What Makes the VIX Tick?

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Abstract

We study associations of the VIX implied volatility index and volatility risk premium with measures of public information, private information, and investor sentiment over 1-minute intervals. VIX rises with S&P 500 returns, suggesting leverage or increased pessimism during market downturns. Some findings on VIX and Eurodollar futures suggest flight-to-quality or heightened uncertainty associated with expected Fed monetary easing. Gold prices do not reflect "fear" in the same manner as the VIX, although other gold-related trading and sentiment measures suggest commonalities with VIX. Finally, there appears to be a common element in the risk premium component of VIX and credit default spreads.

Keywords: VIX, implied volatility, volatility risk premium, investor sentiment

JEL classifications: G11, G12, G13

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Introduction

Why does stock volatility change over time? Schwert (1989) examines this question but reports little evidence of causality from the volatility of macroeconomic fundamentals to stock market volatility. The only robust finding seems to be that the stage of the business cycle affects stock market volatility. A potential constraint on many studies of fundamental volatility and stock volatility is the low frequency of realized volatility dictated by the use of daily stock returns.

Our study takes a fresh look at the underlying causes of volatility using high frequency data from markets for index option derivatives, equity, futures contracts, and credit default spreads. We identify three potential sources of volatility to motivate our empirical specifications and to interpret our results: public information, private information, and investor sentiment.

Ross (1989) argues that stock return volatility is directly related to the flow of information. Ederington and Lee (1993) attribute intraday and day-of-the-week volatility patterns in interest rate and exchange rate futures to macroeconomic announcements. Andersen and Bollerslev (1998) and Anderson, Bollerslev, Diebold, and Vega (2006) examine the effect of public news shocks on high frequency return volatility. Other studies based on intraday data (Andersen et al, 2003, 2006) document the real-time impact of public information shocks on returns themselves, rather than on return volatility. Therefore, our first set of explanatory variables reflects the notion that public information, in the form of news arrival and changes in securities prices, drives the volatility of securities prices.

Second, not all information relevant for securities pricing is public. Private information features in much of the finance literature, ranging from early formulations of market efficiency (Fama, 1965) to models of informed and liquidity-motivated traders (Kyle, 1985; Glosten and Milgrom, 1985; Admati and Pfleiderer, 1988). Empirical work demonstrates how the order flow imbalance reveals private information flow in markets for stocks (Hasbrouck, 1991; Berry

and Howe, 1994), foreign exchange (Evans and Lyons, 2008), and Treasury bonds (Brandt and Kavajecz, 2004; Green, 2004; Pasquariello and Vega, 2007; Jiang and Lo, 2011). Other authors use microstructure models to measure explicitly the extent of informed trading in the record of orders and trades (for example, Easley, Kiefer, O'Hara, and Paperman, 1996). Thus, order flow imbalances and other measures that reflect trading on private information serve as our second set of explanatory variables.

Third, beyond public and private information, another potential source of stock price volatility is investor sentiment. The noise trader model of De Long et al (1990) motivates many papers that explore the effect of noise trader risks on returns (Lee, Shleifer and Thaler, 1991; Neal and Wheatley, 1998; Baker and Wurgler, 2006).[1] In particular, we exploit the idea of Lee, Shleifer, and Thaler (1991) that small investor sentiment is partly reflected in trading of closed end funds, though this interpretation is not without controversy.[2] Therefore, our third set of explanatory variables measures facets of investor sentiment.

We apply these three sets of explanatory variables to stock index implied volatility, an increasingly popular tool among both academic researchers and sophisticated practitioners. Implied volatility can be computed using either parametric or nonparametric methods. Parametric implied volatilities are inferred from market prices of options or other derivatives

[1] A few papers investigate the relationship between sentiment and volatility. Brown (1999) and Lee, Jiang, and Indro (2002) document weekly associations between sentiment proxies and equity price volatility. Han (2008) relates daily pricing of S&P 500 index options to daily and weekly measures of institutional investor sentiment. In his keynote address to the European Financial Management Association, Schwert (2011) suggests that perceptions of the link between readily-observed measures of stock market volatility and broader economic indicators can be biased.

[2] Klibanoff, Lamont, and Wizman (1998) confirm the interpretation of the closed end fund discount as a sentiment indicator with their study of the reaction to news arrival. However, this interpretation remains controversial (Chen, Kan, and Miller, 1993). Other studies ascribe closed end fund discounts to market segmentation (Swaminathan, 1996), arbitrage costs (Gemmill and Thomas,, 2002), and illiquidity of underlying assets (Cherkes, Sagi, and Stanton, 2009), rather than an irrational sentiment factor. See Baker and Wurgler (2006) for a detailed discussion.

based on a derivative pricing model such as the Black and Scholes (1973) model. For example, the Chicago Board Option Exchange's first implied volatility index, VXO, was computed from S&P100 index option prices. The evidence on the information content of VXO is mixed (Harvey and Whaley, 1992; Canina and Figlewski, 1993; Blair et al; 2001), perhaps because VXO concentrates on near-the-money options. In contrast, nonparametric implied volatilities derived by Britten-Jones and Neuberger (2000) and Jiang and Tian (2005) rely on no-arbitrage conditions and include all option strike prices traded at a particular time. The information content of nonparametric implied volatility is superior to that of its parametric counterparts (Jiang and Tian, 2005).

The Chicago Board Option Exchange replaced VXO with an S&P500 volatility index, VIX, which is a weighted average computed from mid-point prices of a wide range of options across different strikes. It approximates the model-free implied variance of Britten-Jones and Neuberger (2000) and the risk-neutral expected value of return variance of Carr and Wu (2009) over a 30-day horizon (Chicago Board Options Exchange, 2009). VIX has become widely reported by the financial press and financial web sites, and even appears on the ticker of the CNBC financial news cable television network during trading hours. VIX is perceived by practitioners as both a measure of fear and a price for portfolio insurance (Whaley, 2000; 2008). It is also well-accepted in the academic literature as a measure of the market's price of future stock index volatility. VIX is particularly suitable for a high frequency study of equity volatility because the underlying stock index options are heavily traded and, as a consequence, VIX changes very frequently during trading hours.

Our paper examines the impact of public news, private information, and investor sentiment on intraday implied volatility measured with the VIX index. We construct a variety of intraday proxies for these three factors and use them to understand the intraday evolution of the VIX from January 2005 to June 2010. Our findings serve several purposes. First, we document in great detail the linkages between volatility, economic and financial fundamentals,

and investor sentiment that academics and practitioners have studied since the dawn of financial markets centuries ago.[3] Second, we offer insights into the relationships that govern the risks and rewards associated with stock market investment, a question of practical concern to market participating ranging from ordinary investors to professional portfolio managers. Third, the associations we document in high-frequency data are of use to a range of sophisticated financial market techniques ranging from high-frequency trading to derivatives valuation.

The balance of this paper is organized as follows. Section 2 describes our empirical methodology and data. Section 3 discusses preliminary empirical results. Section 4 summarizes, concludes, and sketches additional work that is underway.

2. Empirical design

2.1 Methodology

2.1.1 Explaining the high frequency evolution of the VIX index

We use the following empirical specifications. We begin by estimating associations between the VIX index and proxies for the three categories of factors previously described:

$$VIX_t = a + \sum_{i=1}^{I} b_i VIX_{t-i} + \sum_{j=0}^{J}\sum_{k=1}^{K} c_{kj} r_{k,t-j} + \sum_{l=1}^{L}\sum_{p=1}^{P} d_{lp} NEWS_{l,t-p} + \sum_{m=1}^{M}\sum_{q=1}^{Q} e_{mq} TRADE_{m,t-q} + \sum_{n=1}^{N}\sum_{s=1}^{S} f_{ns} SENTIMENT_{n,t-s} + \varepsilon_t \quad (1)$$

[3] John Maynard Keynes noted the significance of "animal spirits" for economic decision-makers. See Akerlof and Schiller (2009) for a comprehensive treatment.

VIX_t is the VIX implied volatility index at the close of intraday interval t.[4] The notation indicates the three sources of volatility we use to explain VIX. The first is public information shocks consisting of the return, yield, and spread change series, r, and the macroeconomic news surprises, NEWS. The second is measures of trading activity, TRADE, that proxy for trading motivated by private information, which includes differences of opinion and information processing of public information. The third is measures, SENTIMENT, of the optimism or pessimism of market participants.

Specifically, $r_{k,t}$ is the kth financial market return, price, or spread change. These series include the S&P 500 index represented by the SPDR S&P 500 ETF (SPY), the short maturity gold futures contract price, the short maturity Eurodollar deposit futures contract price, and the 5-year Markit CDX spread. $NEWS_{l,t}$ is the surprise of component of macroeconomic announcements at time t. $TRADE_{m,t}$ is the mth measure of trading activity and direction at time t. $SENTIMENT_{n,t}$ is the nth measure of investor sentiment at time t.[5] If the lags of independent variables are kept identical, then I, J, P, Q and S are equal.

We can further model the dynamics of volatility as a function of public and private information as well as sentiment by adding error term dynamics to (1):

$$|\varepsilon_t| = \sum_{i=1}^{I} \beta_i |\varepsilon_{t-i}| + \sum_{l=1}^{L}\sum_{p=1}^{P} \gamma_{lp} NEWS_{l,t-p} + \sum_{m=1}^{M}\sum_{q=1}^{Q} \eta_{mq} TRADE_{m,t-q} + \sum_{n=1}^{N}\sum_{s=1}^{S} \lambda_{ns} SENTIMENT_{n,t-s} + u_t \quad (2)$$

This extension to (1) allows the volatility of the noise term to depend on its own lag and the measures of public information, private information, and sentiment.

[4] Interval length is set at 1 minute, though some results in this draft also use 5 minutes. While the high frequency of trades in these markets suggests working in transactions time, Engle and Lunde (2003) and others find that working with more than one series in transactions time is difficult or intractable.

[5] Sentiment variables, as detailed below, are used in abnormal or excess form.

2.1.2 Explaining the high frequency evolution of the variance risk premium

Recent empirical work on stock returns (Ang, Hodrick, Xing, and Zhang, 2006) suggests that volatility earns a risk premium in the stock market. Other recent research proposes a measure, the Variance Risk Premium (VRP), of the premium for exposure to variance risk. VRP is defined as the difference between the implied volatility measure from option prices and the expected realized variance of the underlying return series. Carr and Wu (2009) shows that VRP for major U.S. stock indexes is consistent with a significant premium for exposure to stochastic variance risk. Bollerslev et al (2010) finds that VRP explains a large fraction of the variation in quarterly stock returns from 1990 to 2005. The model of Drechsler and Yaron (2011) shows how aversion to long-run risks generates a VRP that can predict stock returns. Bollerslev and Todorov (2011) shows that, on average, "disaster risk" drives most of the variation in VRP. Bali and Zhou (2011) shows that equity portfolios that mimic the variance risk premium earn a substantial monthly risk premium. VRP is positively correlated with macroeconomic risks, extreme downside risk of financial institutions, the credit risk of financial institutions, and aggregate investor disagreement. Bekaert, Hoerova, and Lo Duca (2011) document significant monthly associations between VIX and measures of monetary policy and macroeconomic conditions.

The basic idea is that VIX represents the risk neutral volatility expressed in standard deviation terms while the realized variance is actual volatility. For example, suppose institutional investors buy S&P500 options to hedge the risk of their positions. If risk averse, they offer a premium and, as a consequence, the spot VIX computed from those option prices exceeds expected realized volatility.[6] Put another way, VIX is the certainty-equivalent of ex ante volatility, reflecting both an expectation and a risk premium. The risk neutral probability

[6] Carr and Wu (2009) study realized volatility minus risk neutral volatility, so their risk premiums are opposite in sign from ours. They find negative risk premiums for all stock indexes and for most stocks.

puts more weight on the bad state and the bad state induces additional variance, rendering the variance premium positive. The higher is risk aversion, the higher is the variance premium.

