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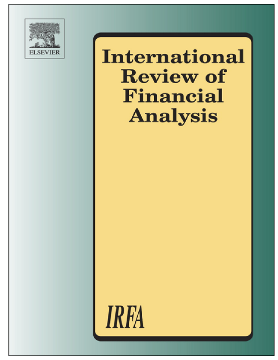

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Market Risk and Market-Implied Inflation Expectations

by Lucjan T. Orlowski [1)] * and Carolyne Soper [2)]

Abstract:

We examine interactions between market risk and market-implied inflation expectations. We argue that these interactions are asymmetric and varied in time. Specifically, market risk becomes elevated by expectations of either very low or high expected inflation. Market risk does not react to expectations of moderate, stable inflation. In our analysis, market risk is proxied by VIX and market-implied inflation expectations are reflected by five- and ten-year breakeven inflation. We use daily data for 5 and 10 year breakeven inflation and VIX for the sample period January 3, 2003 – January 24, 2019 for empirical testing. We employ asymptotic VAR, multiple breakpoint regression and Markov switching tests to examine changeable patterns in these interactions. Our tests indicate prevalence of responses of expected low inflation or deflation to higher market risk, mainly for the 5-year breakeven inflation series. These responses are particularly significant during the run-up and aftermath of the 2008 financial crisis.

Keywords: Market risk; VIX; Inflation risk; Breakeven inflation;
Bai-Perron multiple breakpoint regression; Asymptotic VAR; Markov switching

JEL Classification: C22, C58, E31, E44, G12.

Highlights:

- We show that market risk is exacerbated when market-based inflation expectations are either very high or unusually low
- The impact of market risk proxied by VIX on breakeven inflation is asymmetric, following three discernible zones of interactions
- The prevalent Zone 1 reflects periods of benign interactions between low inflation and low market risk, Zone 2 combines fears of deflation and high market risk, Zone 3 reflects high risk and high inflation
- High market risk is associated mainly with fears of disinflation and deflation during the examined 2003-2019 sample period of daily data

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I. Introduction

We aim to examine interactions between equity market risk and inflation expectations perceived by bond market participants. Market risk is proxied in our study by the Chicago Board Options Exchange VIX volatility index[1]. Inflation expectations are reflected by five-year and ten-year breakeven inflation (BEI) that measure a path of anticipated inflation derived from the yield on Treasury Constant Maturity Securities and the corresponding maturity rate on Treasury Inflation-Indexed Constant Maturity Securities. Our underlying hypothesis is that during tranquil market periods low market risk is associated with low, stable expected inflation. Surges in market risk are associated with fears of deflation or high inflation. We propose three Zones in interactions between market risk and market-implied inflation expectations. The neutral Zone 1 combines periods of low market risk and low, stable expected inflation. Since it reflects conditions of tranquil financial markets, it is expected to be dominant. The remaining two extreme, 'tail' Zones are subordinate as they occur during turbulent markets. Zone 2 encompasses episodes of high market risk and fears of deflation and Zone 3 reflects periods of interplay between high market risk and high expected inflation.

Our paper contributes to the existing literature on the nexus between market risk and inflation expectations in several ways. First, while most of the published studies focus on survey-based inflation projections, we analyze market-implied expectations. Second, we identify breakpoints and phases in interactions between market risk and inflation expectations. The

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[1] As a barometer of the expected future (30 day) equity market volatility, CBOE VIX is calculated by using the midpoints of real-time S&P500 Index option bid/ask quotes.

discernible phases reflect the periods of rising inflation, stable inflation and declining inflation along with deflation. Third and perhaps most importantly, these different states of reactions lead us to introduce an argument that market risk and market implied inflation expectations interact only in 'tails' i.e. during the periods of high, or very low inflation (or deflation), but not at times of moderate inflation and tranquil markets. Fourth, using vector autoregression (VAR) tests and impulse response functions we aim to identify transmission and feedback effects between breakeven inflation and market risk.

More specifically, we assume that under expectations of low inflation or, particularly, deflation, there is a strong inverse relationship between inflation and market risk, as declining prices are associated with increasing market risk. We believe that moderate inflation that is confined within the range targeted by monetary authorities does not exacerbate market risk, thus a relationship between these variables becomes insignificant. Under moderate inflation, there is a weaker relationship in either a positive or inverse direction, as the 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 pronounced and positive.

We use daily, rather than monthly data because it provides more observation points and reflects bond market participants' expectations of inflation more accurately. Daily average data series capture important, potentially destabilizing shocks responding to unanticipated news. Monthly data would dull these market-based responses and relate the analysis only to the trends in market and inflation risks.

We assume prevalence of a one-way causal transmission of shocks in market risk into inflation expectations of market participants. This causal reaction differs from the opposite transmission of shocks in expected inflation into market risk, which has been emphasized and examined empirically in the literature by Söderlind, (2011) and Christensen/Gillan (2012), among others.

We examine whether the rising volatility of US equity prices became associated with expectations of disinflation and deflation during the run-up to and the immediate aftermath of the 2008 financial crisis. This would imply a reversal of a weak, indeterminate relationship between these variables during the periods of tranquil market conditions.

Within the time frame of our analysis, we focus particularly on the episodes of low expected inflation or deflation. In such cases, increases in market risk are seemingly related to expectations of economic slowdown, thus also to decreasing (demand-side) inflation. Similarly to Fleckenstein et al. (2017), we assume that deflation risk is associated with declining consumer confidence that exacerbates market risk. Our analysis 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 relationship has been examined by Adrian/Wu (2009), Bomfin/Rudebusch (2000), Gürkaynak et al., (2010), Söderlind (2011), Christensen/Gillan (2012), Fleckenstein et al. (2014), among others, all pointing to a prevalence of such direct interactions, albeit at different intensities, which depend on varied market volatility conditions and macroeconomic fundamentals. In essence, the literature generally concludes that the directional changes and the intensity of the impact of inflation risk on market risk are asymmetric. They 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 sixteen 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 January 3, 2003 – January 24, 2019 sample period, we employ the asymptotic vector autoregression (VAR), impulse response functions, the Bai-Perron multiple breakpoint (MBP) regression and the three-state Markov switching process to examine intensity and directional changes in the interactions between 5-year, 10-year BEI and VIX.

