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# Smooth Transition Patterns in the Realized Stock-Bond Correlation*

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# Smooth Transition Patterns in the Realized Stock-Bond Correlation

**Abstract:** We analyze the realized stock-bond correlation. Gradual transitions between negative and positive stock-bond correlation is accommodated by the smooth transition regression (STR) model. The changes in regime are defined by economic and financial transition variables. Both in sample and out-of-sample results document that STR models with multiple transition variables outperform STR models with a single transition variable. The most important transition variables are the short rate, the yield spread, and the VIX volatility index.

**Keywords:** realized correlation; smooth transition regressions; stock-bond correlation; VIX index

**JEL Classifications:** C22; G11; G12; G17

# 1 Introduction

Understanding the nature of the stock-bond correlation has crucial implications for asset allocation and risk management as bonds and stocks are the two main asset classes. Therefore, it is of interest to analyze the economic forces driving the time varying stock-bond correlation.

This paper investigates the nature of the realized stock-bond correlation using high frequency returns. So far, little attention has been given to high frequency data in the stock-bond correlation literature. We put forward a smooth transition regression (STR) for the correlation with two extreme regimes corresponding to large negative and large positive correlations. This specification is attractive as it allows for a continuum of states between the two extreme correlation regimes. The transitions between regimes are ascribed to economic variables. The STR model is new to the stock-bond correlation literature and it provides a promising methodology.

Most studies on high frequency data focus on realized volatility with only few recent papers analyzing the realized correlations. High frequency data are appealing in that they contain as much information as possible and therefore provide accurate correlation measures. Aslanidis and Christiansen (2010) document large differences between stock-bond correlations based on high and low frequency data. The recent studies by Audrino and Corsi (2010) and Christiansen and Ranaldo (2007) use high frequency data in the analysis of the stock-bond correlation. The first paper adopts a heterogeneous autoregressive model and shows that its out-of-sample forecasts are more accurate than those of standard autoregressive models. On the other hand, Christiansen and Ranaldo (2007) look at how the stock-bond correlation changes when (surprises to) scheduled macroeconomic news are announced. Aslanidis and Christiansen (2010) show that the quantiles of the stock-bond correlation is explained by economic variables such as the short rate, the yield spread, and the VIX volatility index.

The literature exploring the economic determinants of the stock-bond correlation are mainly based upon low frequency data. Li (2002) shows that the unexpected inflation is the most important determinant of the stock-bond correlation and addresses the welfare effects of correlation changes for investors. Ilmanen (2003) argues that stock-bond correlations depend upon the business cycle of the macro economy as well as upon the inflation rate. Pastor and Stambaugh (2003) find that changes in stock-bond correlations are related to different levels of liquidity. By advocating the use of regime switching models, Guidolin and Timmermann (2006) argue for the role of the macro economy in determining correlation regimes. In a similar spirit, Bansal, Connolly and Stivers (2010) use a Hamilton (1988) regime switching model and find regime shifts in the stock-bond correlation. They argue that the state of the regime switching model may be linked to the VIX volatility index. Baur and Lucey (2009) use the DCC model of Engle (2002) and document significant time variation in stock-bond correlations. Yang, Zhou and Wang (2009) investigate the correlations over the last 150 years and document significant differences across the business cycle. On the other hand, Connolly, Stivers and Sun (2007) and Connolly, Stivers and Sun (2005) reveal the importance of stock market volatility as a major determinant for correlations. Finally, Baele, Bekaert and Inghelbrecht (2010) investigate various possible economic sources of the stock-bond correlation. Macroeconomic factors play only a minor role and, therefore, they conclude that the debate remains open on how the time variation in the stock-bond correlation is driven by changing macroeconomic conditions.

The present paper contributes to the existing literature as follows. We analyze stock-bond correlation based on high frequency data. We show that there are large gains from using STR models with multiple transition variables compared to using STR models with a single transition variable. The two extreme regimes in the STR models are large negative and large positive correlations. The most important transition variables are the short rate, the yield spread, and the VIX volatility index. The larger the short rate and the yield spread are, the more likely it is that the stock-bond correlation is positive. In contrast, the larger the VIX volatility index is, the more likely it is that the stock-bond correlation is negative. The findings are consistent with positive stock-bond correlation when the economy is in good shape and negative stock-bond correlation when high uncertainty causes flight to safety investor behavior. The results apply both in sample and out-of-sample and they are robust to different forecast horizons.

The remaining part of the paper is structured as follows. Section 2 introduces the econometric framework and Section 3 contains the data description. Sections 4 and 5 provide the empirical results based upon in sample and out-of-sample estimations. Section 6 concludes.

# 2 The Smooth Transition Regression Model

One of the most prominent regime switching models is the smooth transition regression (STR) class of models promoted by Teräsvirta and Anderson (1992), Granger and Teräsvirta (1993), and Teräsvirta (1994). Modelling the realized stock-bond correlation within the STR context has three advantages. First, the regime switching mechanism is controlled by observable transition variables, second, the transitions between regimes is smooth which allows for a continuum of states between the two extreme regimes, and three, there can be several transitions between regimes.

