Stochastic Economic Uncertainty, Asset Predictability Puzzles, and Monetary Policy Target*

Hao Zhou†
Federal Reserve Board

January 2009

Abstract

Motivated by the implications from a stylized self-contained general equilibrium model incorporating the effects of time-varying economic uncertainty (Tauchen, 2005; Bollerslev, Tauchen, and Zhou, 2008), I show that variance risk premium, or the difference between implied variance and realized variance, can be used to back out the unobserved economic uncertainty risk. Such an "observable" economic uncertainty risk measure has important implications for the short term predictability in equity returns, bond returns, forward premiums, and credit spreads. Stochastic economic uncertainty has important implications for the conduct of monetary policy, especially during the recent credit-liquidity crisis.

JEL classification: G12, G13, G14.
Keywords: Stochastic economic uncertainty, variance risk premia, monetary policy target, long-run risk, external habit, recursive preference.

*__Preliminary and incomplete. Comments are welcome.__ I benefited greatly from the helpful discussions with Ravi Bansal, Tim Bollerslev, David Bowman, Mike Gibson, Michael Gordy, Jinill Kim, Sydney Ludvigson, George Tauchen, and Jonathan Wright. Paul Reverdy provided excellent research assistance. The views presented here are solely those of the authors and do not necessarily represent those of the Federal Reserve Board or its staff.

†Risk Analysis Section, Federal Reserve Board, Mail Stop 91, Washington DC 20551 USA, E-mail hao.zhou@frb.gov, Phone 202-452-3360, Fax 202-728-5887.

Stochastic Economic Uncertainty, Return Predictability Puzzles, and Monetary Policy Target

Abstract

Motivated by the implications from a stylized self-contained general equilibrium model incorporating the effects of time-varying economic uncertainty (Tauchen, 2005; Bollerslev, Tauchen, and Zhou, 2008), I show that variance risk premium, or the difference between implied variance and realized variance, can be used to back out the unobserved economic uncertainty risk. Such an "observable" economic uncertainty risk measure has important implications for the short term predictability in equity returns, bond returns, forward premiums, and credit spreads. Stochastic economic uncertainty has important implications for the conduct of monetary policy, especially during the recent credit-liquidity crisis.

JEL classification: G12, G13, G14.

Keywords: Stochastic economic uncertainty, variance risk premia, monetary policy target, long-run risk, external habit, recursive preference.

1 Introduction

Wall Street Journal, November 12, 2008, Money & Investment Section:

> *In the last five weeks, the Chicago Board Option Exchange's volatility index, or the VIX, has closed above 50 on every single day with the exception of one, and should it continue, threatens to match the kind of volatility in markets not seen since the* **Great Depression***.....there are so many things that we really don't know, and all those unknowns are a greater cloud of what we call* **uncertainty***.....*

Difference between implied volatility (VIX) and realized volatility has been interpreted as an indicator of time-varying risk aversion (Bollerslev, Gibson, and Zhou, 2004). An alternative interpretation is that the implied-realized variance difference, or variance risk premium, is due to time-varying economic uncertainty. In a recent paper, we developed a methodology to implement this alternative interpretation (Bollerslev, Tauchen, and Zhou, 2008). We show that under the Epstein and Zin (1991) and Weil (1989) recursive utility function, both consumption volatility risk and stochastic economic uncertainty risks command time-varying risk premia, which otherwise would not be priced under the usual time-separable expected utility framework.[1] This approach follows the spirit of long-run risks models as pioneered by Bansal and Yaron (2004), which have been shown to be able to resolve various asset pricing puzzles.

Our approach emphasis the role time-varying economic uncertainty in financial markets, which behaves quite differently comparing with the external habit variable in Campbell and Cochrane (1999) and the long-run risk component in Bansal and Yaron (2004). In particular, our model shuts down the the long-run component in consumption growth, and attributes all the time-variation in risk premia to the consumption volatility and volatility-of-volatility processes. Such an approach to the high degree of time-varying risk premia also distinguishes us from the literature of introducing agent learning and information or model uncertainty into the long-run risk models. In our model, the higher order time-variation in financial market

[1] Unless there is an assumed statistical linkage between the uncertainty risk factors and the consumption growth rate, power utility function will not generate endogenous uncertainty risk premia.

risk premia is achieved by introducing the a stochastic volatility-of-volatility component as a priced fundamental risk factor. See Zhou (2006) for a general discussion of the asset pricing implications for such a modeling approach.