The changeable time patterns of 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 is presented and estimated with the Bai-Perron MBP regressions in Section IV. A three-state 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 proxied by BEI using daily frequency, rather than survey-based expectations that are reported on a monthly basis. In essence, BEI represents an 'inflation compensation' as it is a real-time proxy for market participants' inflation expectations (Kim et al., 2019). 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/ Gillan, 2012). This suggests a direct relationship with 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.

We recognize that BEI has not always adequately reflected inflation risk premia due to illiquidity of Treasury Inflation Protected Securities (TIPS), particularly in the early 2000's. As argued by Zeng (2013) BEI has often overestimated expected inflation due to liquidity risk. Moreover, D'Amico et al. (2018) decompose BEI into three components – inflation expectation, inflation risk premium and TIPS liquidity premium. Nevertheless, a more recent evidence by Kim et al. (2019) suggests that the liquidity of TIPS has been significantly improved, enabling BEI to reflect inflation expectations more accurately. This point is supported by the evidence provided by Güler et al. (2017) who show that inflation-indexed bonds have been increasingly liquid both in mature and emerging financial markets. Using the example of Turkey, they show that the inflation-indexed bonds are at times even more liquid than the nominal government bonds. We also recognize that the overall risk of 10-year TIPS is more pronounced than that of 5-year TIPS due to liquidity and maturity risks.

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 conducting a deeper, time-varying analysis of interactions between market risk and market-implied inflation expectations, we show in Figure 1 the time pattern of log of VIX and 5-year as well as 10-year BEI for the January 3, 2003 – January 24, 2019 sample period of daily data.

….. insert Figure 1 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 have a divergent path. Specifically, VIX declines while inflation expectations increase. The main factor contributing to the divergence of VIX and BEI at the beginning of our sample is the surge in the liquidity risk premium embedded in BEI. This interaction coincides with the monetary easing conducted by the Federal Reserve during the 2003-2005 period. The subsequent reversal to monetary tightening by the Federal Reserve corresponds with synchronous, positively related co-movements between VIX and BEI that last until the first signs of the recent financial crisis in

August 2007[2]. At the onset of the crisis, market risk increases significantly, while inflation expectations are stabilized. From the collapse of Bear Sterns in March 2008 through the demise of Lehman in October/November 2008, market risk increases sharply, while inflation expectations plummet due to the anticipated economic recession. Since the end of 2009 to the end of our sample period, the outbreaks of market risk are accompanied by sharp declines in BEI, particularly in 5-year BEI. It can be therefore argued that the changes between VIX and BEI are synchronous during the period of monetary policy tightening (i.e. 2005-2008). These variations are visibly asynchronous at times of monetary expansion (i.e. during the 2003-2004 and 2009-2015 periods).

In addition, Figure 1 shows a negative correlation and asynchronous interactions between BEI and VIX that are particularly pronounced during the global recession of 2010-2013 following the financial crisis. This observation is consistent with the findings of Yarovaya et al. (2017) who underscore dominance of negative shocks to global stock indexes at that time. Furthermore, Chau and Deesomsak (2014) provide evidence of strong volatility spillovers from U.S. debt to equity and subsequently to other financial markets during the crisis and its aftermath. Their finding suggests transmission of market implied expectations of disinflation onto equity market risk. It can be therefore argued that fears of prolonged recession and deflation exacerbated market risk in the aftermath of the financial crisis.

Figure 1 also suggests prevalence of a synchronous relationship between BEI and VIX during the period of monetary tightening in 2005-2007. Monetary expansion with massive injections of liquidity in response to the financial crisis has entailed asynchronous co-movement between VIX

[2] For a detailed examination of interactions between changes in US monetary policy and in both market-based and survey-based inflation expectations see for instance Ciccarelli et al. (2017) and Stillwagon (2018).

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 and 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 an asymptotic vector autoregression (VAR) model and the corresponding impulse response functions. We conduct VAR tests 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 VAR tests is optimized for the number of response lags by minimizing the Schwartz information criterion (SIC) at different lag specifications. SIC results suggest VAR optimization with 2 lagged terms for both 5-year and 10-year BEI series. Our VAR(2) tests assume Monte Carlo distribution of error terms. From VAR(2) tests we derive un-accumulated impulse response functions that are shown in Figure 2.

….. insert Figure 2 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. This leads us to conclude that the (one standard deviation) shocks to inflation do not exacerbate market risk. However,

Figure 2 shows that positive shocks to VIX dampen market-based inflation expectations[3]. The transmission of shocks from VIX to BEI is reflected by the two reaction functions shown in the lower-row graphs in Figure 2. 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 one-way causal impact of a surge in market risk on expected disinflation. It can be further noted that similar inverse reactions are implied by the time patterns of VIX and BEI in Figure 1, particularly during the 2008-2010 financial crisis. At that time, the rising market risk was accompanied by the declining or even negative BEI, particularly for the 5-year BEI series.

Furthermore, the causal reaction, i.e. the inverse relationship found in our study differs from the opposite transmission of shocks in expected inflation into market risk, which has been emphasized and examined empirically in the literature by Söderlind, (2011) and Christensen/Gillan (2012), among others.

IV. The Underlying Model and Its Multiple Breakpoint Regression Estimation

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

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

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

[3] This reaction is consistent with the transmission of market risk into the trend in inflation expectations evidenced by Bomfim and Rudebusch (2000).

Based on our initial observation inferred from Figure 1, we argue that interactions between BEI and VIX are unstable and varied over time. The co-movement between these variables is mostly divergent, although they tend to move together during the 2005-2007 period. Evidently, there are heterogeneous time patterns and discernible phases in the relationship between market-implied inflation expectations and market risk. In order to account for heterogeneous interactions between BEI and VIX, we test Eq.1 with a multiple breakpoint regression. We employ the Bai-Perron multiple breakpoint (MBP) tests, separately for the 5-year and 10-year BEI series as a function of percent changes in VIX[4]. The MBP estimation representations are shown in Table 1.

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

The discernible phases identified in the 5-year and the 10-year BEI estimations are somewhat different as their days of breakpoints are rather misaligned. Nevertheless, their directional relations to VIX and the statistical significance in each of the identified phases are nearly the same.

Our optimized MBP tests identify three breakpoints and four sub-periods in the relationship between the 5-year BEI and VIX. There are two breakpoints and three sub-periods in the relationship between the 10-year BEI and VIX.

