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VIX and Market-Implied Inflation Expectations

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Abstract:

Our study shows that market-implied inflation expectations proxied by the breakeven inflation are directly related to market risk in high inflation environments and inversely during the periods of declining inflation or deflationary expectations. We use daily data series of percent changes in VIX as a proxy of market risk and changes in 5-year and 10-year breakeven inflation reflecting expectations of bond market participants. We employ Bayesian VAR, multiple breakpoint and Markov switching tests to examine the functional relationship between VIX and breakeven inflation for the January 3, 2003 – April 5, 2016 sample period. Our tests indicate a significant inverse relationship between VIX and, particularly, the 5-year breakeven inflation, which holds mainly during the recent financial crisis and the post-crisis periods.

Keywords: market risk; VIX; inflation risk; breakeven inflation; quantitative easing; Bai-Perron multiple breakpoint regression; Bayesian VAR; Markov switching

JEL Classification: C58, G13.

Highlights:

- Recent increases in market risk are associated with deflationary expectations
- Significant negative relationship between 5Y &10Y BEI, and VIX prevails in 2008-2013
- 5Y BEI inflation expectations relate with market risk better than 10Y BEI
- Partial regime switching between VIX and BEI occurs during turbulent markets

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I. Introduction

We aim to examine the intricate relationship between equity market risk and inflation expectations perceived by market participants. We particularly consider whether deflation expectations that have become prevalent in the aftermath of the recent financial crisis are altering the previously prevalent positive relationship between market risk and market-implied inflation expectations. We choose the Chicago Board of Option Exchange VIX volatility index as a proxy measure of market risk and relate it to the 5-year and the 10-year breakeven inflation as these two measures reflect inflation expectations of bond market participants for the respective time horizons.

Our original hypothesis is that surges in market risk, reflected by positive shocks to VIX, are associated with either high inflation expectations or deflationary expectations, i.e. lower BEI. Moderate inflation, normally associated with economic recoveries, is not presumed to be associated with higher market risk. More specifically, we believe that under expectations of deflation, there is a strong inverse relationship between inflation and market risk, as declining prices are associated with increasing market risk. Under moderate inflation, there is a weaker relationship in either a positive or inverse direction, as market risk is subdued at moderately increasing or decreasing prices. In contrast, high inflation is normally associated with higher market risk, thus in the environment of excessive inflation expectations, the relationship between inflation and market risk becomes positive.

Within the time frame of our analysis, we focus mainly on deflationary expectations. In other words, increases in market risk are seemingly related to expectations of economic slowdown, thus also to decreasing (demand-side) inflation. Our analysis focuses on this causal relationship. This differs from the prevalent analytical approach in the literature suggesting a positive, contemporaneous relationship between inflation risk and market risk that normally holds in the environment of high inflation expectations. Such a relationship has been discussed and documented in the literature by Adrian/Wu (2009), Bomfin/Rudebusch (2000), Gürkaynak et al., (2010), Söderlind (2011), Christensen/Gillian (2012), Fleckenstein et al. (2014), among others, all pointing to a prevalence of such direct interactions, albeit at different intensities, depending upon changes in market volatility conditions and in macroeconomic fundamentals. In essence, the literature generally concludes that the directional changes and the intensity of the impact of inflation risk on market risk vary significantly at different levels of interest rates, monetary policy stance and overall systematic risk conditions in the economy.

We use a range of econometric methods to investigate the interplay between VIX and 5-year as well as 10-year BEI in the U.S. markets over the past fourteen years, i.e. since the beginning of 2003 when the data on BEI became available. Using daily data series on BEI and VIX for a sample period of January 3, 2003 – April 5, 2016, we employ Bayesian vector autoregression, impulse response functions, Bai-Perron multiple breakpoint (MBP) regression and Markov switching tests to ascertain intensity and directional changes in this relationship.

The changeable interactions between VIX and BEI are shown and discussed in Section II. Causal relationships between percent changes in VIX and changes in 5-year as well as 10-year BEI are examined in Section III. Our analytical model reflecting changes in BEI as a function of changes in VIX, both under normal and turbulent market conditions is presented and estimated with OLS and Bai-Perron MBP regressions in Section IV. A two-regime Markov switching process of interactions between BEI and VIX is examined in Section V. A summary and policy conclusions are presented in Section VI.

II. Interactions between Breakeven Inflation and VIX

Our underlying assumption is that government bond markets display a fairly high predictability for expected inflation, which is embedded in inflation risk premium over real risk-free rates. For this reason, we investigate interactions between VIX and market-based inflation expectations using daily frequency, rather than survey-based expectations that are reported on a monthly basis. Inflation expectations derived from bond markets have a number of advantages over the survey-based expectations. Specifically, they are corrected on a daily basis and they quite accurately reveal expectations across a large number of market participants and a wide range of forecasts (Cunningham et al., 2010). We acknowledge that the historical evidence points out to a strong positive relationship between market risk and inflation risk, with increasing inflation risk having positive spillover effects on market risk (Söderlind, 2011; Christensen/ Gillian, 2012). This points out to a direct relationship, or a synchronous co-movement between VIX, interest rates and BEI. For this reason, changes in interest rates, reflecting market risk and inflation risk premiums, can be reasonably viewed as a catalyst of the dynamics between the two types of risk.