Economic uncertainty and its impact on asset prices can be dealt with under a variety of different techniques within the general framework of recursive preference. One novel approach, advocated by Bansal and Shaliastovich (2008); Shaliastovich (2008), is to introduce learning and information uncertainty into the long-run risk model, such that endogenously asset return have jumps and requires compensation for the *endogenous* jump risks, even though the underlying consumption endowment dynamics entertain no jumps at all. On the other hand, Chen and Pakos (2008) models the growth rate of endowment as a Markov switching process with constant consumption volatility, where learning brings about an *endogenous* uncertainty premium, which is absent in typical learning-based asset pricing models. Ai (2008) discusses the welfare implications for learning and information uncertainty of a long-run risk production model. In contrast, Drechsler (2008) combines the Knightian uncertainty on model misspecification with realistic dynamics of long-run risk, jump risk, and stochastic volatility to explain the pronounced variance risk premium and option pricing puzzles. The implications of information quality for the cross-sectional pattern of stock returns are examined by Croce, Lettau, and Ludvigson (2006) among others. Finally, Lettau, Ludvigson, and Wachter (2008) use a Markov switching learning model to describe the long horizon changes in constant consumption volatility—Great Moderation—and to draw important implications for equity risk premiums.

In this paper, we try to model the economic uncertainty and interpret its asset pricing implications without relying on the assumptions of information quality, agent learning, or model uncertainty. Instead, we focus on the rich dynamics of the consumption volatility and the volatility-of-volatility processes. The key insight to this approach is that the difference between model-free risk-neutral implied variance and model-free high-frequency realized variance is able to pin down the stochastic volatility of economic uncertainty, which otherwise could not be accurately measured without high quality derivatives market data (Drechsler and Yaron, 2008). One important implication is that monetary policy decision should be,

or may have already been, targeting the difference between implied and realized variances of financial market, which reveal the fundamental uncertainty risk of the underlying real economy. In future revision of this paper, I will describe the rich dynamics of the underlying economic uncertainty, and conduct a more comprehensive comparison with the traditional Taylor Rule, which targets output gap and inflation rate.

The rest of the paper will be organized as the following, the next section briefly describes the general equilibrium model of stochastic economic uncertainty, and then derives the critical restrictions on the difference between implied and realized variances; Section 3 presents the implementation strategy based on high quality options market data (VIX) and high-frequency equity market return data. The following section relates the model implied risk measure of economic uncertainty to the Federal Funds Rate (FFR)—monetary policy target, and Section 5 concludes.

2 An Equilibrium Model of Economic Uncertainty

To begin with, suppose that the geometric growth rate of consumption in the economy, $g_{t+1} = \log(C_{t+1}/C_t)$, is unpredictable,

$$g_{t+1} = \mu_g + \sigma_{g,t} z_{g,t+1}, \tag{1}$$

where μ_g denotes the constant mean growth rate, $\sigma_{g,t}$ refers to the conditional volatility of the growth rate, and $\{z_{g,t}\}$ is an i.i.d. $\mathrm{N}(0,1)$ innovation process. Further, assume that the economic uncertainty or the consumption volatility process is governed by the following discrete-time stochastic volatility process

$$\sigma^2_{g,t+1} = a_\sigma + \rho_\sigma \sigma^2_{g,t} + \sqrt{q_t} z_{\sigma,t+1}, \tag{2}$$

$$q_{t+1} = a_q + \rho_q q_t + \varphi_q \sqrt{q_t} z_{q,t+1}, \tag{3}$$

where the parameters satisfy $a_\sigma > 0, a_q > 0$, $|\rho_\sigma| < 1, |\rho_q| < 1$, $\varphi_q > 0$, and $\{z_{\sigma,t}\}$ and $\{z_{q,t}\}$ are i.i.d. $\mathrm{N}(0,1)$ processes jointly independent of $\{z_{g,t}\}$. The stochastic volatility process $\sigma^2_{g,t+1}$ represents time-varying economic uncertainty in consumption growth, with the

volatility-of-volatility process q_t in effect inducing an additional source of temporal variation in that uncertainty process. Both processes play a crucial role in generating the time varying volatility risk premia discussed below, with the uncertainty volatility risk q_t driving the variance risk premia and having implications for monetary policy target.

