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Futures Market Volatility:
What Has Changed?

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Executive Summary

Sparked by increased competition and advances in technology, futures markets have undertaken a number of structural changes during the past few years. Some market observers have voiced concern regarding the impact these changes have had on market quality, and in particular whether futures market volatility has increased. This study provides a systematic and comprehensive analysis of whether futures return volatility has changed through time.

Modeling the impact of changes in market microstructure on the volatility of futures returns is no straightforward task. Observed or realized volatility can certainly be affected by market microstructure, including bid/ask spreads, electronic versus pit trading, and the rise in algorithmic trading. However, futures prices also respond rapidly and differently to new information; hence changes in the rate of information flow, such as the increase that occurred during the financial crisis, also have a direct effect on volatility. As a consequence, it is very difficult to tease out the microstructural component of realized volatility so that statements can be made about market quality.

In this study, we identify two benchmarks for intraday futures return volatility with which we can assess the impact of microstructural changes on intraday volatility. In both cases, the benchmarks control for changes in the rate of information flow and allow us to focus on any changes due to market microstructure.

The first is the use of implied volatility in equity index options markets. The level of the CBOE Market Volatility Index or "VIX," for example, is the market's best assessment of the expected return volatility of the S&P 500 index over the next 30 days. If market microstructure considerations play an important role in the measurement of realized volatility for the CME Group's e-mini S&P 500 futures contract, then the realized volatility should exceed the level of VIX. Indeed, just the reverse is true. The difference between implied and realized volatility for the S&P 500 index is positive, and there is evidence to suggest it has increased through time. The same is true for the relation FTSE 100 Volatility Index or "VFTSE," the implied return volatility of the FTSE 100 index, and the realized volatility of the corresponding NYSE Liffe FTSE 100 index futures contract. Realized volatility for Eurex's DAX futures contract, in contrast, has risen relative to the corresponding DAX Volatility Index or "VDAX". However, this change has occurred only in the last year of the sample, and so is likely due to recent increases in macro-economic uncertainty related to the Euro zone crisis.

The second experiment that we perform involves computing return volatility over different holding periods. To understand how this approach works, assume that futures prices are noisy due to microstructural effects such as bid/ask price bounce, price discreteness, and price impact. The amount of noise in the futures price is constant on average and is independent of whether you measure returns over five minutes or ten days. Consequently, the "signal-to-noise ratio" (i.e., amount of true information about price change that you are extracting from the data relative to the amount of microstructural noise) is much greater for longer distancing intervals than short ones. When we compute volatility for different holding periods, we find that realized volatility for longer periods is lower than for shorter holdings, thereby confirming the presence of microstructural effects. But, more importantly, the relative magnitudes have not increased meaningfully through time.

Taken together, these two results indicate that, after controlling for changes in the rate of information flow, there is no evidence to suggest that realized return volatility in electronically-traded futures markets has changed through time, at least with respect to the fifteen contract markets that were examined.

Futures Market Volatility: What Has Changed?

This report was prepared at the request of the Futures Industry Association. The purpose of this study, sponsored by the Intercontinental Exchange, Eurex, NYSE Euronext, and The CME Group, is to provide a systematic and comprehensive analysis of whether futures return volatility has changed through time, and, if so, identification of the likely causes.

The outline for the study is as follows. In the first section, we provide an overview of stock market volatility through time and show that observed upward spikes in its behavior are associated with unexpected macroeconomic or political announcements. In the second section, we provide our framework for measuring volatility. Specifically, we use both intraday volatility measures as well as range-based estimators to test for robustness. In the third section, we provide details about the sample used in our analysis, which includes the trade histories of fifteen electronically-traded futures contracts with underlying ranging from crude oil to stock indexes. Section four contains the chief results of the study. In controlled environments, we show that there is no discernible change in futures return volatility in recent years, a period in which high frequency/algorithmic trading has become increasingly popular. The final section provides a brief summary, and the study's main conclusions.

1. Volatility and macroeconomic events

Volatility changes through time as new information arrives in the marketplace. A popular measure of U.S. stock market volatility is the CBOE's market volatility index or VIX.[1] Figure 1 shows the behavior of VIX from January 1986 through June 2012. Several features are salient.

First, there are periodic spikes in volatility, twenty of which we have labeled and included corresponding macroeconomic events. Unexpected changes in interest rates or oil production, inflation fears, recession fears, and bank failures are some events that have a hand in affecting the level of anxiety in the marketplace as measured by implied market volatility.

[1] The series plotted in Figure 1 is actually the VXO, the original form of the VIX when it was released in 1993. For an explanation of the differences between the indexes, see Whaley (2009).

Second, there are two large spikes that are far larger than the others, let alone typical levels of volatility. The first, event number four in our list, corresponds to the stock market crash of October 19, 1987, a day on which the Dow Jones Industrial Average dropped 22%. The VIX actually closed over 150 on that day, well beyond the maximum on our scale. The second extreme spike, number eighteen on our list, occurred on November 20, 2008 at the height of the current global financial crisis. On this day, the VIX closed at about 87. These spikes are quite transient, indicating that implied volatility, as a measure of perceived uncertainty and risk, can change as quickly as the rate of information flow.

Third, in addition to the temporary spikes described above, volatility appears to go through long periods of relatively elevated or depressed levels. The five-year period of 1992 through 1996, for example, was relatively benign, featuring an average VIX level of just 14.3. In contrast, the following six-year period of 1997 through 2002 included a number of important events, including the Asian crisis, the September 11, 2001 attacks, and, of course, massive and persistent drops in stock prices, especially those of technology stocks on NASDAQ associated with the dot-com bubble. The average level of VIX over this period was 26.7, almost double what it was previously. Similarly, the last five years of the sample, July 2007 through June 2012, corresponds to the global financial crisis and features an average level of 26.2. In contrast, the average was just 14.1 in the four years prior, from July 2003 through June 2007. These results illustrate that volatility features transient spikes, as well as persistent periods of high or low levels, reflecting the relative degree of uncertainty generated by macroeconomic events.

Figure 2 provides a more granular view of the VIX in the time surrounding the October 2008 financial crisis. Macroeconomic phenomena including the European debt crisis, bankruptcy filings, and regulatory uncertainty all contributed to prolonged levels of high volatility reaching into 2011. Markets were rocked by events that no one could have foreseen, including a downgrade of the U.S. Treasury's credit rating and a tsunami that spawned a nuclear disaster in Japan. This long list of fundamental sources of risk and uncertainty complicates any study of market microstructure and its potential impact on volatility. As a consequence, we develop two measures that are relatively free of microstructure effects in order to construct appropriate benchmarks for futures return volatility. We describe the variety of approaches we use to measure volatility over the next three sections.

2. Realized volatility measurement

Realized volatility measurement has a long history in financial economics. A central building block of modern asset pricing models is the assumption that price changes are governed by a continuous-time jump diffusion process. Empirical analysis can use discretely sampled returns at reasonably high frequency to accurately estimate the continuous time process. More concretely, define returns measured over some arbitrary increment of time Δt as follows:

$$r_t = \ln\left(p_t \,/\, p_{t-\Delta t} \right) \tag{1}$$

where t is some integer unit measure of time, typically days, and Δt is a fractional unit. The realized volatility over a unit of time is then defined as:

$$RV_t = \sum_{j=1}^{1/\Delta t} r_{t-1+j\Delta t}^2 \tag{2}$$

As shown by Andersen and Bollerslev (1998), among others, this measure of realized volatility converges to the variation implied by the continuous-time model integrated over the unit of time specified by the econometrician, reflecting both the diffusion component and the jump component of the price process.

In contexts such as derivative pricing with jumps, separating the diffusion and jump components of variation is necessary. Estimation methods are available, as developed by Andersen, Bollerlev, and Diebold (2007). For the purpose of this study, however, we are concerned with the combined effects of the diffusive and jump components of price changes. Hence, the realized volatility as defined in (2) serves as our workhorse estimator for intraday volatility.

Empirical analyses of realized volatility in financial markets include studies by Andersen, Bollerslev, Diebold, and Labys (2001) and Andersen, Bollerslev, Diebold, and Ebens (2001) of exchange rate and stock return volatility, respectively. In both papers, the focus is on the distribution of realized volatility, constructed from five-minute returns, as well as its serial correlation. Realized volatility features positive skewness and substantial excess kurtosis, whereas log realized volatility appears close to Gaussian, which can be exploited in the subsequent statistical analysis. Thomakos and Wang (2003) find similar results using five-minute returns of Treasury Bond, S&P 500, and Eurodollar futures contracts. To mitigate the impact of bid-ask bounce, the data are first filtered by estimating an MA(1) model and using the resulting residuals as a proxy for the true return of the asset. Daily log volatility is persistent with autocorrelations significant for over 50 days in all three studies, consistent with the voluminous GARCH literature that relies on estimates of latent volatility inferred from daily returns.

Based on these results, standard ARIMA models are the obvious choice for modeling and forecasting realized volatility. Andersen, Bollerslev, Diebold, and Labys (2003), for example, use a fifth-order fractionally integrated auto-regressive model. More recently, several studies develop models that attempt to infer information jointly from latent volatility using a typical GARCH structure as well as realized volatility. Shephard and Sheppard (2010) introduce high-frequency based volatility (HEAVY) models, constructed to provide volatility forecasts. In its simplest form, the HEAVY model consists of two linear equations, one defining the process for squared daily returns, the other defining the process for a daily realized volatility measure. Hansen, Huang, and Shek (2011) develop realized GARCH (RealGARCH) more squarely in the standard GARCH framework, in which realized volatility is related explicitly to latent volatility and the innovation in daily returns in a new "measurement" equation. In both cases, the new models are shown to provide empirical performance superior to typical GARCH models.

Realized volatility is used widely in microstructure studies, including recent work on high frequency trading, as in Broggard (2012). Other volatility measures are used in high frequency studies, however. Hendershott, Jones, and Meukveld (2011), for example, use the spread between the high and low transaction prices observed each day as a measure of daily volatility, following Parkinson (1980). Similarly, Hasbrouck and Saar (2011) use the spread between high and low midpoint quotes over ten-minute windows as a measure of volatility over a much shorter horizon. We choose to use realized volatility in order to leverage all the information available to us. For robustness, we also implement range-based estimators to provide a comparison.

A. Constructing daily realized volatility

Daily measurements of realized return variance are constructed by first dividing each 24-hour day on which trading occurs into 288 five-minute periods, denoted by t where t = 1, …, 288. For each five-minute period within which a trade occurred, the last trade price is recorded, denoted by p_t. Starting with the second five-minute period, a return is computed as

$$r_t = \ln\left(p_t / p_{t-1} \right) \tag{3}$$

if both period t and the previous contained a trade, otherwise the period does not contribute to the day's variance measurement. Realized return variance, v^2, is then computed as the sum of squared returns, scaled as follows

$$v^2 = \frac{288}{n} \sum_{t=2}^{288} r_t^2 \tag{4}$$

where n is the number of five-minute returns recorded during the period. Scaling by 288 standardizes the measure to allow comparison across days and across contracts with different trading hours. We define "daily realized volatility" as the square root of equation (4).