High sensitivity of market risk to inflation expectations is particularly prevalent when stock prices are undervalued relative to their fundamental level (Thorbecke, 1994; Rigobon and Sack, 2003). In this case, central banks normally enact monetary expansion causing stock prices increase to their fundamental level, as shown empirically by Hung and Ma (2017). When stock prices reach their fundamental level, monetary policy is neutral, while being accompanied by inflation expectations. However, when stock prices are overvalued, monetary authorities are likely to enact monetary contraction, which dampens inflation expectations (Hung/Ma, 2017). These interactions did not hold during the run-up and immediate aftermath of the 2008-2010 financial crisis, as the extraordinary monetary expansion responded to a combination of high market risk and deflationary expectations. The post-crisis policy mix also broke international transmission of inflation impulses and weakened co-movements of major exchange rates (Orlowski, 2016).

Before directly examining the relationship between market risk and inflation risk, we wish to draw attention to the complex relationship between changes in short-term market rates, specifically in the effective federal funds rate (FFR), and both the 5-year and the 10-year BEI. It shall be noted that our empirical analysis is based on daily data for BEI, FFR and VIX covering a January 3, 2003 – April 5, 2016 sample period (3311 observations). The starting date of our sample period corresponds with the earliest availbility of BEI data. All data are obtained from the Federal Reserve Bank of St. Louis FRED database.

….. insert Figure 1 around here ….

The time patterns of 5-year, 10-year BEI and FFR are shown in Figure 1. There is a misalignment of BEI and FFR during the initial two-year period, with the market-implied inflation steadily rising and the FFR stabilized at a one percent level, reflecting considerable easing of the US monetary policy. During the next phase of monetary tightening in 2005-2007, the interaction became reversed. Interest rates were rising while BEI reached a steady course within a 2 to 3 percent range. At the early stage of the financial crisis during August 2007-November 2008, interest rates declined sharply and when the crisis became apparent, BEI fell significantly, reflecting impending deflationary pressures. During the era of quantitative easing (QE), moderate inflation expectations were coupled with short-term interest rates at near-zero levels. With the recent exit from the QE strategy of the Federal Reserve, a closer synchronization or co-movement between the FFR and BEI can be reasonably expected, as also suggested for instance by Ciccarelli, et al. (2017). We can conceivably argue that a positive spread between BEI and FFR indicates net liquidity injections, while the negative spread implies a liquidity drainage. In essence, the path of the effective FFR has been detached from the market-implied inflation expectations, seemingly due to the high market risk conditions as affected by the global financial crisis and the unconventional ultra-easy monetary policy. We show the variable paths of FFR and BEI over the past fourteen years to underscore the lack of synchronization between short-term interest rates and market-implied inflation expectations.

The above asynchronous relationship motivates us to refocus on co-movements between market risk and market-implied inflation expectations, which are reflected by VIX and BEI respectively. Interactions between the log of VIX and both 5-year and 10-year BEI are shown in Figure 2 for the same 2003-2016 sample period of daily data.

….. insert Figure 2 around here …..

We observe mostly asynchronous interactions between VIX and BEI. From the beginning of the sample period in January 2003 until the fourth quarter of 2004, the trends in BEI and VIX showed a divergent path. Specifically, VIX declined while inflation expectations increased. The main factor contributing to the divergence of VIX and BEI is the surge in the liquidity risk premium embedded in BEI series. This interaction coincided with the monetary easing phase. The subsequent reversal to monetary tightening by the Federal Reserve corresponded with synchronous, positively related co-movements between VIX and BEI that lasted until the first signs of the recent financial crisis in August 2007 (Stillwagon, 2015). At the onset of the crisis, market risk increased significantly, while inflation expectations were stabilized. From the collapse of Bear Sterns in March 2008 through the demise of Lehman in October/November 2008, market risk increased sharply, while inflation expectations plunged due to the anticipated economic recession. Since the end of 2009 to the end of our sample period, the outbreaks of market risk have been accompanied by sharp declines in BEI, particularly in 5-year BEI. It can be generally argued that the changes between VIX and BEI were synchronous during the period of monetary policy tightening (i.e. 2005-2008). Their changes have been visibly asynchronous at times of monetary expansion (i.e. during the 2003-2004 and 2009-2015 periods). A comparison between Figures 1 and 2 suggests prevalence of a synchronous relationship between BEI and VIX during the period of monetary tightening in 2003-2005. Monetary expansion with massive injections of liquidity in response to the financial crisis entailed asynchronous co-movement between VIX and BEI. This observation confirms the findings of Söderlind (2011) that financial market turbulence is likely to raise the real liquidity premium, which subsequently tends to decrease market-based inflation expectations. It is also consistent with Christensen/Gillan (2012), who argue that the second round of the Federal Reserve quantitative easing reduced liquidity premiums in the market for TIPS and inflation swaps thus lowered BEI.