We assume that the representative agent in the economy is equipped with Epstein-Zin-Weil recursive preferences. Consequently, the logarithm of the intertemporal marginal rate of substitution, $m_{t+1} \equiv \log(M_{t+1})$, may be expressed as,

$$m_{t+1} \;=\; \theta \log \delta - \theta \psi^{-1} g_{t+1} + (\theta - 1) r_{t+1}, \tag{4}$$

where

$$\theta \;\equiv\; (1-\gamma)(1-\psi^{-1})^{-1}, \tag{5}$$

δ denotes the subjective discount factor, ψ equals the intertemporal elasticity of substitution, γ refers to the coefficient of risk aversion, and r_{t+1} is the time t to $t+1$ return on the consumption asset. We will maintain the key assumptions that $\gamma > 1$, implying that the agents are more risk averse than the log utility investor; and $\psi > 1$, which in turn implies that $\theta < 0$ and that agents prefer an earlier resolution of economic uncertainty. These restrictions ensure, among other things, that uncertainty and its variation carry positive risk premia.

It is now relatively straightforward to deduce the reduced form expressions for other variables of interest, using the standard Campbell-Shiller approximation $r_{t+1} = \kappa_0 + \kappa_1 w_{t+1} - w_t + g_{t+1}$. In particular, the time t to $t+1$ return must satisfy the following relation,

$$\begin{aligned} r_{t+1} \;=\; -\log\delta \;+\; \psi^{-1}\mu_g \;-\; \frac{(1-\gamma)^2}{2\theta}\sigma_{g,t}^2 \;+\; (\kappa_1\rho_q - 1)A_q q_t \;+ \\ \sigma_{g,t} z_{g,t+1} \;+\; \kappa_1 \sqrt{q_t}\,\left[A_\sigma z_{\sigma,t+1} + A_q \varphi_q z_{q,t+1}\right]. \end{aligned} \tag{6}$$

Denote the conditional variance of the time t to $t+1$ return as $\sigma_{r,t}^2 \equiv \mathrm{Var}_t(r_{t+1})$. It follows from equation (6) that

$$\sigma_{r,t}^2 \;=\; \sigma_{g,t}^2 + \kappa_1^2 \left(A_\sigma^2 + A_q^2 \varphi_q^2\right) q_t, \tag{7}$$

which is directly influenced by each of the two stochastic factors, the underlying economic volatility, $\sigma_{g,t}^2$, and the volatility of that volatility, q_t.

To further appreciate the implications of richer time-varying volatility dynamics, it is instructive to consider the model-implied equity premium, $\pi_{r,t} \equiv -\text{Cov}_t(m_{t+1}, r_{t+1})$,

$$\pi_{r,t} \;=\; \gamma\sigma_{g,t}^2 \;+\; (1-\theta)\kappa_1^2(A_q^2\varphi_q^2 + A_\sigma^2)q_t. \tag{8}$$

The premium is composed of two separate terms. The first term, $\gamma\sigma_{g,t}^2$, motivated the classic risk-return tradeoff relationship, which has undergone extensive, yet empirically elusive, investigations. The term doesn't really represent a volatility risk premium *per se*, however. Instead, it arises within the model as the presence of time-varying volatility in effect induces shifts in the price of consumption risk. The second term, $(1-\theta)\kappa_1^2(A_q^2\varphi_q^2 + A_\sigma^2)q_t$, represents a true premium for uncertainty risk. It is a confounding of a risk premium on shocks to economic uncertainty, $z_{\sigma,t+1}$, and shocks to the volatility-of-uncertainty, $z_{q,t+1}$. As such it represents a fundamentally different source of risk from that of the traditional consumption risk term. The existence of the volatility or uncertainty risk premium depends crucially on the dual assumptions of recursive utility, or $\theta \neq 1$, as uncertainty would otherwise not be a priced factor, and time varying volatility-of-uncertainty, in the form of the q_t process. This additional source of uncertainty is absent in the model of Bansal and Yaron (2004). The restrictions that $\gamma > 1$ and $\psi > 1$ implies that the volatility risk premium is positive.

2.1 Variance Risk Premia and Economic Uncertainty

The difference between the objective and risk-neutral expectations of $\sigma_{r,t+1}^2$ as of time t will depend upon the way in which uncertainty risk is priced. It follows readily that the time t objective conditional expectation equals,

$$E_t(\sigma_{r,t+1}^2) = a_\sigma + \kappa_1^2\left(A_\sigma^2 + A_q^2\varphi_q^2\right)a_q + \rho_\sigma\sigma_{g,t}^2 + \kappa_1^2\left(A_\sigma^2 + A_q^2\varphi_q^2\right)\rho_q q_t. \tag{9}$$

