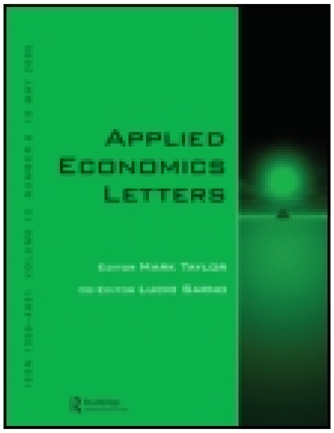


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# Predicting regime switches in the VIX index with macroeconomic variables

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# Predicting regime switches in the VIX index with macroeconomic variables

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In this article, we investigate the role of US macroeconomic variables as leading indicators of regime shifts in the VIX index using a regime-switching approach. We find that there are three distinct regimes in the VIX index during the 1990 to 2010 period: tranquil regime with low volatility, turmoil regime with high volatility and crisis regime with extremely high volatility. We also show that the regime shift from the tranquil to the turmoil regime is significantly predicted by lower term spreads.

## I. Introduction

In this article, we investigate the role of macroeconomic variables in predicting the regime shifts in the VIX index. The VIX index is a 30-day model-free, implied volatility based on the S&P 500 options and often referred to as 'the fear index'. The high VIX index has not only triggered massive selling spree in stock markets, but also induced a wider range of speculative trading and its unwinding in the form of carry trade positions and emerging market CDS spread portfolio, among others (Brunnermeier *et al.*, 2009; Pan and Singleton, 2008).

A considerable number of studies have attempted to improve the predictability of financial market crises with macroeconomic and other variables. For instance, Bussiere and Fratzscher (2006) find that overvaluation of exchange rate and lending boom significantly predict currency crises using a multinomial logit model. Chen (2009) also shows that inflation rates and term spreads have a significant role in predicting stock market recession using a regime-switching model, where stock market recession is defined as the regime with low return and high volatility of the S&P 500 price index.

To the best of our knowledge, however, no research has been done thus far to attempt to predict the stock market turbulences that showed up as regime switches in the VIX index.[1] Guo and Wohar (2006) regress the VIX index on a constant term and find its structural breaks using the method proposed by Bai and Perron (1998).[2] Their method has difficulty associating the regime transition with observable variables, however. To overcome this shortcoming and to investigate which macroeconomic variables trigger regime shifts in the VIX index, we utilize the Markov regime-switching approach.[3] Our conjecture is that the crisis regime can be characterized as the regime with the highest level and SD of the VIX index.

Our empirical result shows that there are three distinct regimes in the VIX index during the 1990 to 2010 period: tranquil regime with low volatility, turmoil regime with high volatility and crisis regime with extremely high volatility. We also find that the regime-switching probability from the tranquil regime to the turmoil regime is significantly influenced by term spreads.

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[1] One closely related study is of Chen and Clements (2007), who investigate the impact of monetary policy announcement on the VIX index, although they do not investigate regime switches.

[2] The structural breaks are detected by minimizing the sum of squared errors of each partitioned period.

[3] Bussiere and Fratzscher (2006) suggest the usefulness of a regime-switching approach in the early warning system model because it can determine the timing and the length of different regimes endogenously.

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The rest of the article is organized as follows: Section II describes the regime-switching approach used in this article. Section III gives the data details. Section IV reports the estimation results. Section V concludes the article.

## II. Regime-Switching Approach

We assume that the VIX index follows AR (1) process with the Markov regime-switching parameters

$$V_t = a_{S_t} V_{t-1} + b_{S_t} + \varepsilon_t, \quad \varepsilon_t \sim \text{i.i.d.} \quad N(0, \sigma_{S_t}) \quad (1)$$

where $S_t$ is the latent state variable and $a_{S_t}, b_{S_t}$ and $\sigma_{S_t}$ are the state-dependent parameters. Suppose that there are three distinct states. The state variable $S_t$ takes the value of 0, 1 or 2. We name regime 0, 1 and 2 as tranquil regime, turmoil regime and crisis regime, respectively. The regime switch from one state to another depends on the probabilities of

$$P_{ij} = \Pr(S_t = i | S_{t-1} = j) \quad (2)$$

To make the computation efficient, we assume direct switches from the tranquil (crisis) regime to the crisis (tranquil) regime.[4] Then, the transition probability matrix can be written as

$$\begin{aligned} P &= \begin{bmatrix} P_{22} & P_{21} & P_{20} \\ P_{12} & P_{11} & P_{10} \\ P_{02} & P_{01} & P_{00} \end{bmatrix} \\ &= \begin{bmatrix} 1 - P_{12} & P_{21} & 0 \\ P_{12} & 1 - P_{21} - P_{01} & P_{10} \\ 0 & P_{01} & 1 - P_{01} \end{bmatrix} \end{aligned} \quad (3)$$

Following Dai *et al.* (2007) and Bussiere and Fratzscher (2006), we specify the functional form of transition probabilities, $P_{10}$, $P_{12}$, $P_{01}$ and $P_{21}$, as a logit function,

where we use 1-month lagged series of macroeconomic variables $macro_{t-1}$ as a possible predictor of regime switches. The estimation is done following Hamilton's (2008) algorithm.