III. Causal Relationships

Before properly designing the analytical model reflecting interactions between VIX and BEI, we first examine causal directions and transmission of shocks between these variables. For this purpose, we employ Bayesian vector autoregression (BVAR) analysis and the corresponding impulse response functions. We test BVAR separately for stationary changes in 5-year and 10-year BEI in their first differences in relation to percent changes $(\Delta \log s)$ in VIX. The order of our BVAR tests is optimized for the number of response lags by minimizing the Schwartz information criterion (SIC) at different lag specifications. SIC results suggest BVAR optimization with 2 lagged terms for both 5-year and 10-year BEI series. Our BVAR(2) tests assume Monte Carlo distribution of error terms. From BVAR(2) we derive un-accumulated impulse response functions that are shown in Figure 3.

….. insert Figure 3 around here …..

Based on the obtained impulse response functions, we argue that there is no transmission of shocks from BEI to VIX, as shown by the two upper-row graphs. Namely, one standard deviation shocks in either 5-year or 10-year BEI do not cause any reactions in VIX. In general terms, we find that unexpected shocks to inflation do not exacerbate market risk, which instead normally reacts to changes in the expected inflation trend (Bomfim/Rudebusch, 2000). In contrast, there is a discernible transmission of shocks from VIX to BEI, as reflected by the two reaction functions shown in the lower-row graphs in Figure 3. Specifically, a positive one standard deviation shock in market risk (VIX) results in an immediate reduction of market based inflation expectations lasting up to two days. This suggests a strong impact of a surge in market risk on deflationary pressures. It can be further noted that similar inverse reactions are implied by the time patterns of VIX and BEI in Figure 2, particularly during the 2008-2010 financial crisis. At that time, the rising market risk was accompanied by declining BEI, particularly for the 5-year BEI series.

IV. The Underlying Model and Its Multiple Breakpoint Regression Estimation

Considering the prevalent transmission of shocks from VIX to BEI, we devise the following simple functional relationship underlying the rest of our analysis:

$$\Delta\pi_t = \beta_0 + \beta_1 \Delta \log(VIX_t) + \varepsilon_t \qquad (1)$$

with $\Delta\pi_t$ representing changes in BEI and $\Delta\log(VIX_t)$ reflecting percent changes in VIX.

In order to account for different patterns in the relationship prescribed by Eq. 1 at tranquil vs. turbulent markets that we observed in Figure 2, we augment Eq. 1 with a dummy variable $DVIX$ assuming the value of 1 at turbulent market periods when VIX exceeds the threshold of 25.94 and 0 for the tranquil market days of VIX remaining below the threshold. We have identified the VIX threshold of 25.94 by running the Bai-Perron Threshold estimation of the stochastic VIX series for the entire sample period, permitting just one structural break. The threshold test has identified 2914 tranquil market days, i.e. VIX oscillating below the obtained threshold, and 496 days of turbulent markets.

The modified functional relationship that accounts for market turbulence by adding our $DVIX$ variable is represented by:

$$\Delta\pi_t = \beta_0 + \beta_1\Delta\log(VIX_t) + \beta_2 DVIX + \beta_3\Delta\log(VIX_t) * DVIX + \varepsilon_t^{'} \qquad (2)$$

The ordinary least square (OLS) regression estimation of Eq. 2 for the entire sample period is shown in Table 1. The estimation shows that increasing percent changes in market risk are associated with a declining inflation. This inverse relationship is particularly pronounced at times of market distress as reflected by the significant negative estimated coefficient $\hat{\beta}_3$ of the interactive term between VIX and DVIX. These findings hold for both 5-year and 10-year BEI tests. However, the 10-year BEI estimation is somewhat more robust with a higher absolute value and a greater statistical significance of the interactive term coefficient.

..... insert Table 1 around here .....

The impact of turbulent market times on the relationship between BEI and VIX has played a significant role during our 2003-2016 period of daily data series, although the intesity of these interactions may have changed at the different times of perception about overall market risk conditions. Changes in these interactions are visible in Figure 2, indicating that there are several distinctive periods or phases in the interactions between market risk and market-based inflation expectations. In order to identify such distinctive phases we estimate Eq. 1, with the Bai-Perron multiple breakpoint (MBP) regression, separately for 5-year and 10-year BEI series as a function of percent changes in VIX[1]. The MBP estimation representations are shown in Table 2.

..... insert Table 2 around here .....

The discernible phases identified in the 5-year and the 10-year BEI estimations are somewhat different as their breaks are rather misaligned. Nevertheless, their directional relation to VIX and the statistical significance in each of the three identified phases are nearly the same. Phase I in the 5-year BEI series begins on January 6, 2003 and ends on December 1, 2008. There is no association between 5-year BEI and VIX during that period. A similar lack of relationship between breakeven inflation and market risk is observed in Phase I in the 10-year BEI series estimation, with the breakpoint taking place a bit earlier on August 15, 2008. Phase II in both examined relationships corresponds with the crisis-resolution policies enacted in the aftermath of the recent financial crisis. In both 5-year and 10-year- BEI estimations, there is a significant inverse relationship between breakeven inflation and market risk. More specifically, market risk tends to increase along

[1] Our multiple breakpoint regression estimations allow for a maximum of 5 structural breaks in both series. Our tests are based on the sequential L+1 vs. L breaks estimations, allowing error distributions to differ across the breaks. In both 5-year and 10-year BEI series, we obtain 3 breaks and their selection is optimized by minimizing the Schwartz information criterion.

with declining inflation (or deflation) expectations. A plausible explanation for this inverse reaction is provided by Söderlind (2011), who argued that market shocks at times of financial distress entail higher real liquidity premium, which in turn tends to reduce breakeven inflation.