The corresponding model-implied risk-neutral conditional expectation $E_t^Q(\sigma_{r,t+1}^2) \equiv E_t(\sigma_{r,t+1}^2 M_{t+1})E_t(M_{t+1})^{-1}$ cannot easily be computed in closed form. However, it is possible to calculate the following close log-linear approximation,

$$E_t^Q(\sigma_{r,t+1}^2) \;\approx\; \log\left[e^{-r_{f,t}}E_t\left(e^{m_{t+1}+\sigma_{r,t+1}^2}\right)\right] - \frac{1}{2}\text{Var}_t\left(\sigma_{r,t+1}^2\right)$$

$$= E_t(\sigma^2_{r,t+1}) + (\theta - 1)\kappa_1 \left[A_\sigma + A_q \kappa_1^2 \left(A_\sigma^2 + A_q^2 \varphi_q^2\right) \varphi_q^2\right] q_t, \tag{10}$$

where $r_{f,t}$ denotes the one-period risk free rate implied by the model. A number of interesting implications arise from comparing these two different expectations of the same future variance.

In particular, any temporal variation in the endogenously generated variance risk premium,

$$E_t^Q(\sigma^2_{r,t+1}) - E_t(\sigma^2_{r,t+1}) = (\theta - 1)\kappa_1 \left[A_\sigma + A_q \kappa_1^2 \left(A_\sigma^2 + A_q^2 \varphi_q^2\right) \varphi_q^2\right] q_t, \tag{11}$$

is due solely to the volatility-of-volatility or economic uncertainty risk, q_t, but not the consumption growth risk, $\sigma^2_{g,t+1}$. Moreover, provided that $\theta < 0$, $A_\sigma < 0$, and $A_q < 0$, as would be implied by the agents' preference of an earlier resolution of economic uncertainty (intertemporal elasticity of substitution—IES—bigger than one), this difference between the risk-neutral and objective expected variation is guaranteed to be positive. If $\varphi_q = 0$, and therefore $q_t = q$ is constant, the variance premium reduces to,

$$E_t^Q(\sigma^2_{r,t+1}) - E_t(\sigma^2_{r,t+1}) = (\theta - 1)\kappa_1 A_\sigma q,$$

which, of course, would also be constant. Comparing the expression in equation (11) to the expression for the equity premium in equation (8), suggests that the variance risk premium should serve as an almost perfect measure of the elusive economic uncertainty's volatility risk, or q_t, as advocated by the modeling framework adopted here.

The preceding theoretical analysis motivates our approach based on information from derivatives markets (or Q-measure information) for better estimating the so-far elusive notion of economic uncertainty risk. From equation (11) the variance difference $E_t^Q(\sigma^2_{r,t+1}) - E_t(\sigma^2_{r,t+1})$ is directly related to the uncertainty volatility risk factor, q_t. The use of derivatives market data allows us to directly measure $E_t^Q(\sigma^2_{r,t+1})$. Thus, using the derivatives data to get $E_t^Q(\sigma^2_{r,t+1})$ along with empirical proxies for the actual volatility, we can potentially get a "cleaner" measure of the factor that drives the economic uncertainty risk premium, in fact backing out the market implied measure of economic uncertainty risk directly.

3 Implementation with Derivatives Market Data

The theoretical model outlined in the previous sections suggests that the difference between current return variation and the market's risk-neutral expectation of future return variation may serve as a useful input for backing out the unobserved economic uncertainty risk factor. To measure the variance risk premium and investigate this conjecture, we rely on two relatively new non-parametric "model-free" variation concepts.

To formally define the procedure that we use in quantifying the market's expected return variation, let $C_t(T,K)$ denote the price of a European call option maturing at time T with strike price K, and $B(t,T)$ denote the price of a time t zero-coupon bond maturing at time T. As shown by Carr and Madan (1998), Demeterfi, Derman, Kamal, and Zou (1999) and Britten-Jones and Neuberger (2000), the market's risk-neutral expectation of the total return variation between time t and $t+1$ conditional on time t information, or the implied variance $IV_{t,t+1}$, may then be expressed in a "model-free" fashion as the following portfolio of European calls,

$$IV_{t,t+1} \equiv 2\int_0^\infty \frac{C_t\left(t+1,\frac{K}{B(t,t+1)}\right)-C_t\left(t,K\right)}{K^2}\,dK \;= E_t^Q[\text{Return Variation}(t,t+1)], \quad (12)$$

which relies on an ever increasing number of calls with strikes spanning zero to infinity. This "model-free" measure therefore provides a natural empirical analog to $E_t^Q(\sigma_{r,t+1}^2)$ in the discrete-time model discussed in the previous section. This equation follows directly from the classical result in Breeden and Litzenberger (1978) that the second derivative of the option call price with respect to strike equals the risk-neutral density. In practice, of course, $IV_{t,t+1}$ must be constructed on the basis of a finite number of strikes. Fortunately, even with relatively few different options this tend to provide a fairly accurate approximation to the true (unobserved) risk-neutral expectation of the future return variation, and, in particular, a much better approximation than the one based on inversion of the standard Black-Scholes formula with close to at-the-money option(s) (see, e.g., Jiang and Tian, 2005; Bollerslev, Gibson, and Zhou, 2004).