In the case of 5-year BEI, there is no association between these variables in Period I, which begins January 3, 2003 and ends on December 1, 2008. A similar lack of association between

[4] 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. The selection of the number of breaks is optimized by minimizing the Schwartz information criterion.

breakeven inflation and market risk is observed during Period I in the 10-year BEI series estimation, with the breakpoint taking place a bit earlier on August 15, 2008.

Period II in both examined relationships corresponds with the crisis-resolution policies enacted in the aftermath of the recent financial crisis. For the 5-year BEI series, Period II begins December 2, 2008 and ends July 7, 2011. The same sub-period for the 10-year BEI series begins August 18, 2008 (right before the peak of the recent financial crisis) and ends July 30, 2012. In both cases there is a strong, significant inverse relationship between market risk and market-based inflation expectations implied by similar estimated negative $\hat{\beta}_1$ coefficients. This implies that surges in market risk are coupled with expectations of disinflation, or even deflation for the 5-year BEI series. A plausible explanation for this strong inverse reaction is provided by Söderlind (2011), Fleming/Krishnan (2012), and Andreasen et al. (2018), who argue that market shocks at times of financial distress entail higher real liquidity premium, which in turn tends to reduce breakeven inflation.

There are two additional sub-periods for the 5-year BEI series. Period III (July 8, 2011 – August 24, 2016) indicates a bit weaker (a less negative $\hat{\beta}_1$), albeit statistically significant association between BEI and VIX. Apparently, fears of economic slowdown and disinflation still persist during that time. The most recent Period IV (August 25, 2016 – January 24, 2019) signifies a considerably weaker relationship (implied by a small negative $\hat{\beta}_1$) between VIX and BEI, underpinning weaker fears of economic slowdown and disinflation by market participants. There is just one phase in the case of 10-year BEI series covering the most recent period. A small negative $\hat{\beta}_1$ coefficient indicates a weakening inverse relationship between market risk and breakeven inflation in this case as well.

In sum, our tests show prevalence of an inverse relationship between BEI and VIX, particularly during the recent crisis and its aftermath. This implies a combination of higher market risk with expectations of disinflation stemming from both the anticipated economic slowdown and reduced liquidity premium in the market for TIPS (Christensen/Gillan, 2012)[5]. Arguably, elevated market risk has been accompanied by expectations of disinflation and economic weakness during the financial crisis and its aftermath. It shall be further noted that the association between higher market risk and rising inflation expectations discussed in the early literature covering this subject (Gürkaynak et al., 2010) has not been detected in our tests at any time interval since 2003, i.e. since the beginning of our sample period. Nevertheless, we refrain from dismissing a possibility that a positive relationship between BEI and VIX may re-emerge in the future, as higher inflation expectations stemming from a sustained economic recovery will likely exacerbate market risk.

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

In order to verify robustness of the multiple breakpoint regression estimation and the identification of breaks for the BEI series as a function of VIX, we employ a Three-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. The choice of three States stems from our assumptions in terms of the association between market risk and market-implied inflation expectations. We aim to prove that there is no association

[5] As shown by Andreasen et al. (2018), 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 (Fleming and Krishnan, 2012; D’Amico et al., 2018).

between these variables when inflation is subdued and market risk is low, which we define as State 1 in the Markov process. In contrast, there is a strong inverse relationship between these variables in the presence of fears of disinflation or deflation prescribed by State 2. There is also a significant positive link between high inflation expectations and elevated market risk, which corresponds with State 3 in our model. In essence, the three States in the Markov process correspond with the three reaction Zones identified in our initital assumptions. Zone 1 corresponds with State 1 in the Markov process, reflecting interactions during tranquil market periods, i.e. combining low market risk with expectations of low, sustainable inflation. Zones 2 and 3 are consistent with States 2 and 3 respectively, reflecting interactions during turbulent market conditions. Given these assumptions, a three-state Markov switching process to simulate is specified as follows:

The process in State 1 is specified as

$$\Delta\pi_{t|St=1} = c_1 + \gamma_1 \Delta VIX_t + \varepsilon_{1t} \qquad \varepsilon_{1t} \rightarrow N(0,1) \qquad (2)$$

We expect the process estimated for State 1 to follow a weak, insignificant relationship between BEI and VIX during the examined sample period, considering the prior results obtained from the multiple breakpoint regression estimation.

State 2 reflects an inverse relationship between the examined variables, i.e. a combination of fears of deflation and high market risk. State 3 follows a direct relationship between BEI and VIX that is seemingly sporadic, less prevalent during our examined sample period, as implied by our tests discussed so far. State 2 is prescribed by

$$\Delta\pi_{t|St=2} = c_2 + \gamma_2 \Delta VIX_t + \varepsilon_{2t} \qquad \varepsilon_{2t} \rightarrow N(0,1) \qquad (3)$$

State 3 is represented by

$$\Delta\pi_{t|St=3} = c_3 + \gamma_3 \Delta VIX_t + \varepsilon_{3t} \qquad \varepsilon_{3t} \to N(0,1) \tag{4}$$

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

$$P = \begin{bmatrix} p_{11} p_{21} p_{31} \\ p_{12} p_{22} p_{32} \\ p_{13} p_{23} p_{33} \end{bmatrix} \tag{5}$$

The results of the Markov switching estimation for the 5-year and 10-year BEI as a function of changes in VIX are shown in Table 2. In both 5-year and 10-year BEI series estimations, we allow the log of σ error variances to vary across all three States.

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

The characteristics of the obtained States from the Markov switching estimations are quite similar for the 5-year and the 10-year BEI series. The estimated results shown in Table 2 confirm a robust identification of the three States representing the corresponding proposed Zones of interactions between market risk and market-implied inflation expectations. The estimated process for the 5-year BEI is fully consistent with our initial assumptions of three different directional associations between both BEI and VIX. The estimated State 1 reflects a weak, albeit statistically significant relationship between 5-year BEI and VIX, as reflected by the low value and the high statistical significance of the estimated $\hat{\gamma}_1$ coefficient. State 2 shows a strong, inverse relationship between these variables, the estimated $\hat{\gamma}_2$ is negative. State 3 reflects episodes of high market risk coupled with high inflation expectations as indicated by the positive, significant sensitivity coefficient $\hat{\gamma}_3$. In hindsight, the interactions between changes in 5-year BEI and in VIX follow a discernible pattern prescribed by the three distinctive States.