The second breakpoints in the 5-year and the 10-year BEI series (i.e. the starting days of Phase III) are markedly mismatched. The breakpoint in the 5-year BEI series takes place in the beginning of December 2010, while the same breakpoint in the 10-year series is identified for mid-June 2012. During Phase III in both cases, the inverse relationship between market risk and breakeven inflation continues, albeit it is weaker than in Phase II, as implied by lower absolute values of the estimated $\hat{\beta}_1$ coefficients. Arguably, elevated market risk has been accompanied by expectations of disinflation and economic weakness during the most recent period. It shall be noted that the association between higher market risk and rising inflation expectations discussed in the early literature has not been detected in our tests at any time interval since the beginning of 2003. We are led to believe that the positive directional relationship between BEI and VIX may re-emerge in the future, as higher inflation expectations stemming from a faster-track economic recovery may be associated with elevated market risk.

In sum, our tests show prevalence of an inverse relationship between BEI and VIX, particularly in the aftermath of the recent financial crisis. This implies a combination of higher market risk with decreasing inflation expectations stemming from both the anticipated economic slowdown and reduced liquidity premium in the market for TIPS and inflation swaps (Christensen/Gillan, 2012).

V. Stability of Breakeven Inflation and VIX: a Two-State Markov Switching Process

In order to verify the robustness of the multiple breakpoint regression estimation for the BEI series as a function of VIX, we employ a Two-State Markov Switching Model. Its estimation also enables us to show directional changes and stability of either direct or inverse relationships between VIX and BEI during the entire examined sample period.

A two-state Markov switching process to simulate is specified as follows:

The process in State 1 is specified as

$$\Delta\pi_{t|St=1} = c_1 + \gamma_1 \Delta \log VIX_t + \varepsilon_{1t} \qquad \varepsilon_{1t} \to N(0,1) \tag{3}$$

We expect the process estimated for State (or ”Regime”) 1 to follow an inverse relationship between BEI and VIX during the examined sample period, considering the prior results obtained from the multiple breakpoint regression estimation. State (”Regime”) 2 is expected to reflect episodes of a positive relationship between BEI and VIX, which are seemingly less prevalent during our examined sample period. It is prescribed by

$$\Delta\pi_{t|St=2} = c_2 + \gamma_2 \Delta \log VIX_t + \varepsilon_{2t} \qquad \varepsilon_{2t} \to N(0,1) \tag{4}$$

The corresponding transition probability matrix is specified as:

$$P = \begin{bmatrix} p_{11} p_{21} \\ p_{12} p_{22} \end{bmatrix} \tag{5}$$

The results of the Markov switching estimation for the 5-year and 10-year BEI as a function of changes in log of VIX are shown in Table 3. In both 5-year and 10-year BEI series estimations, we have used the first-order autoregressive AR(1) and log sigma terms. Selections of AR(1) have been have been derived from a series of tests assuming different AR orders by minimizing the Schwartz information criterion.

..... insert Table 3 around here .....

The obtained States or Regimes from the Markov switching estimations are different for the 5-year and the 10-year BEI series. The estimated process for the 5-year BEI is fully consistent with our initial assumptions of two different directional associations between both BEI and VIX. The estimated Regime 1 reflects an inverse relationship between 5-year BEI and VIX, while Regime 2 shows a positive relationship between these variables. Estimations of both regimes are robust and statistically significant as implied by both $\hat{\gamma}_1$ and $\hat{\gamma}_2$ terms. Regime 1, i.e. the inverse relationship between 5-year BEI and VIX, dominates the process. Its expected duration is 604 days and the probability of remaining in it on any given day is 99 percent. Regime 2 is characterized by a positive directional relationship between these variables and is clearly subordinate with its expected duration of only 1.4 days, and the probability of remaining in it is 27 percent. Nonetheless, the process prescribed by Regime 2 is strong and decisive, as suggested by the statistically significant $\hat{\gamma}_2$.

Somewhat different results are obtained for the estimation of 10-year BEI as a function of VIX. In this case, the relationship between these variables in both 1 and 2 Regimes is inverse and statistically significant. The estimated Regime 1 is similar to that obtained for the 5-year BEI. It also dominates the Markov switching process, although less decisively, as its expected duration of 116 days is a bit shorter. However, Regime 2 for the 10-year BEI series is different than that for

5-year BEI; it reflects a pronounced, inverse relationship between BEI and VIX[2]. Evidently, long-term market-implied inflation expectations are inversely associated with market risk. This implies that inflation expectations over a longer time horizon are seemingly associated with fears of economic slowdowns, which in turn tends to exacerbate market risk.