In order to define the measure that we use in quantifying the actual return variation, let

p_t denote the logarithmic price of the asset. The realized variation over the discrete t to $t+1$ time interval may then be measured in a "model-free" fashion by

$$RV_{t,t+1} \equiv \sum_{j=1}^{n} \left[p_{t+\frac{j}{n}} - p_{t+\frac{j-1}{n}} \right]^2 \longrightarrow \text{Return Variation}(t, t+1), \tag{13}$$

where p_t is the logarithmic price of the underlying asset, and the convergence relies on $n \to \infty$; i.e., an increasing number of within period price observations. As demonstrated in the literature (see,e.g., Andersen, Bollerslev, Diebold, and Ebens, 2001a; Andersen, Bollerslev, Diebold, and Labys, 2001b; Barndorff-Nielsen and Shephard, 2002; Meddahi, 2002), this "model-free" realized variance measure based on high-frequency intraday data affords much more accurate ex-post observations of the true (unobserved) return variation than do the more traditional sample variances based on daily or coarser frequency returns. It also provides a non-parametric empirical analog to $\sigma_{r,t}^2$ in the discrete-time model in the previous section. In practice, of course, as discussed further below, various market microstructure frictions invariably limit the highest sampling frequency that may be used in reliably estimating $RV_{t,t+1}$.

The variance risk premium, or difference between this ex-ante risk neutral expectation of the future return variation over the $[t, t+1]$ time interval and the objective expectations of the realized return variation over the $[t, t+]$ time interval,

$$VRP_{t,t+1} \equiv IV_{t,t+1} - E_t\left(RV_{t,t+1}\right), \tag{14}$$

affording a "model-free" empirical equivalent to the variance difference, where the objective expectation $E_t\left(RV_{t,t+1}\right)$ is estimated by an AR(12) regression. All the structural parameters of the agents' utility function and underlying consumption dynamics are taken from the established calibration settings that match both the equity risk premia (Bansal and Yaron, 2004) and the variance risk premia (Bollerslev, Tauchen, and Zhou, 2008).

Closely related measures of variance risk premia have recently been investigated from different empirical perspectives in other studies. In particular, Bollerslev, Gibson, and Zhou (2004) find that the temporal variation in a measure of $VRP_{t,t+1}$ for the aggregate market portfolio may in part be explained by a set of macro-finance variables, including nonfarm

payroll, industrial production, S&P 500 P/E ratio, lagged market volatility, housing start, producer price index, and credit spread. Similarly, Todorov (2007) has explored the joint dynamics of $IV_{t,t+1}$ and $E_t\left(RV_{t,t+1}\right)$ within the context of a very general continuous time specification allowing for separate jump and diffusive risk premiums. The difference between implied and realized variance measures has also previously been associated empirically with notions of aggregate market risk aversion by Rosenberg and Engle (2002), while Bakshi and Madan (2006) have formally shown that the volatility spread may be expressed as a nonlinear function of the aggregate degree of risk aversion in a simple representative agent setting.

Once the variance risk premium is estimated, the stochastic volatility of economic uncertainty is recovered as

$$\hat{q}_t = \frac{VRP_t}{(\theta-1)\kappa_1\left[A_\sigma + A_q\kappa_1^2\left(A_\sigma^2 + A_q^2\varphi_q^2\right)\varphi_q^2\right]} \tag{15}$$

In essence, this approach is using jointly the stock market volatility and option-implied volatility to infer the stochastic volatility of economic uncertainty, with the loadings being determined by a general equilibrium model, which embeds economic uncertainty risks and agents' preference for an earlier resolution of economic uncertainty.

In the following calibration exercise, the values for $\kappa_1 = 0.997$, $\delta = 0.997$, $\gamma = 5.0$, $\psi = 2.5$, $\mu_g = 0.0015$, and $E(\sigma_g) = 0.0078$ in the benchmark model specification are all adapted directly from Bansal and Yaron (2004). Additionally, we fix the persistence of the variance at $\rho_\sigma = 0.978$, the persistence of the volatility-of-volatility at $\rho_q = 0.6$, the expected volatility-of-volatility at $a_q(1-\rho_q)^{-1} = 1.0^{-6}$, and the volatility of that process at $\varphi_q = 1.0^{-3}$. The mean annualized risk-free rate and equity premium implied by these particular model parameters equal 0.48 and 8.21 percent, respectively.