B. Range-based estimators of realized volatility

Most of our analysis employs realized volatility, which exploits information throughout the trading day. For robustness, we also compute several range-based estimators of realized variance, which use only the open, high, low, and closing prices observed in a trading day. Let O, H, L, and C denote these prices and define percentage changes from the open as $u \equiv \ln\left(H/O\right)$, $d \equiv \ln\left(L/O\right)$, and $c \equiv \ln\left(C/O\right)$. Parkinson (1980) developed the first range-based estimator using only high and low prices. The intuition is that the higher the volatility, the larger the observed range of prices observed over the course of a trading day. Using the above definitions, and the range observed over n trading days, the Parkinson estimator can be computed as:

$$V_P = \frac{1}{4\ln(2)} \times \frac{1}{n}\sum_{i=1}^{n}(u_i - d_i)^2 \quad (5)$$

The Parkinson estimator is valid only for processes with zero-drift. Rogers and Satchel (1991) derive an alternative estimator that accommodates a non-zero drift and also has substantially lower sampling volatility. The Rogers and Satchel estimator, again using prices from *n* trading days, can be computed as:

$$V_{RS} = \frac{1}{n}\sum_{i=1}^{n}(u_i - c_i)u_i + (d_i - c_i)d_i \quad (6)$$

We compute both estimates and use non-overlapping daily, weekly, and monthly intervals in the calculations.[2]

C. GARCH processes for time variation in volatility

As discussed in Section 1, one of the most salient features of volatility is its time variation. Consequently, it will be useful to implement processes that explicitly accommodate changes in volatility. We use the GARCH(1,1) volatility model, which for daily returns *y*, can be expressed as:

$$\begin{aligned} y_t &= \mu + \varepsilon_t, \\ \varepsilon_t &\sim N(0, \sigma_t^2) \\ \sigma_t^2 &= \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \end{aligned} \quad (7)$$

Two aspects of the GARCH estimates will be especially useful. First, the coefficient β on lagged variance provides a measure of the speed with which volatility reverts to average levels. Short-lived spikes in volatility will result in faster convergence to the long-run mean and lower values for β. Second, the long-run variance implied by the GARCH(1,1) model is given by $\omega/(1-\alpha-\beta)$, which can differ from sample estimates given the ability of the GARCH(1,1) model to accommodate short-run changes in volatility.

[2] Yang and Zhang (2000) modify the Rogers and Satchel estimator to reflect the volatility of overnight returns, which they describe as “opening jumps” between the prior day’s close and the current day’s open. In our study, we are focusing on intraday volatility and so use the Rogers and Satchel estimator.

3. Realized volatility estimates

We now turn to applying the realized volatility measurement technology to five-minute, intraday futures returns. The returns were generated from electronic trade-by-trade data provided by the Intercontinental Exchange (ICE), Eurex, NYSE Euronext (NYSE Liffe), and The CME Group (CME) (hereafter, the "Exchanges").[3] While the trade-by-trade data, in some cases, contained spread trades and block trades, these were eliminated from the subsequent analyses to focus in an unfettered way on trading activity. The fifteen specific contracts are listed in Table 1, together with their ticker symbols and time-series start and end dates. For the remainder of the report, we refer to the contracts by their ticker symbols. Seven are interest rate futures contracts, five are stock index futures contracts, two are crude oil futures contracts, and one is an agricultural futures contract. Three of the exchanges also provided end-of-day data, which included the daily open, high, low, and closing prices of the futures contracts. These data were particularly useful in error-checking the time and sales data for possible outliers. In some instances, it resulted in requesting the exchanges re-filter the data that had been provided to remove off-exchange trades and so on. We also purchased end-of-day data for the futures contracts from Price-Data.com as another check on data integrity. Daily data for three popular stock market volatility indexes—the VIX, VDAX, and VFTSE—were downloaded from Datastream.

A. Summary statistics

Tables 2 and 3 contain summary statistics for the different futures return volatility series. The values are computed from the daily (annualized) estimates. To avoid double-counting of futures contracts, only a single contract on an underlying is used in a given day. Usually it is the contract with the highest trading volume. Appendix 1 contains a list of "roll dates" for the different underlyings (i.e., the day on which we roll from the nearby to the second nearby contracts). They range from 1 to 45 days before expiration. For some contracts like ED, only quarterly expirations were used. Although non-quarterly contracts were available, their trading volumes were meager.

[3] The length of the different time series varies from exchange to exchange, and the time-series generally end in May 2012.

Table 2 contains the average level of annualized realized daily volatility, along with the standard deviation, skewness, and excess kurtosis, over each contract's entire sample period. The volatility estimates across asset classes are in line with expectations. For the CME contracts, for example, CL volatility is highest at 31.7%. ED volatility, at the other end of the risk spectrum, is at 1.1%.[4] The ES and the TY contracts had average volatilities of 20.0% and 6.6%, respectively. Average levels of volatility across exchanges generally correspond along asset classes. For equities, the Z contract, traded on the NYSE Liffe, features average volatility of 24.7%, slightly higher than the ES volatility. The TF contract, traded on the ICE, is higher still, at 34.4%, reflecting the inverse relation between firm size and volatility. The FDAX and FESX have average volatilities of 30.4% and 35.3%, respectively, reflecting the uncertainty surrounding the debt crises in a number of European countries as well as uncertainty about the future of the Euro.

For short-term fixed income securities, the I and L contracts traded on the NYSE Liffe, have average volatilities of 1.0% and 1.7%, respectively, similar to the ED volatility. For longer-term fixed income securities, the FGBL and FGBM contracts, traded on the Eurex, feature average volatilities of 8.7% and 5.6%, respectively, comparable to the TY contract volatility. The R contract, traded on the NYSE Liffe is at 8.3%.

Commodities tend to have the highest volatilities, with the B and SB contracts traded on ICE featuring volatilities of 37.9% and 56.8%, respectively, the former similar in magnitude to the CL volatility.

For all contracts, the Jarque-Bera test easily rejects the hypothesis that volatility is normally distributed, consistent with prior research such as Thomakos and Wang (2003).

Table 3 shows summary statistics for the twelve contracts with data extending back to January 2004 over two sub-periods: a "Pre-crisis" period from January 2004 through June 2007, and a "Crisis" period from July 2007 through the first half of May 2012. Dramatic increases in the average level and volatility of volatility are observed in a

[4] Note that for purposes of comparison, Eurodollar volatility is being expressed in terms of percent change in price. In practice, however, Eurodollar volatility is most often quoted in terms of percent change in the Eurodollar interest rate.

number of contracts. For the four equity index contracts, ES, FDAX, FESX, and Z, for example, the average level of volatility doubles in each case. Substantial increases are also present in CL, FGBL, and FGBM. As described in Section 1, these increases can be attributed to the uncertainty created by the global financial crisis.

The global financial crisis is often thought to have commenced in July 2007, with the collapse of two Bear Stearns hedge funds that had invested heavily in mortgage-related instruments, and to have lasted through February 2009, after which U.S. equity markets began a steady recovery. We therefore also compute summary statistics over a "Crisis" period from July 2007 through February 2009 and a "Post-crisis" period from March 2009 through the end of our data, May 15, 2012. The results are contained in Table 4. The average levels of realized volatility dropped substantially in the U.S. and U.K. equity markets. In the U.S., the ES volatility dropped from 30.0% annually to 19.8%, while TF volatility fell by almost half, from 57.3% to 28.4%. For the Z contract, the reduction was from 38.9% to 24.2%. In contrast, the FDAX volatility has stayed constant at 35%, and the FESX has actually increased from 38.7% to 48.0%, reflecting all the turmoil in the Euro zone, especially related to the ability of Greece to meet its debt service requirements.

Similarly, while R volatility was unchanged, and TY dropped from 8.7% to 6.6%, both the Eurex longer-term fixed income securities saw increased volatility. FGBL volatility rose from 8.6% to 13.0%, while FGBM increased from 5.9% to 7.6%, again the result of uncertainty in the Euro zone.

B. GARCH processes for time variation in volatility

As described above, volatility has undergone cycles of high and low levels over the sample period, and has featured numerous spikes attributable to macroeconomic events. To provide some insight regarding the nature of the time variation in volatility, we plot in Figure 3 daily returns of the three equity index contracts, ES, FDAX, and Z, for which implied volatility indexes are available.

For all three equity index contracts, the daily returns feature the classic volatility "clustering" throughout the sample. Large swings in returns indicate periods corresponding to rapid changes in the macroeconomic environment. Note also that the correspondence between daily variation in returns and daily levels of the volatility indexes is tight, suggesting a strong link between relatively high frequency observations of volatility and the 30 calendar day measures of implied volatility. For this reason, we use implied volatility as one of our volatility benchmarks to provide a more direct test for a change in intraday volatility controlling for changes in the fundamental rate of information flow.

To determine whether volatility processes themselves have changed over the pre-crisis and crisis periods, we estimate parameters of a GARCH(1,1) for each contract. The results are reported in Table 5. For four of the contracts (FGBL, B, L, R), we failed to reject a constant volatility model in favor of the GARCH(1,1) during the pre-crisis period, and for these the constant volatility estimate is listed. Perhaps the most important result here is that the long-run volatility implied by the GARCH parameters features substantial increases for some of the contracts, though not nearly as large as the raw averages. The FDAX long run volatility, for example, increases from 13.4% to 24.1% using the GARCH parameters, whereas the average volatility listed in Table 2 increases from 17.0% to 35.0%. The reason for this is that the GARCH model accounts for the transience of spikes in volatility.

We provide one additional analysis of the time-series behavior of realized variance by computing the autocorrelation function at the daily frequency with 100 lags. We display the autocorrelation functions of the three equity index contracts featured above, the ES, FDAX, and Z, in Figures 4 through 6 respectively. The high level of serial correlation at short lags, and the slow decay, reflects the volatility clustering depicted in Figure 3. More importantly, the differences in the pre-crisis and crisis periods in the bottom panels is stark – in all three contracts serial correlation has increased substantially in recent years, again likely the reflection of an increase in underlying latent volatility.

C. Range-based estimator as a robustness test

To test the robustness of our five-minute return volatility measures, we compare them to the Rogers and Satchel (1991) range-based estimator that relies only on a daily record of the open, high, low, and closing prices for a contract. We compute both of the variance estimators over three observation windows: daily, non-overlapping five-trading-day periods, and non-overlapping 21-trading-day periods. The latter two correspond to weekly and monthly measurements. For each of the fifteen futures contracts, we measure the linear correlation and the Spearman rank correlation between the two estimators over the full sample for each contract.