Further insights on the stability of the obtained Markov switching regimes can be derived from the graphical display of one-step ahead predicted regime probabilities that are shown in Figures 4a and b. Interactions between Regimes 1 and 2 for the 5-year BEI series displayed in Figure 4a suggest that the process has been very stable over the entire sample period, with the exception of the time coinciding with the peak of the recent financial crisis in the fourth quarter of 2008. Evidently, interactions between 5-year BEI and VIX are consistent with our estimated two-stage Markov switching process mainly at tranquil market periods. One should remember however that Regime 1 reflecting an inverse relationship between 5-year BEI and VIX dominates the examined process. There is a sporadic, one-time derailment of this process at the peak of the recent crisis, when key financial market variables exhibited significant tail risks (Orlowski, 2012).

….. insert Figures 4 a and b around here …..

The interactions between 10-year BEI and VIX specified by the estimated Markov switching process and shown in Figure 4b are considerably less stable. There are many, mainly sporadic derailments of this process, specifically in 2003, 2004, early 2008, 2009, 2011 and 2014. These episodes could be attributed to major shocks in VIX, triggered by various systemic factors, to which the long-term market-implied inflation expectations did not react. As in the 5-year BEI

[2] A plausible explanation of the different reactions of 5-year and 10-year BEI to VIX is provided by Gürkaynak et al. (2010), Beechey/Österholm (2012), Netšunajev/Winckelmann (2014) and Strohsal/Winckelmann (2015), who all suggest that medium-term market-based inflation expectations carry information about economic news and forecasts, while long-term expectations are mainly affected by central banks' credibility in ability to control inflation.

case, the relationship between 10-year BEI and VIX became very unstable during the peak of the financial crisis in 2008.

In sum, the Markov switching process holds well for the relationship between 5-year BEI and VIX. It suggests that market risk is inversely related to market-implied inflation expectations at most, as fears of deflation or declining inflation due to anticipated economic slowdown were coupled with elevated market risk. Only during the peak of the recent financial crisis the prescribed process became significantly disrupted.

VI. Conclusions

We find evidence of a significant negative relationship between VIX and both the 5-year and 10-year breakeven inflation at the peak and immediate aftermath of the 2008-2010 financial crisis. This inverse relationship differs from their previously observed positive interactions.

We believe policymakers can increasingly rely on market-based inflation expectations in their interest rate decisions. These market based measures have significant advantages over the survey based methods. Our study shows that an increase in market risk is associated with either extreme, high inflation expectations or deflation. The tests performed in this analysis, i.e. the Bayesian VAR, multiple breakpoint and Markov switching test indicate a significant inverse relationship between VIX and, particularly, the 5-year breakeven inflation. This holds true mainly during the recent financial crisis and the post-crisis periods, but not for the sample period preceding the crisis. The examined relationship is considerably stronger for the 5-year than for the 10-year breakeven inflation, underscoring a pronounced impact of economic fundamentals on 5-year breakeven inflation. The most recent Federal Reserve's path toward gradual tightening of monetary policy will likely restore a more synchronous co-movement between breakeven inflation and VIX.

The research presented in this paper supports the existing literature and generally concludes that the directional changes and the intensity of the impact of inflation risk on market risk vary significantly at different levels of interest rates, monetary policy stance and overall systematic risk conditions in the economy. As an extension to the existing literature, this analysis includes data covering the financial crisis to support the importance of using these variables' relationships as predictors for future financial divergence. Future research on these interactions could expand into other countries to see if the relationship between market risk and market implied inflation expectations holds true in the global economy and among diverse economic systems. Of further interest is how the recent volatility spikes, triggered by the political and economic risks, have compounded this dynamic.

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Table 1: Changes in 5-year and 10-year breakeven inflation as a function of percent change in VIX – estimation of Eq.2.

Dependent variable → Independent variables ↓	Change in 5Y BEI	Change in 10Y BEI
Const. term $\hat{\beta}_0$	0.001 (0.81)	0.001 (1.23)
$\Delta \log$ VIX $\hat{\beta}_1$	-0.097*** (-5.82)	-0.079*** (-7.61)
DVIX $\hat{\beta}_2$	-0.005* (-1.68)	-0.004** (-2.21)
$\Delta \log$ VIX*DVIX $\hat{\beta}_3$	-0.077** (-2.39)	-0.159*** (-8.00)
Diagnostic statistics:		
Adjusted R^2	0.022	0.074
F-statistics	26.80	89.60
Schwartz Info. Criterion	-2.928	-3.880
Durbin-Watson Stat.	1.809	1.789

Notes: January 6, 2003 – April 5, 2016 sample period; t-statistics in parentheses; *** denotes significance at 1%, ** at 5%, * at 10%.

Source: Authors' own estimation based on the Federal Reserve Bank of St. Louis FRED daily data.

Table 2: Changes in 5-year and 10-year breakeven inflation as a function of changes in log of VIX: Bai-Perron multiple breakpoint estimation of Eq.1.

