Variance Premiums in an Equilibrium Model with Two Stochastic Volatility Factors

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Abstract

Variance premium is studied under a discrete-time consumption-based equilibrium model, with two stochastic volatility factors. The formulas for VIX and variance premium term structure are derived. As an empirical application of the model, the predicion power of VIX and variance premium term structure are studied, under the context of aggregate market return prediction. The implication of the model is that variance premium term structure contains information about two underlying volatility factors, and attitude of risks, therefore, should have prediction power for future equity returns. Use data of returns, realized variance and VIX term structure for S&P 500 index, the R^2 of quarterly horizon prediction regression can achieve as high as 12%.

1 Introduction

As is well-known, return variance is stochastic. Thus, when investing in a security, an investor faces at least two sources of uncertainty, which comes from return and return variance. It is important to know how investors deal with the randomness in return variance for pricing and hedging various derivatives and for asset portfolio allocation.

Roughly speaking, there are two branches in literature about variance risk premium. The first one is related to so called volatility spread. volatility spread means that generally, the at-the-money implied volatility of option price exceeds the physical index return volatility. Such volatility spread has economical meanings. Bakshi and Kapadia (2003a, b) show the existence of a negative market volatility risk premium in index and individual stock options has effect on delta-hedged gains. Bakshi and Madan (2006) provide a very general model to illustrate the source of such volatility spread. The authors show that such spread generated from investors preference and high moments of return distributions, especially skewness and kurtosis. Bali and Hovakimian (2009) show that volatility spreads has prediction power for cross-section stock returns. Yan (2011) further show that the term structure of implied volatility also plays a role in cross-section stock return prediction.

The second branch of literature is related to VIX. VIX can be calculated via a model-free method proposed by Carr and Madan (2002), Britten-Jones and Neuberger (2000) and Jiang and Tian (2005, 2007). There are several studies link variance premium calculated by VIX and realized variance to the aggregate stock market return prediction, such as Carr and Wu (2009), Bollerslev, Tauche and Zhou (2009), Bollerslev, Gibson and Zhou (2011), Todorov (2010) and Drechsler and Yaron (2011).

Bollerslev, Tauche and Zhou (2009) and Drechsler and Yaron (2011) illustrate the source of variance premium via general asset pricing models. Both papers postulate that the return predictability power arises because the time-series of the variance risk premium and the equity risk premium are correlated. Bollerslev, Tauchen and Zhou (2009) derives this correlation in a discrete-time model with time variation in both consumption volatility and the volatility of consumption volatility. They show that the variance risk premium captures time variation in the volatility of consumption volatility, which is also correlated with the time variation in risk premium. Drechsler and Yaron (2011) derives the correlation between equity and variance risk premium in a broader setting that incorporates the long-run risk dynamics in Bansal and Yaron (2004) and can simultaneously match the magnitudes of the equity risk premium and volatility risk premium in the data. In their model, the variance risk premium comes from a drift difference in the consumption volatility process between Q and P measure and from priced jump risk.

These two areas, volatility spread and variance premium, are similar yet important differences. The papers are similar in the sense that all the papers examine gap between implied volatility (variance) and the volatility (variance) under real world measure, hence are related to researches using various variables computed from the options data to predict the underlying stock returns, such as spreads between call and put option implied volatilities (Bali and Hovakimian, 2009), the slope of option implied volatility smile (Xing, Zhang and Zhao, 2010; Yan, 2011), put-call parity deviations (Cremers and Weinbaum, 2010) and innovations in option implied volatilities (Ang, Bali and Cakici, 2012), among others.

The most essential difference lies in the fact that studies via volatility spread rely on parametric option pricing models, most commonly, the Black-Scholes model, to calculate implied volatility. In contrast, the relatively new studies about variance premium use model free implied variance measure VIX. The nonparametric nature of VIX makes these results more general and more robust. Moreover, VIX has very clear economical meaning, which is the variance swap rate. The difference of these two approaches are partially illustrated in the paper of Carr and Wu (2006).

The developments of volatility spread literature shed some lights on the directions for variance premium studies. First of all, the term structure matters. Johnson (2011) examines relation of equity risk premium and VIX term structure, finds that there are four factors in VIX term structure have prediction power. But it is well-known that risk neutral implied variance such as VIX contains two part of information: investors preference (pricing kernel) and physical expected variance. Johnson does not distinguish these two. From various previous literature, we know that generally speaking, merely variance itself has little prediction power for equity risk premium.

Secondly, application of variance premium and cross-section stock returns worth some further attention. Using data between 1996 and 2003, Driessen, Maenhout and Vilkov (2009) and Carr and Wu (2009) find large variation in the individual stock variance risk premium across 127 and 35 stock respectively, and Han and Zhou (2010) find the similar results for a large scale of 5000 stocks during 1996-2009. However, the effect of term structure for variance premium is untouched yet.

Moreover, there are some evidence that jumps play an important role in variance premium. The well-cite paper of Pan (2002) suggest that there is a significant jump risk premium priced in options under the one-factor affine framework. Recently, Duan and Yeh (2011) also find similar results under the one-factor CEV framework using VIX term structure data. Besides, Todorov (2010) studied the variance risk premium due to jump risk over a single, 30-day time horizon with new techniques develop by recent nonparametric high frequency data literature. He established that investors' willingness to insure against a market crash increases after a price fall and has a persistent impact on the variance premium. Therefore, it is important to study the influence of variance premium on equity premium by separating jumps from stochastic variance.

The structure of the paper is as follows. In section 2, the two-factor stochastic volatility model is built. In Section 3, empirical test about prediction power of variance premium term structure is conducted. The last section makes conclusion and lists some possible directions for future research. Section 4 makes conclusions.

2 Model Specification

All the papers for variance premium studies try to answer one question: what is the information contained in variance premium? Various and quite different answers are provided. Bollerslev, Tauchen and Zhou (2009), for instance, argue that the variance premium contains information of volatility of consumption volatility. Todorov (2010) studies the variance premium, and provides evidence that there is a significant contribution of jumps. Drechsler and Yaron (2011), based on the long-run risk model of Bansal and Yaron (2004), think variance premium contains information about latent jump intensity for poisson jumps in both consumption and consumption volatility. While Bollerslev, Gibson and Zhou (2011) provide evidence that variance premium has more information about aggregate time-varying risk aversion rather than latent factors in consumption and volatility dynamics. Branger and Clemens (2012), Zhou and Zhu (2012) build new long-run risk model with 2 factors for stochastic consumption volatility dynamics and jumps under continuous-time framework.

Earlier models, such as those in Bollerslev, Tauchen and Zhou (2009) and Drechsler and Yaron (2011), leave no room for variance term structure, because one time series of variance premium is able to pin down the latent variables. However, prediction power difference between variance premium and its term structure (Table 4 and Table 6 in later section) makes it clear that term structure play a role. In this paper, a discrete-time two-factor stochastic volatility model is proposed. The model dynamic is given by

$$\begin{cases} g_{t+1} = \mu_g + z_{g,t+1}, \\ z_{g,t+1} \mid \mathcal{F}_{t+1} \sim \mathcal{N}(0, \sigma^2_{g,t+1}), \\ \sigma^2_{g,t+1} = V_{1,t+1} + V_{2,t+1}, \\ V_{1,t+1} \sim \mathrm{ARG}(\delta_1, \beta_1 V_{1,t}, c_1), \\ V_{2,t+1} \sim \mathrm{ARG}(\delta_2, \beta_2 V_{2,t}, c_2), \end{cases}$$

where g_{t+1} is the geometric growth rate of consumption in the economy, $g_{t+1} = \log(C_{t+1}/C_t)$. $\sigma^2_{g,t+1}$ refer to the conditional variance of the growth rate at $t+1$. $\sigma^2_{g,t+1}$ contains two factors, $V_{1,t+1}$, $V_{2,t+1}$, following autoregressive gamma process (Gourieroux and Jasiak (2006)). The properties of autoregressive gamma process $V_{t+1} \sim \mathrm{ARG}(\delta, \beta V_t, c)$ is given by

$$\begin{aligned} &\mathbf{E}_t[V_{t+1}] = c\delta + c\beta V_t; \\ &\mathbf{Var}_t[V_{t+1}] = c^2\delta + 2c^2\beta V_t; \\ &\mathbf{E}_t[V_{t+\tau}] = \frac{c\delta(1-\rho^\tau)}{1-\rho} + \rho^\tau V_t, \quad \rho = c\beta < 1; \\ &\mathbf{Var}_t[V_{t+\tau}] = \frac{c^2\delta(1-\rho^\tau)^2}{(1-\rho)^2} + 2\rho^\tau \frac{c(1-\rho^\tau)}{1-\rho} V_t, \quad \rho = c\beta < 1; \end{aligned}$$

There are two reasons to use such a model structure. One reason is that although Bollerslev, Tauchen and Zhou (2009) argue that the vol-of-vol can summary economic uncertainty, however, it is not enough to think that long-run economic uncertainty will be represented by a variable looking forward only 30 days. It is reasonable to think that one volatility factor represents short-term uncertainty, and the other represents long-term uncertainty, and these two factors represent further some economic factors having both short and long-term influence on consumption volatility. The same setting is widely used in multi-factor option pricing models, and VIX term structure models.