To gauge statistical importance of each macroeconomic variable in the regime shifts in the VIX index, we rely on the following two criteria. The first one is $t$-tests on the coefficients $c_{ij}$ of macroeconomic variables in the transition probability matrix (3). The second one is the likelihood ratio test between the model with a macroeconomic variable and the model without it in terms of an increase in predictive power of each macroeconomic variable. Here, to facilitate economic interpretation, we impose the restriction that $c_{21}$ has the opposite sign of $c_{01}$.

## III. Data

We use the monthly VIX index measured as of the beginning of each month. Figure 1 displays the monthly VIX index from January 1990 through June 2010. Evidently, the VIX index is very volatile and sensitive to global financial market disturbances such as the Asian currency crisis in 1997, the Long-Term Capital Management (LTCM) crisis following the Russian financial crisis in 1998 and the recent subprime crisis that surfaced in 2007.

In the analysis that follows, we use the following seven macroeconomic variables to test their influence on the switching probabilities from one regime to another: Consumer Price Index ($CPI_t$), Producer Price Index of finished goods ($PPI_t$), manufacturing Capacity Utilization ($CU_t$), Industrial Production ($IP_t$), the Federal Funds rate ($FF_t$), the difference between 5-year US government yield over 3-month Treasury bill rate ($TERM\ 5Y_t$) and the difference between 10-year US government yield over 3-month Treasury bill rate ($TERM\ 10Y_t$).[5]

$$\begin{aligned} P_{10} &= \frac{1}{1 + \exp(c_{10} macro_{t-1} + d_{10})}, \qquad P_{12} = \frac{1}{1 + \exp(c_{12} macro_{t-1} + d_{12})} \\ P_{21} &= \frac{\exp(c_{21} macro_{t-1} + d_{21})}{1 + \exp(c_{21} macro_{t-1} + d_{21}) + \exp(c_{01} macro_{t-1} + d_{01})} \\ P_{01} &= \frac{\exp(c_{01} macro_{t-1} + d_{01})}{1 + \exp(c_{21} macro_{t-1} + d_{21}) + \exp(c_{01} macro_{t-1} + d_{01})} \end{aligned} \quad (4)$$

[4] For a robustness check, we also estimated three-regime-switching model without this restriction. We conducted likelihood ratio test and found that the model without the restriction did not significantly outperform the model with the restriction at the 5% level.
[5] All the macroeconomic variables are obtained from Bloomberg.

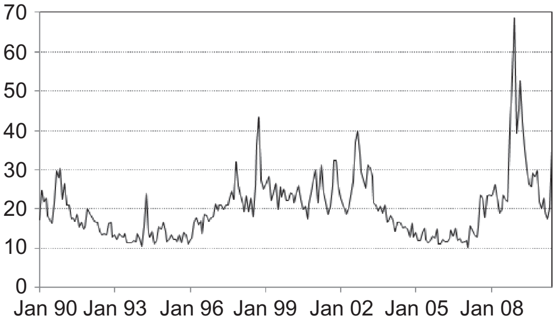


**Fig. 1. The VIX index**

$CPI_t$, $PPI_t$ and $IP_t$ are calculated as $\text{in}(X_t/X_{t-12})$, where $X_t$ is the original index level of each variable at time $t$ and $CU_t$, $FF_t$, $TERM\ 5Y_t$ and $TERM\ 10Y_t$ are measured in level. In estimation, we use standardized series with zero mean and one standard for all the variables to facilitate the comparison of parameter estimates across the macroeconomic variables.

## IV. Estimation Results

### *Selecting the number of regimes*

As a preliminary step, we first compare the fitting performance between the single-, two-, three- and four-regime Markov-switching model with no macroeconomic variables. We calculate Markov-Switching Criterion (MSC) to select the appropriate number of regimes. MSC is an information criterion, proposed by Smith *et al.* (2006), which enables us to measure the distance between true and candidate models in Markov-switching regression models. As shown in Table 1, three-regime Markov-switching model gives minimum MSC.