The correlation results, reported in Table 6, are noteworthy in a number of respects. First, the correlations tend to increase with the length of the measurement window. For the ES contract, for example, the linear correlation between the two variance estimators is 0.40 at the daily frequency compared to 0.73 at the weekly frequency. Second, the correlations are generally quite high. At the monthly frequency, ten of the fifteen contracts feature a linear correlation above 0.85. Third, the Spearman rank correlations generally correspond quite closely to the linear correlations, suggesting that the linear correlations are not spuriously high due to outliers or non-normalities in variance.

Figures 7 through 10 show monthly time-series comparisons of the realized variance and the Rogers and Satchell (1991) range-based variance. We average the measures across the days in a month, and then annualize assuming a 252-trading day year. In all cases, the two series track quite closely, consistent with the high degree of correlation as listed in Table 6. The realized variance tends to be higher than the range-based estimate. What is important, though, is whether the wedge between the two has changed over time, as this might indicate a change in any microstructure effects that might be driving the realized variance to diverge from the range-based variance. The range-based estimate can be viewed as a benchmark for volatility, a topic we turn to in the next section.

For most of the contracts, the difference between the two variance measures is remarkably constant. The exceptions are the FESX, FGBL, and FGBM contracts traded on the Eurex, for which the realized variance has diverged upwards away from the range-based estimate in the last year of the sample period. A likely explanation for this result is the heightened uncertainty resulting from the Euro crisis. In summary, the range-based estimators indicate that our measurements of realized volatility are similar to the simpler, and more familiar, measurements based on daily price ranges.

4. Benchmarking realized volatility movements

As noted earlier, realized volatility changes as news disseminates into the marketplace. We have documented significant changes in the level of volatility for all fifteen futures contracts, reflecting the dramatic events of the financial crisis and the resulting uncertainty in markets around the world. Realized volatility is also affected by microstructural considerations. Changes in market structure, including the dominance of electronic platforms and the rise in algorithmic trading, have occurred contemporaneously with the increase in fundamental volatility in recent years, making inference difficult regarding the impact of changes in market structure on market quality.

To make this more concrete, note that observed trade prices are noisy due to market microstructure issues such as bid-ask price bounce, price discreteness (minimum tick size),[5] and price impact, and this noise inflates the level of realized price (return) volatility in the following fashion,

$$\sigma_{\text{realized}} = \sigma_{\text{true}} + \sigma_{\text{microstructure}} \tag{8}$$

In the analyses conducted thus far in this study, we do not explicitly address the distinction between realized volatility and true volatility. In this section, we do.

The first component is “true” volatility or “macro-level” volatility. The second component is not related to fundamental economics and is a product of market microstructure. One way to mitigate the effects of microstructure volatility on realized volatility is to use bid-ask price midpoints throughout the day rather than trade prices. Hasbrouck and Saar (2011), for example, used the spread between high and low midpoint quotes over ten-minute windows. Unfortunately, this approach was infeasible since intraday bid-ask quote data were unavailable. A potential alternative method is the Smith and Whaley (1994) generalized method of moments procedure. Using the sequence of trade prices, they showed how true volatility and microstructure volatility can be estimated simultaneously. Indeed, this estimation procedure was developed specifically for time and sales data from the futures exchanges in an era when historical bid-ask price quotes were not recorded. Unfortunately, this approach, too, was set aside because

[5] The bid-ask price bounce, for example, acknowledges that trade prices are likely to have occurred at the bid or the ask, depending on the motive for the trade. Indeed, Roll (1980) shows that the serial covariance of the sequence of trade prices can be used to infer the size of the bid-ask spread in an informationally efficient market.

bid/ask spreads in many markets have become so small that the estimator arrives a corner solution.

A. Using implied volatility as a benchmark

One way to distinguish between realized volatility and true volatility is to use option prices. Since volatility is a parameter in the option valuation formula, and all of the remaining parameters are known, we can equate the formula to the observed option price to infer the level of expected future volatility in the underlying asset market. This serves as our proxy for true volatility,[6] unfettered by microstructural considerations. Since we do not have access to futures option prices, we rely on published volatility indexes, of which we identified three: (a) the CBOE's Volatility Index VIX, which provides an estimate of volatility for the CME's e-mini S&P 500 futures contract, (b) the VDAX, which provides an estimate of the volatility for Eurex's DAX futures contract, and (c) the VFTSE, which provides an estimate of the volatility of the FTSE stock index futures contract.

Figure 11 focuses on the comparison of realized volatility of the ES contract and the VIX index over the period January 3, 2000 through May 15, 2012. Since the VIX is a measure of annualized volatility in percentage points, we scale our measure of daily realized volatility appropriately. Figure 11A shows the individual daily estimates of realized volatility. Three features are apparent. First, in general the two series track each other extremely closely, and in fact have a linear correlation of almost 80%. Considering that the VIX is a forward-looking estimate of the following 30 days of volatility derived from index option prices, whereas the realized variance is a backward-looking estimate derived from futures prices, this correlation is somewhat surprising. One interpretation is that market participants weigh heavily the intraday volatility of the ES contract in their assessment of fundamental volatility. Second, though the two series are highly correlated, the VIX tends to exceed the realized volatility quite dependably. The average level of the VIX is 22.2% over this period, for example, compared to 20.0% for realized variance. The difference can be interpreted as a volatility risk premium incorporated into index

[6] While it is true that option prices are also subject to microstructural effects just like futures, the effects can be mitigated by using bid/ask price midpoints and multiple option contract prices. Indeed, the CBOE uses hundreds of out-of-the-money S&P 500 options in its determination of the level of VIX.

option prices. Bollen and Whaley (2004) show that this premium is driven largely by the demand for stock portfolio insurance. An important attribute of the figure is, however, that the difference in the difference between implied and actual volatility appears to have increased in the latter part of the sample. In other words, realized volatility appears to have decreased relative to implied volatility even after the volatility risk premium is taken into account. Third, the spikes in the VIX are much smaller than the spikes in realized variance. The reason is clear: as a forward-looking 30-day forecast of variance, the VIX downplays the impact of volatility on any given day.

Figure 11B compares realized variance to VIX by first averaging the current and past 20 observations of realized volatility before annualizing.[7] Here the spikes in realized variance are generally equal in magnitude to the spikes in the VIX.[8] The correlation between the two series is close to 90%. In our opinion, it is difficult to overstate the importance of this result. The VIX represents a benchmark for fundamental volatility that is free from microstructural effects in the underlying futures market. Figures 11A and 11B show that our measure of realized volatility based on five-minute returns tracks the VIX consistently from January 2000 through May 2012. If changes to market structure affected intraday volatility in a meaningful way, we would expect to see a divergence between realized volatility and the VIX after the changes were made. No such divergence is apparent.

In Figure 12, we compare the realized variance of the FDAX contract to the VDAX volatility index. Figure 12A shows results using individual daily measures of realized variance. The two series track each other quite closely, though not as closely as the E-mini realized volatility tracks the VIX. During the last 12 months of the sample, for example, the realized variance consistently far exceeds the VDAX, and averages 51.8% versus 29.6% for the VDAX. One explanation for this phenomenon is the turmoil created by Germany's central role in maintaining financial order in the Euro zone. FDAX market uncertainty was undoubtedly affected by events like the credit downgrades in countries such as Ireland in April 2011 and Cyprus in September 2011 and the political upheaval

[7] The 30-day horizon of VIX corresponds to roughly 21 trading days.
[8] The spike in realized variance in October 2002 can be traced to questionable prices late in the trading day on October 9 which we are currently investigating.

arising from changes in governmental leadership in Ireland in February 2011, Portugal in June 2011, Spain in July 2011, Italy and Greece in November 2011, and France in May 2012. In Figure 12B, we see the same divergence between realized volatility in the FDAX and the level of volatility as measured by the VDAX. The correlation between the two series is close to 90%, just like the E-mini and the VIX, though again the divergence in the last 12 months is clear.

We compare the realized variance of the Z contract to the VFTSE in Figure 13. Here the situation looks very similar to that of the ES contract and the VIX. A plausible macro-economic explanation is that the U.K. financial market is less affected by trouble in the Euro zone than is the Germany financial market.

B. Using longer horizon volatility as a benchmark

A second way to create a benchmark that abstracts from market microstructure effects is to compute volatility using close-to-close returns of varying time horizons. Naturally, the measure of realized volatility from five-minute returns can be significantly affected by microstructure effects including the bid-ask spread, high-frequency interactions between trading algorithms, and changes in liquidity. When returns are measured over weekly or bi-weekly horizons instead, and sample volatility is estimated over the course of the year from these low-frequency returns, then volatility measures will be relatively free of microstructure effects. We therefore compare the annual volatility of each contract using the five-minute returns to the annual volatility using weekly and bi-weekly returns to test for temporal changes in the impact of microstructure on market quality.

For each contract, each year from 2006 through 2011, we construct an annual volatility by taking the square root of the sum of daily realized variance, in turn created from the sum of intraday squared five-minute returns. These annual volatilities are standardized to a 252-trading day year. We then measure low-frequency volatility by creating weekly and bi-weekly returns from the closing prices from the OHLC files, and computing sample volatility of these two return series. Table 7 shows the ratio of the high-frequency volatility measure to the volatility of weekly returns (Panel A) and bi-weekly returns (Panel B) for each contract.

The volatility ratios reported in Table 7 are noteworthy in a number of respects. First, in almost all cases they are greater than one, which is to be expected since the realized five-minute return volatility is more inflated than the weekly and biweekly volatility measures by the impact of microstructure. Put differently, the "signal-to-noise ratio" (i.e., amount of true information about price change that you are extracting from the data relative to the amount of microstructural noise) is much greater for longer distancing intervals than short ones. Second, while the ratios vary over time for each contract, there is generally no temporal trend. The four CME contracts, for example, have ratios in 2011 very close to the ratios in 2006. Third, the only apparent uptrend occurs for the four Eurex contracts in 2011 relative to the corresponding levels in 2010. Note, however, that the levels on Eurex for 2006 through 2010 are essentially flat, indicating that the increase in 2011 is likely due to the continued liquidity problems caused by the Euro crisis rather than changes in market structure which have occurred over a longer period in time.

5. Conclusions

The purpose of this study is to provide a systematic and comprehensive analysis of whether realized futures return volatility has changed through time, and, if so, identification of the likely causes. Modeling true futures return volatility is no straightforward task. Futures prices respond rapidly and differently to new information, and no valuation model is comprehensively identifies all of the determinants of futures prices. Moreover, realized futures volatility is also affected by changes in market microstructure, including the dominance of electronic platforms and the rise in algorithmic trading. In general, it is very difficult to tease out the microstructural component of realized volatility so that statements can be made about market quality.

In this study, we identify two benchmarks for fundamental volatility that permit direct tests for the impact of microstructure changes on intraday volatility. The first is the use of implied volatility in equity index options markets. The level of VIX, for example, is the market's best assessment of the expected return volatility of the S&P 500 index over the next 30 days. If market microstructure considerations play an important role in the measurement of realized volatility for the ES contract, then the realized volatility should exceed the level of VIX. Indeed, just the reverse is true. The difference between implied and realized volatility is positive, and there is mild evidence to suggest it may be increasing. The same is true for the relation between VFTSE and the realized volatility of the corresponding Z contract. In terms of extending this analysis, computing implied volatilities (for markets which do not have published indexes) and investigating the differences between implied and realized volatilities would be worthwhile.