The other reason is that for discrete-time models involving stochastic volatility, AR(1) process is widely used. However, such process cannot guarantee that variance is always positive. Such problem will disappear if autoregressive gamma process is applied. The conditional distribution of autoregressive gamma process is a non-central gamma distribution, therefore, always positive. The persistence of variance process is controlled by $\beta_i V_{i,t}$. Besides, gamma process is the simplest process with infinite jump intensity, therefore, jumps in variance are also considered in a parsimonious way.

Following conventions in long-run risk models, we assume the representative agent has the Epstein-Zin utility function, thus, the logarithm of pricing kernel $m_{t+1} = \log M_{t+1}$ is

$$m_{t+1} = \theta \log \delta - \theta \Psi^{-1} g_{t+1} + (\theta - 1) r_{t+1} = b_{m0} + b_{mg} g_{t+1} + b_{mr} r_{t+1}, \tag{1}$$

where δ denotes the subjective discount factor. Ψ equals the intertemporal elasticity of substitution, γ refers to the coefficient of risk aversion. $\theta = (1-\gamma)(1-\Psi^{-1})^{-1}$. r_{t+1} is return from t to $t+1$ on the consumption asset, could be market portfolio. Using Campbell and Shiller (1988) log-linear approximation, we have

$$r_{t+1} = \kappa_0 + \kappa_1 \nu_{t+1} - \nu_t + g_{t+1}, \tag{2}$$

where the logarithm price-consumption ratio has following form

$$\nu_t = A_0 + A_1 V_{1,t} + A_2 V_{2,t}. \tag{3}$$

By solving the Euler equation,

$$\mathbf{E}_t(e^{(m_{t+1} + r_{t+1})}) = 1, \tag{4}$$

we get solutions for A_0, A_1, and A_2,

$$
\begin{aligned}
A_0 &= \frac{\gamma\mu_g - \theta\log\delta + (1-\theta)\kappa_0 + \sum_{i=1}^{2}\delta_i\log(1+c_i(1-\theta)A_i\kappa_1 - c_i\gamma^2/2)}{(1-\kappa_1)(1-\theta)}; \\
A_1 &= \frac{(\beta_1 c_1\kappa_1 + c_1\gamma^2/2 - 1) + \sqrt{(\beta_1 c_1\kappa_1 + c_1\gamma^2 - 1)^2 - 2c_1^2\gamma^2\beta_1\kappa_1}}{2c_1\kappa_1(1-\theta)}; \\
A_2 &= \frac{(\beta_2 c_2\kappa_1 + c_2\gamma^2/2 - 1) + \sqrt{(\beta_2 c_2\kappa_1 + c_2\gamma^2 - 1)^2 - 2c_2^2\gamma^2\beta_2\kappa_1}}{2c_2\kappa_1(1-\theta)}.
\end{aligned} \tag{5}
$$

The innovation of log-pricing kernel is give by

$$
m_{t+1} - \mathbf{E}_t(m_{t+1}) = -\gamma\cdot z_{g,t+1} - (1-\theta)\kappa_1 A_1(V_{1,t+1} - \mathbf{E}_t(V_{1,t+1})) - (1-\theta)\kappa_1 A_2(V_{2,t+1} - \mathbf{E}_t(V_{2,t+1})). \tag{6}
$$

The market price of risk for uncertainty of consumption growth innovation is $-\gamma$, and market price of risk for variance components are $-(1-\theta)\kappa_i A_i$.

The Radon-Nikodym derivative is given by

$$
\begin{aligned}
\frac{dQ}{dP} &= \frac{\exp(m_{t+1})}{\mathbf{E}_t(\exp(m_{t+1}))} \\
&= \frac{\exp(-(1-\theta)A_1\kappa_1 V_{1,t+1} - (1-\theta)A_2\kappa_1 V_{2,t+1} - \gamma z_{g,t+1})}{\mathbf{E}_t(\exp(-(1-\theta)A_1\kappa_1 V_{1,t+1} - (1-\theta)A_2\kappa_1 V_{2,t+1} - \gamma z_{g,t+1}))}.
\end{aligned}
$$

Then, further simply by setting $\xi_1 = (1-\theta)A_1\kappa_1$ and $\xi_2 = (1-\theta)A_2\kappa_1$, and $\xi_3 = \gamma$, we can perform measure transform via

$$
\frac{dQ}{dP} = \frac{\exp(-\xi_1 V_{1,t+1} - \xi_2 V_{2,t+1} - \xi_3 z_{g,t+1})}{\mathbf{E}_t(\exp(-\xi_1 V_{1,t+1} - \xi_2 V_{2,t+1} - \xi_3 z_{g,t+1}))}. \tag{7}
$$

Proposition 2.1. *The one-step-ahead moment generating function under P measure is given by*

$$
\begin{aligned}
& \mathbf{E}_t^P[\exp(-\alpha_1 V_{1,t+1} - \alpha_2 V_{2,t+1} - \alpha_3 z_{g,t+1})] \\
=\ & \mathbf{E}_t^P[\exp(-(\alpha_1 - \frac{\alpha_3^2}{2})V_{1,t+1} - (\alpha_2 - \frac{\alpha_3^2}{2})V_{2,t+1})] \\
=\ & \varphi_1(u_1)\cdot\varphi_2(u_2),
\end{aligned} \tag{8}
$$

where $u_1 = \alpha_1 - \alpha_3/2$, $u_2 = \alpha_2 - \alpha_3/2$. $\varphi_i(\cdot)$ is moment-generating function of autoregressive gamma process,

$$
\varphi_i(\eta) = \mathbf{E}_t[\exp(-\eta V_{i,t+1})] = \exp(-\frac{c_i\eta}{1+c_i\eta}\beta_i V_{i,t} - \delta_i\log(1+c_i\eta)). \tag{9}
$$

□

Proposition 2.2. *The one-step-ahead moment generating function under Q measure is given by*

$$
\begin{aligned}
& \mathbf{E}_t^Q[\exp(-\alpha_1 V_{1,t+1} - \alpha_2 V_{2,t+1} - \alpha_3 z_{g,t+1})] \\
= \; & \mathbf{E}_t^P[\frac{dQ}{dP} \cdot \exp(-\alpha_1 V_{1,t+1} - \alpha_2 V_{2,t+1} - \alpha_3 z_{g,t+1})] \\
= \; & \frac{\mathbf{E}_t(\exp(-(\alpha_1+\xi_1)V_{1,t+1} - (\alpha_2+\xi_2)V_{2,t+1} - (\alpha_3+\xi_3)z_{g,t+1}))}{\mathbf{E}_t(\exp(-\xi_1 V_{1,t+1} - \xi_2 V_{2,t+1} - \xi_3 z_{g,t+1}))} \\
= \; & \frac{\varphi_1(u_5)\cdot\varphi_2(u_6)}{\varphi_1(u_3)\cdot\varphi_2(u_4)}, \qquad (10)
\end{aligned}
$$

where $u_3 = \xi_1 - \xi_3/2$, $u_4 = \xi_2 - \xi_3/2$, $u_5 = (\alpha_1 + \xi_1) - (\alpha_3 + \xi_3)^2/2$, $u_6 = (\alpha_2 + \xi_2) - (\alpha_3 + \xi_3)^2/2$. $\varphi_i(\cdot)$ *is moment-generating function of autoregressive gamma process. The parameters under Q and P measures have following relations*

$$\beta_1^* = \frac{\beta_1}{1 + c_1 u_3}; \qquad \beta_2^* = \frac{\beta_2}{1 + c_2 u_4}; \qquad (11)$$

$$\delta_1^* = \delta_1; \qquad \delta_2^* = \delta_2; \qquad (12)$$

$$c_1^* = \frac{c_1}{1 + c_1 u_3}; \qquad c_2^* = \frac{c_2}{1 + c_2 u_4}. \qquad (13)$$

□

Proposition 2.3. *The risk free rate between time t and $t+1$ is a linear function of two state variable $V_{1,t}$ and $V_{2,t}$,*

$$r_{t,t+1} = -\log(\mathbf{E}_t[\exp(m_{t+1})]) = r_0 + \sum_{i=1}^{2}(\frac{c_i u_i \beta_i}{1 + c_i u_i} - \frac{u_i + \gamma^2/2}{\kappa_1})V_{i,t}, \qquad (14)$$

where $u_i = (1-\theta)A_i\kappa_1$, $r_0 = \theta \log\delta - \gamma\mu_g + (\theta-1)\kappa_0 + (\theta-1)A_0(\kappa_1 - 1) + \sum_{i=1}^{2}\delta_i \log(1 + c_i u_i)$, *is a constant.*

□

Proposition 2.4. *The conditional variance of market return $\sigma_{r,t}^2 = Var_t(r_{t+1})$ is*

$$\sigma_{r,t}^2 = \sigma_0^2 + \sum_{i=1}^{2}\sigma_V^i V_{i,t}, \qquad (15)$$

where $\sigma_0^2 = \sum_{i=1}^{2}(A_i^2\kappa_i^2 c_i^2 \delta_i + c_i\delta_i)$. $\sigma_V^i = 2A_i^2\kappa_i^2 c_i^2\beta_i + c_i\beta_i$.