The STR model is given by

$$FRC_t = \alpha_1 + \alpha_2 F\left(s_{t-1}\right) + \varepsilon_t \tag{1}$$

where $FRC_t$ is the realized correlation.[1] $\alpha_1$ is the constant correlation in regime 1 and $(\alpha_1 + \alpha_2)$ is the constant correlation in regime 2. Thus, the realized correlation follows the simplest possible structure. The function $F\left(s_{t-1}\right)$ is the transition function, which is assumed to be continuous and bounded by 0 and 1. Then, values of $F(s_{t-1})$ between 0 and 1 define situations where the relationship is a mixture of the two regimes.

Due to the simplicity of the STR model at the regimes, it is feasible to allow for $K$ transition variables instead of the customary 1. The $K$ variables in the $K \times 1$ vector $s'_{t-1} = \begin{pmatrix} s_{1,t-1} & s_{2,t-1} & \cdots & s_{K,t-1} \end{pmatrix}$ act as the transition variables. With the exception of Christiansen, Ranaldo and Söderlind (forthcoming), using multiple transition variables is new in the finance literature. The transition function $F\left(s_{t-1}\right)$ is the logistic function

$$F\left(s_{t-1}\right) = \frac{1}{1 + \exp\left(-\gamma'\left(s_t - c\right)\right)} \tag{2}$$

where the parameter $c$ is the threshold value of the $FRC_t$ that defines the two regimes, i.e. $c$ indicates the location of the transition function. The $K \times 1$ multiple transition variable vector minus the threshold is defines as $\left(s_{t-1} - c\right)' = \begin{pmatrix} (s_{1,t-1} - c) & (s_{2,t-1} - c) & \cdots & (s_{K,t-1} - c) \end{pmatrix}$, while the vector $\gamma' = \begin{pmatrix} \gamma_1 & \gamma_2 & \cdots & \gamma_K \end{pmatrix}$ holds the slope coefficients of the transition variables. The latter determines the smoothness of the change in the value of the logistic function and thus the speed of transition between the extreme regimes.

Estimation of the STR model in equations (1)-(2) is carried out by nonlinear least squares (NLS), which is equivalent to the maximum likelihood estimation in the case of normal errors. We use Newey and West (1987) standard errors that allow for heteroskedasticity and autocorrelation.[2]

[1] $FRC_t$ is the Fisher transformation of the realized correlation. The exact definition is provided below.

[2] All results are obtained using EViews.

## 3 Data Description

The data are recorded at a weekly frequency on Fridays. The sample covers the period January 1986 to May 2009, a total of 1,222 observations.

We obtain trade data from TickData on the futures contracts on the S&P 500 and the 10-year Treasury note. They have the symbols $SP$ and $TY$ and trade at the Chicago Mercantile Exchange (CME) and the Chicago Board of Trade (CBOT), respectively. The CME is open 9.00-15.15 (Eastern Standard Time) whereas the CBOT is open 8.00-14.00. The CME and CBOT have overlapping trading sessions from 9.00-14.00. We obtain the 5-minute returns on the $SP$ and $TY$ during 9.00-14.00 each day. Thus, we leave out the returns during periods when both exchanges are not open (including overnight and weekend returns). The realized stock-bond correlation for week $t$ is noted $RC_t$. First, we calculate the realized covariance for that week as the sum of the cross multiplied 5-minute stock and bond returns. Then, the realized correlation is the realized covariance divided by the product of the realized bond and stock volatilities. We make use of the Fisher transformation of the realized correlation which is a continuous variable not bounded between $-1$ and 1. The Fisher transform is given as:

$$FRC_t = \frac{1}{2} \ln \left( \frac{1 + RC_t}{1 - RC_t} \right). \tag{3}$$

We use of the following transition variables: $VXO_t$, $R_t$, $SPR_t$, $RSP_t$, $RTY_t$, $INF_t$, and $GDP_t$.

The $VXO_t$ is the CBOE (Chicago Board of Options Exchange) volatility index that is based upon the trading of options on the S&P100 index. The launch of the VXO determines the starting point of our sample. Before 2003 the VXO was denoted the VIX index, now the VIX index measures the volatility of options on the S&P 500 index. The VXO/VIX volatility index plays an important role in describing the relationship between bond and stock returns, cf. Connolly et al. (2005) and Aslanidis and Christiansen (2010).

The short rate series is denoted $R_t$. We use the 3-month US Treasury bill middle rate from the secondary market. The T-bill rates are available from DataStream. The yield spread $SPR_t$ is defined as the 10-year constant maturity Treasury bond yield minus the 3-month T-bill rate. Baele et al. (2010) use the short rate as explanatory variable. Both the short rate and the yield spread are important for the realized bond beta, cf. Viceira (forthcoming) and for the high and low quantiles of the stock-bond correlation, cf. Aslanidis and Christiansen (2010).

The realized stock return is denoted $RSP_t$ and it is calculated as the sum of all the 5-minute stock returns during that week. Similarly, the weekly realized bond return on week $t$ is denoted $RTY_t$.

We obtain a series of weekly inflation rates, $INF_t$, using US Core CPI available from the Bureau of Labor Statistics. The CPI data area available monthly. From these we calculate the monthly inflation rates as the log-returns. Then for each week we use the most recent monthly inflation observation. This means that the inflation variable will be constant for (most often) four weeks in a row. Li (2002) documents the relevance of inflation to the stock-bond correlation.