Table 1 also reports that the stationary levels of the VIX index under the tranquil and turmoil regimes are estimated to be about 14.1 $(=4.18/(1.00-0.70))$ and 22.9 $(=12.08/(1.00-0.47))$, respectively. Under the crisis regime, however, no stationary level can be computed because $a_{s_t=2}$ exceeds 1. Furthermore, estimated SDs of the VIX index under the tranquil, turmoil and crisis regime are found to be about 1.73, 3.21 and 4.89, respectively. The estimation result of the probability transition matrix implies that the tranquil and turmoil regimes persist for 29.0 $(=1/(1-(1-0.034)))$ and 9.1 $(=1/(1-(1-0.075\text{–}0.035)))$ months on average, respectively. By sharp contrast, crisis regime persists for only 2.0 $(=0.50/(1-0.50))$ months. Figure 2 shows the filtered probability of the three regimes. We can observe that the smoothed probability of staying in the crisis regime is close to one just after the bankruptcy of Lehman Brothers in September 2008. Our regime shifts are similar to the structural breaks found in Guo and Wohar (2006).

**Table 1. Selecting the number of regimes**

| Number of regimes | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $b(0)$ | 3.06** | 3.38** | 4.18** | 4.23** |
| $b(1)$ | | 9.41** | 12.08** | 12.03** |
| $b(2)$ | | | 6.82** | 0.00 |
| $b(3)$ | | | | 19.47** |
| $a(0)$ | 0.85** | 0.78** | 0.70** | 0.70** |
| $a(1)$ | | 0.71** | 0.47** | 0.47** |
| $a(2)$ | | | 1.06** | 1.18** |
| $a(3)$ | | | | 0.86** |
| $\sigma(0)$ | 4.30** | 1.98** | 1.73** | 1.72** |
| $\sigma(1)$ | | 6.86** | 3.21** | 3.20** |
| $\sigma(2)$ | | | 4.89** | 3.78** |
| $\sigma(3)$ | | | | 1.12* |
| $P(10)$ | | 0.08** | 0.04** | 0.03** |
| $P(01)$ | | 0.23** | 0.03** | 0.04** |
| $P(21)$ | | | 0.50 | 0.11** |
| $P(12)$ | | | 0.07** | 0.42 |
| $P(32)$ | | | | 0.92** |
| $P(23)$ | | | | 0.50 |
| Log likelihood | −705.1 | −637.91 | −614.55 | −612.25 |
| MSC | 1662.30 | 1547.47 | 1533.25 | 1571.94 |

*Notes*: $P(xy)$ refers to the transition probability from regime $x$ to $y$. We estimate coefficient $d$ in the functional form (4) and report statistical significance of $t$-test for $d$. To facilitate interpretation, we show the transition probability $P(xy)$ computed from $d$ in the table. * and **Indicate significance at 5% and 1% levels, respectively.

### *Testing the role of macroeconomic variables as a predictor*

Table 2 shows the estimation result of the three-regime model with each macroeconomic variable. The two term spreads, $TERM\ 5Y_t$ and $TERM\ 10Y_t$, are found to have statistically significant positive coefficients in the transition probability from tranquil to turmoil regime. This indicates that lower term spreads lead to a higher transition probability from tranquil to turmoil regime. The likelihood ratio test also supports the models with each term spread, in that they have a significantly higher explanatory power compared with the baseline model without a macroeconomic variable.

Table 2 also reports that $FF_t$ has a statistically significant coefficient in the transition probabilities. However, the likelihood ratio test shows that the model with $FF_t$ has no significantly higher explanatory power compared with the baseline model.

## V. Concluding Remarks

In this article, we have investigated whether macroeconomic variables can predict the regime switches in the VIX index. Main empirical findings are as follows: First, we find three distinct regimes in the VIX index