The instantaneous VIX_t is

$$VIX_t = \mathbf{E}_t^Q[\sigma_{t+1}^2] = \sigma_0^{*2} + \sum_{i=1}^{2} \sigma_V^{*i} \mathbf{E}_t^Q[V_{i,t+1}] = \sigma_0^{*2} + \sigma_V^{i*} c_i^* \delta_i^* + \sum_{i=1}^{2} \sigma_V^{*i} c_i^* \beta_i^* V_{i,t}. \tag{16}$$

For VIX term structure $VIX_{t,t+\tau}$ is given by

$$\begin{aligned} VIX_{t,t+\tau} &= \sum_{h=1}^{\tau} (\mathbf{E}_t^Q[\sigma_{t+h}^2] = \sum_{h=1}^{\tau} (\sigma_0^{*2} + \sum_{i=1}^{2} \sigma_V^{*i} \mathbf{E}_t^Q[V_{i,t+h}]) \\ &= \tau\sigma_0^{*2} + \sum_{h=1}^{\tau}\sum_{i=1}^{2} \sigma_V^{*i} (\frac{c_i^* \delta_i^* (1-\rho_i^{*h})}{1-\rho_i^*} + \rho_i^{*h} V_{i,t}) \\ &= \sum_{i=1}^{2} (\frac{\sigma_V^{*i} \rho_i^* (1-\rho_i^{*\tau})}{1-\rho_i^*} V_{i,t} - \frac{\sigma_V^{*i} c_i^* \delta_i^* \rho_i^* (1-\rho_i^{*\tau})}{(1-\rho_i^*)^2}) + \tau(\sigma_0^{*2} + \sum_{i=1}^{2} \frac{\sigma_V^{i*} c_i^* \delta_i^*}{1-\rho_i^*}). \end{aligned} \tag{17}$$

Similarly, the instantaneous variance premium VRP_t is

$$\begin{aligned} VRP_t &= \mathbf{E}_t^Q[\sigma_{t+1}^2] - \mathbf{E}_t^P[\sigma_{t+1}^2] = (\sigma_0^{*2} - \sigma_0^2) + \sum_{i=1}^{2} \sigma_V^{*i} \mathbf{E}_t^Q[V_{i,t+1}] - \sigma_V^i \mathbf{E}_t^P[V_{i,t+1}] \\ &= (\sigma_0^{*2} - \sigma_0^2) + (\sigma_V^{i*} c_i^* \delta_i^* - \sigma_V^i c_i \delta_i) + \sum_{i=1}^{2} (\sigma_V^{*i} c_i^* \beta_i^* - \sigma_V^i c_i \beta_i) V_{i,t}. \end{aligned} \tag{18}$$

For variance premium term structure $VRP_{t,t+\tau}$ is given by

$$\begin{aligned} VRP_{t,t+\tau} &= \sum_{h=1}^{\tau} \mathbf{E}_t^Q[\sigma_{t+h}^2] - \mathbf{E}_t^P[\sigma_{t+h}^2] = \sum_{h=1}^{\tau} (\sigma_0^{*2} - \sigma_0^2) + \sum_{i=1}^{2} \sigma_V^{*i} \mathbf{E}_t^Q[V_{i,t+h}] - \sigma_V^i \mathbf{E}_t^P[V_{i,t+h}] \\ &= \tau(\sigma_0^{*2} - \sigma_0^2) + \sum_{h=1}^{\tau}\sum_{i=1}^{2} \sigma_V^{*i} (\frac{c_i^* \delta_i^* (1-\rho_i^{*h})}{1-\rho_i^*} + \rho_i^{*h} V_{i,t}) - \sigma_V^i (\frac{c_i \delta_i (1-\rho_i^h)}{1-\rho_i} + \rho_i^h V_{i,t}) \\ &= \sum_{i=1}^{2} (\frac{\sigma_V^{*i} \rho_i^* (1-\rho_i^{*\tau})}{1-\rho_i^*} - \frac{\sigma_V^i \rho_i (1-\rho_i^\tau)}{1-\rho_i}) V_{i,t} - (\frac{\sigma_V^{*i} c_i^* \delta_i^* \rho_i^* (1-\rho_i^{*\tau})}{(1-\rho_i^*)^2} - \frac{\sigma_V^i c_i \delta_i \rho_i (1-\rho_i^\tau)}{(1-\rho_i)^2}) \\ &\quad + \tau(\sigma_0^{*2} - \sigma_0^2 + \sum_{i=1}^{2} (\frac{\sigma_V^{i*} c_i^* \delta_i^*}{1-\rho_i^*} - \frac{\sigma_V^i c_i \delta_i}{1-\rho_i})). \end{aligned} \tag{19}$$

□

Therefore, variance premium has three sources of information: information about risk aversion, and information about two stochastic volatility components. Only 1-month variance premium cannot precisely distinguish all kinds of variations. Therefore, variance premium term structure will provide less noisy information.

3 Empirical Studies

This section is about the prediction power of variance premium term structure. First of all, the realtions of variance premium and variables related to macro-economic condition are examined. Secondly, the return predition test is conducted, via S&P 500 index returns and variance premium term structures. Moreover, some robustness checks are applied.

3.1 Data Description and Summary Statistics

The empirical study is about aggregate index return prediction use daily data. For each day t, the variance premiums for different horizon τ, $VRP_{t,\tau}$, are calculated via daily VIX and daily realized variance data. The future returns of different horizons τ are calculated from daily S&P 500 returns, downloaded from bloomberg. Time horizons τ in the paper are 1 month, 2 months, 3 months, 6 months, 9 months and 12 months.

Daily realized variance is calculated via intraday high frequency data, from the year 2000 to 2012, downloaded from an open-access data source: The Oxford-Man Institute's realised library. The calculation method follows the way proposed by Barndorff-Nielsen and Shephard (2004). For risk-neutral variance, VIX is used, VIX term structure of 1 month, 2 months, 3 months, 6 months, 9 months and 12 months are downloaded from website of Prof. Travis L. Johnson, from the year 1996 to 2010. Theoretically, the variance premium at time t, for τ-month horizon ($\tau = 1, 2, 3, 6, 9, 12$), is given by difference between risk-neutral variance and expected variance under physical measure,

$$VRP_{t,\tau} = VIX_{t,\tau}^2 - \sum_{i=1}^{30\tau} \mathbf{E}_t[RV_{d,t+i}], \tag{20}$$

where $RV_{d,t+i}$ is expected variance of the day $t+i$, conditioned on time t information set. Since $RV_{d,t+i}$ is unknown, one solution is to use certain forecasting model to generate future variance, the other solution is to use past realized variance. Since use of forecasting model will introduce model errors, and variance is persistent, past realized variance is applied, the variance premium is calculated as follows,

$$VRP_{t,\tau} = VIX_{t,\tau}^2 - \sum_{i=1}^{30\tau} \mathbf{E}_t[RV_{d,t-i}], \tag{21}$$

where $RV_{d,t-i}$ realized daily variance. Table 5 presents summary statistics for variance premium of various horizons. The mean of variance premiums calculated as above have significant non-zero mean values, and median are positive, which eases the concerns that variance premiums are just noise and contain no information.

Figure 1 plots time series of variance premiums and the slope of variance premium term structure. The patterns in the figure convey that risk premium is small in usual peace time, and become larger during the crisis. Within the period from the year 2004 to 2007, the variance premiums are small, and the slope of term structure is flat. During the crisis, variance premiums increase significantly and the slope become large and positive. At the end of the crisis, variance premiums decrease and the slope become negative. This phenomenon is reasonable given the excessive fear of market participants about what is going on in the markets during the crisis, at the end of the crisis, investors think the future will be better, thus, the long-run variance premium will decrease first to its normal level.