Phases based on breakpoints	Changes in 5Y BEI as a function of changes in log of VIX		Phases based on breakpoints	Changes in 10Y BEI as a function of changes in log of VIX	
	Const. term $\hat{\beta}_0$ Coefficient $\hat{\beta}_1$	Association based on $\hat{\beta}_1$		Const. term $\hat{\beta}_0$ Coefficient $\hat{\beta}_1$	Association based on $\hat{\beta}_1$
Phase I: 01/06/2003 – 12/01/2008 1476 obs.	-0.001 (-0.61) -0.034 (-1.22)	None, statistically insignificant	Phase I: 01/06/2003 – 08/15/2008 1404 obs.	0.001 (0.56) -0.019 (-1.54)	None, statistically insignificant
Phase II: 12/02/2008 – 12/02/2010 501 obs.	0.003 (1.21) -0.284*** (-7.04)	Strong negative significant	Phase II: 08/18/2008 – 06/13/2012 956 obs.	-0.001 (-0.01) -0.251*** (-11.57)	Strong negative significant
Phase III: 12/03/2010 – 04/05/2016 1331 obs.	-0.001 (-0.10) -0.138*** (-9.97)	Strong negative significant	Phase III: 06/14/2012 – 04/05/2016 948 obs.	-0.001 (-0.71) -0.095*** (-8.87)	Strong negative significant
Diagnostic tests:	F-statistics = 21.412 Log likelihood = 4872.7 Schwartz Info. Criterion = -2.931 Durbin Watson stats. = 1.816		Diagnostic tests:	F-statistics = 63.952 Log likelihood = 6456.9 Schwartz Info. Criterion = -3.889 Durbin Watson stats. = 1.793	

Notes and source: as in Table 1.

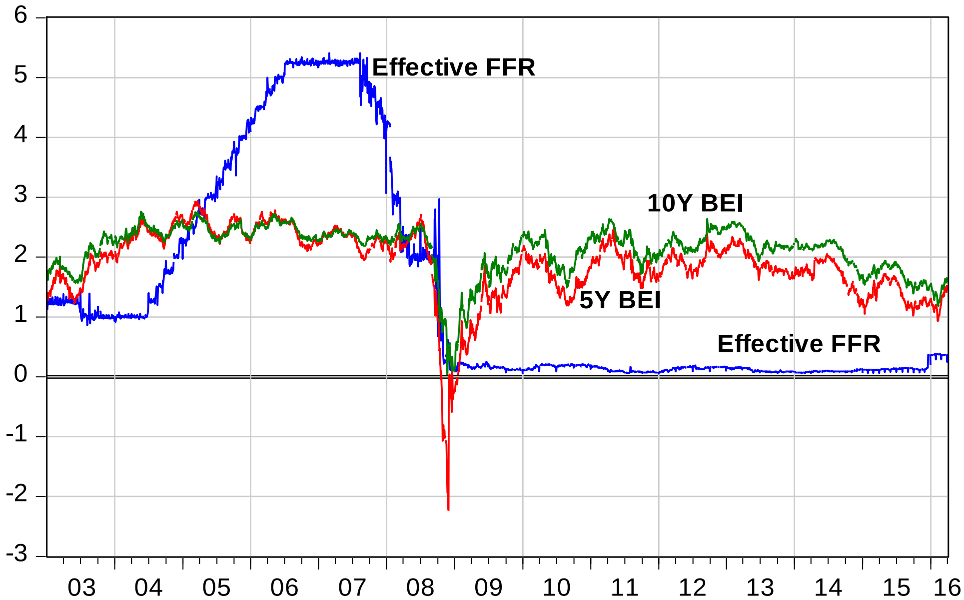
Table 3: Estimations of Two-State Markov Switching for changes in 5-year and 10-year breakeven inflation in relation to changes in logs of VIX (Equations 3, 4 and 5).

	Changes in 5Y BEI as a function of changes in log of VIX	Changes in 10Y BEI as a function of changes in log of VIX
Regime I	$\hat{c}_1$ = -0.001 (-0.54) $\hat{\gamma}_1$ = -0.143*** (-12.91)	$\hat{c}_1$ = 0.002*** (2.62) $\hat{\gamma}_1$ = -0.101*** (-12.14)
Regime II	$\hat{c}_2$ = 0.205*** (10.85) $\hat{\gamma}_2$ = 7.915*** (42.16)	$\hat{c}_2$ = -0.128*** (-16.35) $\hat{\gamma}_2$ = -0.225*** (-3.82)
Common terms: AR(1) Log Sigma	 0.088*** (4.93) -3.138*** (-252.9)	 0.100*** (20.80) -3.454*** (-265.0)
Diagnostic tests:	Log likelihood = 5646.5 Schwartz Info. Criterion = -3.396 Durbin Watson stats. = 1.852	Log likelihood = 6563.8 Schwartz Info. Criterion = -3.951 Durbin Watson stats. = 2.018
Constant transition probabilities, Probability of staying (switching): Regime I Regime II	 0.99 (0.01) 0.27 (0.73)	 0.99 (0.01) 0.31 (0.67)
Constant expected durations: Regime I Regime II	 604 days 1.4 days	 116 days 1.5 days

Notes: as in Table 1, z-statistics in parentheses.