In an earlier paper by Bollerslev, Gibson, and Zhou (2004), we attributed this difference between implied and realized variances to the market implied risk aversion, and try to associate it with various macroeconomic and financial variables. Such an approach has been accepted by some central banks around the world in conducting their current policy analysis. However, in the general equilibrium approach adopted here, the risk aversion coefficient γ is constant, so the interpretation is fundamentally changed to be a risk measure of economic

uncertainty, which is indeed the main driver of the time-variations in variance risk premia and equity risk premia.

4 Implications for Short Term Asset Predictability

To be completed soon.....

5 Relating Economic Uncertainty to Monetary Policy

To appreciate why stochastic economic uncertainty plays an important role in affecting the monetary policy rule, we show the real risk-free rate in this economy as (see Tauchen, 2005, for more detail),

$$\begin{aligned} r_{ft} \;=\; \theta \log \delta \;-\; \gamma\mu_g \;+\; (\theta-1)\left[\kappa_0 + (\kappa_1 - 1)A_0 + \kappa_1(A_\sigma a_{\sigma c} \;+\; A_q a_q)\right] \\ +(\theta-1)\left[A_\sigma(\kappa_1\rho_{\sigma g}-1)\sigma^2_{g,t} \;+\; A_q(\kappa_1\rho_q - 1)q_t\right] \\ +\frac{1}{2}\gamma^2\sigma^2_{g,t} + \frac{1}{2}(\theta-1)^2\kappa_1^2(A_\sigma^2 + A_q^2\varphi_q^2)q_t \end{aligned} \tag{16}$$

where the first line corresponds to the standard consumption-based asset pricing models without time-varying consumption volatility or economic uncertainty, and the third line belongs to the well known *Jensen's Inequality* terms. More important is the second line in the above equation, where the term related to $\sigma^2_{g,t}$ is the time-varying consumption volatility, and the term related to q_t is the volatility-of-volatility or stochastic economic uncertainty.

It is very important to note that we want to access the response of short term interest rate (as a proxy for the monetary policy target) to the economic uncertainty risk measure, but we are not trying provide the best forecast of the policy rate. If one need to know the "pure best bet" of the Federal Funds target rate, one can just read off from the Federal Funds futures curve. In other words, we are trying to answer the question "what the rate should be" not the question "what the rate will be".

This approach is applied to the S&P 500 index, and the visual results are shown in Figure 1, where the risk measure for economic uncertainty is derived from the difference between option-implied variance and smoothed realized variance of the S&P 500 market returns (in the top panel). For a robustness check, we also include the uncertainty risk measure based on

the difference between implied and realized volatilities (in the bottom panel). We can see that the recovered economic uncertainty risk is almost always positive, and show significant time-variation. Also, during the periods when the level and volatility of economic uncertainty risk are high, the monetary policy target—Federal Funds Rate (FFR) is either falling or staying low. In contrast, when the level and volatility of economic uncertainty risk are low, the FFR target is either rising or staying high. Such a pattern is muted during the period from 1992 to 1997, but is very clear either before 1992 or after 1997.

We also run Taylor Rule type regressions—with the FFR target as the dependent variable, the economic uncertainty risk measure as the independent variable, and incorporating the lagged FFR to capture the effect of monetary inertia. The results are reported in Table 1. It seems that the response of FFR target to economic uncertainty risk, when only economic uncertainty risk is included, is either statistically insignificant (for both the variance-based and the volatility-based measures) for the period from January 2000 to September 2008; or being significant but with a wrong sign—positive sign suggesting that the FFR rate rises with heightened uncertainty risk in the real economy—for the entire period from January 1990 to September 2008. However, once the lagged FFR is included to control for the policy inertia, the uncertainty risk coefficient is always negative for the entire sample period from January 1990 to September 2008, and becomes statistically significant for the variance-based measure. While for the period from January 2000 onward, the uncertainty risk is statistically significant at a 5 percent level for the volatility-based measure and significant at a 1 percent level for the variance-based measure.

Focusing on the period since 2000, the economic significance can be stated as .01 unit increase of the uncertainty risk in real economy will reduce the FFR target by 3 basis points for the variance-based measure (bottom left panel of the table); and reduce by 8 basis points for the volatility-based measure (bottom right panel of the table). Looking back at the top panel of Figure 1, the huge jump of uncertainty risk in real economy in September 2008, about .09 unit, suggests that the expected drop of FFR target is about 27 basis points.