Returns of different horizons τ at day t are calculated as follows

$$R_{t,\tau} = \sum_{i=1}^{30\tau} R_{d,t+i}, \tag{22}$$

where $R_{d,t+i}$ is daily return of S&P 500 index at day $t+i$. For prediction test of variance premiums, the following regressions are applied

$$R_{t,\tau_R} = \alpha + \beta' \underline{VRP}_{t,\tau_V} + \epsilon_t, \tag{23}$$

where $\underline{VRP}_{t,\tau_V}$ is a vector, containing variance premium of different horizon, or factors extracted from variance premium term structure via principle component analysis, and horizons for returns and variance premiums τ_R and τ_V could be different.

Some macroeconomic variables used in the paper are: the difference of yields between 10-Year treasure bills and 1-Year treasure bills; federal fund rate; credit spread between Aaa bond and Baa bond.

An index of economic uncertainty (EPU) constructed by Baker, Bloom and Davis (2013). The first three variables are commonly used to represent economic environment, started from the seminal paper of Chen, Roll and Ross (1986). They are downloaded from website of Federal Reserve Bank of New York. The economic uncertainty index is download from http://www.policyuncertainty.com/. The index is built on three components: the frequency of newspaper references to economic policy uncertainty, the number of federal tax code provisions set to expire, and the extent of forecaster disagreement over future inflation and government purchases. This EPU index spikes near consequential presidential elections and major events such as the Gulf wars and the 9/11 attack. It also rises steeply from 2008 onward.

3.2 Relation of Variance Premiums and Macro-variables

Previous researchers, such as Bollerslev, Tauche and Zhou (2009) and Drechsler and Yaron (2011), argue that variance premium summarises information about economic uncertainty. We shows the correlation of variance premiums and several macro-economic variables in Table 2. IRSlope is the difference of yields between 10-Year treasure bills and 1-Year treasure bills. FFD is federal fund rate. CS is credit spread between Aaa bond and Baa bond. EcoUncertain is an index of economic uncertainty constructed by Baker, Bloom and Davis (2013).

Roughly speaking, the correlation of variance premiums and various macro-economic variables are around 20% - 30%. The correlation between yield curve slope and variance premiums are positive. The reason is that variance premium tend to be higher during period of crisis or recession, either due to higher investors' risk aversion or higher variance. During recession, the interest rate is low, therefore, the expected long-term interest rate will increase, predicting a positive relation between yield curve slope and variance premium. Following the same logic, the correlation of federal fund rate and variance premiums should be negative. During bad time, variance premium is high, while in order to stimulate economy, interest rate should be low, and federal fund rate is closely related to interest rate level. The correlation between default spread and varianc premium is positive, because during recession, low rating firms tend to have greater probability of default than high rating firms.

Finally, correlation between economic policy and variance premium is positive, because during recession, the uncertainty of government policy is also high.

Further analysis uses these variables to predict future future variance premium of different horizons. The results, use 1-day-lag economic variables, are shown in Table 3. The overall R^2 is around 15%, coefficient for economic uncertainty is always significant at least at 5% level, while coefficients of other three variables are significant for variance premium with longer horizons. The sign is consistent with correlation and analysis just mentioned above. When the 1-day-lag variance premium of the same horizon is included as an explanatory variable, it wipes out all the significance of macro variables, and the R^2 is high, which means that variance premium is high persistent and contains information about macro economic environment.

3.3 Prediction Power

In this section, the prediction power of variance premium and its term structure for future index returns are examined, results in Table 4 are similar with those in Table 2 of Bollerslev, Tauchen and Zhou (2009). There are several phenomenons worth some discussions. First of all, consistent with literature, Panel A. shows that 1-month variance premium does have certain prediction power for returns of various horizons, and such power reaches its peak on quarterly and semi-annually prediction. To better appreciate such predictability, according to regression analysis in Bollerslev, Tachen and Zhou (2009), in quarterly regression, P/E ratio generate a $R^2 = 6.55\%$, P/D ratio generate a $R^2 = 4.19\%$, and CAY (Lettau and Ludvigson, 2001) generate a $R^2 = 18.15\%$. Thus, variance premium is an important factor for equity premium prediction, and the prediction power is at the same level with other popular factors.

Secondly, Panel B and C shed light on the relation between aggregate returns and aggregate variance. The theoretical relation is summarised in the following relation

$$\mathbf{E}(r_{t+1}|\mathcal{F}_t) = \alpha + \beta \mathbf{E}_t(\sigma^2_{t+1}|\mathcal{F}_t), \tag{24}$$

where r_{t+1} is return for market portfolio at time $t+1$, $\mathcal{F}_t$ is time t information set. σ^2_{t+1} is variance of market portfolio at time $t+1$. In a seminal paper, French et al. (1987) study the following regression equation for return-variance relation of aggregate market,

$$r_{m,t+1} - r_{f,t+1} = \gamma_0 + \gamma\sigma_t^2 + \epsilon, \tag{25}$$

where σ_t^2 is realized variance calculated from square of daily returns. However, the estimated γ is insignificant. Many other followers try to explain the puzzle and the real sign of return-variance relation. For instance, Glosten et al (1993) use GARCH-in-mean for variance dynamics, and get a significant negative γ. While Ghysels et al (2005) use a mixed data sampling (MIDAS) method to estimate the conditional variance of returns using daily return data, and get a significant positive γ.

There are three main reasons for these inconsistent regression results. Firstly, according to Merton (1973) ICAPM model, the univariate regression above suffers from omitted variable problem. Although Merton argues that, under certain conditions, the covariance component is negligible and the conditional expectation of the excess market return is proportional to its conditional variance, potential problem still exists. Secondly, the theoretical prediction is about expected returns and expected variance, while in the regressions, realized variance is used. Since expected risk-neutral variance is ready to get in the form of VIX, it is reasonable to check γ with VIX as a measure of variance. Moreover, realized variance calculated directly by square daily returns suffers from great measurement error, as is illustrated in Andersen et al. (2003). It is well known that measure error will drive estimation of parameters down to zero and insignificant.

Panel B in Table 4 uses one-month VIX as a regressor, the estimators of γ for different return horizons are all positive, although two out of 6 is insignificant, and the prediction power is greater for longer horizon. Panel C in Table 4 use one-month realized variance calculated from intraday returns as a regressor, in order to address the measurement error problem. The estimated γ for different horizons are all significant, while the sign changed from short horizon to long horizon. The prediction power for longer horizons are similar with that via VIX. Overall, results shows that long term return-variance relation, from 6 month to one year, is positive, however, the sign of such relation may change.

Besides, Table 4 shows that although 1-month variance premium is the difference between 1-month VIX and realized variance, it has superior prediction power, especially for short-term future returns. The possible reason is illustrated in Proposition 2.3, variance premium not only has information about latent stochastic factors, but has information of risk premium as well.

However, according to the model, one time series of variance premium cannot disentangle all kinds of information sources. Therefore, although 1-month variance premium can predict future returns, it use noisy information altogether. Provided that variance premium term structure is available, clean information for different sources can be obtained, then superior prediction power can be obtained. Hence, in the rest of this section, the prediction ability of variance premium term structure is studied.

Table 5 conducts univariate regression to examine prediction power of variance premium to future returns for different horizons. For one thing, short-term variance premiums have superior prediction than long-term ones. For another, short-term variance premium positively predict future returns, while long-term one negatively predict future returns. The intuition is as follows, when short-term variance premium (1-month VRP) is high, either due to high risk aversion of investors, or due to high variance, the near future uncertainty and risk premium should also be high, because of the persistence of stochastic variance dynamics. Then near future returns should be high. However, high long-term variance premium (12-month VRP) means deteriorative investment oppotunity in long future. Since stock price is the discount future cash flow, high long-term variance premium means less future cash flow and lower price now. As a summary, short-term risk factor positively predicts future returns, while long-term risk factor negatively predicts future returns within horizons studied in the paper.

Comparing Table 6 and Table 4, we can see the prediction power increase significantly when variance premium term structure are included. The general pattern about prediction is preserved. The peak is still at quarterly and semi-annually prediction. After conducting principle component analysis, the first four factors of variance premium term structure are extracted. As shown in Figure 2, the first four factors can explain 86% variations in the term structure, and R^2 is doubled for return prediction with horizons less than 6 months, up to 12.6%.

3.4 Robustness Check for Prediction Power

In this section, some robustness checks are conducted. First of all, one question needed to answer is that "Does the prediction power only appear due to 2008 crisis sample period?" As is known, one widely cited paper about volatility and cross section stock returns is the one from Ang, Hodrick, Xing and Zhang (2006). The authors demostrate that aggregated volatility risk is priced in cross section stock returns. However, recently, Anderson (2013) show that the significance of volatility as a risk factor only generate from 1987 cash in the sample of An et al. (2006). Since the sample period of our data is from 2001 - 2010, including the 2008 crisis, it is reasonable to doubt whether the prediction power only come from the crisis periods. Results in Table 7 and Table 8 eliminate such concerns. As is shown, the prediction power in period 2001 - 2007 is similar with results using whole sample. Actually, the prediction power is much more significant during the crisis period, which is interesting and is worth of further thinking.