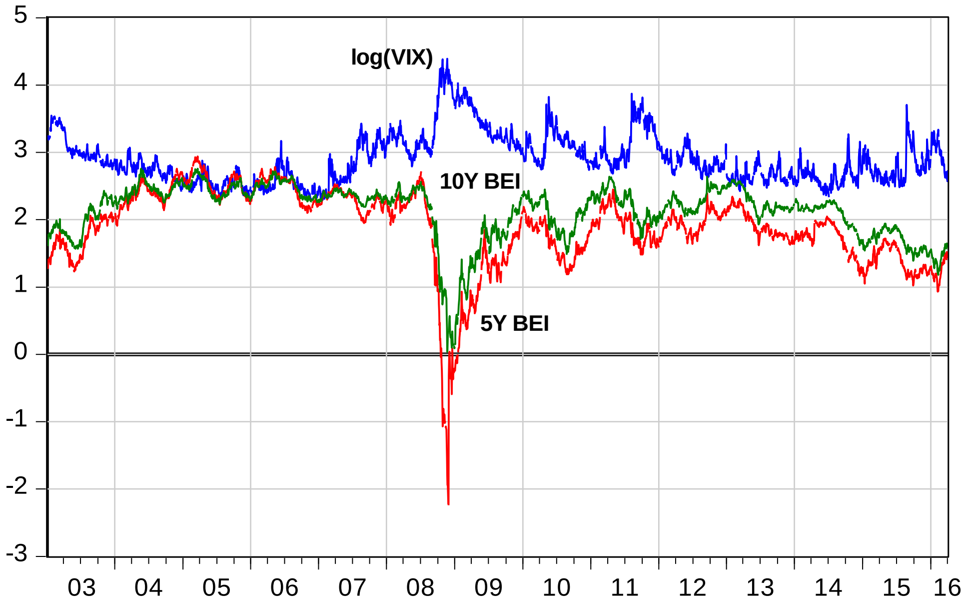
Source: as in Table 1.

Figure 1: Effective federal funds rate, 10-year and 5-year breakeven inflation.



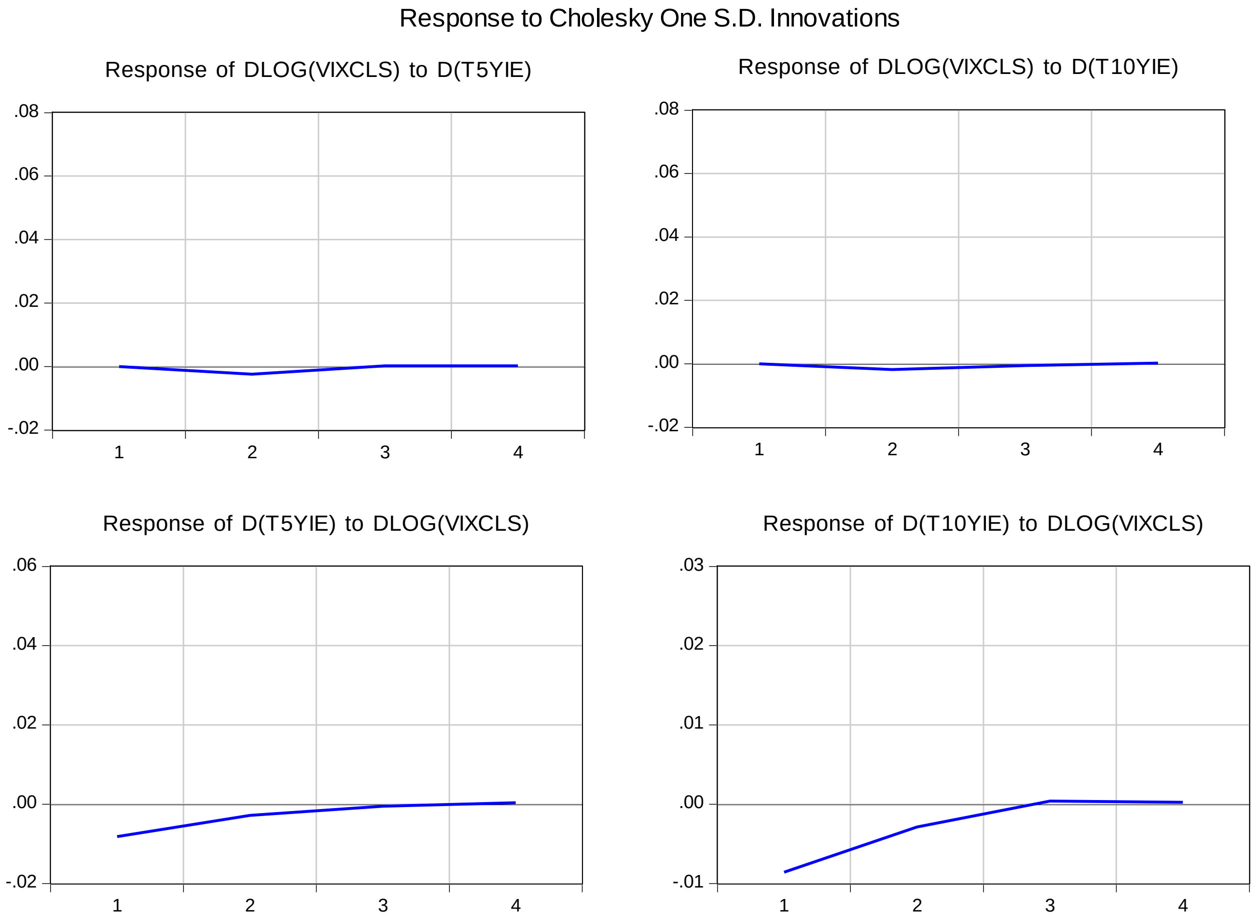
Source: own compilation based on the Federal Reserve Bank of St. Louis FRED daily data.