The second experiment that we perform involves computing return volatility over different holding periods. To understand how this approach works, assume that futures prices are noisy due to microstructural effects such as bid/ask price bounce, price discreteness, and price impact. The amount of noise in the futures price is constant on average and is independent of whether you measure returns over five minutes or ten days. Consequently, the "signal-to-noise ratio" (i.e., amount of true information about price change that you are extracting from the data relative to the amount of microstructural noise) is much greater for longer distancing intervals than short ones. When we compute volatility for different holding periods, we find that realized volatility for longer periods is lower than for shorter holdings, thereby confirming the presence of microstructural effects. But, reassuringly the relative magnitudes have not increased meaningfully through time. In other words, there is scant evidence to suggest that realized return volatility in electronically-traded futures markets has changed through time, at least with respect to the fifteen markets that were examined.

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Table 1. Fifteen futures contract time-series provided by futures exchanges.

Listed are futures contracts time-series that serve as the basis of our analysis. The time and sales data provided by the exchanges contain time-stamped trade information. The end-of-day (EOD) summary data contain daily open, high, low, and close prices as well as number of contracts traded and open interest, and were also provided by the exchanges. The Price-Data data are also daily summary data and were purchased from Price-Data.com.

		Time and sales data			EOD summary data		Price-Data		
Exchange	Contract	Ticker	Begins	Ends	Begins	Ends	Ticker	Begins	Ends
Intercontinental Exchange (ICE)									
	Brent Crude Futures	B	11/4/2004	7/9/2012	2/27/2003	12/31/2012	LO	8/17/1990	7/4/2012
	Russell 2000 Index Futures	TF	1/2/2008	7/9/2012	1/2/2008	12/31/2012	RU*	2/4/1993	9/18/2008
	Sugar #11 Futures	SB	1/2/2008	7/9/2012	1/2/2008	12/31/2012	ISB	4/14/1998	7/3/2012
Eurex									
	DAX Futures	FDAX	5/2/2002	5/15/2012	Data not supplied.		DY	11/7/1997	7/4/2012
	Euro-Stoxx 50 Index Futures	FESX	5/2/2002	5/15/2012	Data not supplied.		EX	6/22/1998	7/4/2012
	Euro-Bund Futures	FGBL	5/2/2002	5/15/2012	Data not supplied.		EBI	11/23/1990	7/4/2012
	Euro-Bobl Futures	FGBM	5/2/2002	5/15/2012	Data not supplied.		EBM	1/4/1999	7/4/2012
NYSE Liffe									
	FTSE 100 Index Futures	Z	1/4/2000	5/31/2012	1/4/2000	5/31/2012	LFX	5/3/1984	7/4/2012
	Three Month Euro (Euribor) Futures	I	1/4/2000	5/31/2012	1/4/2000	5/31/2012	XY	2/17/1999	1/4/2011
	Three Month Sterling (Short Sterling) Fut	L	1/2/2001	5/31/2012	1/2/2001	5/31/2012	LFL	6/20/1983	7/4/2012
	Long Gilt Futures	R	1/4/2000	5/31/2012	1/4/2000	5/31/2012	LFG	1/12/1987	7/4/2012
CME Group (CME)									
	Eurodollar Futures	ED E	8/6/1992	5/31/2112	1/4/1982	2/6/2013	GE	9/20/2004	7/4/2012
	E-mini S&P 500 Index Futures	ES	1/1/2000	5/31/2012	9/9/1997	2/6/2013	ES	9/9/1997	7/4/2012
	Light Sweet (WTI) Crude Oil Futures	CL E	11/30/1999	5/31/2012	7/1/1986	2/6/2013	YC	2/12/2002	7/4/2012
	10-Year U.S. Treasury Note Futures	TY E	1/1/2004	5/31/2012	5/3/1982	2/6/2013	ZN	5/25/1995	7/4/2012

Table 2. Summary statistics.

Listed are summary statistics of daily observations of realized variance, computed as the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. Realized variance is converted to annualized volatility assuming a 252-trading day year.

	CME			
	CL	ED	ES	TY
# Obs.	3,114	2,148	3,118	2,353
First	19991201	20040105	20000103	20040102
Last	20120515	20120515	20120515	20120515
Avg.	31.66	1.07	20.01	6.64
Std. Dev	16.44	0.50	13.48	2.91
Skewness	2.43	3.34	6.11	2.69
Kurtosis	11.59	19.22	98.08	19.27
J-B	12,632.75	27,550.55	1,193,850.81	28,794.25
p-value	0.00	0.00	0.00	0.00

	Eurex			
	FDAX	FESX	FGBL	FGBM
# Obs.	2,555	2,558	2,559	2,559
First	20020502	20020502	20020502	20020502
Last	20120515	20120515	20120515	20120515
Avg.	30.37	35.28	8.70	5.61
Std. Dev	20.65	26.12	6.18	3.49
Skewness	2.39	2.67	3.00	2.93
Kurtosis	12.52	14.63	14.23	15.25
J-B	12,075.21	17,457.76	17,274.91	19,661.81
p-value	0.00	0.00	0.00	0.00

	ICE		
	B	SB	TF
# Obs.	1,877	1,101	1,065
First	20050214	20080102	20080319
Last	20120515	20120515	20120515
Avg.	37.85	56.84	34.40
Std. Dev	18.08	17.42	20.36
Skewness	2.37	1.29	2.34
Kurtosis	10.05	6.65	11.75
J-B	5,650.15	914.37	4,371.38
p-value	0.00	0.00	0.00

	NYSE Liffe			
	I	L	R	Z
# Obs.	3,002	2,093	3,036	2,935
First	20000104	20010102	20000104	20000104
Last	20120515	20120515	20120515	20120515
Avg.	1.00	1.69	8.27	24.72
Std. Dev	0.37	0.58	3.14	15.23
Skewness	4.37	5.51	2.00	2.69
Kurtosis	36.76	72.80	11.82	15.06
J-B	152,094.52	435,519.13	11,873.67	21,336.56
p-value	0.00	0.00	0.00	0.00

Table 3. Summary statistics over pre-crisis and crisis subsets.

Listed are summary statistics of daily observations of realized variance, computed as the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. Realized variance is converted to annualized volatility assuming a 252-trading day year. "Pre-crisis" uses data from January 2, 2004 through June 29, 2007. "Crisis" uses data from July 2, 2007 through May 25, 2012.

	Panel A. Pre-crisis				Panel B. Crisis			
	CME				CME			
	CL	ED	ES	TY	CL	ED	ES	TY
# Obs.	903	878	881	879	1,510	1,270	1,232	1,474
Avg.	23.80	0.95	11.54	5.58	34.97	1.15	23.25	7.26
Std. Dev	7.13	0.32	3.34	2.38	19.35	0.58	15.42	3.01
Skewness	1.88	5.60	1.26	4.77	2.00	2.69	3.15	2.24
Kurtosis	10.49	56.73	4.94	39.12	7.99	13.24	19.13	17.20
J-B	2,645.00	110,216.63	371.88	51,100.76	2,570.83	7,075.48	15,392.93	13,623.46
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Eurex				Eurex			
	FDAX	FESX	FGBL	FGBM	FDAX	FESX	FGBL	FGBM
# Obs.	892	894	894	894	1,242	1,242	1,242	1,242
Avg.	17.04	18.12	5.34	3.74	35.04	44.85	11.50	7.05
Std. Dev	5.85	5.72	1.59	1.69	22.61	30.31	7.68	4.18
Skewness	1.34	1.65	2.92	9.17	2.58	2.44	2.16	2.20
Kurtosis	6.22	7.50	19.21	133.97	13.49	12.19	8.26	9.49
J-B	653.03	1,157.51	11,060.26	651,460.95	7,078.67	5,600.01	2,401.08	3,179.84
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	NYSE Liffe				NYSE Liffe			
	I	L	R	Z	I	L	R	Z
# Obs.	864	468	861	860	1,227	1,127	1,203	1,209
Avg.	0.81	1.58	6.04	13.95	1.07	1.66	10.05	29.26
Std. Dev	0.15	0.41	1.76	4.84	0.45	0.64	3.37	17.60
Skewness	1.68	2.12	3.55	2.66	4.18	6.60	2.29	2.69
Kurtosis	11.31	15.60	29.67	16.22	30.59	86.22	13.43	13.43
J-B	2,892.37	3,447.01	27,329.87	7,271.99	42,481.45	333,365.01	6,499.79	6,936.41
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Summary Statistics over crisis and post-crisis subsets.

Listed are summary statistics of daily observations of realized variance, computed as the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. Realized variance is converted to annualized volatility assuming a 252-trading day year. "Crisis" uses data from July 2007 through February 2009. "Post-crisis" uses data from March 2009 through May 15, 2012.

	Panel A. Crisis				Panel B. Post-crisis			
	CME				CME			
	CL	ED	ES	TY	CL	ED	ES	TY
Avg.	42.99	1.68	29.98	8.72	30.78	0.87	19.78	6.56
Std. Dev	26.07	0.70	21.33	3.38	12.81	0.20	9.52	2.52
Skewness	1.33	2.03	2.38	1.08	1.43	3.08	2.00	3.65
Kurtosis	4.28	8.69	11.17	4.62	6.26	17.71	9.54	43.20
	Eurex				Eurex			
	FDAX	FESX	FGBL	FGBM	FDAX	FESX	FGBL	FGBM
Avg.	35.11	38.73	8.63	5.92	35.01	48.00	12.98	7.63
Std. Dev	24.23	25.20	3.11	2.16	21.74	32.19	8.83	4.81
Skewness	2.11	2.18	3.72	1.13	2.90	2.43	1.65	1.85
Kurtosis	8.23	9.11	35.51	4.68	17.36	12.08	5.67	7.16
	ICE				ICE			
	B	SB	TF		B	SB	TF	
Avg.	51.61	58.14	57.25		32.76	56.38	28.35	
Std. Dev	27.12	14.32	26.63		12.72	18.40	12.73	
Skewness	1.20	0.97	1.72		1.60	1.35	1.75	
Kurtosis	3.58	4.94	7.15		6.34	6.70	8.00	
	NYSE Liffe				NYSE Liffe			
	I	L	R	Z	I	L	R	Z
Avg.	1.27	1.86	10.01	38.94	0.97	1.56	10.08	24.22
Std. Dev	0.61	0.84	3.29	22.99	0.28	0.47	3.41	11.05
Skewness	3.33	3.00	1.37	2.01	3.76	14.48	2.71	2.29
Kurtosis	19.22	21.70	5.67	8.00	24.78	316.96	16.85	12.48

Table 5. GARCH parameter estimates.