Our purpose is to uncover the underlying high frequency drivers of the variance risk premium. This leads to the next empirical specification.

$$VRP_t = a + \sum_{i=1}^{I} b_i VP_{t-i} + \sum_{j=0}^{J}\sum_{k=1}^{K} c_{kj} r_{k,t-j} + \sum_{l=1}^{L}\sum_{p=1}^{p} d_{lp} NEWS_{l,t-p} + \sum_{m=1}^{M}\sum_{q=1}^{Q} e_{mq} TRADE_{m,t-q} + \sum_{n=1}^{N}\sum_{s=1}^{S} f_{ns} SENTIMENT_{n,t-s} + \varepsilon_t \quad (3)$$

VRP is the variance risk premium, the difference between the squared VIX index (expressed in annualized terms) and expected annualized realized return variance[7] over the same 30-day horizon as VIX:

$$VRP_t = VIX_t^2 - E_t(RV_{t,t+N}) \quad (4a)$$

We estimate the expected annualized realized volatility with a linear forecast of realized volatility with one lag of squared VIX and one lag of realized volatility as follows:

$$E_t(RV_{t,t+N}) = \hat{\alpha} + \hat{\beta} VIX_t^2 + \hat{\gamma} RV_{t-N,t} \quad (4b)$$

where the annualized realized variance at t over the past 30 days (typically 22 trading days) horizon to t is measured by:

$$RV_{t-N,t} = \{\sum_{n=1}^{N} r_{t-N+n/N}^2\} \times 12 \quad (4c)$$

[7] Realized returns include ex post risk premiums from the stock market, which is distinct from VRP, the ex ante premium for exposure to stochastic volatility risk paid by the derivatives market.

t represents a particular date and interval in the sample. N is the number of intraday returns used to estimate realized volatility from t to 30 days beyond. On average, N equals 22 trading days per month times the number of intraday intervals from 8:30am to 15:15pm in a trading day. r^2 is the square of the return, expressed in percent to parallel the scale of squared VIX.[8] The multiplier 12 annualizes monthly realized volatility. Note that VRP is in terms of basis points while VIX is in terms of percentage.

In a manner similar to equations (1) and (2), equation (3) can be extended with an equation governing the dynamics of the distribution of the error term as a function of public and private information and sentiment.

2.2 Testable hypotheses

To organize our exploration of the high-frequency evolution of the VIX index and the volatility risk premium, VRP, we develop a few testable propositions regarding the slope coefficients in our empirical specifications.

In equation (1) for VIX, the b coefficients represent serial correlation in the dependent variable, VIX. Persistence or clustering of volatility can be caused by gradual incorporation of information or dispersion in beliefs of traders. This idea has been used to explain clustering in longer-horizon return volatility, though its power weakens in intraday data (Andersen and Bollerslev, 1997). Given that the VIX is the certainty-equivalent of ex ante volatility, rather than realized volatility, its behavior may differ from what previous authors have found for realized volatility. As a starting point, however, our null is that the persistence coefficients, b, are positive.

The slope coefficients, c, measure the contemporaneous and lagged effects of asset returns, money market yields, and credit spreads on VIX. First, the contemporaneous slope on SPY return is easiest to predict. By the leverage argument (Merton, 1974, Black 1976), the

[8] VIX has the scale of the annualized standard deviation of percentage return.

coefficient should be negative. Alternatively, the coefficient is negative if S&P500 returns reflect expectations of the state of the business cycle and expectations of volatility recede in a growing economy, We can also offer a prediction about the relationship between VIX and subsequent SPY returns. By the risk premium argument (Campbell and Hentschel, 1992; Ang, Hodrick, Xing, and Zhang, 2006), VIX at t should be negatively associated with the SPY return from t to t+1. Second, given a hedging or sentiment argument, the contemporaneous slope on the gold futures return should be positive.

Third, predicting the sign of the contemporaneous slope on the Eurodollar yield is complex. A flight-to-quality effect, for example, predicts that increases in VIX are associated with decreases in the interest rate. [9] A risk premium effect predicts that increases in VIX are associated with increases in the credit risk component (that is, the TED spread) of the Eurodollar deposit yield. The interest rate can also reflect expectations of forthcoming monetary policy actions. Furthermore, the riskless interest rate can be thought of as including both real and expected inflation terms, implying further predictions though we are unable to detect them without high-frequency data on expected inflation.

Fourth, we expect a positive slope on the Markit CDX index since it represents the degree of corporate credit risk and risk premium in the economy.[10] It is unclear what we can predict about the lag coefficients, c, though they will allow us to gauge whether there is any feedback to the VIX from the equity, gold, money, and credit markets.

The coefficients, d, measure the impact of contemporaneous macroeconomic news surprises, NEWS, on VIX. A straightforward hypothesis is that surprises of any sign increase uncertainty and, therefore, the d coefficients are predicted to be positive. Alternatively,

[9] In a simple general equilibrium model with a representative investor and a stochastic variance production technology, Bailey and Stulz (1989) demonstrate a negative association between stock index volatility and the interest rate akin to "flight to quality".

[10] Bali and Zhou (2011) show that monthly credit default swap and VIX are positively correlated.

surprises can resolve uncertainty (Patell and Wolfson, 1979; Bailey, 1988), predicting that the d coefficients are negative. There are further complications: the impact of positive and negative surprises can differ or can depend on the stage of the business cycle (Boyd, Hu, and Jagannathan, 2005). For example, positive surprises in some indicators (such as GDP) can be thought of as good news while positive surprises in other indicators (such as CPI) can be thought of as bad news.

The slope coefficients, e, measure the impact of the TRADE indicators. If SPY trading volume and buying pressure indicate greater confidence in the future performance of common stocks, the slope coefficients, e, for SPY-related indicators are negative. Alternatively, if the SPY-related TRADE indicators signal informed trading, large realizations are associated with heightened concern about adverse selection, the uncertainty of future SPY returns increases, and estimated slopes, e, are positive. We also study gold using trading indicators for StreetTRACKS SPDR Gold Trust (GLD), an ETF that holds gold bullion. If GLD trading volume and buying pressure indicate less confidence in the economy and common stock performance, then slopes, e, for GLD-related indicators are positive.

The slope coefficients, f, measure associations between the SENTIMENT indicators and VIX. If equity sentiment measures indicate investor confidence (rational or otherwise), increases in those measures are negatively correlated with VIX. Put another way, higher confidence is associated with, or even causes, a lower VIX as investors impound smaller volatility estimates and risk premiums into the prices at which they are willing to trade S&P500 index options. As a result, the slope coefficients, f, are negative. Alternatively, if increased positive sentiment reflects an increased presence of unpredictable noise traders in the stock market, the slopes f are positive. Gold sentiment measures, in contrast, are predicted to have coefficients that are positive since bullishness about gold can be interpreted as concern about the economy and the stock market.

In addition to predictions about the slope coefficients for VIX, we also offer some predictions for the slope coefficients on VRP in equation (3). The contemporaneous slope coefficients, c, on other measures of risk, hedging demand, or fear, such as the return on gold and the CDX spread, should be positive. The relationship with the CDX spread can be particularly strong if credit spreads primarily reflect risk premiums, rather than the probability of default (Giesecke, Longstaff, Schaefer, and Strebulaev 2011).[11] The signs of the slope coefficients, e, on SPY-related trade indicators are negative if volume and buying pressure reflect investor demand driven by confidence or positive if they indicate trading on private information. Coefficients on GLD-related trade indicators should be positive if interest in gold rises with uncertainty. Slope coefficients, f, on equity sentiment measures are negative if rising confidence reduces the variance risk premium. Slope coefficients on gold sentiment measures are positive if both gold and the variance risk premium increase at uncertain times.

2.3 Data

The time period we study is January 2005 to the end of June 2010. Fifteen-second ticks of the VIX spot index are purchased from the Chicago Board Options Exchange's Market Data Express service.[12] They represent the spot value of the VIX, that is, the implied volatility average itself, rather than the VIX futures contracts traded on it. Note that the spot VIX measures the market's current expectation of future stock index volatility over the next 30 days. In contrast, VIX futures measure the expectation of 30-day volatility starting at the point in the future when the contract matures.

The first group of explanatory variables measure public information, and they include both continuous measures of market prices and macroeconomic news releases. We begin with

[11] See Stanton and Wallace (2011) for broadly similar evidence on the relationship between mortgage-related credit spreads and the fundamentals of the underlying mortgages.

[12] Every 15 seconds, CBOE samples S&P500 index option quotes, computes the spot VIX as described in Chicago Board Options Exchange (2009), and disseminates the spot VIX publicly.

four series constructed from financial market prices ("r" in Equation 1 above). They can be thought of as continuously-observed public information. As we discuss later, at least one of them can also reflect investor sentiment.

To measure the evolution of the price series underlying VIX, we use intraday trade returns on the SPDR S&P 500 exchange traded fund (SPY) from TAQ. SPY returns represent broad movement in stock prices and, more broadly, the market's estimate of changes in future economic growth. Given the structure of the SPY ETF which allows arbitrage by certain traders, SPY tracks the S&P 500 index very closely (Ackert and Tian, 2000).

To measure the intraday evolution of information about interest rates and monetary policy we use the rate of change of short maturity Eurodollar futures contract prices at the Chicago Mercantile Exchange. The rate of change of the Eurodollar futures contract price (which is essentially 100 minus the annualized yield) represents short term interest rates, the state of the business cycle, actual and expected monetary policy, and bank credit risk.[13] Another measure of macroeconomic conditions, risks, and uncertainty is the rate of change of short maturity gold futures contract prices at COMEX. The rate of change of the price of gold futures reflects changes in the demand for gold due to inflation expectations, consumption demand, and hedging against economic and political uncertainty around the world.[14]

Finally, given the importance of ongoing global credit crises, our fourth series is intraday ticks of the Markit 5 year CDX NAIG index of credit default swap spreads of investment grade North American firms.[15] Longstaff, Mithal, and Neis (2005) describe how credit default swap spreads reflect both corporate default risk and bond market liquidity. The VIX is derived from

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[13] Knez, Litterman, and Scheinkman (1994) decompose money market yields and find that the 3-month eurodollar yield and other non-sovereign yields have substantial loading on an unobserved third factor which the 3-month T-bill has only trivial loading on. This is consistent with a credit risk element in the Eurodollar yield.

[14] See, for example, Bessembinder (1992), Bailey and Chan (1993), and Pukthuanthong and Roll (2011).

[15] The 5 year CDS is the most liquid market and has most dense intraday data. However, it only starts from September 30, 2008. We use the mid-quote, that is, the average of bid and ask spreads.

prices of stock index options, which can be thought of as the price of stock portfolio insurance (Whaley, 2009), so it is plausible that VIX is correlated with the price of corporate bond portfolio insurance. Indeed, Bali and Zhou (2011) report that monthly VRP is strongly correlated with credit default swap spreads. Furthermore, given that our sample includes the crisis period, this variable can reveal associations between VIX and the evolution of the broader crisis. Given the sustained upsurge (Figure 1) in VIX starting around the time of the collapse of Bear Stearns in March 2008, we will also present results for the crisis period only.

Our announcement measures of public information (NEWS in Equation 1 above) consist of the surprise component of principal US macroeconomic announcements. The standardized announcement surprise (actual minus forecast, all divided by standard deviation of surprise) follows Andersen et al (2003; 2006) and is applied to the ten macroeconomic announcements from 9:30 to 16:00 used by Pasquariello and Vega (2007). Source is Bloomberg. Many previous authors have shown that such announcements contribute significantly to explaining the evolution of stock returns, presumably because changes in economic conditions affect expected corporate cash flows, risk exposures, and risk premiums that underlie stock prices.