We obtain a series of weekly GDP growth rates, $GDP_t$. Again, these are obtained from the monthly GDP figures and are calculated in the same way as the inflation rates. The macroeconomic conditions are important for the stock-bond correlation, cf. Ilmanen (2003) and Guidolin and Timmermann (2006). The GDP is a measure of the general state of the macro economy.

All variables except the $FRC_t$ are standardized to have mean 0 and variance 1. Table 1 shows their descriptive statistics.

Figure 1 shows the graph of the realized stock-bond correlation. Although the realized correlation is somewhat erratic, it still has clear trends. The series starts out being positive, with a maximum of about 0.8, and then turns negative in the middle of the sample period, with a minimum of $-0.7$.

# 4 In Sample Results

## 4.1 Single Transition Variable

We estimate the STR model (i) using competing 1-week lagged transition variables one at a time, that is we consider the simple case of $K = 1$ in equation (1):

$$s_{t-1} = \{VXO_{t-1}, R_{t-1}, SPR_{t-1}, RSP_{t-1}, RTY_{t-1}, INF_{t-1}, GDP_{t-1}\} \tag{4}$$

This amounts to making 1-week ahead in sample predictions. We denote the STR model with a single transition variable as model (i).

The estimation results of model (i) are shown in Table 2. The explanatory power is greatest from using the short rate ($R_{t-1}$) as transition variable (adjusted $R$-squared of 0.34), the VXO/VIX volatility index (for the $VXO_{t-1}$ the adjusted $R$-squared is 0.18), and inflation (for $INF_{t-1}$ the adjusted $R$-squared is 0.17). For the remaining transition variables the adjusted $R$-squared is small and below 0.08.

Consider first the short rate used as transition variable. At the extremes, the model implies two regimes where the realized correlation changes smoothly between them. In particular, regime 1 applies when the interest rate is low and is associated with a negative correlation of $\widehat{\alpha}_1 - 0.64$. On the other hand, regime 2 takes effect when the short rate is high and the stock-bond correlation now becomes positive ($\widehat{\alpha}_1 + \widehat{\alpha}_2 = 0.37$). The estimated threshold parameter ($c = -0.68$) is insignificantly different from 0.

The picture is different when using the VXO/VIX volatility index as the transition variable. The estimated slope parameter $\widehat{\gamma}$ is negative implying that regime 1 applies when volatility is low. In this case, $F(s_{t-1}) = 1$ and the stock-bond correlation is positive ($\widehat{\alpha}_1 + \widehat{\alpha}_2 = 0.19$). On the other hand, regime 2 is in effect during periods of high volatility and the correlation now becomes negative ($\widehat{\alpha}_1 = -0.43$).

Comparing across models, the $\gamma$ parameter is typically low implying smooth transition between the two extreme regimes. Thus, the STR is a more suitable specification than a threshold model, which implies an abrupt switch in the regimes. Moreover, for most transition variables there is a positive $\gamma$ coefficient. Exceptions are the realized bond return and the VXO/VIX volatility index.

## 4.2 Multiple Transition Variables

We estimate the STR model using all the transition variables from above simultaneously so that $K = 7$, that is

$$s'_{t-1} = \begin{pmatrix} VXO_{t-1} & R_{t-1} & SPR_{t-1} & RSP_{t-1} & RTY_{t-1} & INF_{t-1} & INF_{t-1} \end{pmatrix} \tag{5}$$

We denote this model (ii). The results are shown in Table 3. The realized correlation changes smoothly from being negative in regime 1 at $\widehat{\alpha}_1 = -0.58$ to being positive in regime 2 at $\widehat{\alpha}_1 + \widehat{\alpha}_2 = 0.41$. The STR model is strongly improved by considering multiple transition variables. The explanatory power is much higher; the adjusted $R$-squared is 0.71 (compared to at most 0.34 in model (i)). The characteristics of the regimes are similar in model (i) (single transition variable STR) and model (ii) (multiple transition variable STR). Therefore, the improvements in model (ii) come with respect to describing the transitions between the regimes and to timing when the realized correlation is in the two regimes.

We access the importance of the different transition variables by considering the size (normalized variables) and significance of their parameters in the $\gamma$ vector. The short rate ($R_{t-1}$) and the yield spread ($SPR_{t-1}$) have the strongest positive effects upon the smooth changing in the realized correlation; the coefficients amount to $\widehat{\gamma}_R = 3.40$ and $\widehat{\gamma}_{SPR} = 2.00$. The coefficients are also statistically significant. So, the larger these term structure variables are, the more likely it is that the realized correlation is in the positive regime. The third most important transition variable is the VXO/VIX volatility index ($VXO_{t-1}$) which has a negative effect upon the realized correlation, $\widehat{\gamma}_{VXO} = -1.66$. So, the larger the VXO/VIX volatility index is, the more likely is negative stock-bond correlation.

The remaining transition variables are either insignificant ($RSP_{t-1}$ and $INF_{t-1}$) or have very low $\gamma$ coefficients ($RTY_{t-1}$ and $GDP_{t-1}$). Therefore, we test the joint hypothesis of these four transition variables being insignificant: $H_0$: $\gamma_{RSP} = \gamma_{RTY} = \gamma_{INF} = \gamma_{GDP} = 0$. This is not rejected as the robust Wald test statistics has a p-value of 6.64%.

The threshold parameter is significant and is estimated to be $\widehat{c} = -0.24$ which implies that the realized correlation changes from the negative to the positive regime when the transition variables increase above $-0.24$.