Listed are GARCH(1,1) parameter estimates based on de-meaned daily open-to-close returns. Below each coefficient estimate is the associated *p*-value testing for statistical significance. Also listed is the long-run annualized volatility (LR) implied by the parameter estimates. "Pre-crisis" uses data from January 2, 2004 through June 29, 2007. "Crisis" uses data from July 2, 2007 through May 15, 2012. For four of the contracts (FGBL, B, L, R) we failed to reject a constant volatility model in favor of the GARCH(1,1) during the Pre-crisis period, and for these the constant volatility estimate is listed.

	Panel A. Pre-crisis				Panel B. Crisis			
Ticker	ω	α	β	LR	ω	α	β	LR
CL	0.0977	0.0236	0.9408	26.30	0.0445	0.0457	0.9419	30.11
	0.0966	0.0202	0.0000		0.0558	0.0000	0.0000	
ED	0.0001	0.3100	0.5754	0.55	0.0000	0.1442	0.8458	0.69
	0.2834	0.0801	0.0244		0.0806	0.0002	0.0000	
ES	0.0395	0.0537	0.8527	10.32	0.0373	0.1135	0.8667	21.76
	0.0151	0.0091	0.0000		0.0055	0.0000	0.0000	
TY	0.0017	0.0202	0.9564	4.29	0.0052	0.0476	0.9200	6.38
	0.3423	0.0426	0.0000		0.9033	0.7459	0.0235	
FDAX	0.0284	0.0306	0.9299	13.45	0.0740	0.1006	0.8674	24.12
	0.0924	0.0894	0.0000		0.0225	0.0000	0.0000	
FESX	0.0196	0.0246	0.9462	12.98	0.0808	0.1065	0.8692	28.98
	0.0972	0.1213	0.0000		0.0027	0.0000	0.0000	
FGBL	0.0544			3.70	0.0035	0.0546	0.9237	6.42
	0.0000				0.0706	0.0001	0.0000	
FGBM	0.0002	0.0113	0.9787	2.30	0.0009	0.0412	0.9454	4.10
	0.8703	0.5111	0.0000		0.0558	0.0033	0.0000	
B	2.3716			24.45	0.0336	0.0517	0.9364	26.63
	0.0000				0.1218	0.0009	0.0000	
I	0.0000	0.2302	0.7519	0.40	0.0001	0.2234	0.7471	0.81
	0.0016	0.0000	0.0000		0.1534	0.0657	0.0000	
L	0.0006			0.40	0.0000	0.1590	0.8310	0.70
	0.0000				0.0504	0.0001	0.0000	
R	0.0594			3.87	0.0060	0.0391	0.9255	6.55
	0.0000				0.7620	0.3915	0.0000	
Z	0.0341	0.1044	0.7941	9.21	0.0544	0.1332	0.8459	25.56
	0.0105	0.0005	0.0000		0.0067	0.0000	0.0000	

Table 6. Correlations across variance measures.

Listed are correlations between realized variance based on the sum of squared 5-minute returns and the Rogers and Satchell (1991) range-based variance based on daily open, high, low, and closing prices. Variance measures are computed over single day periods as well as non-overlapping 5-day and 21-day periods. Linear correlations and Spearman rank correlations are listed. All Spearman correlations are statistically significant at the 1% level.

Ticker	Daily Obs.	Correlation	1 Day	5 Day	21 Day
CL	3,114	Linear	0.7544	0.9199	0.9555
		Spearman	0.5121	0.6190	0.7332
ED	2,148	Linear	0.8522	0.9617	0.9867
		Spearman	0.5998	0.7836	0.8243
ES	3,118	Linear	0.3993	0.7346	0.8587
		Spearman	0.6522	0.8207	0.8548
TY	2,353	Linear	0.7883	0.9111	0.9700
		Spearman	0.6307	0.7639	0.8452
FDAX	2,555	Linear	0.7299	0.8835	0.8957
		Spearman	0.6451	0.6978	0.6719
FESX	2,558	Linear	0.6008	0.6842	0.6813
		Spearman	0.6151	0.6562	0.6187
FGBL	2,559	Linear	0.5544	0.7101	0.7311
		Spearman	0.5407	0.6649	0.6850
FGBM	2,559	Linear	0.5537	0.6659	0.6348
		Spearman	0.5384	0.6405	0.6810
B	1,877	Linear	0.7971	0.9515	0.9849
		Spearman	0.5423	0.7195	0.7349
SB	1,101	Linear	0.7405	0.9116	0.9533
		Spearman	0.5494	0.7283	0.8130
TF	1,065	Linear	0.8250	0.9618	0.9649
		Spearman	0.6056	0.6778	0.7355
I	3,002	Linear	0.1867	0.3800	0.5562
		Spearman	0.5480	0.7412	0.8103
L	2,093	Linear	0.1619	0.3137	0.4688
		Spearman	0.3931	0.5739	0.6176
R	3,036	Linear	0.7458	0.9029	0.9581
		Spearman	0.5740	0.7664	0.8238
Z	2,935	Linear	0.8415	0.9581	0.9853
		Spearman	0.6595	0.8105	0.8738

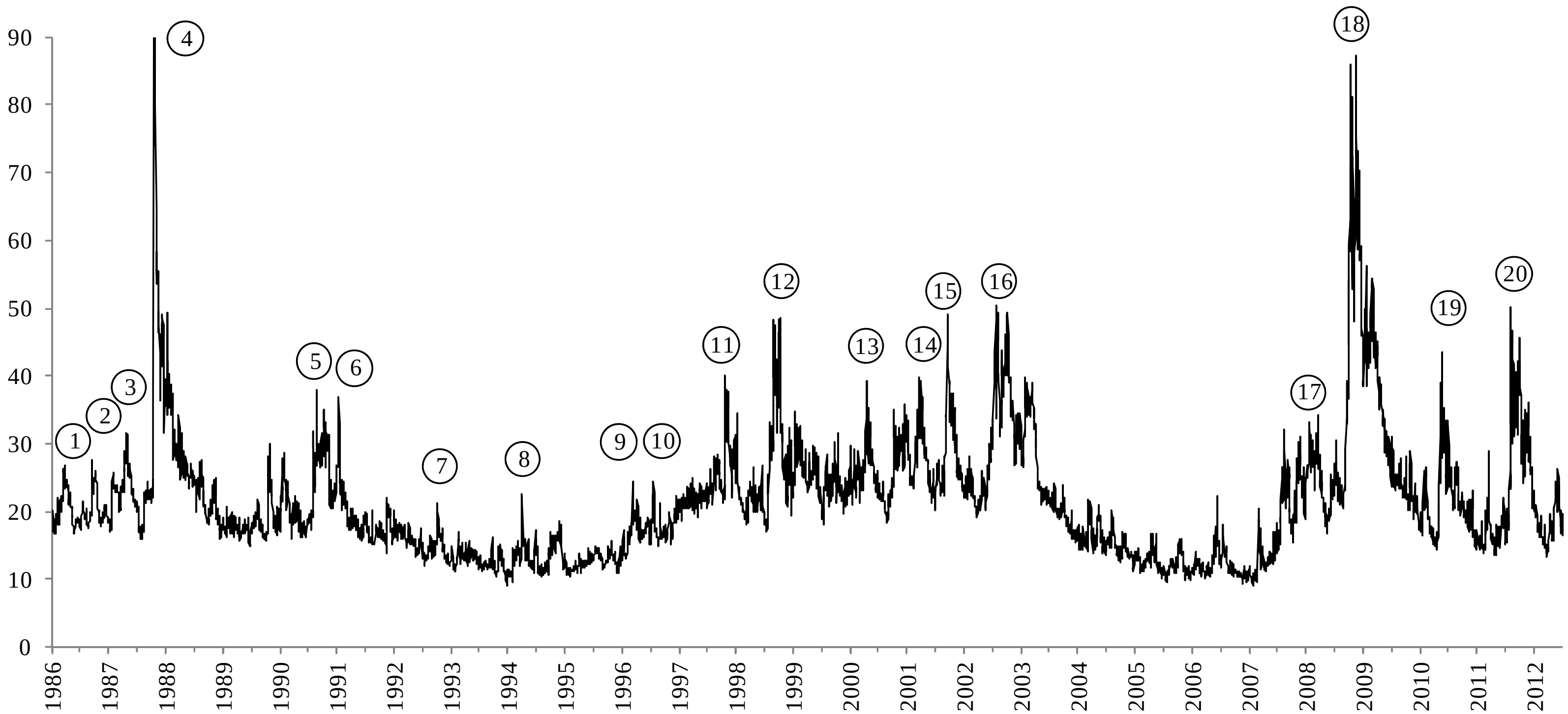
Table 7. Volatility ratios.

Listed are ratios of annualized volatility constructed from five-minute squared returns to annualized volatility constructed from weekly (Panel A), and bi-weekly (Panel B) returns.

	Year					
	2006	2007	2008	2009	2010	2011
Ticker	Panel A. Weekly					
CL	1.015	1.021	1.086	1.289	1.120	1.015
ED	2.225	1.693	1.390	1.780	2.125	2.239
ES	1.368	1.323	1.106	1.148	1.197	0.848
TY	1.464	1.405	1.232	1.157	1.227	1.106
FDAX	1.126	1.119	1.398	1.167	1.333	1.872
FESX	1.349	1.445	1.465	1.252	1.412	2.671
FGBL	1.279	1.244	1.266	1.263	1.525	2.946
FGBM	1.396	1.307	1.230	1.365	1.415	2.691
B	1.423	1.415	1.274	1.509	1.232	1.212
SB			1.178	1.497	1.263	1.381
TF			1.579	1.375	1.206	1.110
I	1.353	1.981	1.062	1.718	2.499	1.364
L	4.025	1.901	1.031	2.435	3.843	4.427
R	1.578	1.453	1.309	1.227	1.446	0.683
Z	1.354	1.841	1.537	1.416	1.138	1.377
Ticker	Panel B. Bi-Weekly					
CL	1.088	1.032	1.004	1.268	1.115	1.143
ED	2.007	1.645	1.272	2.005	1.987	2.226
ES	1.538	1.582	1.890	1.027	1.346	0.852
TY	1.488	1.389	1.137	1.174	1.156	1.472
FDAX	1.458	1.126	1.468	1.153	1.433	2.189
FESX	1.813	1.408	1.593	1.394	1.626	3.153
FGBL	1.044	1.181	1.300	1.322	1.361	3.092
FGBM	1.241	1.205	1.253	1.394	1.257	2.850
B	1.728	1.298	1.174	1.483	1.190	1.238
SB			1.201	2.107	1.426	1.284
TF			1.766	1.325	1.408	1.222
I	1.454	2.237	1.005	2.056	2.698	1.273
L	4.343	1.857	0.951	3.053	5.623	4.617
R	1.547	1.415	1.263	1.182	1.435	0.666
Z	1.635	2.323	1.526	1.493	1.664	1.423

Figure 1. Volatility from January 1986 – June 2012.