In consistency with our previous results, the weak relationship prescribed by State 1 dominates the Markov process in the 5-year BEI case, as its expected duration is 151 days and the probability of staying in it on any given day is 98 percent. State 2 occurs sporadically. It is subordinate with its expected duration of 1.8 days and the 45 percent probability of remaining in it on any given day. State 3 combining high inflation and high market risk is also subordinate. Its expected duration is 1.3 days and probability of staying in it is merely 22 percent. In sum, the prevalence of the weak relationship between changes in 5-year BEI and changes in VIX at tranquil markets that is prescribed by State 1 is consistent with our prior findings.

The estimated two-state Markov switching process for the 10-year BEI as a function of changes in VIX is similar and it confirms our prior identification of three distinctive interactive patterns. In this case, State 1, i.e. a weak relationship between low market risk and low expected inflation dominates the Markov process. However the degree of this dominance is a bit weaker than that identified in the corresponding State 1 in the 5-year BEI series. Its expected duration is 16 days and the probability of remaining in it on any given day is 94 percent. State 2 combining the fears of deflation with high market risk is subordinate, as its expected duration is 2.6 days and probability of staying in it is 62 percent. Noticeably, the results for State 2 are somewhat more pronounced for the 10-year than for the 5-year BEI series. In addition, the estimated $\hat{\gamma}_2$ coefficient in the 10-year BEI series has a lower absolute value, indicating that the fears of deflation in the longer time horizon are less prevalent. State 3 combining high market risk and high expected inflation is also significant, although its $\hat{\gamma}_3$ coefficient is a bit lower in the 5-year BEI case.

The Markov switching estimation results shown in Table 2 can be summarized as follows. First, the dominant State 1 reflecting tranquil market conditions is more prevalent for the 5-year than for the 10-year BEI, as its expected duration is longer and the probability of remaining in it is higher. Second, the estimation of the extreme Zones reflecting times of turbulent markets is more robust for the 5-year BEI series, as the absolute values of $\hat{\gamma}_2$ and $\hat{\gamma}_3$ coefficients are higher. It can be therefore argued that the interactions between market risk and market-implied inflation expectations are stronger over the shorter time horizon.

Furthermore, the obtained results from the three-state Markov process are consistent with our initial specification of three Zones in the relationship between market risk and market-implied inflation expectations. The results shown in Table 2 also suggest that long-term market-implied inflation expectations are mainly inversely associated with market risk[6]. 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 filtered regime probabilities of remaining in the given State that are shown in Figures 3 and 4. The probabilities of staying in States 1-3 for the 5-year BEI series derived from the estimated Markov process are shown in Figure 3. The probability of remaining in the dominant State 1 is usually high, it hovers around the estimated 98 percent most of the times during the prevalent tranquil market conditions. There is a strong tendency of switching to the

[6] 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.

extreme States 2 and 3 during the peak of the financial crisis in 2008 and 2009. There are also sporadic switching episodes in: 2012, 2014 and weaker ones in 2016 and 2018. They roughly coincide with announcements of monetary policy easing or more gradual tightening (in 2018). The significant derailment of this process at the peak of the recent crisis may be attributed to episodes of pronounced tail risks of key financial market variables (Orlowski, 2012).

….. insert Figures 3 and 4 around here …..

The probability of staying in States 1-3 for the 10-year BEI series is shown in Figure 4. In this case, the Markov process is considerably less stable. The probability of remaining in State 1 on any given day oscillates around 94 percent, but the switching episodes are ubiquitous. The instability of this process is particularly pronounced during the 2008-2009 crisis and its aftermath in 2010-2012. There are other, less pronounced switching episodes that 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.

In sum, the Markov switching process holds better for the relationship between 5-year BEI and VIX. It suggests that market risk is rather unrelated to market-implied inflation expectations at tranquil market periods. Their interactions become stronger at turbulent times. Market risk is inversely related to market-implied inflation expectations during the peak of the 2008 financial crisis and its immediate aftermath due to fears of disinflation or even deflation that increase the probability of incumbent economic recession.

VI. Conclusions

Our study identifies three discernible zones in interactions between market risk and market-implied inflation expectations. Market risk is proxied by VIX and inflation expectations are reflected by the 5-year and the 10-year breakeven inflation. The neutral Zone 1 combining a low market risk a low, stable inflation is prevalent during the examined January 3, 2003 – January 24, 2019 sample period. The two remaining zones in these interactions take place at times of market turbulence. Zone 2 combines fears of deflation and high market risk. Such interactions between changes in VIX and in BEI are evident during the peak of the 2008 financial crisis and its immediate aftermath. This inverse relationship is more prevalent and persistent for the 5-year than the 10-year BEI. Our finding of a distinct inverse relationship differs from their usual positive interactions that have been previously discussed in the literature.

Our empirical tests allow us to determine that interactions between market risk and market implied inflation expectations take place only in 'tails'. Specifically, moderate inflation that is confined within the range targeted by monetary authorities does not exacerbate market risk, thus a relationship between these variables becomes insignificant. Under moderate inflation, there is a weaker relationship in either a positive or inverse direction, as the 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 pronounced and positive. Fears of deflation exacerbate market risk even more, the examined relationship becomes inverse. By supplementing our exercise with VAR tests, we have identified a negative transmission of market risk to both 5-year and 10-year breakeven inflation that lasts up to three days.

In hindsight, a crucial finding of our exercise is that reactions between VIX and BEI are significant only in extreme conditions, i.e. when inflation expectations are either distinctively positive or negative, both triggering elevated market risk. This argument stems directly from our estimations of the three-state Markov switching process.

The three different patterns in interactions between the market and the inflation risks are useful for formulating market sentiments and inflation forecasts. They can provide expedient signals for monetary policymakers. We believe that monetary authorities 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 perceptions of strong disinflation or, in the case of 5-year BEI, deflation. The tests that we have performed, i.e. the asymptotic VAR, multiple breakpoint and Markov switching, all indicate recurrent episodes of 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 stronger for the 5-year than for the 10-year breakeven inflation, underscoring a pronounced impact of economic fundamentals on 5-year breakeven inflation. We further believe that the recent Federal Reserve's path toward gradual tightening of monetary policy will likely restore a more synchronous co-movement between breakeven inflation and VIX.