6 Conclusion

We focus on an important implication from a simple representative agent economy with recursive preferences that explicitly incorporates the equilibrium effects of economic uncertainty and time-varying volatility-of-volatility. The short term interest rate depends on the stochastic economic uncertainty risk, which can be revealed perfectly by the difference between model-free implied variance and model-free realized variance of the financial markets. This important result is driven by the fact that the economic uncertainty risk is priced in the framework of recursive utility function, even though the consumption volatility risk and economic uncertainty risk are uncorrelated with the consumption growth process.

The wedge between the "model-free" risk-neutral expected and actual variance, or variance risk premia (Bollerslev, Tauchen, and Zhou, 2008), may alternatively be seen as a proxy for the aggregate degree of risk aversion in the market (Bollerslev, Gibson, and Zhou, 2004). Although it might be difficult to contemplate systematic changes in the level of risk aversion at the frequencies emphasized in our empirical work, time-varying volatility risk *and* time-varying risk-aversion likely both play an important role in explaining temporal variation in the variance risk premia. Given our modeling framework, the variance difference is a perfect empirical measure of the stochastic economic uncertainty, which should play an important role in explaining various asset pricing puzzles (Zhou, 2006), as well as interpreting recent drastic movements of the Federal Funds Rate targets.

There seems to be tentative evidence that the monetary policy decision should be, or may have already been, targeting the difference between implied and realized variances for financial market, which reveals the uncertainty risk of the real economy. In future revisions, I will adopt such a general equilibrium approach to describe the rich dynamics of the underlying economic uncertainty, and conduct a more comprehensive comparison with the traditional Taylor Rule, which targets output gap and inflation rate.

References

Ai, Hengjie (2008), "Information Quality and Long-run Risk: Asset Pricing and Welfare Implications," Working Paper, Duke University.

Andersen, Torben G., Tim Bollerslev, Francis X. Diebold, and Heiko Ebens (2001a), "The Distribution of Realized Stock Return Volatility," *Journal of Financial Economics*, vol. 61, 43–76.

Andersen, Torben G., Tim Bollerslev, Francis X. Diebold, and Paul Labys (2001b), "The Distribution of Realized Exchange Rate Volatility," *Journal of the American Statistical Association*, vol. 96, 42–55.

Bakshi, Gurdip and Dilip Madan (2006), "A Theory of Volatility Spread," *Management Science*, vol. 52, 1945–1956.

Bansal, Ravi and Ivan Shaliastovich (2008), "Learning and Asset-Price Jumps," Working Paper, Duke University.

Bansal, Ravi and Amir Yaron (2004), "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles," *Journal of Finance*, vol. 59, 1481–1509.

Barndorff-Nielsen, Ole and Neil Shephard (2002), "Econometric Analysis of Realised Volatility and Its Use in Estimating Stochastic Volatility Models," *Journal of Royal Statistical Society, Series B*, vol. 64, 253–280.

Bollerslev, Tim, Mike Gibson, and Hao Zhou (2004), "Dynamic Estimation of Volatility Risk Premia and Investor Risk Aversion from Option-Implied and Realized Volatilities," Working Paper, Federal Reserve Board.

Bollerslev, Tim, George Tauchen, and Hao Zhou (2008), "Expected Stock Returns and Variance Risk Premia," *Review of Financial Studies*, forthcoming.

Breeden, Douglas and Robert Litzenberger (1978), "Prices of State-Contingent Claims Implicit in Option Prices," *Journal of Business*, vol. 51, 621–651.

Britten-Jones, Mark and Anthony Neuberger (2000), "Option Prices, Implied Price Processes, and Stochastic Volatility," *Journal of Finance*, vol. 55, 839–866.

Campbell, John Y. and John H. Cochrane (1999), "By Force of Habit: A Consumption Based Explanation of Aggregate Stock Market Behavior," *Journal of Political Economy*, vol. 107, 205–251.

Carr, Peter and Dilip Madan (1998), "Towards a Theory of Volatility Trading," *in Volatility: New Estimation Techniques for Pricing Derivatives*, chap.29, 417-427, Robert Jarrow (ed.). London: Risk Books.

Chen, Hui and Michal Pakos (2008), "Asset Pricing with Uncertainty for the Long Run," Working Paper, MIT.