Our second group of explanatory variables (TRADE in Equation 1 above) is inspired by the work of previous authors on private information and stock trading. They include SPY trading volume, the price-setting or aggressive buy-sell imbalance of SPY, and the new VPIN measure (Easley, Lopez de Prado, and O'Hara, 2010) of the extent of informed trading of SPY.[16] These three series are computed from the trade and quote information on the TAQ database.[17] They reflect trading interest, buying or selling pressure, and, thus, the extent to which differentially-informed traders are present in the market. If these measures reflect the trading of informed investors, they can contribute to the volatility of stock returns perceived by

[16] We also own data which tags each SPY trade as a short sale or not. We may include this in future revisions, though it is unclear whether shorting should be thought of as informed trading or an indicator of sentiment.

[17] For tests based on fixed-length intervals, we compute VPIN using 50 "buckets" per 1 or 5 minute interval.

uninformed traders who fear trading at a disadvantage. Given that a gold ETF (symbol: GLD) is also publicly-traded and has data recorded on TAQ that spans the time period we study, we also compute trading volume, buy-sell imbalance, and VPIN for gold thereby allowing us to observe trading interest and direction for this key indicator, in addition to SPY.[18]

Our third set of explanatory variables measures dimensions of the investor sentiment that can affect stock index option pricing as reflected in VIX. The construction of proxies, SENTIMENT, for investor sentiment is severely constrained by our need for high-frequency variables to match our VIX series and other data. For example, the discount or premium on closed end equity funds is a classic measure of the optimism or pessimism of small investors (Lee, Shleifer, and Thaler, 1991). However, intraday net asset values of closed-end funds are not available so that intraday discounts or premiums relative to trading prices cannot be computed. Thus, the low frequency series proposed by Baker and Wurgler (2006, 2007) are not feasible for our purposes.

For our first sentiment indicator, we construct a high frequency proxy for the closed end equity fund premiums that we cannot observe directly as follows. First, we identify closed end equity funds for which the daily NAV closely tracks SPY by regressing the daily rate of change of individual fund NAVs on daily SPY returns. We form a capitalization-weighted portfolio, CEF, of such funds.[19] Second, we construct a common stock portfolio, CEF_NAV, that mimics

[18] Although our gold futures data extend back to January 2005, we only have trades so we cannot compute quote based measures like the buy-sell imbalance and VPIN.

[19] We begin with all closed end funds classified online as "general equity funds", excluding those that are not listed on the NYSE. We then collect daily NAVs from Bloomberg for each remaining fund for the period 2005 to June 2010, and regress each fund's rate of change of NAV on the rate of change of the price of SPY. We retain only those funds which display a reasonably high r-squared and slope reasonably close to one from those regressions. They are (slope and r-squared in parentheses): Adams Express (0.918, 94.2%), Denali Fund (1.302, 46.4%), Gabelli Equity Trust (1.259, 88.0%), General American Investors (1.108, 83.9%), Royce Micro Cap Trust (1.076, 79.3%), Royce Value Trust (1.172, 86.3%), and Tri Continental (1.047, 95.8%).

the daily cap-weighted NAV of the CEF portfolio and compute its intraday returns.[20]Third, our proxy for the intraday change in closed end fund premium is ln{CEF(t)/CEF(t-1)} – ln{CEF_NAV(t)/CEF_NAV(t-1)}. . Later in the paper, we provide some simple tests of the behavior of this proxy following Lee, Shleifer, and Thaler (1991).

Our second sentiment indicator is the difference between price-setting buy-sell imbalance for the previously-identified portfolio, CEF, and the price-setting buy-sell imbalance for the CEF_NAV mimicking portfolio. This measures the abnormal buying or selling pressure of CEF, an indication of whether closed end fund investors are optimistic or pessimistic relative to typical common stock investors.[21]

In addition to these two broad equity market sentiment indicators, we are aware of a closed-end fund devoted to gold, ASA Gold and Precious Metals Ltd (formerly known as American South African Fund). The fund's assets currently consist of a mix of gold mining stocks and gold bullion, implying that its NAV may not track the price of gold exclusively.[22] Nonetheless, we use it to compute two sentiment indicators for gold, a proxy for the change in gold-oriented closed end fund premium and abnormal buying or selling pressure of the gold-oriented closed end fund,[23] Their construction parallels what has been described previously for common stock closed end funds sentiment measures.

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[20] We identify the 100 most heavily-traded CRSP common stocks during our sample period. Daily returns of each are regressed on an intercept, daily CRSP index excess return, and daily change on the NAV of the CEF portfolio. We then construct a set of portfolio weights with minimum variance, zero intercept, zero market beta, and unit CEF NAV beta. These weights are then applied to intraday returns to generate CEF_NAV, the intraday mimicking portfolio returns.

[21] Alternatively, the CEFs buy-sell imbalance can be orthogonalized over the SPY buy-sell imbalance, rather than just taking their difference.

[22] See "The wacky world of gold: Why gold bugs no longer love gold miners" from *The Economist* print edition 2nd June 2011. A regression of the daily rate of change of ASA's NAV on the daily rate of change of the spot price of gold yields a slope coefficient of 1.202 and an r-squared of 17.1%.

[23] The mimicking portfolio for gold sentiment measures is computed with all CRSP stocks from SIC codes 1041 (gold ores), 1044 (silver ores),).

Akerlof and Schiller (2009) discuss a confidence multiplier effect that results in a time-varying impact of economic information. Therefore, we also construct variables that interact SENTIMENT variables with shocks to NEWS variables (particularly Consumer Confidence) that reflect consumer sentiment.

Finally, note that we include the rate of change of gold futures prices among the financial market series, r, described earlier. To the extent that the price of gold reflects fear about financial and economic conditions, it can be thought of as a sentiment indicator, in addition to incorporating beliefs about inflation or the consumption demand for gold.[24]

2.3 An overview of the data

Figure 1 shows 1-minute ticks of VIX and VRP during our sample period 9:30 to 16:00 of each trading day from the beginning of 2005 to the end of June 2010. Note that VIX is expressed in standard deviation terms while VRP is in variance terms so that the levels of the two series cannot be directly compared. It is clear that the VIX peaked during the 2008 financial crisis. Also notably, the VIX typically remained below 20 before August 2007 near the start of the crisis, and increased well above 20 afterward. Similarly, VRP has fluctuated a lot since the summer of 2007.

Figure 2 shows the prices of the gold ETF, GLD, and short maturity gold futures. Both the gold ETF and futures follow the same rising pattern since 2005. Figure 3 presents the prices of SPY (the ETF of S&P500) and Euro dollar futures. They typically moved in the opposite direction, increasing SPY price coinciding with decreasing Eurodollar price until the middle of 2009 and then reversing starting in the middle of 2009. Figure 4 shows cumulative versions of the sentiment measures derived from equity and gold closed end fund prices. The premiums appear larger and more volatile around the financial crisis.

[24] For a good summary of fundamental and sentiment influences on the gold market, see "Gilt-edged argument: The battle to explain the remorseless rise of the bullion price" from *The Economist* print edition 28th April 2011.

Table 1 reports the numbers of available and missing observations for principal intraday data series at 1-minute and 5-minute frequencies. We exclude overnight intervals. There are 530,124 1-minute and 106,509 5-minute VIX observations respectively. Any missing value of VIX generates a missing observation. Among the explanatory variables, the series of ASA-GLD and CEF-SPY return spreads and abnormal imbalance have the most missing observations, due to the relatively thin trading of the closed end fund components of those two series, CEF and ASA. Although the CDX spread change is only available from September 30, 2008, its missing observations are substantial. The Eurodollar and gold futures price rates of changes also have substantial missing observations. To make best use of our intraday data, missing values of explanatory variables (that is, volumes, imbalances, VPINs, price changes of SPY, the Eurodollar futures price, gold, and the CDX index) are replaced with zero. We also estimate results for both 1-minute and 5-minute intervals.

Table 2 summarizes the macro news announcements. They are broadly consistent with Anderson et al (2007). However, note that news surprises have values at the announcement time while they are zeros at other times, creating a severe multi-colinearity problem. To address this, we reduce NEWS to a simple series that sums across all the different NEWS variables. This creates simple indicators of whether any macro news arrived during that particular interval and how large a surprise that news is.

Table 3 reports summary statistics for dependent variables. At 1-minute intervals, the average VIX is 21.70, which means that the annualized standard deviation expected over the coming 30 calendar days is about 22%. To state this number in variance terms, square 0.2170 and multiply by 100 to yield 4.71%. The average VRP is 166.82 basis points, meaning that the expected annualized variance risk premium over the coming 30 calendar days is 1.67%. This suggests that, on average, the risk premium, 1.67%, is a substantial component of the certainty equivalent ex ante volatility expressed in squared terms, 4.71%. Also, all four variables exhibit significant serial correlation at 1-minute intervals at the 1% level. In particular, VIX and VRP

are quite persistent while their changes are not. Furthermore, squared terms are strongly serial correlated across all four variables, suggesting ARCH effects. In Panel B, 5-minute ticks display similar characteristics. In Panel C, we consider three subsamples: pre-crisis period from January 2005 to January 2007, crisis period from February 2007 to March 2009, and post-crisis period from April 2009 to June 2010. It is obvious that VIX and VRP increase and become more volatile during the crisis period. After the crisis, VIX and VRP decrease but a still higher and more volatile than their pre-crisis levels.

Given that VIX and VRP are quite persistent, we must address concerns about stationarity. Therefore, we apply the augmented Dickey-Fuller unit root test to VIX, and VRP to test for the presence of a unit root. Table 4 reports the ADF t-test statistics in the regressions with an intercept and the ADF ρ-test statistics in the regressions with an intercept and a time trend. In Panel A for 1-minute ticks, the statistics for VIX and VRP are smaller than the critical values at the 5% and 1% significant levels respectively. Therefore, we can reject the null hypothesis that VIX and VRP follow unit root processes. In other words, VIX and VRP can be considered stationary series.

Prior to running regressions, it is important to understand the degree of correlation among the explanatory variables. Table 5 presents the Pearson correlation matrix at the one-minute interval among regression variables, with zeros inserted for missing regressors.

Some highlights of the cross correlations of VIX and VRP with other variables are as follows. The small negative correlation of SPY return with VIX is consistent with the standard leverage story. At the same time, the small positive correlation with the VRP component of VIX suggests that the risk premium rises with the market. The small positive correlation of VRP and the CDX spread suggests a common risk premium. VIX and VRP increase with SPY trading volume. VIX and VRP decline with SPY VPIN, which is not consistent with informed trading increasing uncertainty. The strong positive correlation of VIX and VRP with GLD

trading volume is consistent with a common fear effect. However, strong negative correlations of VIX and VRP with GLD buying pressure are not consistent.

Table 5 also presents interesting correlations among the explanatory variables themselves. SPY and gold futures returns are positively correlated, which is not consistent with gold as a safe haven from declining equity markets. The SPY return goes up with SPY buying pressure and the gold return goes up with GLD buying pressure, which makes sense. The SPY return and buying pressure decline as equity closed end fund sentiment rises, which can indicate that small investors are contrarians (Grinblatt and Keloharju, 2000).

3. Empirical results

3.1 Single-equation regression estimates

Prior to estimating regressions, we use the Bayesian information criterion (BIC) to choose AR terms for VIX and VRP and then include other explanatory variables with and without their lags. We report results first for VIX and VRP for 1 minute and 5 minute intervals for the entire January 2005 to June 2010 sample, which means we must exclude the CDX credit spread variable. We then report sub-period results to make use of the CDX spread variable and to isolate relationships during the height of the financial crisis.

3.1.1 Full sample results

Table 6 shows regression results for 1-minute VIX for the entire time period. VIX is highly persistent, with statistically significant AR terms out to ten lags. Slopes on the SPY return are significantly negative, which is consistent with the leverage effect. A one percent positive SPY price change is associated with a decline of 0.464 in VIX.

