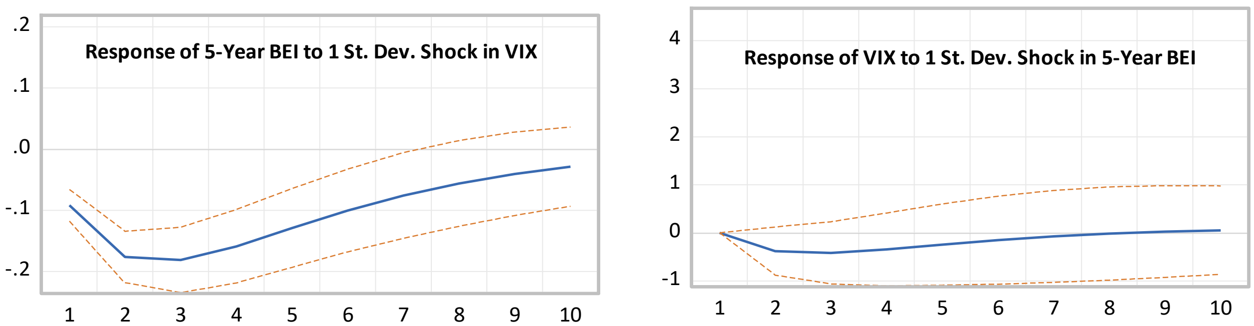
Source: as in Figure 1.

Figure 4: Markov Switching Estimation of VIX and CPI Inflation:



Source: as in Figure 1.

Figure 5: Impulse Responses between VIX and the 5-Year Breakeven Inflation Rate.

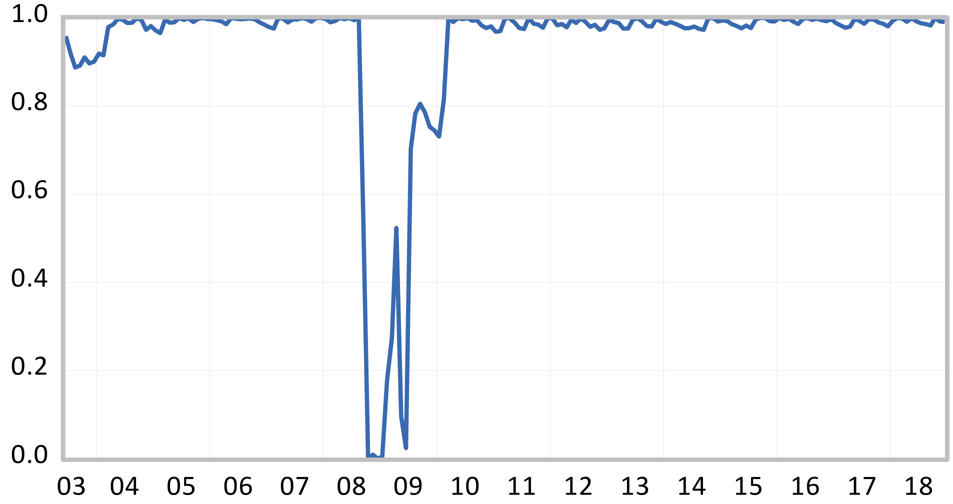


Notes: Un-accumulated impulse response functions derived from VAR(2), optimized for lagged terms by minimizing the Schwartz Information Criterion. Monthly data for the January 2003 – December 2018 sample period (190 observations).

Source: as in Figure 1.

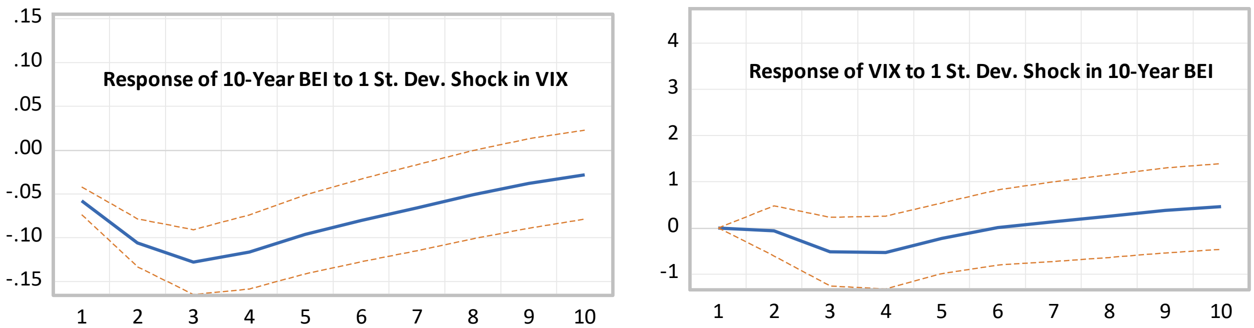
Figure 6: Markov Switching Estimation of VIX and 5-Year Breakeven Inflation:

Markov Switching Filtered Regime Probability of Remaining in the Dominant State 2



Source: as in Figure 1.

Figure 7: Impulse Responses between VIX and the 10-Year Breakeven Inflation Rate.

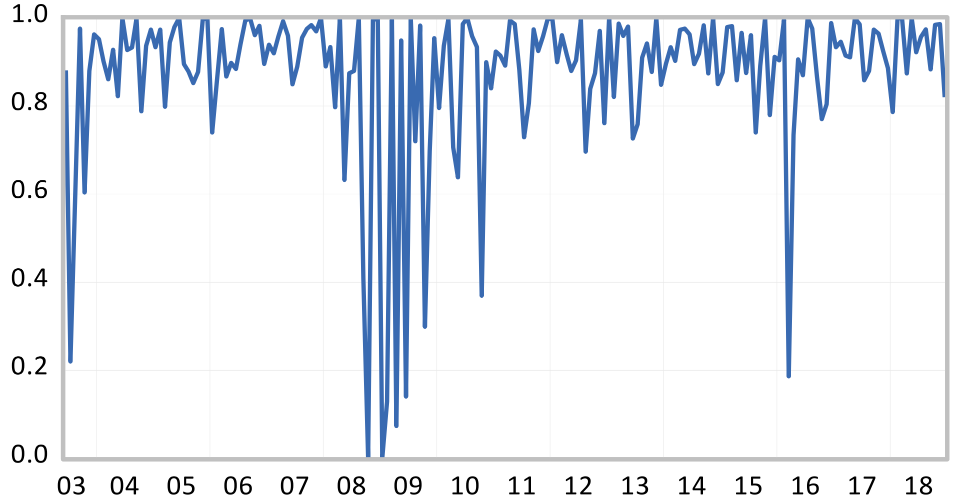


Notes: Un-accumulated impulse response functions derived from VAR(3), optimized for lagged terms by minimizing the Schwartz Information Criterion. Monthly data for the January 2003 – December 2018 sample period (190 observations).

Source: as in Figure 1.

Figure 8: Markov Switching Estimation of VIX and 10-Year Breakeven Inflation:

Markov Switching Filtered Regime Probability of Remaining in the Dominant State 2



Source: as in Figure 1.