In brief, our analysis suggests that the directional changes and the intensity of the impact of market risk on market based inflation expectations are asynchronous. Their relationship becomes particularly pronounced at turbulent market periods. Their interactions seem to 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 stability. It is important to note the asymmetric reaction found is sample sensitive, as it strongly influenced by the financial crisis where the expectations of deflation are prevalent. We recognize this asymmetry may change in the future if inflation expectations return. 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 surges in market risk, 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 changes in log of VIX: Bai-Perron multiple breakpoint estimation of Eq.1.

Periods based on breakpoints	Changes in 5Y BEI as a function of changes in log of VIX		Periods 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 $\hat{\beta}_1$
Period I: 01/03/2003 – 12/01/2008 1542 obs.	-0.001 (-0.62) -0.032 (-1.19)	None, statistically insignificant	Period I: 01/03/2003 – 08/15/2008 1466 obs.	0.001 (0.54) -0.018 (-1.54)	None, statistically insignificant
Period II: 12/02/2008 – 07/07/2011 678 obs.	0.003 (1.45) **-0.256***** (-7.83)	Strong negative significant	Period II: 08/18/2008 – 07/30/2012 1031 obs.	-0.001 (-0.01) **-0.243***** (-11.72)	Strong negative significant
Period III: 07/08/2011 – 08/24/2016 1339 obs.	-0.001 (-0.61) **-0.137***** (-10.33)	Strong negative significant	Period III: 07/31/2012 – 01/24/2019 1693 obs.	-0.001 (-0.43) **-0.082***** (-11.75)	Negative significant
Period IV: 08/25/2016 – 01/24/2019 631 obs.	0.001 (0.40) -0.031** (-2.10)	Negative Significant			
Diagnostic tests:	F-statistics = 18.704 Log likelihood = 6527.5 Schwartz Info. Criterion = -3.100 Durbin Watson stats. = 1.846		Diagnostic tests:	F-statistics = 77.065 Log likelihood = 8524.2 Schwartz Info. Criterion = -4.057 Durbin Watson stats. = 1.809	

Notes: January 2, 2003 – January 24, 2019 sample period (4191 observations); 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.

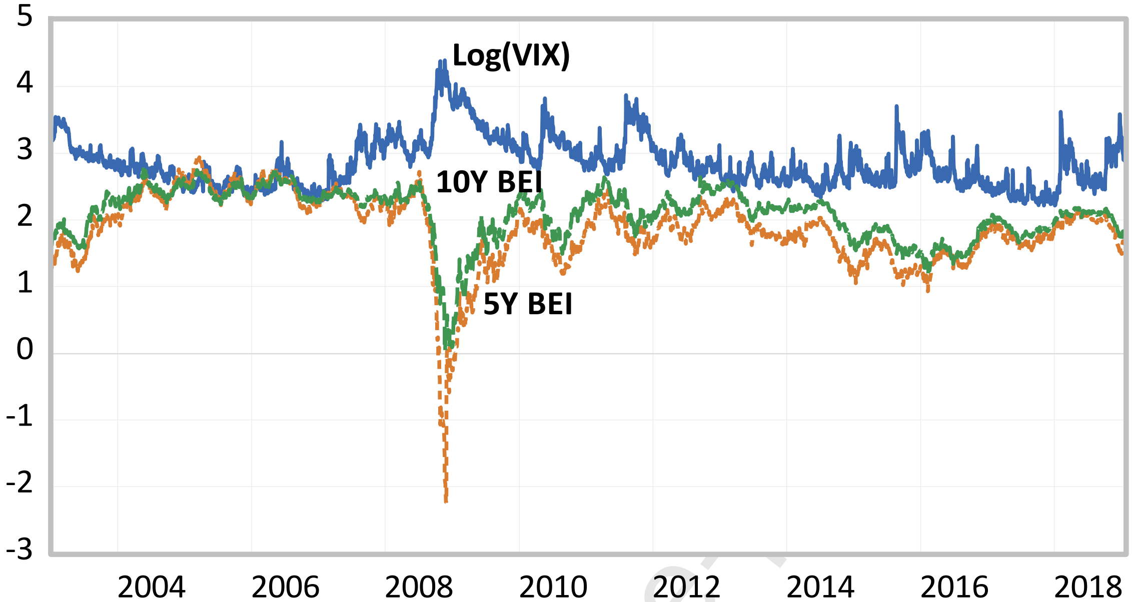
Table 2: Estimations of Three-State Markov Switching for changes in 5-year and 10-year breakeven inflation in relation to changes in VIX (Equations 2, 3 and 4).

	Changes in 5Y BEI as a function of changes in VIX	Changes in 10Y BEI as a function of changes in VIX
State I (low VIX, low, stable BEI)	$\hat{c}_1$ = -0.001 (-0.75) $\hat{\gamma}_1$ = **- 0.004*** (-11.64)**	$\hat{c}_1$ = 0.001 (0.09) $\hat{\gamma}_1$ = **- 0.003*** (-7.86)**
State II (high VIX, declining BEI)	$\hat{c}_2$ = 0.015*** (2.51) $\hat{\gamma}_2$ **= - 0.044*** (-25.98)**	$\hat{c}_2$ = 0.003 (1.35) $\hat{\gamma}_2$ **= -0.021*** (26.70)**
State III (high VIX, rising BEI)	$\hat{c}_3$ = 0.025*** (3.14) $\hat{\gamma}_3$ = **0.138*** (55.01)**	$\hat{c}_3$ = - 0.007 (-1.12) $\hat{\gamma}_3$ = **0.056*** (16.33)**
Common term:	log σ = -3.322 *** (-274.2)	log σ = -3.594 *** (-286.2)
Diagnostic tests:	Log likelihood = 7695.6 Schwartz Info. Criterion = -3.647 Durbin Watson stats. = 1.793	Log likelihood = 8750.1 Schwartz Info. Criterion = -4.151 Durbin Watson stats. = 1.789
Constant transition probabilities, Probability of staying in: State I State II State III	 0.98 0.45 0.22	 0.94 0.62 0.17
Constant expected durations: State I State II State III	 42.1days 1.8 days 1.3 days	 16.1 days 2.6 days 1.2 days