The contemporaneous slope on the Eurodollar futures price is strongly positive. An increase of one percent in the Eurodollar futures price is associated with a contemporaneous

increase of 0.33 percent in the VIX,.[25] It is notable that the raw correlation of VIX and Eurodollar in Table 5 is insignificant but a correlation emerges when the autocorrelation of VIX and explanatory power of other variables is accounted for. The Eurodollar futures price rises as the Eurodollar yield declines. Thus, the VIX rises when the short term interest rate declines.[26] This correlation is consistent with "flight to quality" in which equity market uncertainty increases the demand for Treasury bills, deposits, and other less risky assets, thereby driving down yields. This effect is not consistent with VIX increasing with the risk premium component of the Eurodollar yield. Alternatively, increases in equity market uncertainty coincide with expectations that the Fed will lower its interest rate target to stimulate the economy or support the banking system.

Table 6 also shows that the slope on the contemporaneous gold futures return is small, -0.019, but statistically significant and negative. This is not consistent with the hypothesis that gold is a hedge or fear factor indicator that is positively correlated with VIX. The first lag of the summed NEWS variable is significantly positive. This is consistent with resolution of uncertainty.

Among the TRADE indicators, SPY volume shows slopes of both signs at different lags, which is difficult to interpret. The buy-sell imbalance for SPY is positive at lags 1 and 2, indicating that VIX rises, rather than falls, with rising S&P500 buying pressure. GLD volume is positive at lags 1 and 2, suggesting that gold-buying as hedging or fear factor leads equity market volatility.

Among the SENTIMENT indicators, the contemporaneous return spread between the closed-end equity fund portfolio CEF and its NAV mimicking portfolio is marginally

[25] Since Eurodollar futures prices roughly equal 100 minus the annualized Eurodollar yield, a one percent increase in the futures prices is associated with a substantial change (approximately 100 basis points) in yield.

[26] Using monthly data from 1990 to 2007, Bekaert, Hoerova, and Lo Duca (2011) find substantially different patterns in lower frequency data. Monthly VIX and real interest rate show persistently positively correlation, becoming negative after 13 months.

significantly positive. This suggests that demand for closed end equity funds increases at times of high uncertainty, suggesting contrarian trading, though the economic scale of the effect is small. The return spread between the ASA closed end fund and its NAV mimicking portfolio is not significant contemporaneously but is after 2 lags. .

Table 7 shows regression results for 1-minute volatility risk premium, VRP. On most dimensions, the results for VRP are qualitatively similar to those for VIX in Table 6. Specifically, there is strong persistence in VRP, significant negative contemporaneous and lagged effects of the SPY return, significant contemporaneous and lagged effects of the Eurodollar futures price change, strong negative contemporaneous and lagged effects of the gold futures price change, and significant effects of NEWS. We also note substantial negative effects of the abnormal gold closed end fund return.

We can compare the results of Tables 6 and 7 more precisely by accounting for the different scales in which VIX and VRP are expressed. Recall that, to compare a value of VIX to a value of VRP, VIX is expressed in percent, VRP is a variance expressed in basis points so divide VRP by 100, then take its square root.

Begin with slopes on SPY return, -0.464 for VIX and -45.771 for VRP. The square root of 0.45771 is 0.6765. Therefore, VRP increases much more rapidly with negative index returns than VIX as a whole. The slope on the Eurodollar futures price change is 0.33 for VIX and 14.13 for VRP, and the resulting square root is 0.3758. Thus, VRP is more sensitive to the Eurodollar price than VIX as a whole. With a slope of -0.019 for VIX, -2.101 for VRP, and resulting square root of 0.1449, gold has a much bigger impact on VRP than VIX as a whole. This comparison suggests that key financial indicators are more significant for the risk premium component of VIX. If our Eurodollar measure reflects expectations of forthcoming Fed actions, the slope coefficients suggest an unintended consequence of expected monetary loosening: There is an immediate heightening of the risk premium for uncertainty.

To this point, Tables 6 and 7 show us that the level of short term unregulated interest rates is important for VRP, which rises when the Eurodollar futures price rises (that is, when the Eurodollar yield falls). We also see that the relationship between VIX and gold is not as simple as we had suspected: these two variables are not simply two facets of a basic fear factor in financial markets. Finally, we see that VIX can be related to small investor sentiment as manifested in premiums or discounts for closed end funds. In the case of gold, the demand for a gold-related closed end fund appears to lead rises in VIX. However, the relationship for equity market sentiment does not run in the obvious direction. Higher investor sentiment for S&P500 stocks is associated with higher levels of VIX. Perhaps small investors view uncertain stock market conditions as a buying opportunity, while institutional investors feel otherwise (Grinblatt and Keloharju, 2000).

We also estimate analogous 5-minute regressions to explain VIX and VRP. Relative to 1-minute results, 5 minutes allow for more gradual lead-lag associations and can also alleviate the problem of missing observations. We briefly compare the (unreported) 5 minute interval results for VIX to the 1 minute results in Table 6. The most noticeable differences are that, at 5 minutes, the effects are largely much weaker, except for the Eurodollar price change. This is also evident in the differences between 5 minute interval (unreported) and one minute interval (Table 7) results for VRP. On balance, the comparison between 1 and 5 minute single equation results suggests that these relationships are transitory given that they are mostly more prominent at 1 minute.

3.1.2 Sub period results incorporating CDX corporate credit spread

In this subsection, we report regression results for two sub periods from our full sample of January 2005 to June 2010. First, we report for 30th September 2008 to June 2010, the period for which we have data on the CDX NAIG credit spread. As previously discussed, the CDX variable is perceived as an important barometer of credit risk, particularly during a period of

market turbulence, and it can contribute to our understanding of the forces that move the VIX, and VRP, from minute to minute. Second, we identify the period from February 2007 to March 2009 as the height of the financial crisis. We re-estimate our basic specifications (without the CDX spread) over this sub-period to see if the associations that emerge from our full sample results change during the crisis.

Tables 8 and 9 report regression results for 1-minute VIX and VRP for the sub period when the CDX spread variable is available. The CDX spread change turns out to be very significant in explaining both VIX and its VRP component. In Table 8, the contemporaneous slope coefficient on the CDX spread for VIX is 2.211. That is, a one perfect increase in the spread is associated with a more-than-double increase in VIX. The coefficient at the first lag is larger than the contemporaneous, and statistically significant positive associations extend over all five lags. In Table 9, the contemporaneous slope coefficient on CDX for VRP is 251.047, and, as is the case for VIX, the coefficient at lag1 is larger and significant positive slopes are observed for all lags. To compare the VIX and VRP coefficients, take the square root of the VRP coefficient divided by 100. This yields 1.5844, which is to be compared to 2.211 for VIX as a whole. The comparison indicates that almost all ((1.5844/2.211) = 71.6%) of the effect of the CDX spread on the VIX works through the expected risk premium component, VRP. Put another way, the association between the CDX spread and VIX is mostly a risk premium effect, rather than an expected uncertainty effect.

3.2 Multiple-equation regression estimates

Our previous simple regression specifications view VIX and VRP as endogenous and all other explanatory variables as exogenous. Given, however, the likelihood that many conditions across markets are jointly determined, we next present estimates of systems of equations to accommodate the associations among the variables. Specifically, we estimate VARX models (that is, VARs that also include exogenous variables) for a first look at how associations among variables change using a more exhaustive specification. Given the number of variables

available for study, we begin by assuming VIX, SPY return, Eurodollar futures return, and gold futures return are endogenous variables, and other trade and sentiment indicators are exogenous.

Table 10 summarizes results for VIX over 1-minute intervals over the full sample period. Persistent autoregressive effects for VIX. Significant, persistent negative association of VIX with SPY price changes suggests leverage or increased uncertainty with stock market declines. In contrast to the single equation results, there are no significant associations for Eurodollar futures price change. Significant but small negative correlations with gold futures price change at lags 1 and 2 are not consistent with gold and VIX representing similar risk, fear, or panic factors. Strong negative contemporaneous correlation with NEWS suggests resolution of uncertainty. The small positive contemporaneous association for SPY volume shows VIX rises with trading activity, which is not what we would predict if VIX is a fear index and trading volume is a positive sentiment indicator (Baker and Wurgler, 2006). In contrast, the small negative contemporaneous association for SPY buy-sell imbalance suggests VIX declines as buying pressure rises. Strong positive contemporaneous association for SPY VPIN suggests increased risk of adverse selection raises VIX. Small but significantly positive associations with GLD volume out two lags suggests more gold trading is associated with higher equity market uncertainty, though there is no significant effect for GLD returns. This suggests difference of opinion among traders. Small but statistically significant correlations for GLD VPIN suggest VIX goes up when there is more adverse selection in the gold market, though positive contemporaneous slope for CEF – NAV return spread suggests that investor sentiment is positively correlated with VIX, which is unexpected. There is no significant association for gold sentiment measure ASA – NAV return spread.

Figure 5 shows 1-minute VIX responses to impulses of endogenous variables. The autoregressive effect is largest, followed by the negative impact of SPY return impulses.

Effects of both appear to persist through ten lags. Eurodollar and gold futures are not significant.

Table 11 and Figure 6 report similar tests for the sub period starting 30th September 2011 for which the CDX spread variable is available. Results are qualitatively similar to what is reported for the full sample in Table 10 and Figure 5 except for the following. First, there is a significantly positive effect of the CDX spread change that extends to six lags. This is consistent with a common uncertainty or risk premium element in both VIX and CDX prices. Second, the sign on the SPY buy-sell imbalance switches to negative, suggesting that VIX is higher when buying pressure is heightened. Finally, the significance of the equity market sentiment factor, CEF – NAV return spread, vanishes.

4.0 Preliminary summary, conclusions, and agenda for subsequent drafts

This paper presents preliminary results and an agenda for subsequent work to understand the public information, private information, and investor sentiment components of the widely followed VIX implied volatility index. The results reveal some interesting associations for VIX and its related risk premium relative to our three sets of explanatory variables. The negative association between VIX and S&P 500 basket returns suggests a leverage effect or increasing risk neutral volatility during market downturns. Declining short term interest rates are, in single equation tests, associated with increased VIX, perhaps because of expected Fed action or flight-to-quality. Gold is not synonymous with VIX as a fear indicator: its price is not positively correlated with VIX, although some other gold-related indicators suggest that some investors flee to gold when ex ante stock volatility is high. Associations between VIX and corporate credit default spreads appear driven by common risk premiums, rather than changes in expected volatility. Finally, some associations between VIX and pricing in the equity closed end fund market suggest that some investors use these investments for contrarian purposes,

eagerly buying such funds when the market as a whole signals higher risk with heightened values for VIX.

As outlined earlier, a number of empirical specifications and other tests have yet to be produced, reported, and discussed. In particular, we will model the error process more explicitly (Equation 2) and explore the closed-end fund based sentiment measures following Lee, Shleifer, and Thaler (1991) and Baker and Wurgler (2006). Given that this is, to our knowledge, the first comprehensive very high frequency study of the VIX index, we will provide more univariate statistics on VIX like hourly behavior, day-of-week, roll days, and other seasonal effects. We will estimate a few specifications using daily data, for comparison to 1 minute findings and to gauge the importance of the TED spread (unavailable at very high frequencies due to inactive trading of Treasury bill futures) to Eurodollar futures prices employed in our one and five minute interval tests. We will consider intraday liquidity factors such as the SPY bid-ask spread from TAQ, off-the-run versus on-the-run Treasury bond bid-ask spread (Asness, Moskowitz, and Pedersen, 2009) from GovPX, and the CDX NAIG bid-ask spread from Markit. Trade-by-trade data on NYSE short sales is also available to us, so we may add SPY shorting intensity. Finally, we will think about additional approaches to missing data among our explanatory variables.