Depicted is the daily closing level of the CBOE Volatility Index (VIX) from January 1986 – June 2012. Spikes corresponding to twenty important events are indicated. Note that the VIX closed at 150.19 on the stock market crash of 10/19/1987 although the scale of the chart is capped at 90.



Contract roll dates

Exchange	Contract	Ticker	Begins	Ends	Roll date convention
CME Group (CME)					
	Eurodollar Futures	ED	1/1/2004	5/31/2112	45 days before quarterly contract expiration day
	E-mini S&P 500 Index Futures	ES	1/1/2000	5/31/2012	7 days before contract expiration day
	Light Sweet (WTI) Crude Oil Futures	CL	11/30/1999	5/31/2012	3 days before contract expiration day
	10-Year U.S. Treasury Note Futures	TY	1/1/2004	5/31/2012	22 days before contract expiration day
Intercontinental Exchange (ICE)					
	Brent Crude Futures	B	11/4/2004	7/9/2012	4 days before contract expiration day
	Russell 2000 Index Futures	TF	2/5/2007	7/9/2012	8 days before contract expiration day
	Sugar #11 Futures	SB	8/16/2007	7/9/2012	15 days before contract expiration day
Eurex					
	DAX Futures	FDAX	5/2/2002	5/15/2012	1 day before contract expiration day
	Euro-Stoxx 50 Index Futures	FESX	5/2/2002	5/15/2012	1 day before contract expiration day
	Euro-Bund Futures	FGBL	5/2/2002	5/15/2012	2 days before contract expiration day
	Euro-Bobl Futures	FGBM	5/2/2002	5/15/2012	2 days before contract expiration day
NYSE Liffe					
	FTSE 100 Index Futures	Z	1/4/2000	5/31/2012	1 day before contract expiration day
	Three Month Euro (Euribor) Futures	I	1/4/2000	5/31/2012	last day of month preceding quarterly expiration.
	Three Month Sterling (Short Sterling) Futures	L	1/2/2001	5/31/2012	last day of month preceding quarterly expiration.
	Long Gilt Futures	R	1/4/2000	5/31/2012	last day of month preceding quarterly expiration.

Figure 1. Volatility from January 1986 – June 2012 (continued).

Legen	Date	VIX	Event
1	3/21/1986	26.91	OPEC agrees to drop production resulting in a sharp increase in crude oil prices
2	9/12/1986	27.69	Inflation fears and portfolio insurance programs are blamed for a one-day 4.61% drop in the DJIA
3	4/27/1987	31.46	Dollar falls to 39-year low against the yen and inflation hits 5%
4	10/19/1987	150.19	DJIA drops over 22% on the day called "Black Monday"
5	8/23/1990	38.07	Saddam Hussein appears on state television with Western hostages following the August 2 Iraqi invasion of Kuwait
6	1/15/1991	36.93	Iraq ignores U.N. deadline for withdrawal from Kuwait prompting the beginning of Operation Desert Storm
7	10/7/1992	21.12	Pessimistic economic statistics fuel recession fears
8	4/4/1994	22.50	Stocks drop as long-term interest rates rise unexpectedly
9	3/8/1996	24.37	DJIA drops 3% in contrarian fashion following job growth, lowering likelihood of Fed stimulus
10	7/23/1996	24.43	Jagged trading triggers the NYSE uptick rule for the seventh consecutive trading day
11	10/27/1997	39.96	Stock markets plummet worldwide due to Asian economic crisis
12	8/31/1998	48.33	DJIA drops 19% in August in the weeks following the Russian Default
13	4/14/2000	39.33	Nasdaq drops 25% in one week ushering in the post-bubble period
14	3/22/2001	39.70	CPI rises more than expected, dampening hopes of Fed rate cut
15	9/20/2001	49.04	Markets re-open following September 11 terrorist attack
16	10/9/2002	49.48	Stocks reach 2002 lows culminating an 18-month drop from dot-com era peak
17	9/15/2008	31.70	Lehman Brothers files for Chapter 11 bankruptcy protection
18	11/20/2008	87.24	S&P 500 drops to an 11 1/2 year low following continued signs of economic contraction
19	5/20/2010	43.63	U.S. stock indices fell into correction following continued evidence of a slow economic recovery
20	8/8/2011	50.13	First trading day following S&P downgrade of U.S. credit rating; fears of European debt crisis mount

Figure 2. Crisis timeline.

Depicted is the daily closing level of the CBOE Volatility Index (VIX) from January 2007 – June 2012. Spikes corresponding to twenty of the important events of the global financial crisis are indicated.

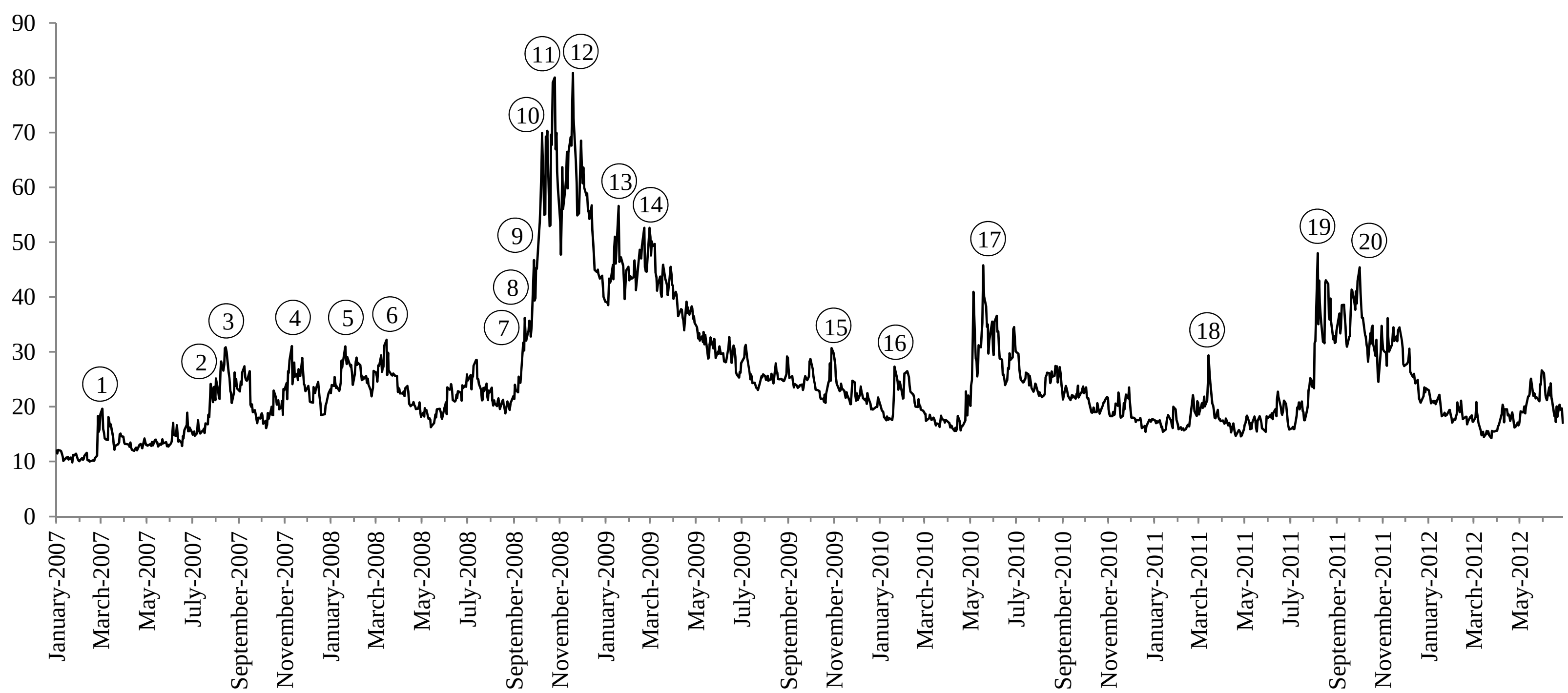


Figure 2. Crisis timeline (continued).

Legend	Date	VIX	Event
1	2/27/2007	18.30	Federal Home Loan Mortgage Corp announces it will no longer buy riskiest subprime securities
2	7/31/2007	23.52	Bear Stearns liquidates two hedge funds that invested in MBS
3	8/16/2007	30.83	Fitch downgrades Countrywide Financial Corp to BBB+
4	11/12/2007	31.09	Bank of America, Citigroup, JPMorgan agree to establish a $75 billion fund to buy troubled assets
5	1/22/2008	31.01	FOMC votes to reduce Federal Funds rate by 75 basis points to 3.5%
6	3/14/2008	31.16	Federal Reserve approves JPMorgan bail out of Bear Stearns
7	9/15/2008	31.70	Lehman Brothers files for Chapter 11 bankruptcy protection
8	9/25/2008	32.82	JPMorgan wins bid to acquire Washington Mutual in FDIC orchestrated auction
9	9/29/2008	46.72	U.S. House of Representatives rejects legislation to authorize the U.S. Treasury to purchase troubled assets
10	10/17/2008	70.33	Disappointing economic statistics lead to dramatic daily changes in equity index levels
11	10/27/2008	80.06	U.S. Treasury injects $125 billion into nine major U.S. banks
12	11/20/2008	80.86	S&P 500 drops to an 11 1/2 year low following continued signs of economic contraction
13	1/20/2009	51.00	U.K. banking crisis intensifies; Barack Obama inauguration
14	3/5/2009	50.17	U.S. equity markets reach new lows dragged down by financials, including Citigroup, which trades at less than $1 per share
15	10/30/2009	30.69	VIX increases by 38% in one week reflecting fears of slowing recovery
16	1/22/2010	27.31	U.S. stocks drop by 2% over concerns of President Obama's banking reform plans
17	5/20/2010	45.79	U.S. stock indices fell into correction following continued evidence of a slowing economic recovery
18	3/16/2011	29.40	Fukushima Nuclear Power Plant situation worsens following Japanese tsunami
19	8/8/2011	48.00	First trading day following S&P downgrade of U.S. credit rating; fears of European debt crisis mount
20	10/3/2011	45.45	Greece misses a deficit target despite austerity measures increasing probability of bankruptcy

Figure 3. Daily returns and volatility indexes.

Depicted are daily open-to-close returns of the ES, FDAX, and Z contracts along with the closing levels of the VIX, VDAX, and VFTSE volatility indexes. The three data series begin January 3, 2000, January 4, 2000, and October 24, 2006, respectively. All series run through May 15, 2012.