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

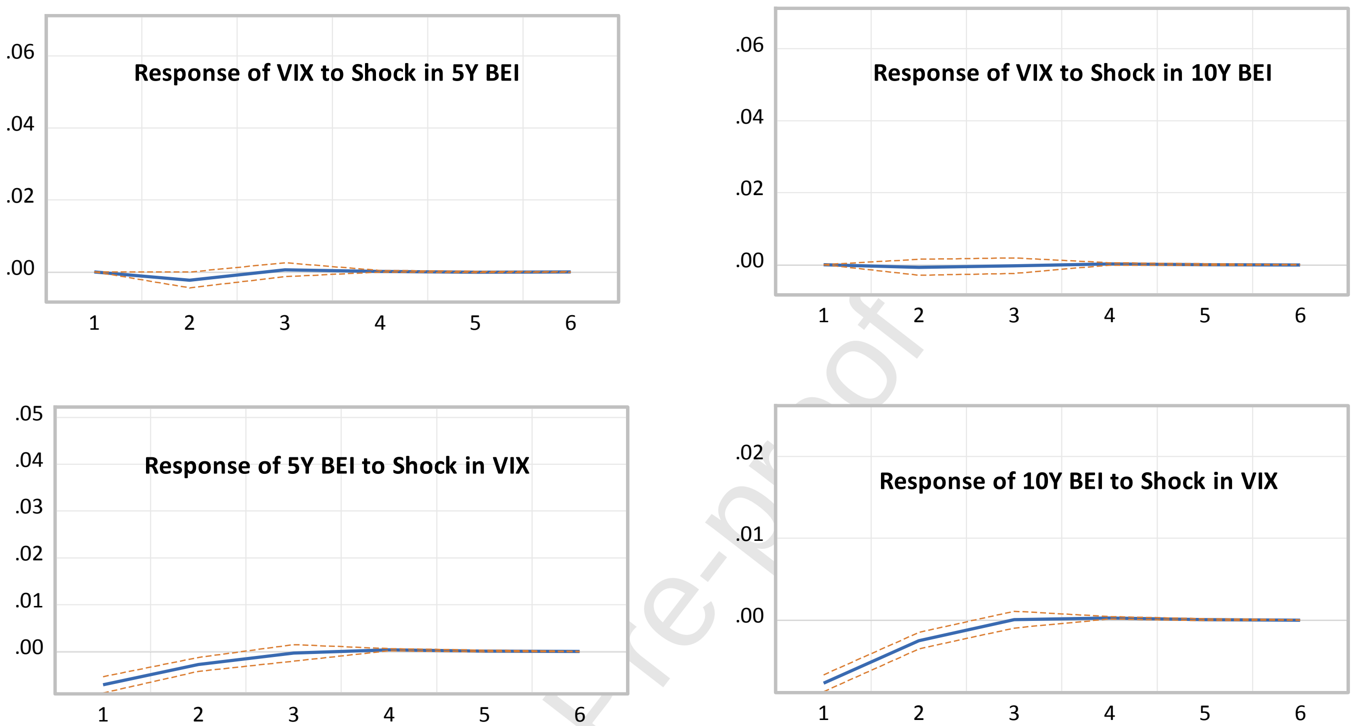
Source: as in Table 1.

Figure 1: Ten-Year, Five-Year Breakeven Inflation Rates and Log of VIX.



Source: Authors' own compilation based on the Federal Reserve Bank of St. Louis FRED daily data for the January 3, 2003 – January 24, 2019 sample period.

Figure 2: Un-accumulated impulse responses between changes in log of VIX, and changes in 5-year and 10-year breakeven inflation. Responses to Cholesky one-standard deviation shocks.

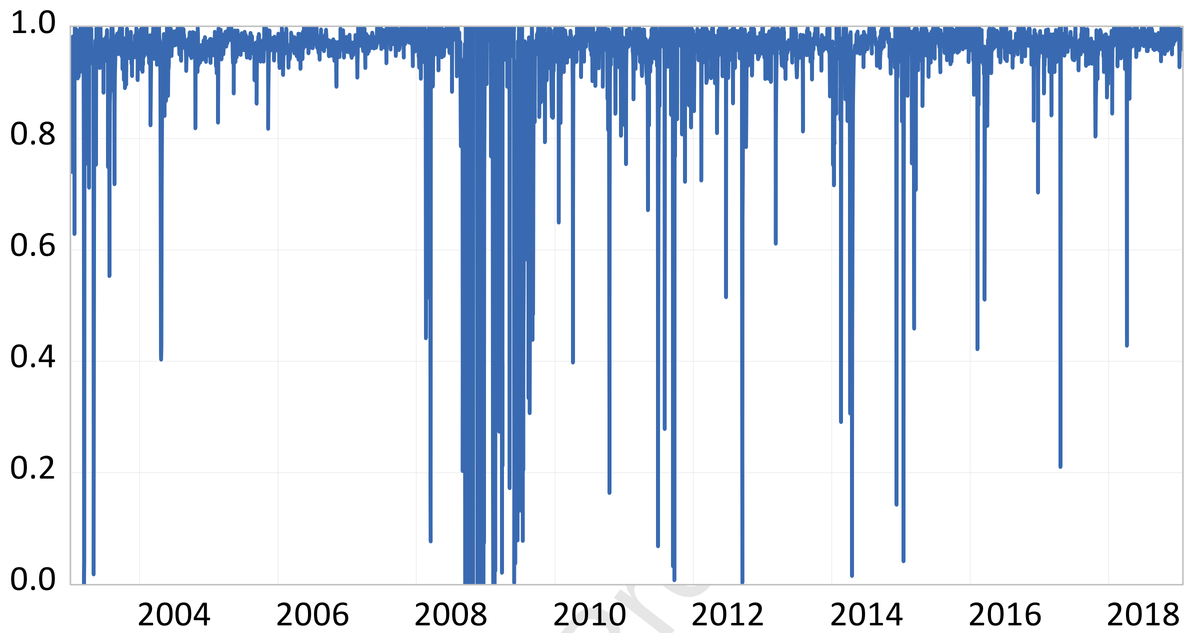


Notes: Impulse response functions derived from asymptotic VAR(2) based on daily data for the sample period January 3, 2003 – January 24, 2019.