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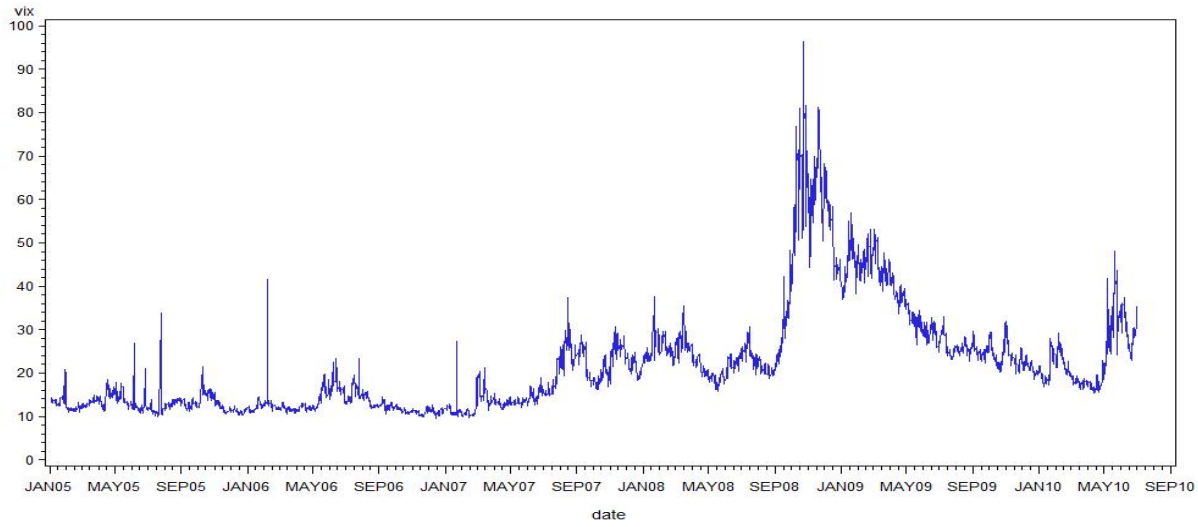
Figure 1. Intraday VIX and VRP at 1-minute intervals

VIX and VRP are expressed in different units but can be compared as follows. Suppose VIX is 21.70. Square 0.2170 and multiply by 100 to yield 4.71%. Suppose VRP is 220.34. Divide by 100 to yield 2.20%. Thus, VRP comprises slightly less than half of VIX.

Panel A: VIX (in percentage)



Panel B: VRP (in basis points)

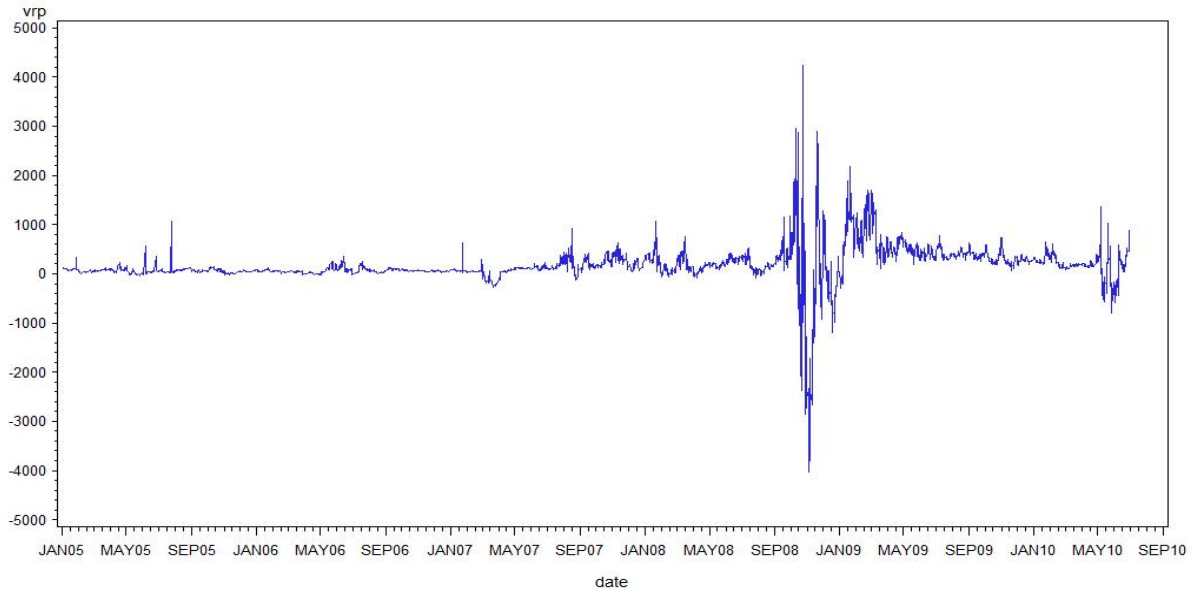
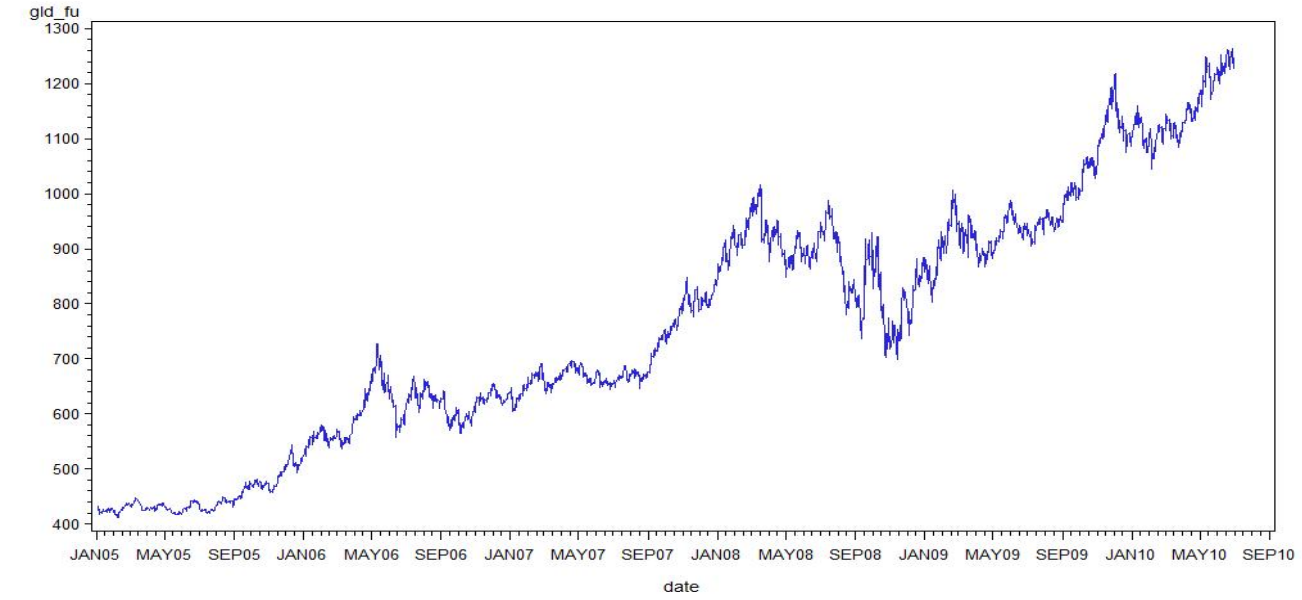


Figure 2. Gold Futures Prices and GLD Gold ETF Prices at 1-minute intervals

The first series is the price for the short maturity COMEX gold futures contract. The second series is the price of the "GLD" exchange traded fund which holds gold bullion.

Panel A: Gold Futures Price

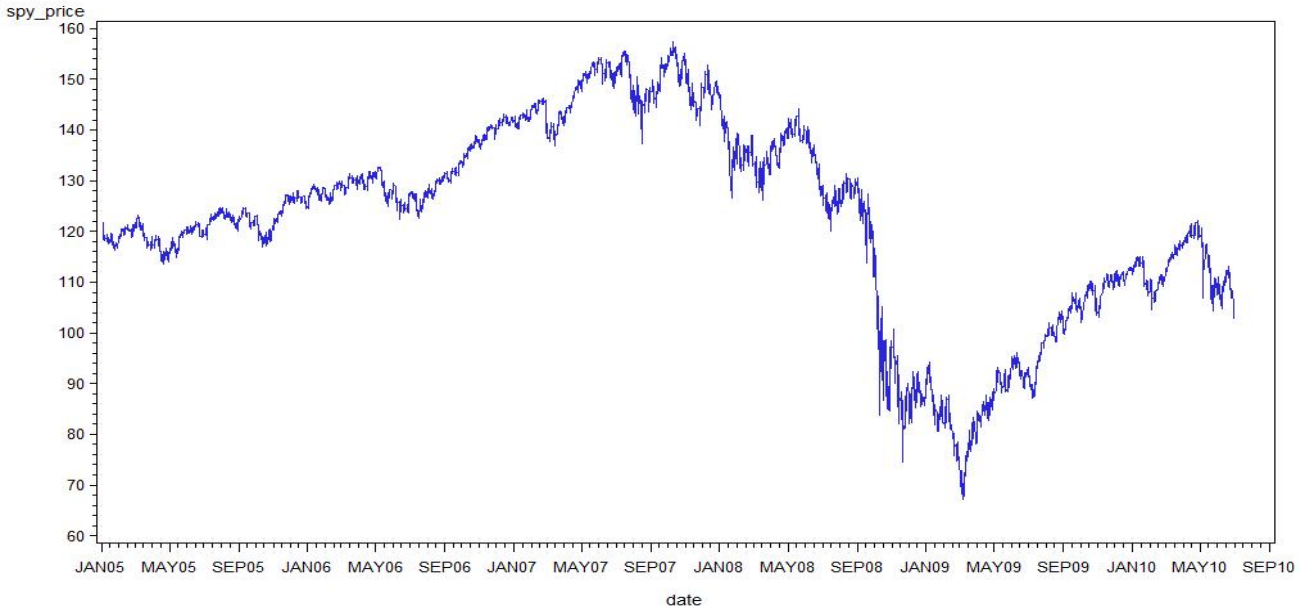


Panel B: GLD Gold ETF Price

Figure 3. SPY S&P 500 ETF Prices and Eurodollar Futures Prices

The first series is the price for the S&P500 exchange traded fund. The second series is the short maturity CME Eurodollar deposit futures contract (100 – annualized percent yield).