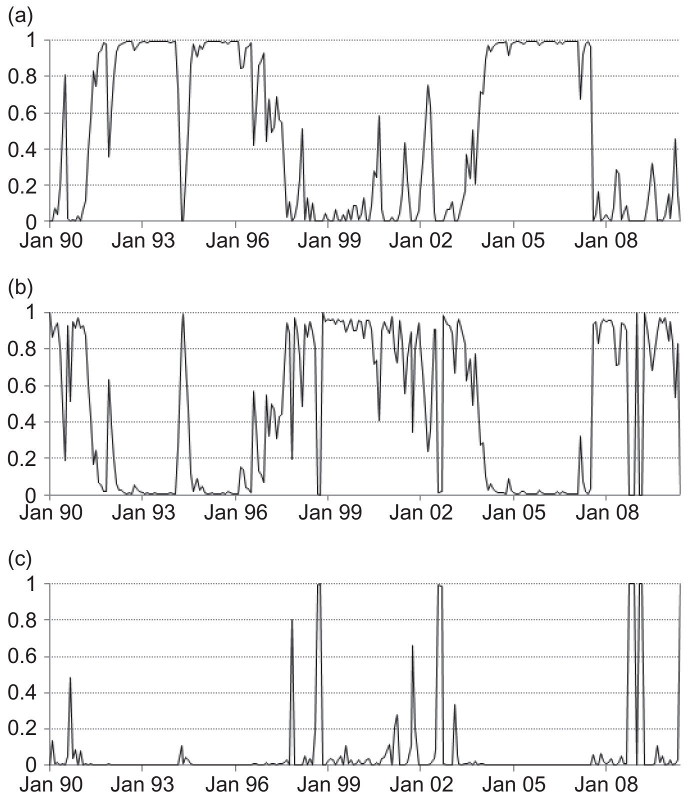


**Fig. 2. Filtered probabilities of three regimes: (a) Tranquil; (b) Turmoil; (c) Crisis**
*Note*: The filtered transition probabilities are computed based on the estimation results of three-regime model in Table 1.

**Table 2. Three-regime-switching model with a macroeconomic variable**

| | $CPI_t$ | $PPI_t$ | $CU_t$ | $IP_t$ | $FF_t$ | $TERM\ 5Y_t$ | $TERM\ 10Y_t$ |
|---|---|---|---|---|---|---|---|
| $b(0)$ | 3.60** | 3.43** | 3.68** | 3.75** | 4.26** | 3.99** | 4.33** |
| $b(1)$ | 12.58** | 12.73** | 12.56** | 12.49** | 12.18** | 12.29** | 12.02** |
| $b(2)$ | 8.66** | 8.75** | 6.18** | 6.54** | 6.81** | 7.10** | 6.60** |
| $a(0)$ | 0.75** | 0.76** | 0.74** | 0.74** | 0.70** | 0.71** | 0.69** |
| $a(1)$ | 0.46** | 0.46** | 0.46** | 0.46** | 0.47** | 0.47** | 0.48** |
| $a(2)$ | 1.02** | 1.02** | 1.07** | 1.06** | 1.06** | 1.05** | 1.06** |
| $\sigma(0)$ | 1.76** | 1.74** | 1.73** | 1.71** | 1.65** | 1.62** | 1.72** |
| $\sigma(1)$ | 3.36** | 3.42** | 3.28** | 3.26** | 3.20** | 3.22** | 3.18** |
| $\sigma(2)$ | 4.80** | 4.80** | 4.94** | 4.92** | 4.87** | 4.88** | 4.91** |
| $d(10)$ | 3.51** | 3.56** | 2.99** | 2.98** | 2.90** | 2.51** | 3.14** |
| $d(01)$ | −2.92** | −2.76** | −2.80** | −2.87** | −2.78** | −2.20** | −3.07** |
| $d(21)$ | −2.62** | −2.59** | −2.23** | −2.31** | −2.41** | −2.38** | −2.46** |
| $d(12)$ | 0.38 | 0.50 | −0.35 | −0.20 | −0.03 | −0.06 | −0.04 |
| $c(10)$ | 2.05 | 1.61 | 0.85 | 0.79 | −0.97* | 1.54* | 1.03* |
| $c(01)$ | 0.01 | −0.59 | −0.66 | −0.65 | 0.52 | −0.10 | 0.80 |
| $c(21)$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $c(12)$ | 0.43 | 0.68 | −0.30 | −0.13 | −0.38 | −0.05 | 0.01 |
| Log likelihood | −612.96 | −611.76 | −614.28 | −613.51 | −613.24 | −611.88 | −612.03 |
| LR test | 3.18 | 5.58** | 0.54 | 2.08 | 2.62 | 5.34** | 5.04** |

*Notes*: The LR test is the chi-squared statistics based on the likelihood ratio test of each model against the baseline three-regime model (no macroeconomic variable) reported in Table 1. * and **Indicate significance at 5% and 1% levels, respectively.

during the 1990 to 2010 period: tranquil regime with low volatility, turmoil regime with high volatility and crisis regime with extremely high volatility.

Second, the regime-switching probability from the tranquil regime to the turmoil regime is significantly influenced by lower term spreads.

## Acknowledgements

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