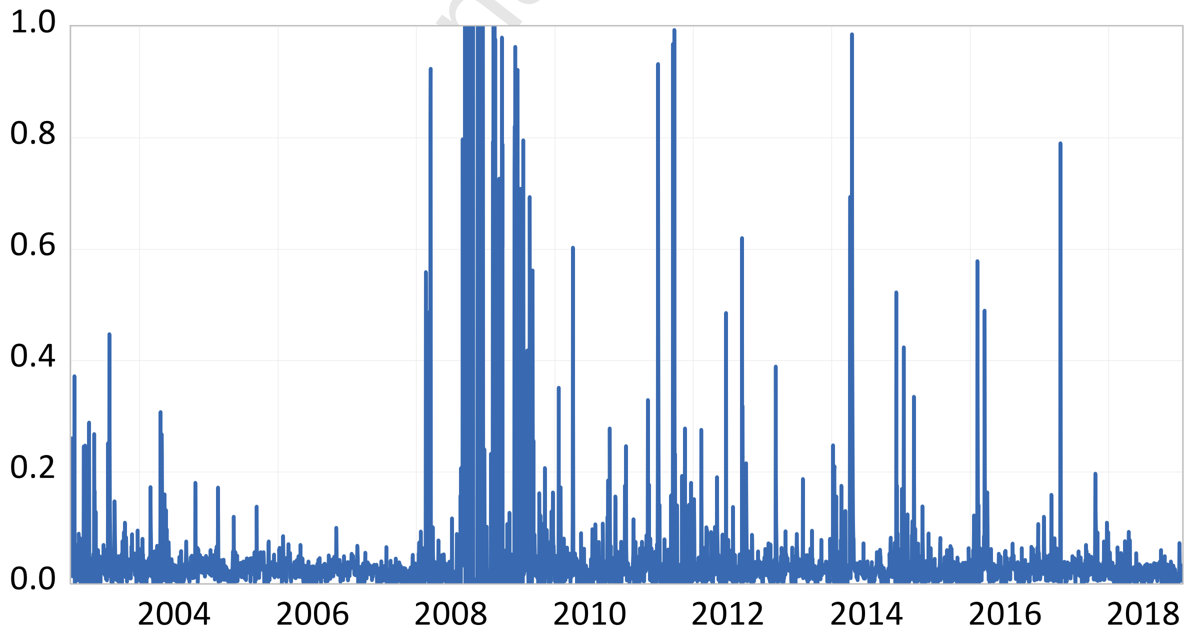
Source: as in Figure 1.

Figure 3: Probability of remaining in the given State on any given day for the 5-year BEI series, Markov switching filtered regime probability.

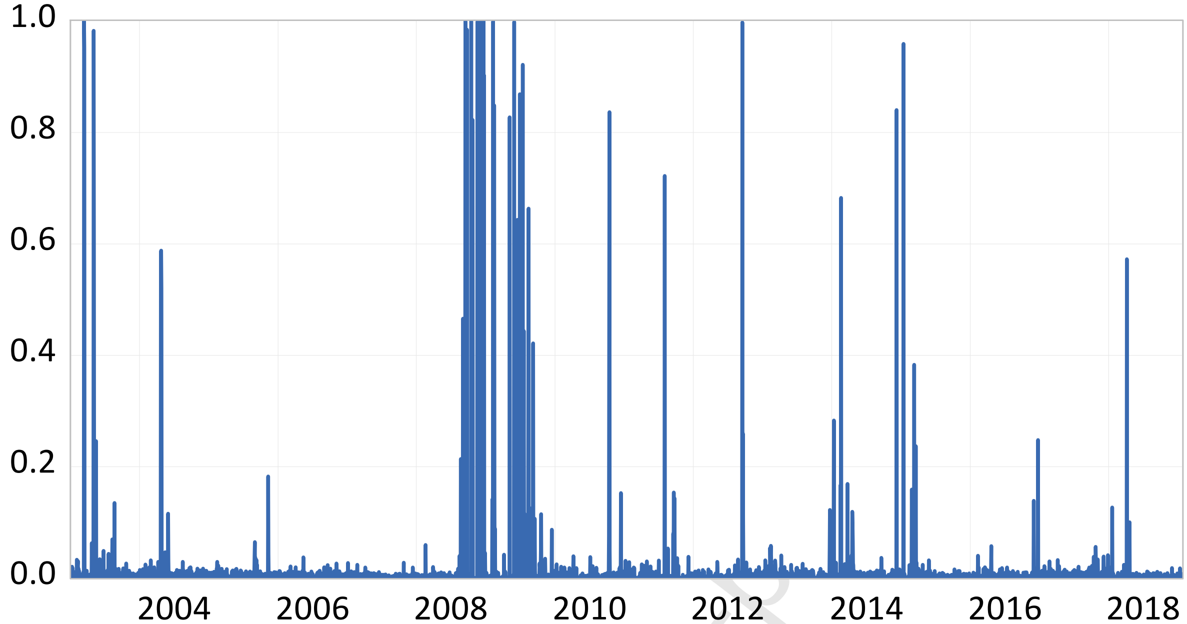
State 1:



State 2:



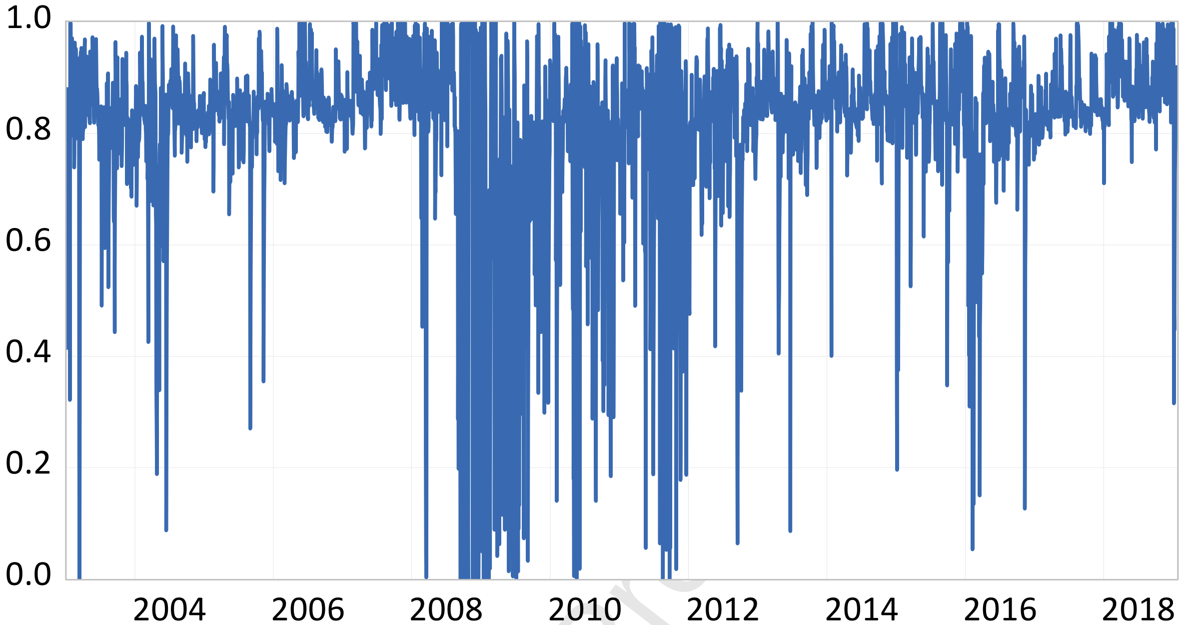
State 3:



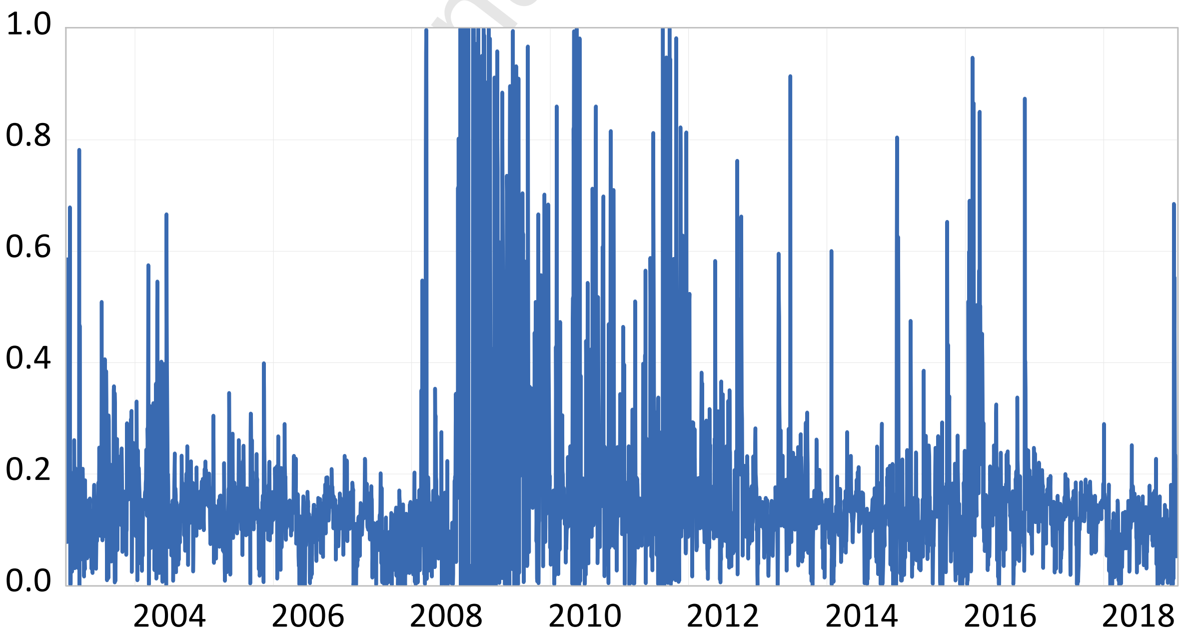
Source: as in Table 1.

Figure 4: Probability of remaining in the given State on any given day for the 10-year BEI series, Markov switching filtered regime probability.

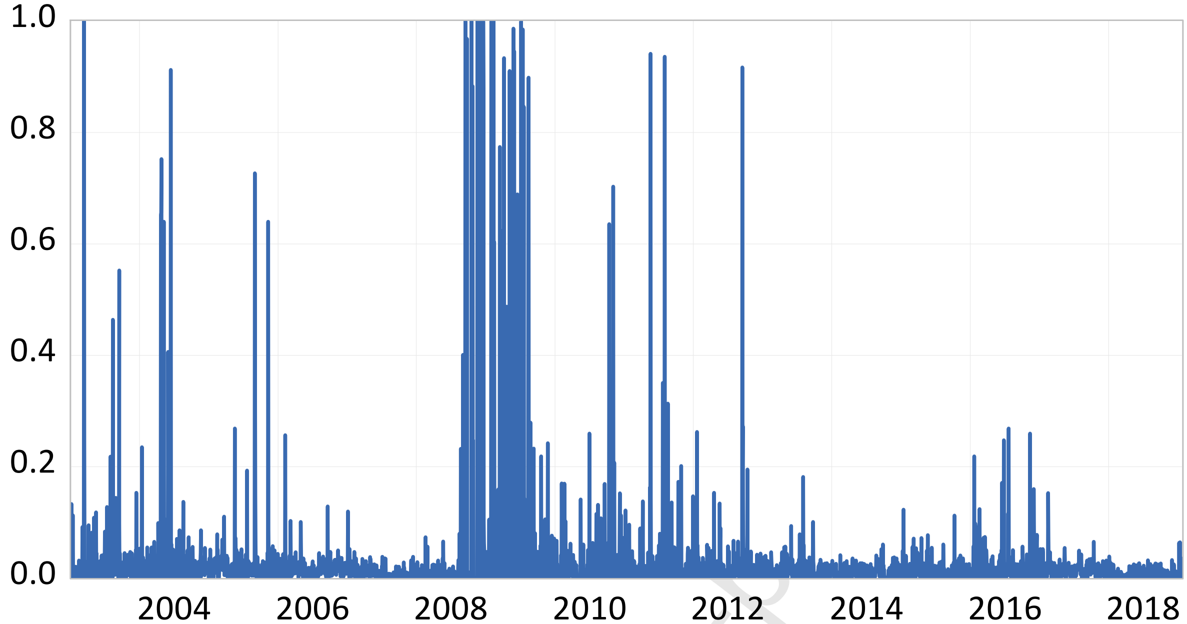
State 1:



State 2:



State 3:



Source: as in Table 1.