Although realized variance calculated from high frequency data suppose to be more accurate, the large data set is not available for everyone and is not easy to handle with. Therefore, we examine whether the prediction results in Table 6 are still there by calculating realized variance using square of daily returns, which are more noisy. Table 9 uses realized variance calculated directly from daily index returns. the patterns are generally the same with variance premium calculated from intrady data, however, due to larger measurement error, R^2 decreases a little.

Since many papers study the information contained in term structure of implied volatility, and VIX is one kind of model-free implied volatility, it is natural to study the prediction power for equity index returns of term structure of VIX, as is done by Johnson (2011).

Besides, it is also interesting to consider the question whether variance premium has some other information than VIX term structure. Because if only factors of volatility and jumps are important for return prediction, VIX term structure along can generate similar prediction power as variance premium term structure.

In Table 10, a series univariate regression are conducted to see the prediction power from VIXs of different horizons along. Consistent with literature, there is almost no prediction powers from short-run and long-run VIX along. In most cases, especially for short-run horizon returns, R^2 is less than 1%.

Table 11 use a multivariate regression to study the prediction power of VIX term structure. There are two important results in this Table. First of all, comparing Table 11 and Table 10, we can see that term structure does matter. When considering VIX term structure, prediction power for all horizons are significantly improved. Secondly, comparing Table 11 and Table 6, we can see that for longer-horizon cases, the prediction power of VIX term structure is superior, compared to that of variance premium term structure. However, for short-horizon cases, the prediction power of variance premium term structure is much better than VIX term structure, which indicates that information contains in these two term structure are different. Similar with previous analysis, a principle component analysis is applied, and examine prediction power of first 4 factors, and replicate the prediction powers for returns of all horizons in Table 11.

Table 12 does one-step further by add 1-month variance premium. Comparing Table 12 and Table 6, we get similar level and patterns for return prediction. Moreover, comparing Table 12 and Table 11, we can see prediction power significantly improved for short horizon. In summary, results show that VIX along provides little prediction power, but VIX term structure has prediction powers. Moreover, variance premium has additional prediction power beyond VIX term structure.

As the last robustness check, variance premium calculated from VIX and realized variance is model free measure. Here we study the prediction power of variance premium using difference between Black-Scholes implied volatility and realized variance. Table 13 and Table 14 generate similar results with their model free counterpart.

4 Conclusions and Future Research Directions

Based on a series of analysis above, we know that consistent with literature, variance risk premium does have significant prediction power for index returns, especially for quarterly expected returns, and the R^2 is at the same level with other well-established factors, such as P/E ratio and P/D ratio.

Although variance premium is widely studied for both index option and return, we still know little about the structure of variance premiums for individual stocks. Hence the first direction of future research is to study the variance premiums of individual stocks, decomposing individual variance premium to seperate influence from systematic risk factors and firms fundamental characteristics. This empirical work is important. The reason is, usually for option pricing literature, we focus on index options to test various model, and we know little about the structure of option price for individual equities. Since variance premium directly influence option price, a better understanding will help us understand more about option prices for individual stocks.

The second direction is to figure out what the information contained in variance premium and how to use it. Although for now, common wisdoms prefer to regard variance premium as a proxy for macro economic uncertainty, for instance, Bollerslev, Tauchen and Zhou (2009) and other papers within the long-run risk models, Bollerslev, Gibson and Zhou (2011) shows that risk aversion time-series extracted from variance premium has superior prediction power than variance premium itself. This results means, compared to information of latent volatility or jump factors, variance premium may have much more information about time-changing risk aversion. Therefore, it is interesting to consider other kinds of models combining time-varying risk aversion and multi-factor models.

Moreover, as is shown, variance premium term structure can significantly improve predictions for future aggregate stock index returns, along certain horizons, the third direction is to build models to explain the sources of variance term structure and to use the information in empirical studies, just as empirical papers for interest rate term structure and credit spread term structure.

Last, but not the least, it may be interesting to link variance premium to behaviral models or heterogeneity in investors' beliefs. Han (2008) shows that investors' sentiment can affect index option prices, in terms of implied volatility curve. Buraschi et al. (2013) build an equilibrium link between investors' disagreement, the market price of volatility and correlation, and the differential pricing of index and individual equity options. Chen et al. (2012) also derive a affine heterogenous belief framework and show that investors disagreement about disastors afffect their risk sharing behaviors.

As a summary, at the bottom line, since variance premium contains investors' attitude towards one of the most important factors for asset pricing, stochastic volatility, the studies about it can link several areas together, for instance, pricing kernel modeling, asset pricing with multi risk factors, effect of rare disasters and behaviral finance, which could be fruitful.

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5 Tables

Table 1: **Summary Statistics for Variance Risk Premiums**

Summary statistics for daily variance premiums with different horizons. VPxM means variance premium with x-month horizon. The sample period is from January, 2001 to December, 2010.

	VP1M	VP2M	VP3M	VP6M	VRP9M	VRP12M
Min.	-0.31680	-0.13400	-0.16500	-0.07062	-0.07921	-0.05576
1st Qu.	0.00816	0.00958	0.01098	0.01176	0.01216	0.01169
Median	0.01614	0.01810	0.01885	0.01793	0.01709	0.01689
Mean	0.02184	0.02299	0.02301	0.02234	0.02135	0.02104
3rd Qu.	0.03068	0.03168	0.03183	0.02984	0.02877	0.02700
Max.	0.26380	0.18510	0.18890	0.22460	0.21190	0.18890
SD	0.02926	0.02469	0.02349	0.02225	0.02504	0.02634
t value	36.05	45.00	47.34	48.50	41.19	38.58

Table 2: **Correlation of Variance Premiums and Macro Economic Variables**

Correlation of daily variance premiums with different horizons and macrovariables. VPxM means variance premium with x-month horizon. IRSlope, the difference of yields between 10-Year treasure bills and 1-Year treasure bills; FFD, federal fund rate; CS, credit spread between Aaa bond and Baa bond; EcoUncertain, an index of economic uncertainty (EPU) constructed by Baker, Bloom and Davis (2013). The sample period is from January, 2001 to December, 2010.

	IRSlope	FFD	CS	EcoUncertain
VP1M	0.2760	-0.2842	0.2821	0.2799
VP2M	0.3362	-0.3172	0.2010	0.3583
VP3M	0.3320	-0.2987	0.1062	0.3276
VP6M	0.2382	-0.2391	0.0482	0.2515
VP9M	0.0998	-0.1618	0.1623	0.2729
VP12M	0.0225	-0.1087	0.3126	0.2949

Table 3: **Prediction of Variance Premiums**

Prediction variance premium term structure. $VP_{t,\tau} = \alpha + \beta' X_{t-1} + \epsilon_t$, VP$x$M means variance premium with x-month horizon. X are control variables, Panel A, uses only macro variables, IRSlope, the difference of yields between 10-Year treasure bills and 1-Year treasure bills; FFD, federal fund rate; CS, credit spread between Aaa bond and Baa bond; EcoUncertain, an index of economic uncertainty (EPU) constructed by Baker, Bloom and Davis (2013). Panel B.use macrovariables and laged variance premium with same horizon. The sample period is from January, 2001 to December, 2010.

	VP1M	VP2M	VP3M	VP6M	VP9M	VP12M
Panel A: laged macro-variables						
IRSlope	0.404*	0.555*	0.59*	0.012	-0.765*	-0.917*
	(0.12)	(0.099)	(0.095)	(0.093)	(0.105)	(0.106)
FFD	0.047	0.126	0.137	-0.271*	-0.708*	-0.618*
	(0.104)	(0.085)	(0.082)	(0.08)	(0.09)	(0.091)
CS	0.938*	0.198	-0.272*	-0.549*	-0.076	0.921*
	(0.127)	(0.105)	(0.1)	(0.098)	(0.11)	(0.112)
EcoUncertain	0.005*	0.008*	0.008*	0.006*	0.008*	0.008*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.135	0.173	0.167	0.101	0.099	0.163
Panel B: laged macro-variables and laged variance premium						
LagVP	0.8*	0.86*	0.912*	0.957*	0.981*	0.986*
	(0.013)	(0.011)	(0.009)	(0.006)	(0.004)	(0.004)
IRSlope	0.055	0.051	0.045	0.016	-0.004	-0.011
	(0.073)	(0.052)	(0.04)	(0.027)	(0.022)	(0.02)
FFD	-0.018	-0.011	0.002	-0.004	-0.011	-0.011
	(0.062)	(0.044)	(0.034)	(0.023)	(0.019)	(0.017)
CS	0.172*	0.01	-0.057	-0.051	-0.039	-0.025
	(0.077)	(0.054)	(0.042)	(0.029)	(0.023)	(0.021)
EcoUncertain	0.001	0.001	0.001*	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)
R^2	0.685	0.777	0.857	0.924	0.962	0.972

Table 4: **Prediction Power of 1-month Variance Premium**

Return prediction. $R_{t,\tau} = \alpha + \beta X_t + \epsilon_t$. R$x$M means x-month future returns. X are control variables, Panel A. uses 1-month variance premium. Panel B. uses 1- month VIX. Panel C. uses one month realized variance. All the variables are calculated at day t. The sample period is from January, 2001 to December, 2010.