We estimate the reduced model that leaves out the four unimportant variables. Model (iii) has

$$s'_{t-1} = \begin{pmatrix} VXO_{t-1} & R_{t-1} & SPR_{t-1} \end{pmatrix} \tag{6}$$

The fit of model (iii) is almost unchanged compared to model (ii). The effects from the included transition variables is somewhat stronger in model (iii) than in model (ii). So, the important transition variables are indeed the short rate, the yield spread, and the VXO/VIX volatility index. This is in line with Viceira (forthcoming) who finds that the short rate and the yield spread are important predictors of the realized bond beta. Our findings are also consistent with Connolly et al. (2005) who show the importance of the VXO/VIX volatility index in explaining the stock-bond comovements. The findings are also in accordance with Aslanidis and Christiansen (2010) who show that these variables the most important variables at explaining the stock-bond correlation at its low and high quantiles.

Figure 2 shows the estimated transition function for model (iii). We plot the effect upon the transition function of changing one transition variable at a time, holding the others constant at their mean value of 0. The larger the $|\gamma|$ parameter is, the more abrupt are the changes between regimes, which is seen by comparing the curves for $R_{t-1}$ and $SPR_{t-1}$. The difference between positive and negative $\gamma$ parameters is also evident by comparing the curves for $R_{t-1}$ and $VXO_{t-1}$.

Generally, we expect a positive correlation between stocks and bonds as these two types of assets are influenced by similar factors in the economy. In particular, large short rates and large yield spread both tend to be associated with a positive stock-bond correlation. The yield spread is known to be a good predictor of the state of the macro economy, where large yield spreads tend to imply future expansions, cf. Estrella and Trubin (2006) and Wright (2006). Thus, our findings are consistent with positive stock-bond correlation being prevalent when the economy is in a good shape. Furthermore, large short rates has similar effects on the present value of future stock and bond returns thus implying positive stock-bond correlation.

Flight to safety is when investors flee stocks and run into bonds. The flight to safety behavior implies negative stock-bond correlations. We document that the negative stock-bond correlation is caused by large values of the VXO/VIX volatility index. The VXO/VIX index is typically seen as a measure of the overall uncertainty in the economy. Thus, the flight to safety behavior in times of high degrees of uncertainty is the reason why the stock-bond correlation turns negative.

Figure 3 shows the time series plot of the estimated transition function for model (iii). There is correspondence such that the transition function equals 1 when the stock-bond correlation is positive and similarly the transition function equals 0 when the stock-bond correlation is negative. In the early part of the sample period, the transition function is fairly stable at 1 that is the positive correlation regime. In contrast, in the last part of the sample, the transition function fluctuates more, but is most often below 0.5 implying the negative regime.

Overall, in sample there are huge gains from using multiple transition variables compared to using just one transition variable. Moreover, we prefer the reduced model (iii) to model (ii) as there is hardly any gain from the additional transition variables used in model (ii).

## 4.3 Different Forecast Horizons

We address the robustness of the results to different forecast horizons. In addition to the base case of $h = 1$ we also estimate model (iii) using lagged transition variables at lags 2 and 4 weeks; $h = \{1, 2, 4\}$. The results are reported in Table 4.

The results are qualitatively similar across the different horizons. The explanatory power decreases only slightly as the horizon becomes longer. Thus, the in sample results are robust to variations in the forecast horizon.

## 5 Out-of-Sample Results

We use an expanding window for the out-of-sample estimation. The first window covers the period January 1986 to March 2005. Using this window we estimate STR models using horizons of $h = \{1, 2, 4\}$. From these estimated models we make an out-of-sample forecast of the realized correlation. Subsequently, the estimation window is expanded with one further observation and the out-of-sample forecasting is repeated. So, the out-of-sample forecast period runs from March 2005 to May 2009, thus providing 219 observations.

For each STR model we access the out-of-sample performance by its root mean squared error (RMSE), mean absolute error (MAE), and Theil's inequality coefficient. The results are shown in Table 5.

As for the in sample analysis, the out-of-sample results are qualitatively identical across horizons. Across the performance measures, the multiple transition variable STR models outperform the single transition variable STR models. The improvement from the multiple transition variable STR models are substantial.

As in the in sample analysis, the best transition variable on its own is the short rate ($R_{t-1}$). Comparing the STR model (i) with the short rate as transition variable with the STR model (iii), the RMSEs equal 0.48 and 0.28, similarly the MAE is reduced from 0.39 to 0.21 Theil's inequality coefficient is also much closer to zero (perfect fit); 0.62 compared to 0.34.

There are hardly any differences between the out-of-sample performance of model (ii) and (iii). This again corroborates the findings from the in sample analysis, namely that the reduced model (iii) is sufficient.

Figure 4 plots the out-of-sample forecasts of model (iii) and the actual realized correlation for the forecast horizon $h = 1$. In general, the STR model tracks the realized correlation well. The correlation forecast is more stable than the realized correlation.

## 6 Conclusion

This study investigates time-varying patterns for the realized stock-bond correlation using high frequency data. High frequency data are appealing in that they provide a more accurate correlation measure compared to other correlation measures. The realized stock-bond correlation is described by smooth transition regressions (STR) with the two extreme regimes corresponding to large negative and large positive correlation. We find that employing multiple transition variables represents an improvement over previous empirical attempts at using a single transition variable. Moreover, our results show that the large values of the short rate and the yield spread tend to make the stock-bond correlation positive. In contrast, large values of the VIX volatility index tends to make the stock-bond correlation negative. The findings apply both in sample and out-of-sample and are robust to the forecast horizon.