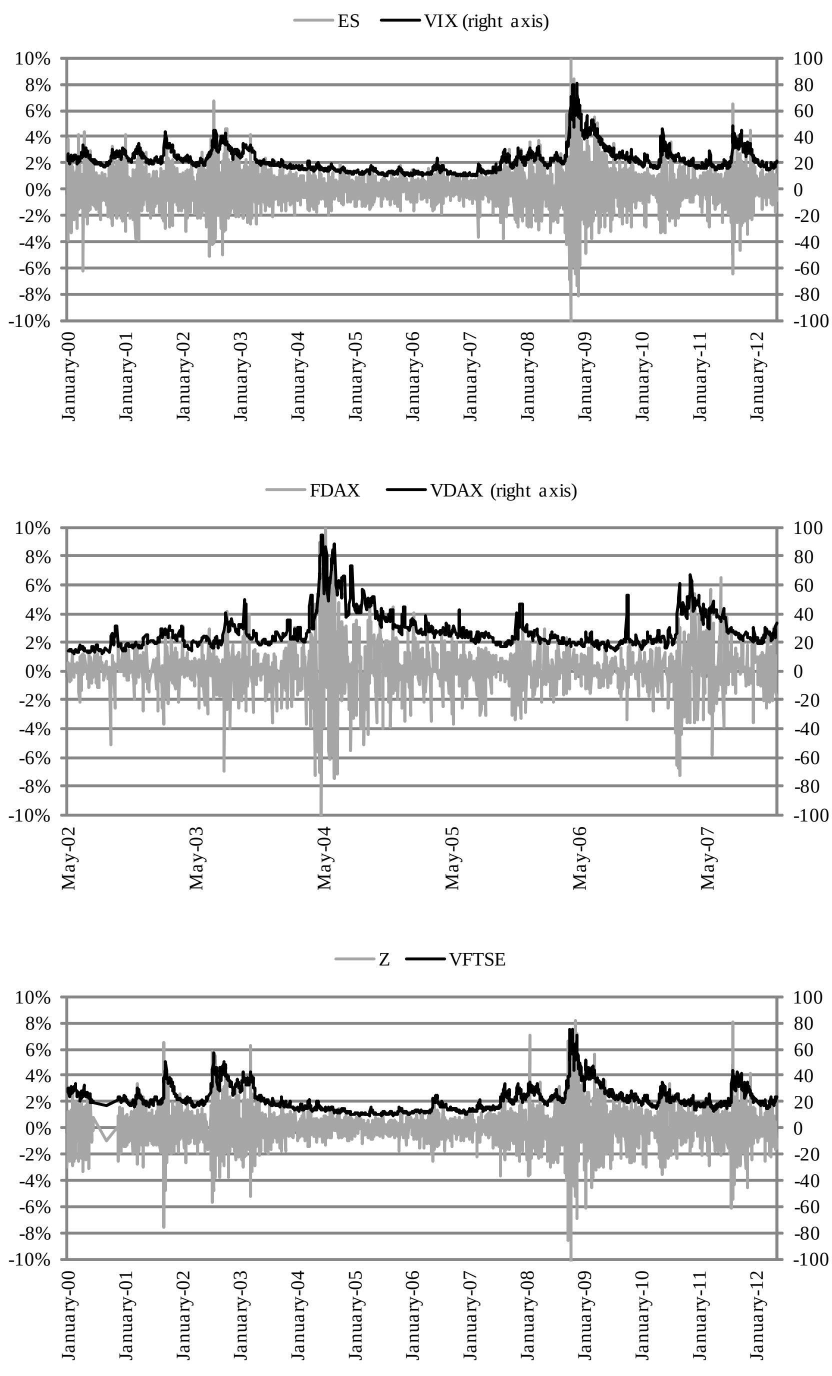
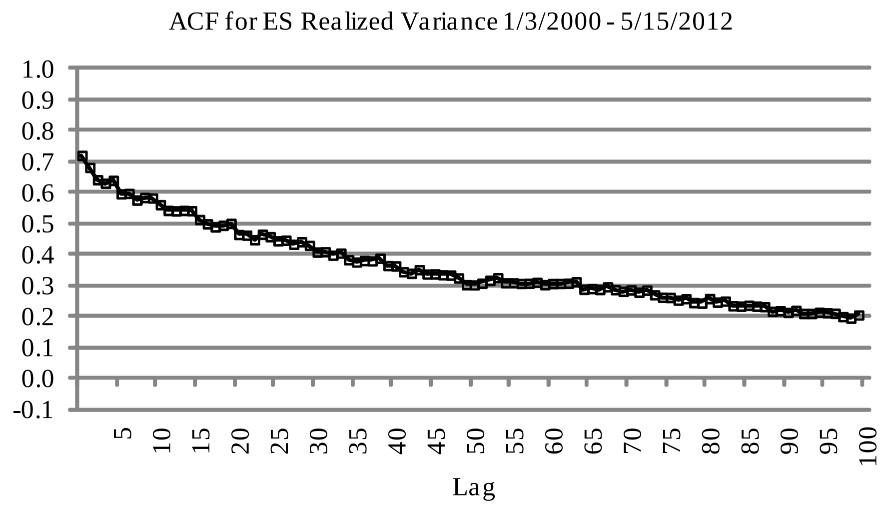


Figure 4. Autocorrelation functions of the E-mini contract.

Depicted are autocorrelation functions of daily measures of realized variance based on five-minute squared returns for the S&P 500 E-mini contract (ES) traded on the CME. The bottom figure shows the functions estimated over two subsets. “Crisis” uses data from July 2, 2007 through May 25, 2012. “Pre-crisis uses data from January 2, 2004 through June 29, 2007.



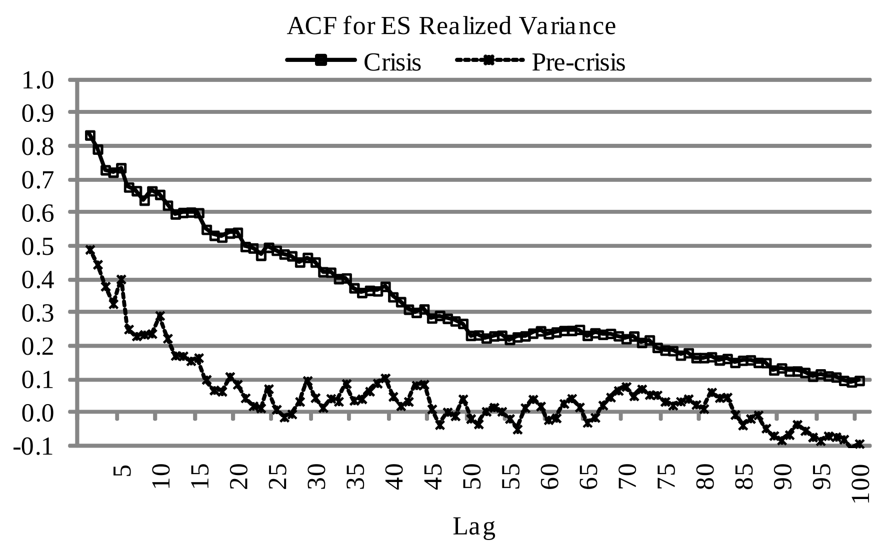
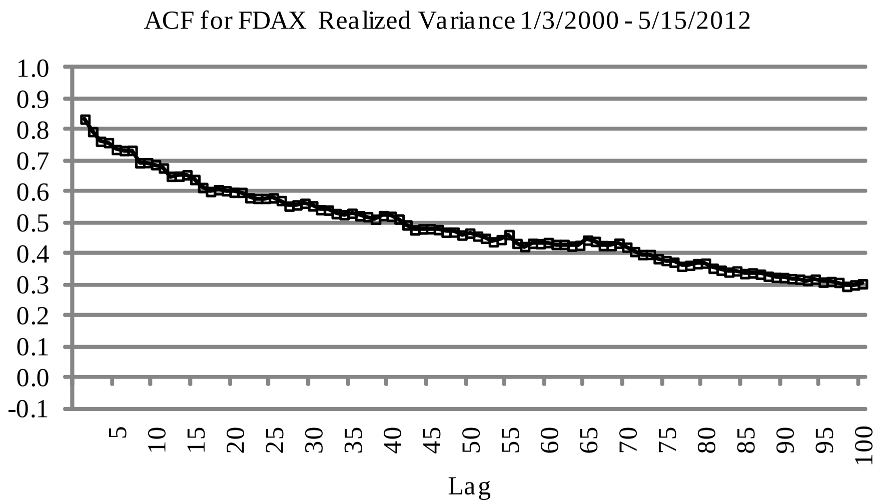


Figure 5. Autocorrelation functions of the DAX contract.

Depicted are autocorrelation functions of daily measures of realized variance based on five-minute squared returns for the DAX contract (FDAX) traded on the Eurex. The bottom figure shows the functions estimated over two subsets. “Crisis” uses data from July 2, 2007 through May 25, 2012. “Pre-crisis uses data from January 2, 2004 through June 29, 2007.



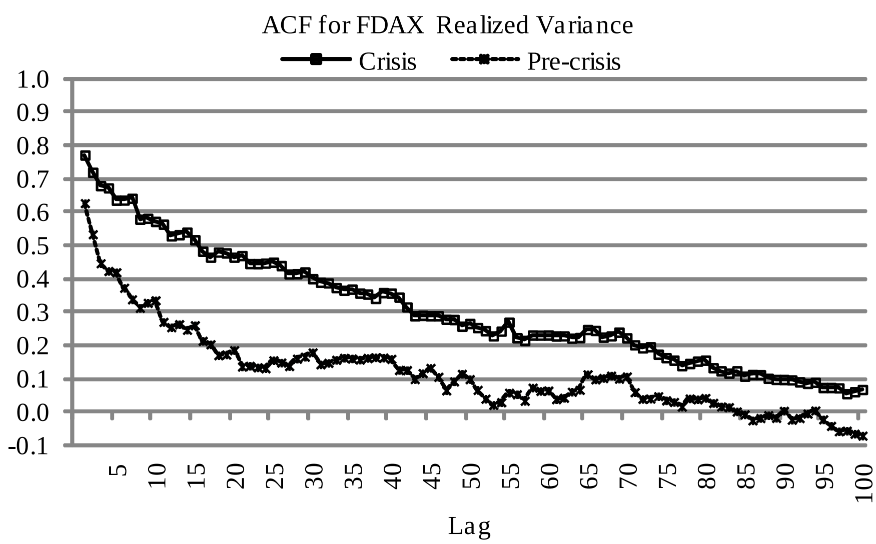
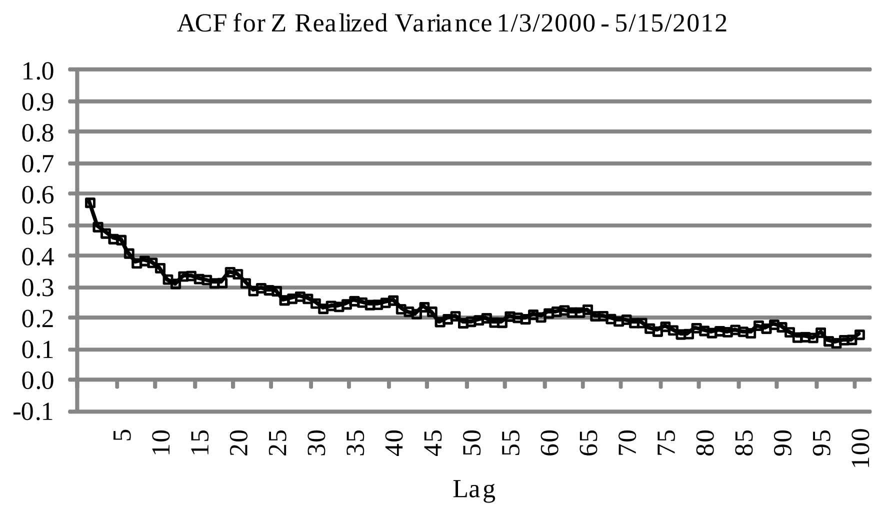


Figure 6. Autocorrelation functions of the FTSE contract.