	R1M	R2M	R3M	R6M	R9M	R12M
Panel A: 1-month variance premium as regressor.						
VRP1M	0.314*	0.419*	0.716*	0.949*	1.095*	1.139*
	(0.038)	(0.053)	(0.065)	(0.1)	(0.126)	(0.144)
R^2	0.029	0.026	0.05	0.037	0.032	0.026
Panel A: 1-month VIX as regressor.						
VIX1M	0.02	0.052*	0.031	0.25*	0.422*	0.554*
	(0.015)	(0.021)	(0.026)	(0.039)	(0.049)	(0.058)
R^2	0	0.002	0	0.011	0.019	0.024
Panel A: 1-month realized variance as regressor.						
RV1M	-0.073*	-0.088*	-0.199*	0.052	0.323*	0.55*
	(0.018)	(0.025)	(0.031)	(0.047)	(0.059)	(0.067)
R^2	0.007	0.005	0.018	0.001	0.013	0.028

Table 5: **Prediction Power of Variance Premium**

Return prediction. $R_{t,\tau_R} = \alpha + \beta VRP_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. VPxM means variance premium with x-month horizon. All the variables are calculated at day t. The sample period is from January, 2001 to December, 2010. The regression is univariate regression, every panel has results for return prediction power of variance premium with one particular horizon.

	R1M	R2M	R3M	R6M	R9M	12M
VP1M	0.314*	0.419*	0.716*	0.949*	1.095*	1.139*
	(0.038)	(0.053)	(0.065)	(0.1)	(0.126)	(0.144)
R^2	0.029	0.026	0.05	0.037	0.032	0.026
VP2M	0.261*	0.696*	1.027*	1.064*	1.103*	1.088*
	(0.045)	(0.062)	(0.076)	(0.119)	(0.149)	(0.172)
R^2	0.014	0.051	0.073	0.033	0.023	0.017
VP3M	0.447*	0.918*	0.899*	0.947*	0.898*	0.866*
	(0.047)	(0.064)	(0.081)	(0.126)	(0.158)	(0.181)
R^2	0.038	0.08	0.051	0.024	0.014	0.01
VP6M	-0.028	-0.114	-0.463*	-0.41*	-0.354*	-0.277
	(0.05)	(0.071)	(0.087)	(0.134)	(0.168)	(0.192)
R^2	0	0.001	0.012	0.004	0.002	0.001
VP9M	-0.142*	-0.322*	-0.622*	-0.423*	-0.182	-0.122
	(0.045)	(0.063)	(0.077)	(0.119)	(0.149)	(0.171)
R^2	0.004	0.011	0.028	0.005	0.001	0
VP12M	-0.177*	-0.349*	-0.575*	-0.208	0.124	0.019
	(0.042)	(0.059)	(0.073)	(0.113)	(0.142)	(0.163)
R^2	0.007	0.015	0.026	0.001	0	0

Table 6: **Return Prediction via Variance Premium Term Structure**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VRP}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VRP}_{t,\tau_V}$ is a vector of variance premium with x-month horizon (VPxM). All the variables are calculated at day t. The sample period is from January, 2001 to December, 2010. Panel A. uses all time series data of variance premium term structure. Panel B. uses first four factors extracted of the term structure via PCA.

	R1M	R2M	R3M	R6M	R9M	R12M
Panel A: variance premium term structure						
VP1M	0.614*	0.292*	0.349*	0.845*	1.036*	1.175*
	(0.059)	(0.081)	(0.101)	(0.16)	(0.202)	(0.234)
VP2M	-1.19*	-0.739*	0.148	-0.544	-0.551	-0.599
	(0.108)	(0.15)	(0.185)	(0.294)	(0.372)	(0.429)
VP3M	1.279*	1.713*	0.97*	1.346*	1.169*	1.038*
	(0.097)	(0.134)	(0.166)	(0.264)	(0.333)	(0.385)
VP6M	-0.384*	-0.631*	-0.662*	-0.808*	-0.946*	-0.999*
	(0.088)	(0.122)	(0.151)	(0.24)	(0.303)	(0.35)
VP9M	0.079	-0.014	-0.19	-0.735*	-0.808*	-0.005
	(0.118)	(0.164)	(0.202)	(0.322)	(0.407)	(0.47)
VP12M	-0.248*	-0.291*	-0.32*	0.502*	0.965*	0.221
	(0.089)	(0.123)	(0.152)	(0.242)	(0.305)	(0.353)
R^2	0.109	0.133	0.129	0.064	0.047	0.032
Panel B: factors extracted from variance premium term structure.						
PCVRP1	-0.107*	-0.188*	-0.188*	-0.33*	-0.445*	-0.448*
	(0.025)	(0.034)	(0.042)	(0.067)	(0.084)	(0.097)
PCVRP2	0.284*	0.551*	0.885*	0.82*	0.717*	0.731*
	(0.031)	(0.042)	(0.051)	(0.082)	(0.103)	(0.119)
PCVRP3	-0.13*	-0.564*	-0.241*	0.239	0.667*	0.659*
	(0.055)	(0.075)	(0.092)	(0.147)	(0.185)	(0.213)
PCVRP4	0.166*	-0.37*	-0.468*	-0.655*	-0.848*	-0.391
	(0.081)	(0.11)	(0.134)	(0.214)	(0.27)	(0.311)
R^2	0.046	0.103	0.126	0.056	0.041	0.029

Table 7: **Return Prediction via Variance Premium Term Structure: 2001-2007**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VRP}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VRP}_{t,\tau_V}$ is a vector of variance premium with x-month horizon (VPxM). All the variables are calculated at day t. The sample period is from January, 2001 to December, 2007.

(Intercept)	-0.002	-0.006	-0.003	0.038*	0.061*	0.087*
	(0.002)	(0.003)	(0.004)	(0.005)	(0.007)	(0.009)
VP1M	-0.477*	0.464*	-0.192	-0.304	-0.269	0.543
	(0.114)	(0.158)	(0.195)	(0.268)	(0.352)	(0.487)
VP2M	2.245*	0.492	0.358	1.497*	1.064	0.67
	(0.234)	(0.323)	(0.399)	(0.547)	(0.718)	(0.995)
VP3M	-2.323*	-1.316*	0.224	-0.18	0.429	-0.27
	(0.265)	(0.366)	(0.453)	(0.62)	(0.814)	(1.128)
VP6M	1.842*	2.23*	1.902*	0.549	-2.132*	-2.411*
	(0.251)	(0.347)	(0.429)	(0.588)	(0.772)	(1.07)
VP9M	-0.401	0.453	0.413	-2.284*	-0.91	0.036
	(0.332)	(0.46)	(0.568)	(0.778)	(1.022)	(1.416)
VP12M	-0.685*	-1.894*	-2.464*	-0.865	-0.764	-2.995*
	(0.239)	(0.331)	(0.409)	(0.56)	(0.736)	(1.019)
R^2	0.101	0.086	0.082	0.067	0.044	0.06

Table 8: **Prediction Power of Variance Premium Term Structure: 2008-2010**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VRP}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VRP}_{t,\tau_V}$ is a vector of variance premium with x-month horizon (VPxM). All the variables are calculated at day t. The sample period is from January, 2008 to December, 2010.