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## Table 1: Descriptive Statistics

| | Mean | St.dev. | Min | Max | Skew | Kurt | St min | St max |
|---|---|---|---|---|---|---|---|---|
| **RC** | 0.04 | 0.39 | -0.81 | 0.78 | -0.37 | 1.89 | - | - |
| **FRC** | 0.03 | 0.43 | -1.12 | 1.05 | -0.42 | 2.18 | - | - |
| **VXO** | 21.21 | 9.05 | 9.04 | 98.81 | 2.20 | 12.27 | -1.35 | 8.58 |
| **R** | 4.34 | 2.01 | 0.01 | 9.04 | -0.20 | 2.46 | -2.16 | 2.34 |
| **SPR** | 1.74 | 1.14 | -0.65 | 3.93 | -0.01 | 1.86 | -2.10 | 1.92 |
| **RSP** | 0.00 | 0.03 | -0.28 | 0.18 | -1.58 | 21.59 | -10.82 | 6.81 |
| **RTY** | 0.00 | 0.01 | -0.11 | 0.08 | -1.20 | 20.00 | -11.53 | 7.54 |
| **INF** | 0.00 | 0.00 | 0.00 | 0.01 | 0.54 | 3.52 | -2.14 | 3.43 |
| **GDP** | 0.01 | 0.01 | -0.02 | 0.02 | -1.01 | 5.46 | -3.83 | 2.08 |

Notes: The left columns show the descriptive statistics (mean, standard deviation, minimum, maxium, skewness, and kurtosis) for the following variables: realized correlation (RC), Fisher transform of RC (FRC), VXO index, short rate (R), yield spread (SPR), realized stock return (RSP), realized bond return (RTY), inflation (INF), and GDP growth rate. The right columns show the minimum and maximum of the standardized variables.

## Table 2: STR Models with Single Transition Variable

| | VXO | | | R | | | SPR | | | RSP | | | RTY | | | INF | | | GDP | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coef | St.err | | Coef | St.err | | Coef | St.err | | Coef | St.err | | Coef | St.err | | Coef | St.err | | Coef | St.err | |
| $\alpha_1$ | -0.43 | (0.07) | *** | -0.64 | (0.23) | *** | -0.18 | (0.06) | *** | -0.39 | (0.10) | *** | -0.02 | (0.05) | | -0.33 | (0.14) | ** | -0.22 | (0.11) | ** |
| $\alpha_2$ | 0.62 | (0.09) | *** | 1.01 | (0.27) | *** | 0.25 | (0.07) | *** | 0.47 | (0.10) | *** | 0.13 | (0.07) | ** | 0.70 | (0.19) | *** | 0.40 | (0.14) | *** |
| $\gamma$ | -2.77 | (1.12) | ** | 1.39 | (0.55) | ** | 21.02 | (19.69) | | 3.12 | (1.16) | *** | -3.07 | (3.26) | | 1.40 | (0.58) | ** | 2.59 | (1.93) | |
| $c$ | 0.59 | (0.19) | *** | -0.68 | (0.43) | | -1.12 | (0.06) | *** | -1.25 | (0.20) | *** | -0.21 | (0.39) | | -0.08 | (0.35) | | -0.31 | (0.34) | |
| Residual variance | 0.39 | | | 0.35 | | | 0.43 | | | 0.42 | | | 0.43 | | | 0.40 | | | 0.42 | | |
| Adjusted R-squared | 0.18 | | | 0.34 | | | 0.04 | | | 0.05 | | | 0.01 | | | 0.17 | | | 0.08 | | |

Notes: The table shows STR model (i) with different transition variables; VXO index, short rate (R), yield spread (SPR), realized stock return (RSP), realized bond return (RTY), inflation (INF), and GDP growth rate. Newey-West standard errors in parenthesis. */**/*** indicates that the variable is significant at the 10%/5%/1% level of significance.

## Table 3: STR Models with Multiple Transition Variables

| | | (ii) | | | (iii) | | |
|---|---|---|---|---|---|---|---|
| | | Coef | St.err | | Coef | St.err | |
| $\alpha_1$ | Cons | -0.58 | (0.04) | *** | -0.56 | (0.04) | *** |
| $\alpha_2$ | Cons | 0.99 | (0.05) | *** | 0.96 | (0.05) | *** |
| $\gamma_{VXO}$ | | -1.66 | (0.26) | *** | -1.84 | (0.31) | *** |
| $\gamma_{R}$ | | 3.40 | (0.48) | *** | 3.81 | (0.58) | *** |
| $\gamma_{SPR}$ | | 2.00 | (0.31) | *** | 2.34 | (0.40) | *** |
| $\gamma_{RSP}$ | | 0.00 | (0.07) | | | | |
| $\gamma_{RTY}$ | | -0.16 | (0.08) | ** | | | |
| $\gamma_{INF}$ | | -0.08 | (0.12) | | | | |
| $\gamma_{GDP}$ | | 0.35 | (0.15) | ** | | | |
| c | | -0.24 | (0.05) | *** | -0.27 | (0.04) | *** |
| Akaike IC | | -0.07 | | | -0.05 | | |
| Schwarz IC | | -0.03 | | | -0.03 | | |
| Residual variance | | 0.23 | | | 0.24 | | |
| Adjusted R-squared | | 0.71 | | | 0.71 | | |

Notes: The table shows STR models (ii) and (iii) with multiple transition variables; VXO index, short rate (R), yield spread (SPR), realized stock return (RSP), realized bond return (RTY), inflation (INF), and GDP growth rate. Newey-West standard errors in parenthesis. */**/*** indicates that the variable is significant at the 10%/5%/1% level of significant. The robust Wald test for the null hypothesis of model (iii) in place of model (ii) has a p-value of 6.64%.