Croce, Mariano M., Martin Lettau, and Sydney C. Ludvigson (2006), "Investor Information, Long-Run Risk, and the Duration of Risky Cash Flows," Working Paper, New York University.

Demeterfi, Kresimir, Emanuel Derman, Michael Kamal, and Joseph Zou (1999), "A Guide to Volatility and Variance Swaps," *Journal of Derivatives*, vol. 6, 9–32.

Drechsler, Itamar (2008), "Uncertainty, Time-Varying Fear, and Asset Prices," Working Paper, University of Pennsylvania.

Drechsler, Itamar and Amir Yaron (2008), "What's Vol Got to Do With It," Working Paper, University of Pennsylvania.

Epstein, Larry G. and Stanley E. Zin (1991), "Substitution, Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: An Empirical Analysis," *Journal of Political Economy*, vol. 99, 263–286.

Jiang, George and Yisong Tian (2005), "Model-Free Implied Volatility and Its Information Content," *Review of Financial Studies*, vol. 18, 1305–1342.

Lettau, Martin, Sydney Ludvigson, and Jessica Wachter (2008), "The Declining Equity Premium: What Role does Macroeconomic Risk PLay?" *Review of Financial Studies*, Forthcoming.

Meddahi, Nour (2002), "Theoretical Comparison Between Integrated and Realized Volatility," *Journal of Applied Econometrics*, vol. 17, 479–508.

Rosenberg, Joshua V. and Robert F. Engle (2002), "Empirical Pricing Kernels," *Journal of Financial Economics*, vol. 64, 341–372.

Shaliastovich, Ivan (2008), "Learning, Confidence, and Option Price," Working Paper, Duke University.

Tauchen, George (2005), "Stochastic Volatility in General Equilibrium," Working Paper, Duke University.

Todorov, Viktor (2007), "Variance Risk Premium Dynamics," Working Paper, Northwestern University.

Weil, Philippe (1989), "The Equity Premium Puzzle and the Risk Free Rate Puzzle," *Journal of Monetary Economics*, vol. 24, 401–421.

Zhou, Hao (2006), "Stochastic Economic Uncertainty and Implications for Asset Pricing Puzzles," Unpublished Techinical Note, Federal Reserve Board.

7 Table and Figure

Table 1 Taylor Rule as Response to Economic Uncertainty Risk

This table report the regression of the Federal Funds Rate target on its own lag and economic uncertainty risk variables. OLS standard error is reported in the parentheses. The top panel reports the regression result from 1990 to 2008 and the bottom panel from 2000 to 2008. The left panel uses the implied-realized variance difference as risk measure for economic uncertainty, and the right panel uses the volatility difference. The statistical significance are indicated by *, **, and *** for 10 percent, 5 percent, and 1 percent levels.

1990-2008	Variance Difference Measure			1990-2008	Volatility Difference Measure		
Constant	.0393***	3.26e-4	4.85e-4	Constant	.0337***	3.26e-4	4.26e-4
(s.e.)	(.0017)	(3.75e-4)	(3.81e-4)	(s.e.)	(.0022)	(3.75e-4)	(3.94e-4)
q_t	.165***		-0.014**	q_t	1.21***		-0.026
(s.e.)	(.0583)		(.0072)	(s.e.)	(.24)		(.032)
FFR_{t-1}		.99***	.99***	FFR_{t-1}		.99***	.99***
(s.e.)		(.0080)	(.0081)	(s.e.)		(.0080)	(.0084)
R^2	.035	0.99	0.99	R^2	.103	0.99	0.99
2000-2008	Variance Difference Measure			2000-2008	Volatility Difference Measure		
Constant	.034***	1.27e-4	6.96e-4**	Constant	.033***	1.27e-4	5.59e-4
(s.e.)	(.0017)	(3.56e-4)	(3.89e-4)	(s.e.)	(.0021)	(3.56e-4)	(4.15e-4)
q_t	-.063		-.030***	q_t	.043		-.079**
(s.e.)	(.066)		(.0090)	(s.e.)	(.29)		(.0398)
FFR_{t-1}		0.99***	.99***	FFR_{t-1}		0.99***	.99***
(s.e.)		(.0093)	(.0090)	(s.e.)		(.0093)	(.0092)
R^2	0.004	0.98	0.98	R^2	0.0001	0.98	0.98

Figure 1 Economic Uncertainty Risk and Monetary Policy Target

This figure compare visually the Federal Funds Rate (FFR) target with the economic uncertainty risk measure—implied-realized variance difference (unit as percentage squared) in the top panel and implied realized volatility measure (unit as annualized percentage) in the bottom panel.