	R1M	R2M	R3M	R6M	R9M	R12M
(Intercept)	-0.006	-0.02*	-0.027*	-0.062*	-0.09*	-0.069*
	(0.004)	(0.006)	(0.008)	(0.013)	(0.016)	(0.016)
VP1M	0.871*	0.311*	0.486*	1.124*	1.401*	1.393*
	(0.082)	(0.12)	(0.15)	(0.261)	(0.32)	(0.322)
VP2M	-1.756*	-0.819*	0.204	-0.329	0.108	0.234
	(0.152)	(0.222)	(0.276)	(0.48)	(0.59)	(0.594)
VP3M	1.711*	1.941*	1.031*	1.405*	1.045*	0.871
	(0.13)	(0.189)	(0.236)	(0.41)	(0.503)	(0.507)
VP6M	-0.622*	-0.766*	-0.698*	-0.491	-0.113	-0.179
	(0.121)	(0.176)	(0.22)	(0.382)	(0.469)	(0.472)
VP9M	0.16	-0.107	-0.326	-0.84	-1.196	-0.431
	(0.157)	(0.229)	(0.285)	(0.496)	(0.609)	(0.614)
VP12M	-0.242*	-0.086	-0.049	0.855*	1.464*	0.821
	(0.119)	(0.174)	(0.216)	(0.375)	(0.461)	(0.465)
R^2	0.257	0.226	0.211	0.113	0.116	0.106

Table 9: **Return Prediction via Variance Premium Term Structure**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VRP}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VRP}_{t,\tau_V}$ is a vector of variance premium with x-month horizon (VPxM). Realized variance is calculated as square of daily returns. The sample period is from January, 2001 to December, 2010. Panel A. uses all time series data of variance premium term structure. Panel B. uses first four factors extracted of the term structure via PCA.

	R1M	R2M	R3M	R6M	R9M	R12M
Panel A: variance premium term structure						
VP1M	-0.367*	-0.256*	-0.367*	-0.534*	-0.46*	-0.353*
	(0.037)	(0.052)	(0.062)	(0.098)	(0.125)	(0.149)
VP2M	0.676*	0.398*	-0.005	0.311	0.502*	0.473
	(0.069)	(0.096)	(0.115)	(0.182)	(0.232)	(0.276)
VP3M	-0.769*	-0.961*	-0.665*	-0.71*	-0.8*	-0.575*
	(0.062)	(0.086)	(0.103)	(0.163)	(0.208)	(0.247)
VP6M	0.126*	0.181*	0.215*	0.255	0.672*	0.883*
	(0.053)	(0.074)	(0.089)	(0.14)	(0.179)	(0.212)
VP9M	0.105	0.25*	0.283*	0.735*	0.503*	-0.138
	(0.074)	(0.102)	(0.123)	(0.194)	(0.248)	(0.294)
VP12M	-0.034	-0.097	-0.084	-0.607*	-0.615*	-0.069
	(0.059)	(0.081)	(0.098)	(0.155)	(0.197)	(0.234)
R^2	0.068	0.09	0.104	0.038	0.019	0.009
Panel B: factors extracted from variance premium term structure.						
PCVRP1	0.159*	0.31*	0.426*	0.319*	0.148*	0.002
	(0.016)	(0.021)	(0.025)	(0.04)	(0.051)	(0.061)
PCVRP2	-0.083*	-0.176*	-0.343*	-0.326*	-0.304*	-0.294*
	(0.019)	(0.025)	(0.031)	(0.048)	(0.061)	(0.073)
PCVRP3	0.067	0.262*	0.083	-0.184*	-0.278*	-0.282*
	(0.034)	(0.047)	(0.056)	(0.089)	(0.113)	(0.134)
PCVRP4	-0.051	0.199*	0.242*	0.362*	0.639*	0.518*
	(0.051)	(0.069)	(0.083)	(0.131)	(0.167)	(0.198)
R^2	0.033	0.075	0.101	0.031	0.014	0.007

Table 10: **Return Prediction via VIX**

Return prediction. $R_{t,\tau_R} = \alpha + \beta VIX_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. VIXxM means variance premium with x-month horizon. All the variables are calculated at day t. The sample period is from January, 2001 to December, 2010. The regression is univariate regression, every panel has results for return prediction power of VIX with one particular horizon.

	R1M	R2M	R3M	R6M	R9M	R12M
VIX1M	0.02	0.052*	0.031	0.25*	0.422*	0.554*
	(0.015)	(0.021)	(0.026)	(0.039)	(0.049)	(0.058)
R^2	0	0.002	0	0.011	0.019	0.024
VIX2M	0.029	0.065*	0.055	0.337*	0.537*	0.667*
	(0.017)	(0.024)	(0.029)	(0.044)	(0.055)	(0.065)
R^2	0.001	0.002	0.001	0.016	0.025	0.028
VIX3M	0.038*	0.084*	0.085*	0.423*	0.643*	0.762*
	(0.019)	(0.026)	(0.031)	(0.047)	(0.06)	(0.07)
R^2	0.001	0.003	0.002	0.021	0.03	0.031
VIX6M	0.062*	0.131*	0.151*	0.593*	0.822*	0.912*
	(0.021)	(0.03)	(0.036)	(0.055)	(0.069)	(0.081)
R^2	0.002	0.005	0.005	0.031	0.037	0.033
VIX9M	0.061*	0.135*	0.173*	0.668*	0.912*	1.001*
	(0.024)	(0.033)	(0.04)	(0.06)	(0.076)	(0.09)
R^2	0.002	0.005	0.005	0.032	0.037	0.032
VIX12M	0.054*	0.12*	0.158*	0.671*	0.871*	0.927*
	(0.025)	(0.035)	(0.042)	(0.063)	(0.08)	(0.094)
R^2	0.001	0.003	0.004	0.029	0.031	0.025

Table 11: **Return Prediction via VIX Term Structure**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VIX}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VIX}_{t,\tau_V}$ is a vector of variance premium with x-month horizon (VIXxM). The sample period is from January, 2001 to December, 2010. Panel A. uses all time series data of VIX term structure. Panel B. uses first four factors extracted of the term structure via PCA.

	R1M	R2M	R3M	R6M	R9M	R12M
Panel A: VIX term structure						
VIX1M	0.025	0.469*	0.37	0.239	-0.092	0.015
	(0.134)	(0.185)	(0.224)	(0.336)	(0.424)	(0.505)
VIX2M	-0.58*	-1.755*	-2.016*	-2.994*	-3.026*	-2.172*
	(0.271)	(0.374)	(0.454)	(0.68)	(0.859)	(1.023)
VIX3M	-0.291	-0.384	-0.316	-0.324	0.448	0.396
	(0.219)	(0.302)	(0.367)	(0.55)	(0.694)	(0.827)
VIX6M	2.124*	3.62*	3.67*	6.428*	6.053*	3.705*
	(0.279)	(0.386)	(0.469)	(0.702)	(0.887)	(1.057)
VIX9M	-0.122	0.451	1.507*	1.629*	4.266*	6.419*
	(0.283)	(0.391)	(0.475)	(0.711)	(0.898)	(1.07)
VIX12M	-1.129*	-2.303*	-3.031*	-4.29*	-6.875*	-7.6*
	(0.2)	(0.276)	(0.335)	(0.502)	(0.634)	(0.755)
R^2	0.023	0.042	0.044	0.077	0.078	0.059
Panel B: factors extracted from VIX term structure.						
PC1	0.002*	0.004*	0.004*	0.019*	0.029*	0.034*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC2	-0.002*	-0.004*	-0.008*	-0.019*	-0.016*	-0.007*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC3	0.002*	0.002	0.004*	0.007*	0.015*	0.015*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC4	0.006*	0.012*	0.015*	0.023*	0.029*	0.028*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
R^2	0.019	0.035	0.041	0.073	0.075	0.056

Table 12: **Return Prediction via VIX Term Structure + Variance Premium**

Return prediction. $R_{t,\tau} = \alpha + \beta' PCx + \gamma VP1M + \epsilon_t$. R$x$M means x-month future returns. PCx is a vector of factors extracted from VIX term structure. $VP1M$ is 1-month variance premium. The sample period is from January, 2001 to December, 2010.

	R1M	R2M	R3M	R6M	R9M	R12M
PC1	0.005*	0.009*	0.011*	0.027*	0.035*	0.04*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC2	0	0	-0.002	-0.013*	-0.011*	-0.003
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC3	0.002*	0.002	0.003*	0.007*	0.015*	0.015*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
PC4	0.006*	0.013*	0.015*	0.023*	0.029*	0.028*
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.003)
VP1M	-0.261*	-0.441*	-0.706*	-0.697*	-0.578*	-0.497*
	(0.024)	(0.033)	(0.039)	(0.06)	(0.076)	(0.092)
R^2	0.049	0.08	0.118	0.105	0.089	0.064

Table 13: **Return Prediction via Variance Spread**

Return prediction. $R_{t,\tau_R} = \alpha + \beta VS_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. VSxM means variance spread with x-month horizon. All the variables are calculated at day t. The sample period is from January, 2001 to December, 2010. The regression is univariate regression, every panel has results for return prediction power of variance spread with one particular horizon.