## Table 4: Different Horizons

| | | h=1 | | | h=2 | | | h=4 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Coef | St.err | | Coef | St.err | | Coef | St.err | |
| $\alpha_1$ | Cons | -0.56 | (0.04) | *** | -0.54 | (0.04) | *** | -0.50 | (0.04) | *** |
| $\alpha_2$ | Cons | 0.96 | (0.05) | *** | 0.94 | (0.05) | *** | 0.89 | (0.05) | *** |
| $\gamma_{VXO}$ | | -1.84 | (0.31) | *** | -1.82 | (0.33) | *** | -1.91 | (0.38) | *** |
| $\gamma_R$ | | 3.81 | (0.58) | *** | 3.76 | (0.59) | *** | 3.98 | (0.69) | *** |
| $\gamma_{SPR}$ | | 2.34 | (0.40) | *** | 2.30 | (0.40) | *** | 2.42 | (0.45) | *** |
| c | | -0.27 | (0.04) | *** | -0.25 | (0.04) | *** | -0.20 | (0.05) | *** |
| Residual variance | | 0.24 | | | 0.25 | | | 0.26 | | |
| Adjusted R-squared | | 0.71 | | | 0.68 | | | 0.65 | | |

Notes: The table shows STR model (iii) with multiple transition variables (VXO index, short rate (R), and yield spread (SPR)) for lags h=(1,2,4) of the transition variables. Newey-West standard errors in parenthesis. */**/*** indicates that the variable is significant at the 10%/5%/1% level of significant.