Figure 2: 10-year and 5-year breakeven inflation and (log) VIX.



Source: as in Figure 1

Figure 3: Un-accumulated impulse responses between (changes in logs of) VIX, 5-year and 10-year breakeven inflation.



Notes: Impulse response functions derived from BVAR(2) based on daily data for the sample period January 3, 2003-April 5, 2016.

Source: as in Figure 1.

Figure 4a: Markov switching one-step ahead predicted regime probability for 5-year breakeven inflation series.

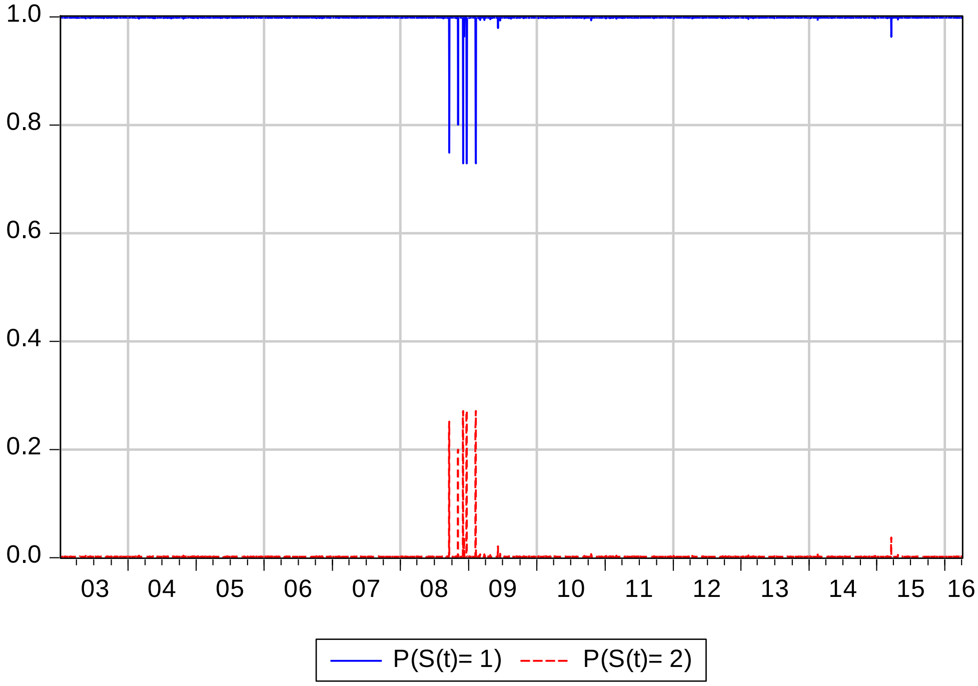
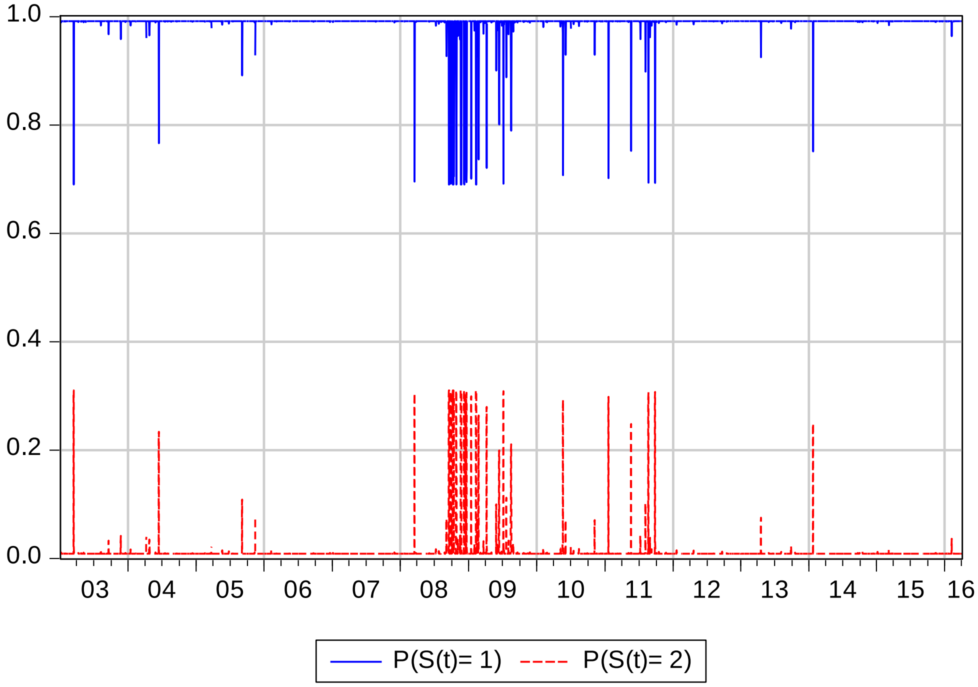


Figure 4b: Markov switching one-step ahead predicted regime probability for 10-year breakeven inflation series.



Source: as in Table 1.