Panel A: SPY ETF price



Panel B: Euro dollar Futures price

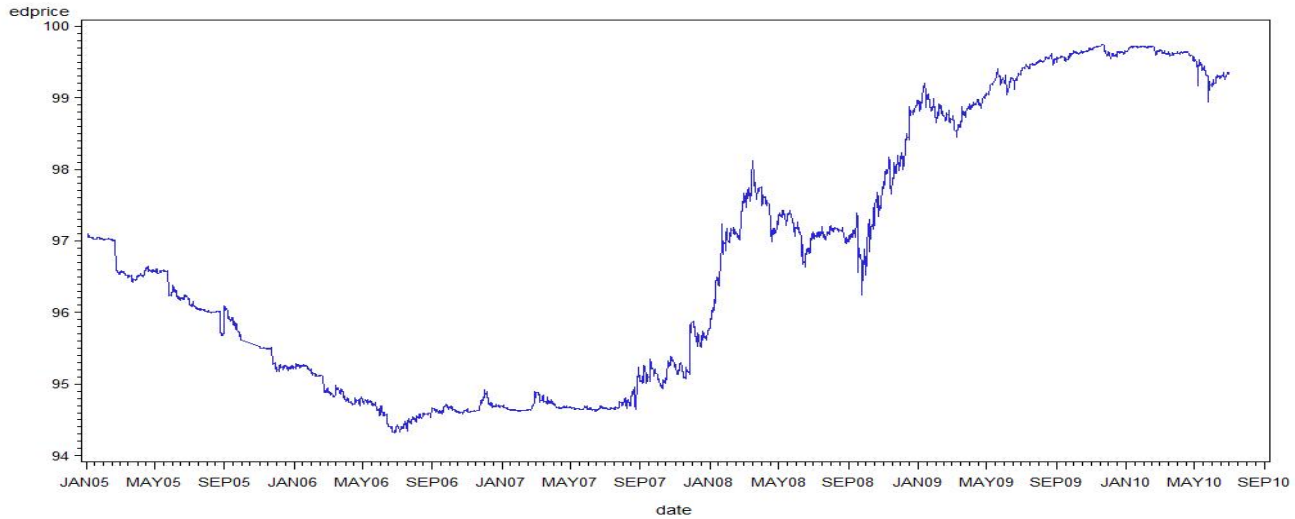
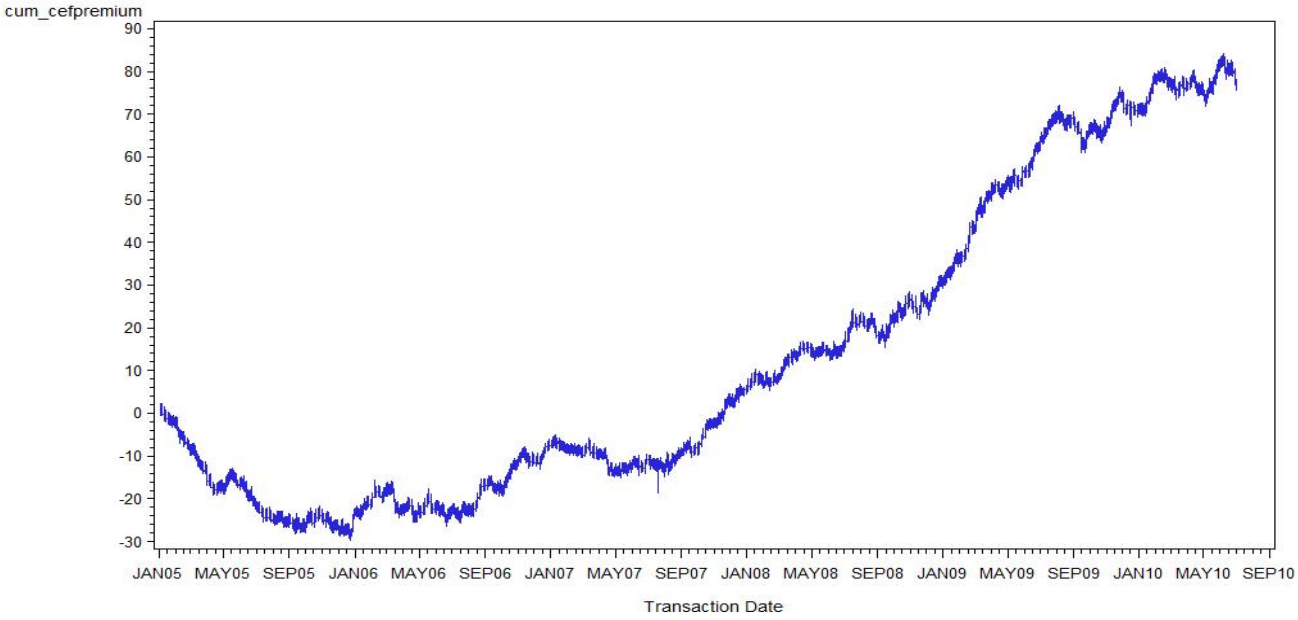


Figure 4. Proxies for S&P500 and Gold closed-end fund price-to-NAV premiums

The plots show cumulative values of the proxy (closed end fund return minus NAV return) for S&P500 and gold closed end fund premiums. First-differences are used in all empirical tests but cumulative values are easier to compare against plots in classic studies like Lee, Shleifer, and Thaler (1991).

Panel A: Cumulative CEF – NAV mimicking portfolio return spread



Panel B: Cumulative ASA – NAV mimicking portfolio return spread

Table 1. Frequency of principal intraday data series

This table summarizes the numbers of available and missing observations for principal intraday data series at 1- minute and 5-minute frequencies. All series are 9:30am to 16;00 from January 2005 to June 2010, except for CDX spread, which is only available from September 30, 2008.

	One minute intervals		Five minute intervals	
Series	**Number of available observations**	**Number of missing observations**	**Number of available observations**	**Number of missing observations**
VIX index	530,124	13,317	106,509	2,479
SPY price rate of change	537,815	5,599	107,623	1,365
Eurodollar futures price rate of change	269,902	275,539	53,579	55,409
Gold futures price rate of change	425,275	118,116	89,071	19,917
CDX spread change	26,028	147,917	20,811	14,058
SPY trading volume	537,988	5,453	107,688	1,300
SPY price-setting buy-sell imbalance	537,985	5,456	107,688	1,300
SPY VPIN	537,988	5,453	107,688	1,300
GLD trading volume	518,621	24,820	107,513	1,475
GLD price-setting buy-sell imbalance	518,621	24,820	107,513	1,475
GLD VPIN	518,621	24,820	107,513	1,475
CEF – NAV return spread	445,774	98,351	107,326	1,662
ASA – NAV return spread	156,099	388,026	15,329	33,659
CEF – SPY buy-sell imbalance spread				
ASA – GLD buy-sell imbalance spread				

Table 2. Frequency, Source, Timing, and Volatility of Macroeconomic News Announcements

Abbreviations are: Bureau of the Census (BC), Federal Reserve Board (FRB), National Association of Purchasing Managers (NAPM), Conference Board (CB), Financial Management Office (FMO).In February 200, business inventory announcement was moved from 8:30 A.M. to 10:00 A.M. Consumer credit and trade balance are rescaled by dividing 10^9. New home sales are rescaled by dividing 10^3 and housing start is rescaled by dividing 10^6. All announcements are monthly unless noted.

Announcement	Observations	Source	Time	Standard deviation
Consumer Credit	66	FRB	3:00 PM	6.506
New Home Sales	66	BC	10:00 AM	67.964
Durable Goods Orders	66	BC	10:00 AM	0.025
Factory Orders	66	BC	10:00 AM	0.781
Construction Spending	66	BC	10:00 AM	0.778
Business Inventories	66	BC	8:30/10:00 AM	0.002
Government Budget deficit	66	FMS	2:00 PM	11.435
Consumer Confidence Index	66	CB	10:00 AM	5.157
NAPM Index	66	NAPM	10:00 AM	2.102
FOMC Target Federal Funds Rate (6 week)	46	FRB	2:15 PM	0.056

Table 3. Summary Statistics

VIX is intraday ticks of the Chicago Board Option Exchange (CBOE) S&P500 volatility spot index from the CBOE's Market Data Express service, which is annualized standard deviation in terms of percentage. VRP is intraday ticks of the variance risk premiums defined as the difference between the squared VIX and expected annualized realized variance, which is in terms of basis points. ΔVIX and ΔVRP are first differences of VIX and VRP respectively "Lag x" denotes autocorrelation at x period lag. LB Q(60) is the Ljung-Box's Q (60) statistics with *, **, and *** denoting significance at 10%, 5%, and 1%, respectively.

Panel A: 1-minute intervals (whole sample)

Variable	Mean	Std	Min	Max	Skew	Kurt	Lag1	Lag60	LB Q (60)	LB Q(60) For squared term
VIX	21.70	12.14	9.39	96.40	1.87	3.92	0.9999	0.9978	3.16+E07***	3.15+E07***
VRP	166.82	368.93	-4039.24	4230.511	-2.21	30.65	0.9959	0.9739	3.07+E07***	3.04+E07***

Panel B: 5-minute intervals (whole sample)

Variable	mean	Std	Min	Max	Skew	Kurt	Lag1	Lag60	LB Q (60)	LB Q(60) For squared term
VIX	21.68	12.13	9.41	87.71	1.88	3.93	0.9997	0.9899	6.32+E06****	6.26+E06***
VRP	94.92	390.35	-4779.63	2418.84	-4.65	46.36	0.9961	0.9102	5.78+E06***	5.82+E06***

Panel C: Financial crisis sub samples for both one (1) and five (5) minute intervals

Variable	Pre Crisis (1/2005 to 1/2007)				Crisis (2/2007 to 3/2009)				Post Crisis (4/2009 to 6/2010)			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
VIX (1)	12.75	1.84	9.39	41.60	28.15	14.97	9.71	96.40	25.70	6.10	15.25	48.20
VRP (1)	58.71	40.04	-35.27	1063.40	193.48	547.73	-4039.24	4230.511	302.15	212.71	-800.07	1358.05
VIX (5)	12.75	1.84	9.41	32.86	28.07	14.97	9.72	87.71	25.70	6.10	15.25	47.57
VRP (5)	58.44	35.90	-33.46	981.64	51.59	598.83	-4779.63	2418.84	229.40	173.31	-454.85	1261.66

Table 4. Results of ADF Tests for Unit Roots

The table reports the results of augmented Dickey-Fuller test for unit roots. VIX is the intraday ticks of the Chicago Board Option Exchange (CBOE) S&P500 volatility spot index from the CBOE's Market Data Express service. VRP is the intraday ticks of the variance risk premiums defined in Equation (4a). "Olags" means the optimal lag length used in regression to test for the presence of a unit root and it is chosen based on Bayesian information criterion (BIC). "Intercept" means that the regression equation used to test for the presence of a unit root includes an intercept term, where the ADF t-test statistics is reported. "Intercept & Trend" means that the regression equation used to test for the presence of a unit root includes an intercept and a time trend term, where the ADF ρ-test statistics is reported. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

	Panel A: 1-minute intervals			Panel B: 5-minute intervals		
Variable	Olags	Intercept	Intercept and Trend	Olags	Intercept	Intercept and Trend
VIX	14	-2.98**	-18.10**	3	-3.02**	-18.56**
VRP	10	-9.85***	-195.77***	13	-9.40***	-179.60***

Table 5. Correlation matrix for regression variables

This table presents contemporaneous Pearson correlations at the one minute interval. "ret" indicates percentage rate of price change, "vol" volume in terms of million, "imb" price setting buy sell imbalance, and "sp" spread between two return series. *, **, and *** denote significance at 10%, 5%, and 1%, respectively. The CDX spread change is only available starting 30th September 2008, unlike other series which start January 2005.