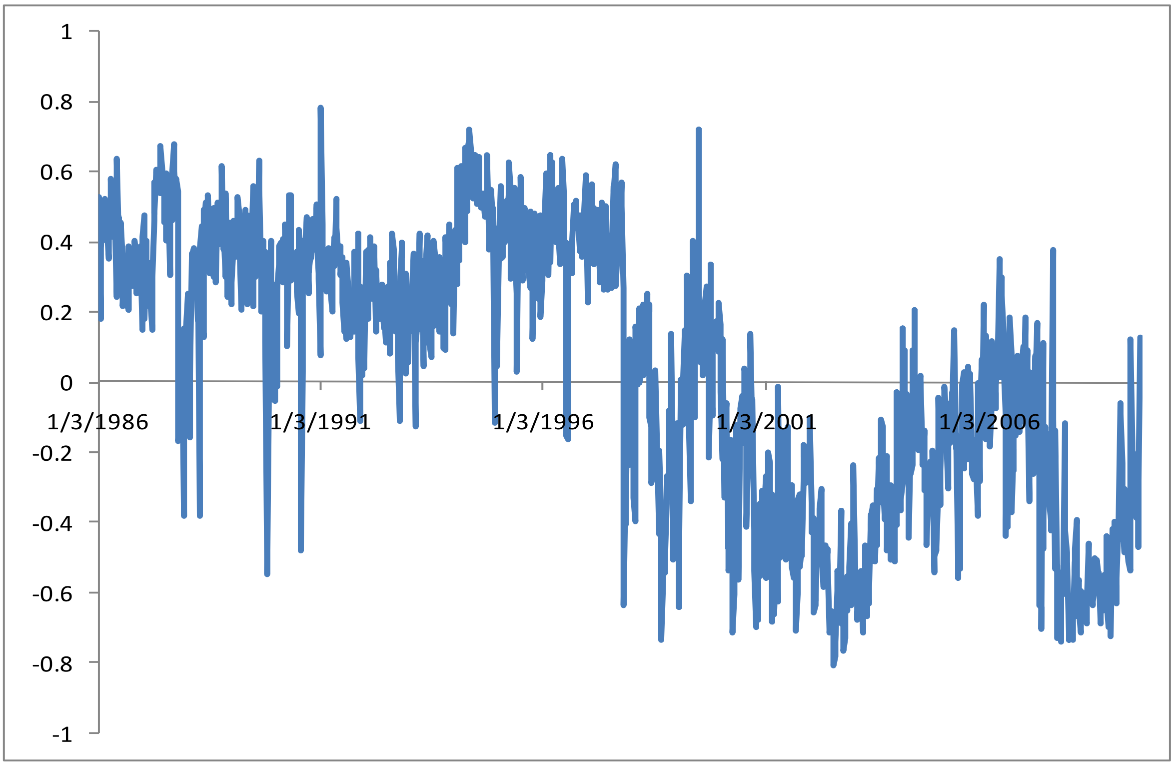
## Table 5: Out-of-Sample Results

| | RMSE | | | MAE | | | Theil | | |
|---|---|---|---|---|---|---|---|---|---|
| | h=1 | h=2 | h=4 | h=1 | h=2 | h=4 | h=1 | h=2 | h=4 |
| Model (i) VXO | 0.560 | 0.565 | 0.572 | 0.478 | 0.482 | 0.491 | 0.739 | 0.754 | 0.775 |
| Model (i) R | 0.484 | 0.489 | 0.498 | 0.386 | 0.390 | 0.397 | 0.624 | 0.632 | 0.646 |
| Model (i) SPR | 0.553 | 0.574 | 0.553 | 0.457 | 0.483 | 0.464 | 0.893 | 0.941 | 0.853 |
| Model (i) RSP | 0.557 | 0.552 | 0.541 | 0.464 | 0.456 | 0.452 | 0.944 | 0.932 | 0.896 |
| Model (i) RTY | 0.556 | 0.555 | 0.555 | 0.463 | 0.463 | 0.463 | 0.938 | 0.942 | 0.939 |
| Model (i) INF | 0.493 | 0.495 | 0.503 | 0.386 | 0.385 | 0.394 | 0.806 | 0.815 | 0.840 |
| Model (i) GDP | 0.508 | 0.511 | 0.514 | 0.414 | 0.415 | 0.417 | 0.907 | 0.913 | 0.918 |
| Model (ii) | 0.280 | 0.289 | 0.294 | 0.217 | 0.216 | 0.219 | 0.334 | 0.354 | 0.363 |
| Model (iii) | 0.279 | 0.291 | 0.296 | 0.217 | 0.219 | 0.223 | 0.338 | 0.362 | 0.384 |

Notes: The table shows out-of-sample RMSE, MAE, and Theil's inequality coefficient for STR models (i)-(iii) where the transition variables are VXO index, short rate (R), yield spread (SPR), realized stock return (RSP), realized bond return (RTY), inflation (INF), and GDP growth rate and the forecast horizons are h=(1,2,4). Forecast period is 2005-2009.