	R1M	R2M	R3M	R6M	R9M	R12M
VS1M	0.381*	0.454*	0.785*	0.779*	0.638*	0.463*
	(0.038)	(0.054)	(0.066)	(0.103)	(0.129)	(0.148)
R^2	0.04	0.029	0.056	0.024	0.01	0.004
VS2M	0.333*	0.741*	1.124*	0.667*	0.229	-0.052
	(0.046)	(0.064)	(0.078)	(0.123)	(0.155)	(0.178)
R^2	0.021	0.053	0.081	0.012	0.001	0
VS3M	0.481*	0.892*	0.873*	0.297*	-0.311	-0.56*
	(0.047)	(0.066)	(0.082)	(0.129)	(0.161)	(0.184)
R^2	0.042	0.072	0.045	0.002	0.002	0.004
VS6M	-0.085	-0.296*	-0.736*	-1.606*	-2.236*	-2.421*
	(0.055)	(0.077)	(0.094)	(0.142)	(0.176)	(0.202)
R^2	0.001	0.006	0.025	0.051	0.064	0.057
VS9M	-0.256*	-0.606*	-1.089*	-1.622*	-1.889*	-2.031*
	(0.052)	(0.072)	(0.088)	(0.134)	(0.168)	(0.194)
R^2	0.01	0.029	0.061	0.058	0.05	0.044
VS12M	-0.314*	-0.651*	-1.064*	-1.267*	-1.337*	-1.581*
	(0.05)	(0.07)	(0.085)	(0.132)	(0.166)	(0.189)
R^2	0.016	0.035	0.062	0.037	0.027	0.028

Table 14: **Return Prediction via Variance Spread Term Structure**

Return prediction. $R_{t,\tau_R} = \alpha + \beta' \underline{VS}_{t,\tau_V} + \epsilon_t$. R$x$M means x-month future returns. $\underline{VS}_{t,\tau_V}$ is a vector of variance spread with x-month horizon (VPxM). The sample period is from January, 2001 to December, 2010. Panel A. uses all time series data of variance premium term structure. Panel B. uses first four factors extracted of the term structure via PCA.

	1M	2M	3M	6M	9M	12M
Panel A: variance spread term structure						
VS1M	0.684*	0.38*	0.317*	0.788*	0.846*	0.827*
	(0.057)	(0.08)	(0.098)	(0.155)	(0.194)	(0.224)
VS2M	-1.302*	-0.904*	0.16	-0.978*	-1.227*	-1.577*
	(0.111)	(0.156)	(0.191)	(0.301)	(0.379)	(0.436)
VS3M	1.385*	1.735*	0.873*	1.346*	1.113*	1.192*
	(0.099)	(0.138)	(0.169)	(0.267)	(0.336)	(0.387)
VS6M	-0.453*	-0.782*	-0.765*	-1.546*	-2.115*	-2.407*
	(0.088)	(0.124)	(0.151)	(0.239)	(0.301)	(0.346)
VS9M	0.106	-0.003	-0.186	-0.513	-0.411	0.118
	(0.119)	(0.167)	(0.205)	(0.324)	(0.407)	(0.469)
VS12M	-0.292*	-0.387*	-0.518*	-0.268	-0.249	-0.869*
	(0.092)	(0.129)	(0.158)	(0.249)	(0.314)	(0.361)
R^2	0.124	0.136	0.146	0.092	0.079	0.07
Panel B: factors extracted from variance spread term structure.						
PCVS1	-0.316*	-0.53*	-0.766*	-0.582*	-0.336*	-0.182
	(0.028)	(0.039)	(0.047)	(0.074)	(0.094)	(0.108)
PCVS2	0.101*	0.251*	0.564*	1.01*	1.307*	1.475*
	(0.033)	(0.045)	(0.055)	(0.086)	(0.109)	(0.125)
PCVS3	-0.081	-0.482*	-0.306*	0.18	0.568*	0.487*
	(0.051)	(0.07)	(0.085)	(0.134)	(0.168)	(0.194)
PCVS4	0.128	-0.375*	-0.448*	-0.725*	-0.968*	-0.758*
	(0.079)	(0.108)	(0.13)	(0.206)	(0.259)	(0.299)
R^2	0.055	0.104	0.144	0.082	0.072	0.061

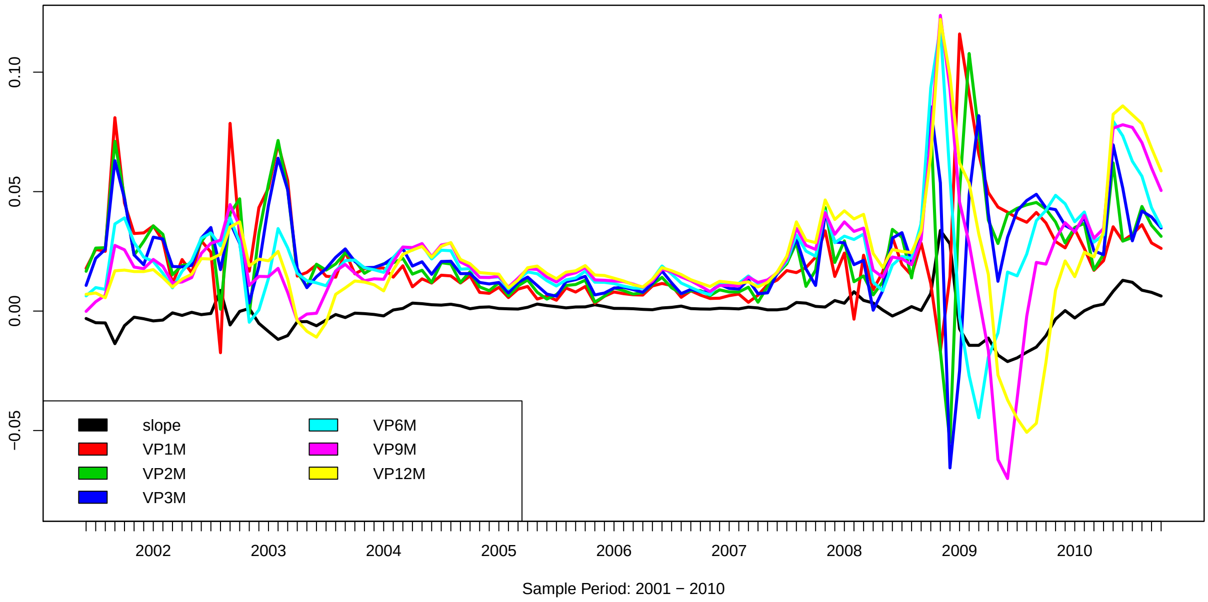

Figure 1: Time Series of Variance Premiums with Different Horizons

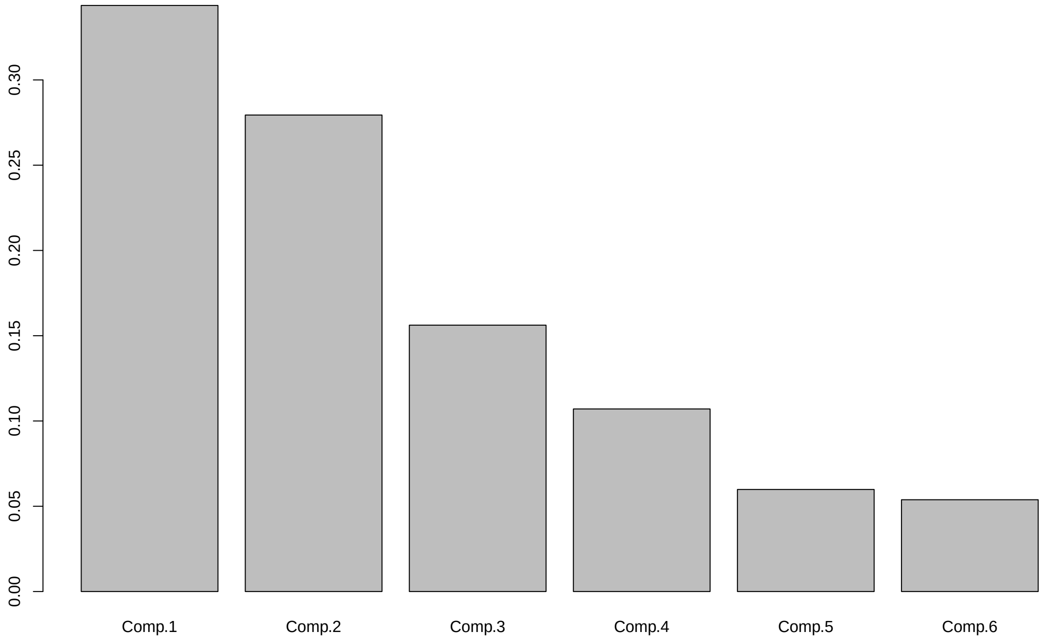

Figure 2: Principle Component Analysis for Variance Premium Term Structure