Variable	VRP	SPY ret	Eurodollar ret	Gold futures ret	CDX spread change	Sum of NEWS	SPY vol	SPY imb	SPY VPIN	GLD vol	GLD imb	GLD VPIN	CEF-NAV sp	ASA-NAV sp	CEF-NAV imb	ASA-NAV imb
VIX	0.221***	0.000	-0.000	-0.001	-0.003	-0.002	0.470***	0.004***	-0.625***	0.220***	-0.041***	-0.125***	0.000	-0.001		
VRP		-0.000	-0.001	-0.001	0.007***	0.001	0.183***	0.002	-0.179***	0.140***	-0.017***	-0.050***	0.000	0.001		
SPY ret			-0.065***	0.087***	-0.004*	0.027***	0.008***	0.402***	-0.003**	0.000	0.039***	0.001	-0.001***	0.014***		
Eurodollar ret				0.004***	0.002	-0.017***	0.005***	-0.037***	-0.001	0.000	-0.002	-0.000	0.002	0.002*		
Gold ret					0.001	-0.005***	-0.002	0.050**	0.002	-0.015***	0.253***	0.006***	0.000	0.045***		
ΔCDX spread						-0.002	0.001	-0.007***	-0.001	0.005**	-0.002	0.002	-0.003	-0.002		
Sum of NEWS							0.002*	0.007***	-0.002	0.002	-0.000	0.001	-0.000	-0.002		
SPY vol								0.009***	-0.470***	0.272***	-0.029***	-0.063***	0.007***	-0.002		
SPY imb									-0.008***	0.004***	0.037***	0.003***	-0.004***	-0.005***		
SPY VPIN										-0.223***	0.039***	0.323***	-0.004***	0.001		
GLD vol											-0.032***	-0.123***	0.001	0.001		
GLD imb												0.036***	-0.000	0.016***		
GLD VPIN													0.000	0.000		
CEF-NAV sp														0.002*		
ASA –NAV sp																
CEF -NAV imb																

Table 6. Regression of 1-minute S&P 500 Volatility Index (VIX) on its lags and explanatory variables (NEW)

This table summarizes regressions for 1-minute intervals and VIX as dependent variable expressed in percentage. SPY, Eurodollar, Gold futures price rates of change, CDX spread change, CEF-SPY and ASA-GLD return spreads are in terms of percentage. SPY and GLD volume are in millions. Buy-sell imbalances and VPINs are between 0 and 1. The numbers in the table are regression coefficients with p-values in the parenthesis. The adjusted R-squared is in the last row. The second row for VIX reports lags 6 through 10. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Slope coefficients on:	Contemporaneous	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
VIX	-	0.748***(0.000)	0.105***(0.000)	0.046***(0.000)	0.042***(0.000)	0.042***(0.000)
	-	0.007***(0.000)	0.010***(0.000)	0.005***(0.000)	0.003***(0.000)	-0.009***(0.000)
SPY price rate of change	-0.464***(0.000)	-0.417***(0.000)	-0.214***(0.000)	-0.142***(0.000)	-0.099***(0.000)	-0.046***(0.000)
Eurodollar futures price rate of change	0.330***(0.000)	0.030 (0.676)	-0.132* (0.068)	0.105 (0.146)	-0.131* (0.068)	0.061 (0.388)
Gold futures price rate of change	-0.019***(0.000)	-0.023***(0.000)	-0.002 (0.538)	-0.010**(0.016)	0.003 (0.455)	-0.003 (0.467)
Sum of NEWS Surprises	-0.055***(0.000)	0.030***(0.000)	0.002 (0.822)	-0.003 (0.633)	-0.004 (0.579)	-0.005 (0.444)
SPY volume	-0.001 (0.290)	-0.002***(0.002)	0.001 (0.192)	0.007***(0.000)	0.001 (0.211)	-0.002***(0.001)
SPY price-setting buy-sell imbalance	-0.001 (0.115)	0.001***(0.005)	0.001***(0.004)	0.000 (0.494)	-0.001 (0.132)	-0.001***(0.009)
SPY VPIN	-0.001 (0.844)	-0.001 (0.647)	-0.003 (0.250)	0.001 (0.727)	0.000 (0.933)	-0.005*(0.088)
GLD volume	-0.005 (0.314)	0.056***(0.000)	0.013**(0.011)	-0.030***(0.000)	-0.012**(0.022)	-0.007 (0.148)
GLD price-setting buy-sell imbalance	0.000 (0.332)	0.001 (0.116)	0.000 (0.217)	0.000 (0.510)	-0.000 (0.870)	-0.000 (0.547)
GLD VPIN	0.001 (0.552)	0.002* (0.084)	-0.001 (0.207)	-0.000 (0.719)	-0.002* (0.094)	-0.001 (0.215)
CEF – NAV return spread	0.001*(0.094)	0.000 (0.822)	0.000 (0.736)	-0.000 (0.936)	-0.000 (0.581)	-0.001 (0.720)
ASA – NAV return spread	-0.008 (0.512)	0.000 (0.968)	-0.037***(0.003)	-0.034***(0.006)	-0.025**(0.041)	0.020*(0.096)
CEF – SPY price- setting buy-sell imbalance spread						
ASA – GLD price -setting buy-sell imbalance spread						
Adjusted R-squared	99.99%					

Table 7. Regression of 1-minute Volatility Risk Premium (VRP) on its lags and explanatory variables (NEW)

This table summarizes regressions for 1-minute intervals and VRP as dependent variable expressed in basis points. SPY, Eurodollar, Gold futures price rates of change, CDX spread change, CEF-SPY and ASA-GLD return spreads are in terms of percentage. SPY and GLD volume are in million. Buy-sell imbalances and VPINs are between 0 and 1. The numbers in the table are regression coefficients with p-values in the parenthesis The adjusted R-squared is in the last row.. The second row for VRP reports lags 6 through 10. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Slope coefficients on:	Contemporaneous	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
VRP	-	0.727***(0.000)	0.081***(0.000)	0.075***(0.000)	0.047***(0.000)	0.027***(0.000)
	-	0.022***(0.000)	0.014***(0.000)	0.005***(0.003)	0.009***(0.000)	-0.008***(0.000)
SPY price rate of change	-45.771***(0.000)	-41.341***(0.000)	-21.591***(0.000)	-14.781***(0.000)	`-9.676***(0.000)	-4.715***(0.000)
Eurodollar futures price rate of change	14.130***(0.051)	-16.578**(0.025)	-26.400***(0.000)	4.699 (0.526)	-20.554***(0.005)	14.286**(0.048)
Gold futures price rate of change	-2.101***(0.000)	-3.304***(0.000)	0.155 (0.706)	-1.722***(0.000)	0.188 (0.647)	-0.516 (0.208)
Sum of NEWS Surprises	-2.758***(0.000)	2.504***(0.000)	0.148 (0.828)	-0.182 (0.790)	-0.493 (0.470)	-0.442 (0.517)
SPY volume	-0.286***(0.000)	-0.513***(0.000)	-0.063 (0.275)	0.869***(0.000)	0.088 (0.124)	-0.264***(0.000)
SPY price-setting buy-sell imbalance	0.960***(0.000)	0.798(0.000)	0.314***(0.000)	0.191***(0.000)	0.056 (0.240)	-0.098**(0.039)
SPY VPIN	-0.439 (0.116)	-0.545* (0.061)	0.117 (0.689)	0.319 (0.275)	0.227 (0.435)	-0.107 (0.701)
GLD volume	-0.938*(0.069)	4.822***(0.000)	1.008*(0.059)	-1.990***(0.000)	-1.042**(0.049)	0.093(0.857)
GLD price-setting buy-sell imbalance	0.079**(0.028)	0.075**(0.036)	0.039 (0.282)	0.009 (0.800)	0.001 (0.972)	-0.013 (0.709)
GLD VPIN	0.051(0.663)	0.144(0.216)	-0.079 (0.498)	0.042 (0.718)	-0.059 (0.615)	-0.040 (0.728)
CEF – NAV return spread	0.035 (0.497)	-0.056(0.358)	-0.046 (0.473)	-0.085 (0.188)	-0.068(0.267)	-0.039(0.453)
ASA – NAV return spread	-2.736**(0.028)	-2.838**(0.023)	-7.239***(0.000)	-5.025***(0.000)	-3.407***(0.006)	2.299* (0.065)
CEF – SPY buy-sell imbalance spread						
ASA – GLD buy-sell imbalance spread						
Adjusted R-squared	99.83%					

Table 8. Subsample regression of 1-minute S&P 500 Volatility Index (VIX) on its lags and explanatory variables including corporate credit spread variable

This table summarizes regressions for 1-minute intervals from September 30, 2008 and VIX as dependent variable expressed in percentage. SPY, Eurodollar, Gold futures price rates of change, CDX spread change, CEF-SPY and ASA-GLD return spreads are in terms of percentage. SPY and GLD volume are in millions. Buy-sell imbalances and VPINs are between 0 and 1. The numbers in the table are regression coefficients with p-values in the parenthesis. The adjusted R-squared in the last row.. The second row for VIX reports lags 6 through 10. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Slope coefficients on:	Contemporaneous	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
VIX	-	0.781***(0.000)	0.046***(0.000)	0.077***(0.000)	0.050***(0.000)	0.035***(0.000)
	-	0.011***(0.000)	0.011***(0.000)	0.014***(0.000)	-0.014***(0.000)	-0.010***(0.000)
SPY price rate of change	-0.459***(0.000)	-0.435***(0.000)	-0.224***(0.000)	-0.146***(0.000)	-0.093***(0.000)	-0.025***(0.000)
Eurodollar futures price rate of change	0.578***(0.001)	-0.551***(0.001)	-0.565***(0.000)	0.306*(0.073)	-0.453***(0.008)	0.090 (0.592)
Gold futures price rate of change	-0.024***(0.007)	-0.041***(0.000)	-0.014(0.110)	-0.020**(0.022)	0.007 (0.412)	-0.000 (0.959)
CDX spread change	2.211***(0.000)	3.087***(0.000)	1.108***(0.000)	0.531***(0.008)	1.123***(0.000)	1.315***(0.000)
Sum of NEWS Surprises	-0.104***(0.000)	0.069***(0.000)	-0.003 (0.846)	-0.000 (0.973)	-0.005 (0.723)	-0.011(0.398)
SPY volume	-0.002**(0.018)	-0.005***(0.000)	0.000 (0.750)	0.014***(0.000)	0.001 (0.338)	-0.003**(0.012)
SPY price-setting buy-sell imbalance	0.003**(0.017)	0.003**(0.037)	0.000(0.847)	-0.001(0.576)	-0.001(0.538)	-0.004***(0.000)
SPY VPIN	-0.013**(0.028)	-0.018***(0.003)	0.007(0.286)	0.009 (0.147)	0.007(0.238)	0.002 (.764)
GLD volume	-0.006(0.482)	0.064***(0.000)	0.008(0.373)	-0.023***(0.006)	-0.019**(0.024)	-0.008 (0.329)
GLD price-setting buy-sell imbalance	0.001 (0.555)	0.001(0.232)	0.000 (0.923)	-0.000 (0.804)	-0.000 (0.895)	0.000 (0.852)
GLD VPIN	0.006(0.376)	0.028***(0.000)	-0.015**(0.031)	0.002(0.081)	-0.010(0.141)	-0.017**(0.012)
CEF – NAV return spread	-0.000(0.997)	-0.002(0.148)	-0.002(0.281)	-0.003**(0.045)	-0.002(0.251)	-0.001(0.224)
ASA – NAV return spread	-0.023(0.368)	-0.006(0.805)	-0.105***(0.000)	-0.071***(0.003)	-0.068***(0.007)	0.061**(0.015)
CEF – SPY buy-sell imbalance spread						
ASA – GLD buy-sell imbalance spread						
Adjusted R-squared	99.98%					

Table 9. Subsample regression of 1-minute Volatility Risk Premium (VRP) on its lags and explanatory variables including corporate credit spread variable