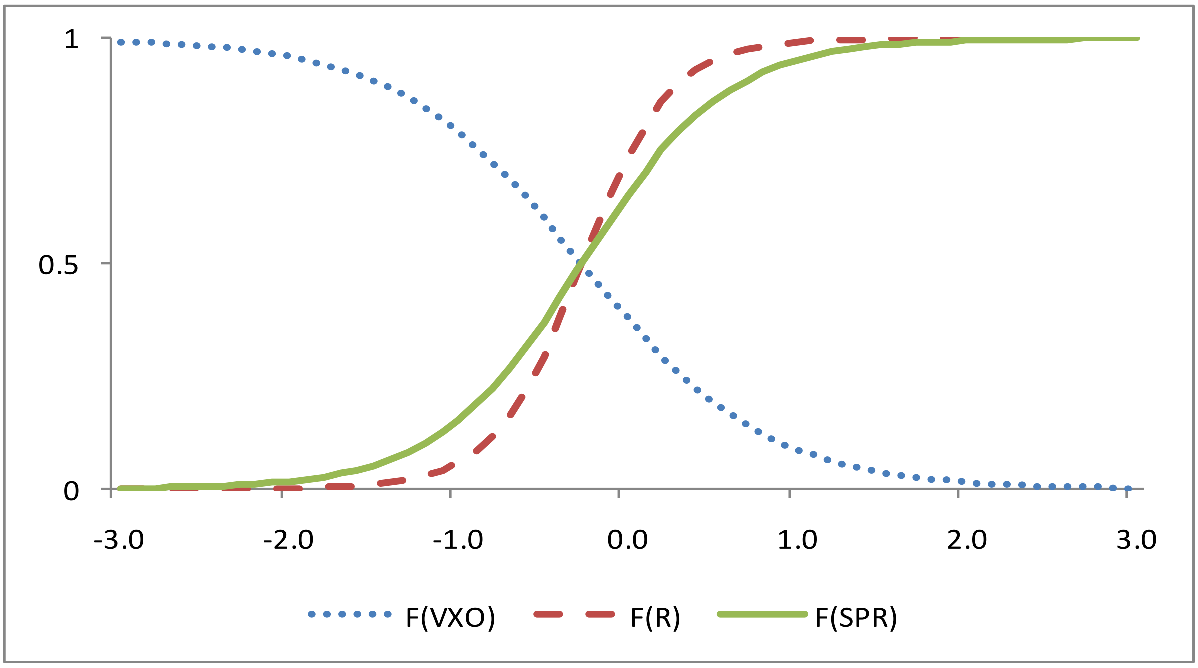
x

**Figure 1: Realized Stock Bond Correlation**



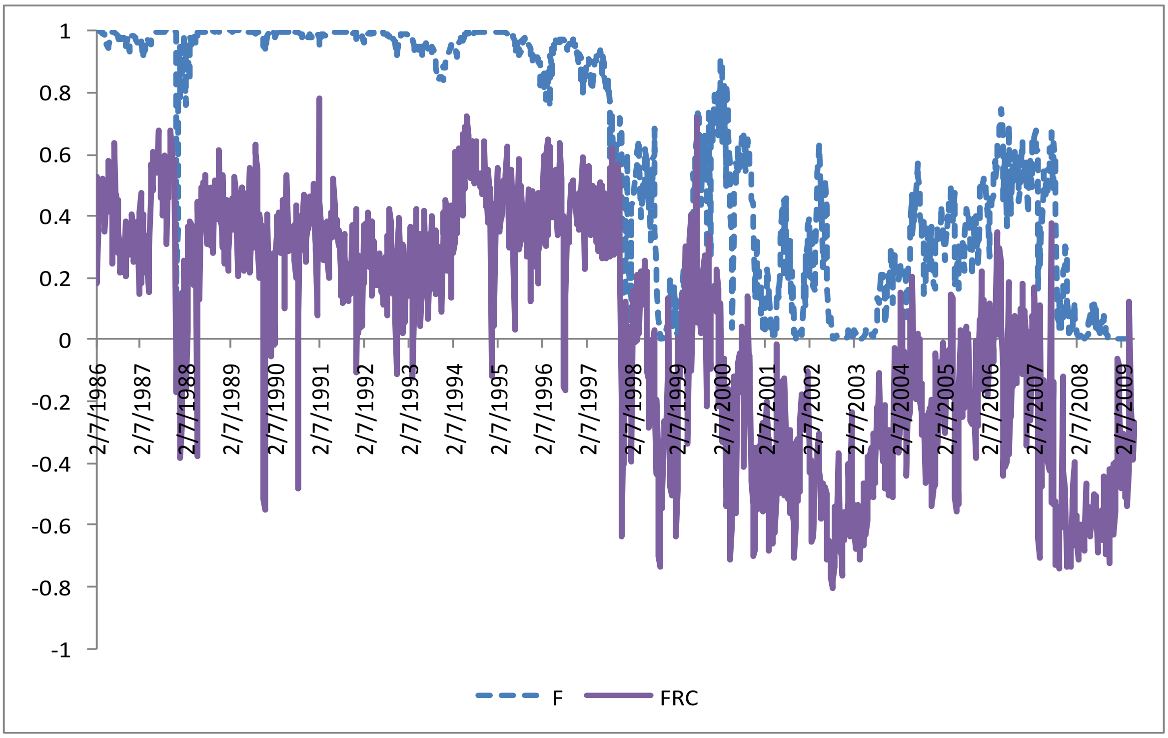

Notes: The graph shows the time series of the weekly realized stock-bond correlation.

**Figure 2: Estimated Transition Function**



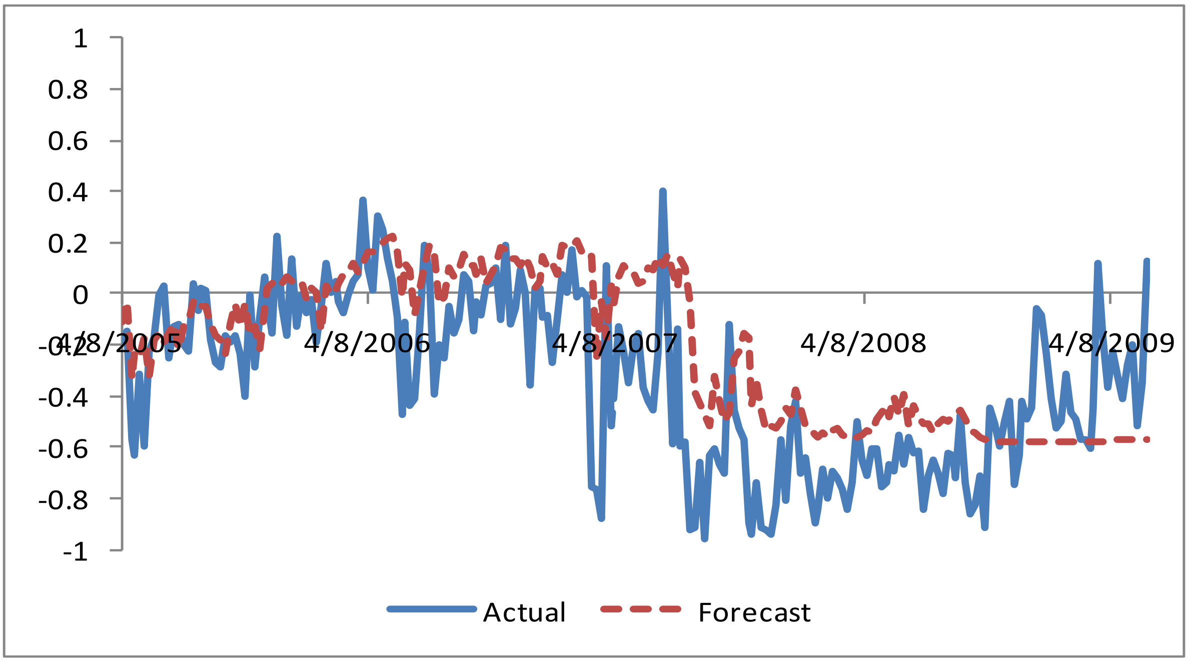

Notes: The graph shows the estimated transition function of model (iii) against each of the transition variables holding the other transition variables constant at their sample mean. The transition variables are VXO index, short rate (R), and yield spread (SPR).

## Figure 3: Estimated Transition Function




Notes: The graph shows the time series of the estimated transition function for model (iii) (F) and the realized correlation (FRC).

**Figure 4: Out-of-Sample Forecasts**




Notes: The graph shows actual and out-of-sample forecasts of the realized stock-bond correlation for model (iii) for h=1.