This table summarizes regressions for 1-minute intervals from September 30, 2008. VRP is dependent variable expressed in basis points. SPY, Eurodollar, gold futures price rates of change, CDX spread change, CEF-SPY and ASA-NAV return spreads are in terms of percentage. SPY and GLD volume are in millions. Buy-sell imbalances and VPINs are between 0 and 1. The numbers in the table are regression coefficients with p-values in parentheses. The second row for VRP reports lags 6 through 10. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Slope coefficients on:	Contemporaneous	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
VRP	-	0.725***(0.000)	0.069***(0.000)	0.002***(0.000)	0.051***(0.000)	0.027***(0.000)
	-	0.025***(0.000)	0.013***(0.000)	0.008***(0.007)	0.005*(0.061)	-0.005**(0.020)
SPY price rate of change	-56.901***(0.000)	-52.879***(0.000)	-27.214***(0.000)	-18.557***(0.000)	-11.565***(0.000)	-4.523***(0.000)
Eurodollar futures price rate of change	104.997***(0.000)	-29.836(0.179)	-63.041***(0.005)	41.743*(0.061)	-50.137**(0.024)	41.648*(0.057)
Gold futures price rate of change	-2.597**(0.023)	-5.793***(0.000)	2.475**(0.031)	-3.293***(0.004)	0.571(0.619)	-0.530(0.643)
CDX spread change	251.047***(0.000)	301.601***(0.000)	142.282***(0.000)	111.900***(0.000)	196.008***(0.000)	183.586***(0.000)
Sum of NEWS Surprises	-5.288***(0.002)	6.127***(0.000)	1.054(0.534)	0.594 (0.726)	-0.482(0.776)	-0.910 (0.591)
SPY volume	-0.592***(0.000)	-1.055***(0.000)	-0.185 (0.178)	1.717***(0.000)	0.193 (0.158)	-0.409***(0.002)
SPY price-setting buy-sell imbalance	2.030***(0.000)	1.557***(0.000)	0.388**(0.017)	0.306*(0.060)	0.116(0.475)	-0.337**(0.037)
SPY VPIN	-1.737**(0.025)	-2.299***(0.004)	0.934 (0.242)	1.145 (0.152)	0.931 (0.242)	0.330 (0.669)
GLD volume	-1.167(0.285)	-6.764***(0.000)	0.735(0.511)	-1.911*(0.088)	-1.539 (0.167)	0.402(0.712)
GLD price-setting buy-sell imbalance	0.224 (0.106)	0.254*(0.067)	0.004 (0.978)	-0.003(0.980)	0.015(0.916)	-0.020(0.888)
GLD VPIN	0.291 (0.736)	2.171**(0.016)	-1.638*(0.070)	1.000 (0.269)	-0.287(0.750)	-1.018(0.238)
CEF – NAV return spread	0.022 (0.887)	0.217 (0.226)	-0.209(0.273)	-0.391**(0.040)	-0.248 (0.166)	-0.162 (0.283)
ASA – NAV return spread	-5.891*(0.073)	-6.337*(0.054)	-17.858***(0.000)	-11.887***(0.000)	-8.874***(0.007)	6.513**(0.048)
CEF – NAV buy-sell imbalance spread						
ASA – NAV buy-sell imbalance spread						
Adjusted R-squared	99.83%					

Table 10. Coefficients from 1-minute VARX regression estimation

The table presents selected coefficients from a VARX in which VIX, SPY return, Eurodollar futures return, and gold futures return are endogenous and other variables are exogenous. To conserve space, only coefficients for the equation in which VIX is the dependent variable are reported. *, **, and *** denote significance at 10%, 5%, and 1%, respectively.

Slope coefficients on:	Lag 0	Lag 1	Lag 2	Lag 3	Lag4	Lag 5	Lag 6	Lag7	Lag 8	Lag9	Lag 10
VIX	-	0.37174***	0.27720***	0.09990***	0.02457***	0.06856***	0.09421***	0.02384***	0.05768***	-0.02414***	0.00575***
SPY price rate of change	-	-0.55378***	-0.43795***	-0.30354***	-0.25972***	-0.19686***	-0.14099***	-0.14006***	-0.08625***	-0.06097***	-0.05895***
Eurodollar futures price rate of change	-	0.10399	-0.10899	-0.02430	-0.09797	0.01842	0.08037	0.05169	0.13127	0.08809	-0.00475
Gold futures price rate of change	-	-0.04153***	-0.01883*	-0.01462	-0.00353	-0.00206	-0.00200	0.00092	0.00823	0.00415	0.01191
Sum of NEWS Surprises	-0.07739***	0.00681	0.00631	-0.00118	-0.00649	-0.00939	0.00090	-0.00617	-0.00226	-0.00318	-0.00611
SPY volume	0.00796***	0.00174	0.00050	0.00772***	0.00397	-0.00035	-0.00106	-0.00157	-0.00222	-0.00309**	-0.00703***
SPY price-setting buy-sell imbalance	-0.02617***	0.00106	0.00320	0.00151	0.00169	0.00137	0.00123	0.00099	0.00235	0.00008	0.00218
SPY VPIN	0.27192***	-0.05921***	-0.02015	-0.05240***	0.05445***	-0.04099***	-0.02123***	-0.02267***	-0.04866***	-0.00598	-0.09772***
GLD volume	0.04308***	0.07405***	0.04285***	-0.01267	-0.00856	-0.00233	-0.01607	-0.01628	-0.00868	-0.04199***	-0.03459
GLD price-setting buy-sell imbalance	-0.00129	0.00026	-0.00054	-0.00056	-0.00038	0.00082	-0.00012	-0.00052	-0.00029	-0.00057	0.00061
GLD VPIN	0.02479***	0.00888***	-0.00048	0.00047	-0.00375	-0.01004***	0.00087	-0.00426	0.00054	-0.01147***	0.00391
CEF – NAV return spread	0.00302**	0.00283	0.00256	0.00211	0.00183	0.00146	0.00110	0.00101	0.00054	0.00033	0.00040
ASA – NAV return spread	-0.03676	-0.00654	-0.02951	-0.03951	-0.03560	0.00018	0.01562	-0.00337	-0.02028	0.02410	-0.02724

Figure 5. Impulse response plot for VIX

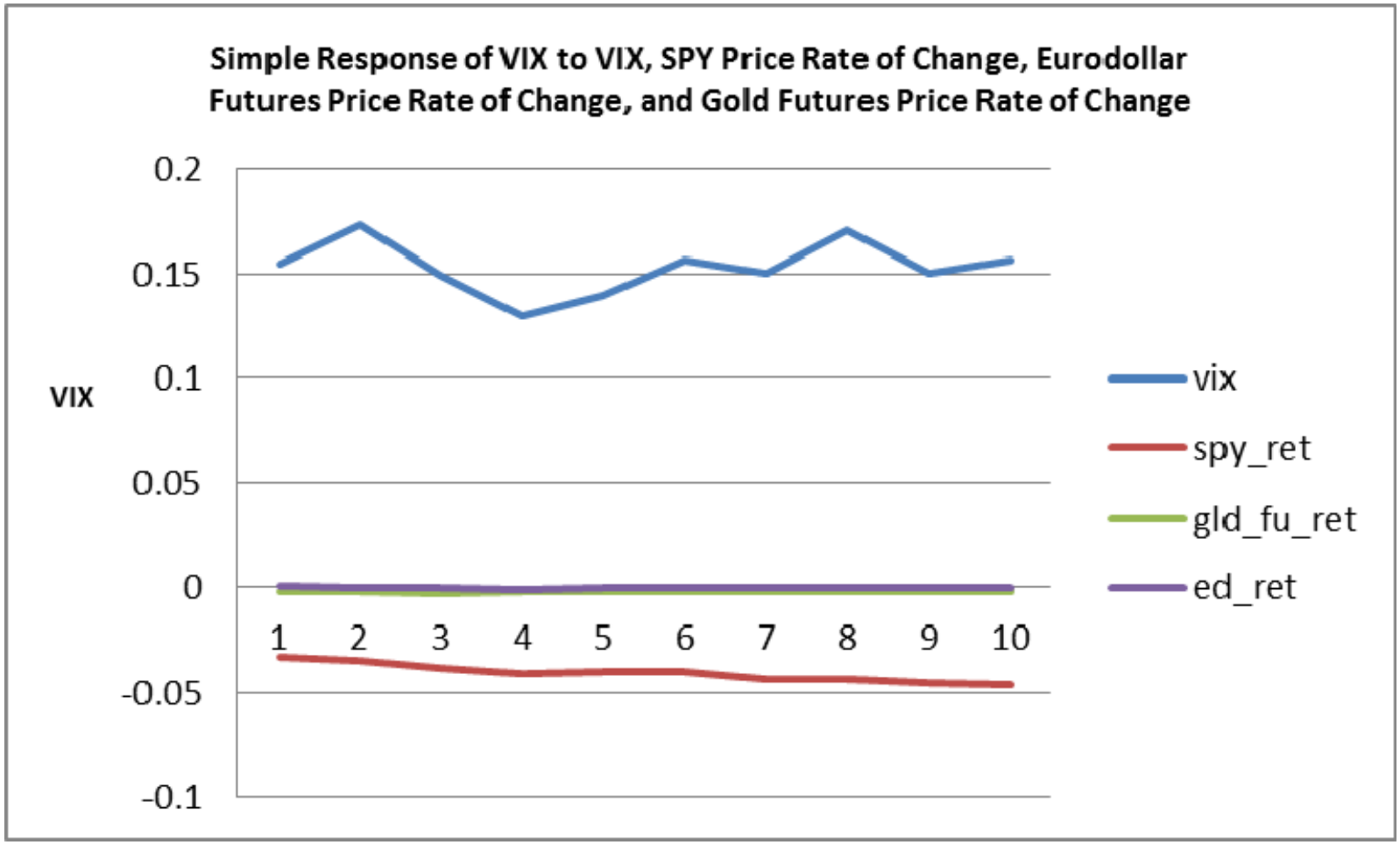


Table 11. Coefficients from 1-minute VARX sub period regression estimation

The table presents selected coefficients from a VARX in which VIX, SPY return, Eurodollar futures return, and gold futures return are endogenous and other variables are exogenous. To conserve space, only coefficients for the equation in which VIX is the dependent variable are reported. *, **, and *** denote significance at 10%, 5%, and 1%, respectively. This table covers the subperiod (starting 30 September 2008) when the CDX spread variable is available.

Slope coefficients on:	Lag 0	Lag 1	Lag 2	Lag 3	Lag4	Lag 5	Lag 6	Lag7	Lag 8	Lag9	Lag 10
VIX	-	0.31130***	0.32074***	0.13635***	-0.00722***	0.05578***	0.10151***	0.02069***	0.08705***	-0.01420***	-0.01308***
SPY price rate of change	-	-0.60046***	-0.48721***	-0.31104***	-0.28041***	-0.21432***	-0.15508***	-0.16493***	-0.09846***	-0.04826***	-0.06534***
Eurodollar futures price rate of change	-	-0.34620	-0.75393	-0.23260	-0.26742	-0.21799	0.11490	0.18758	0.27003	0.21857	0.08187
Gold futures price rate of change	-	-0.08015***	-0.01699	-0.02099	-0.00997	-0.00229	-0.00797	0.01772	0.02916	0.02804	0.03692
CDX spread change	-	4.04332***	2.87734***	1.40452**	1.84473***	2.30858***	1.61219***	0.80684	0.40599	0.58771	0.35802
Sum of NEWS Surprises	-0.13180***	0.01002	0.01866	0.00246	-0.01002	-0.01491	0.00204	-0.01021	0.00823	-0.00230	-0.02009
SPY volume	0.01484***	-0.00110	-0.00185	0.01329***	0.00800**	-0.00151	-0.00031	-0.00143	-0.00694**	-0.00564*	-0.01167***
SPY price-setting buy-sell imbalance	-0.04737***	0.00418	0.00272	-0.00067	0.00519	0.00300	0.00143	-0.00083	0.00093	-0.00123	0.00831**
SPY VPIN	0.45967***	-0.13385***	0.00789	-0.16243***	0.11146***	-0.03121	0.01310	-0.02003	-0.14927***	-0.01794	-0.19345***
GLD volume	0.13006***	0.10930***	0.05202*	0.01652	-0.01751	-0.03301	-0.01635	-0.02544	-0.01741	-0.10587***	-0.03957
GLD price-setting buy-sell imbalance	-0.00223	-0.00021	0.00062	-0.00157	0.00032	0.00114	-0.00103	-0.00207	0.00049	0.00014	0.00279
GLD VPIN	0.26499***	0.03760**	-0.03844*	0.08242***	-0.03580	-0.15896***	0.03099	-0.04191*	0.03627	-0.22736***	0.12093***
CEF – NAV return spread	0.00329	0.00169	0.00121	-0.00098	-0.00007	-0.00064	0.00048	-0.00007	0.00061	0.00078	0.00046
ASA – NAV return spread	-0.09080	-0.02326	-0.09332	-0.09893	-0.10539	0.00914	0.07582	0.03645	-0.04016	0.00650	-0.11599

Figure 6. Impulse response plot for VIX from sub period VARX