Depicted are autocorrelation functions of daily measures of realized variance based on five-minute squared returns for the FTSE contract (Z) traded on NYSE Liffe. The bottom figure shows the functions estimated over two subsets. “Crisis” uses data from July 2, 2007 through May 25, 2012. “Pre-crisis uses data from January 2, 2004 through June 29, 2007.



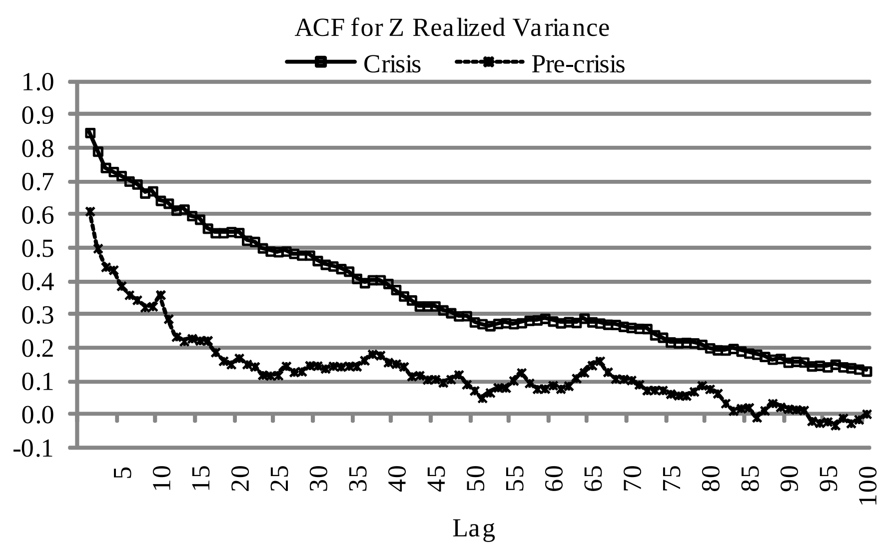


Figure 7. Realized variance and OHLC variance comparisons – CME.

Depicted are monthly estimates of volatility for the four CME futures contracts. Realized variance is the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. OHLC variance uses the Rogers and Satchell (1991) range-based estimator each trading day. Variance measures are standardized by averaging across the days in the month and then annualizing assuming a 252-trading day year.

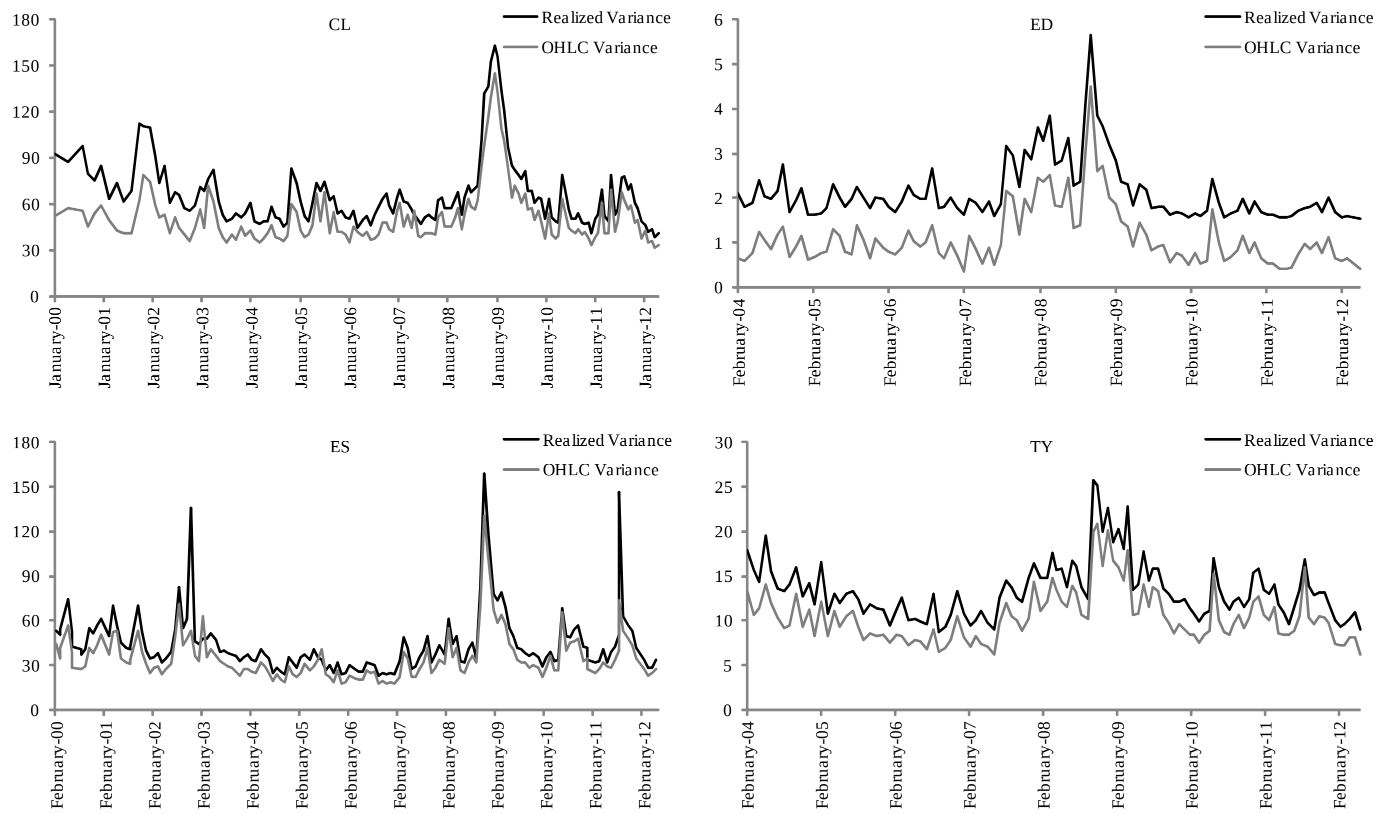


Figure 8. Realized variance and OHLC variance comparisons – Eurex.

Depicted are monthly estimates of volatility for the four Eurex futures contracts. Realized variance is the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. OHLC variance uses the Rogers and Satchell (1991) range-based estimator each trading day. Variance measures are standardized by averaging across the days in the month and then annualizing assuming a 252-trading day year.

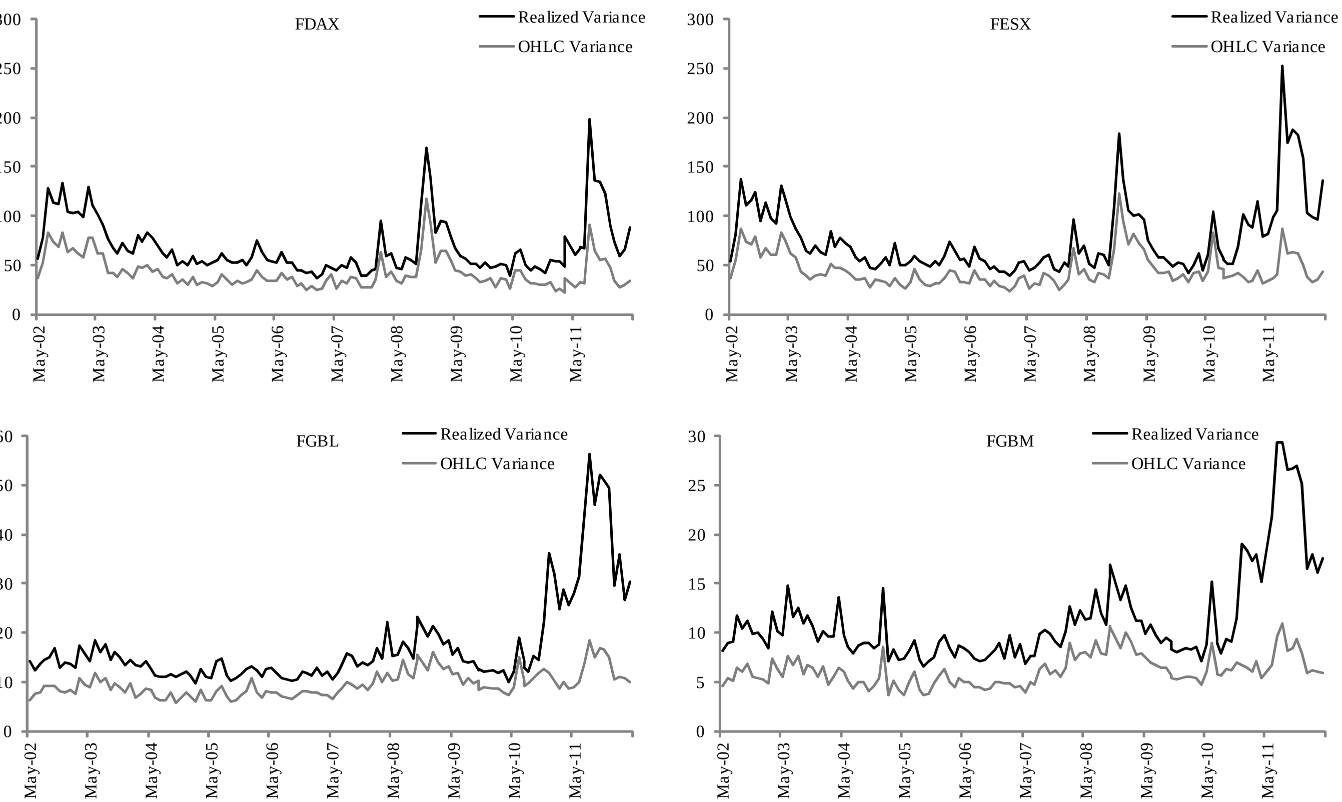


Figure 9. Realized variance and OHLC variance comparisons – ICE.

Depicted are monthly estimates of volatility for the three ICE futures contracts. Realized variance is the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. OHLC variance uses the Rogers and Satchell (1991) range-based estimator each trading day. Variance measures are standardized by averaging across the days in the month and then annualizing assuming a 252-trading day year.

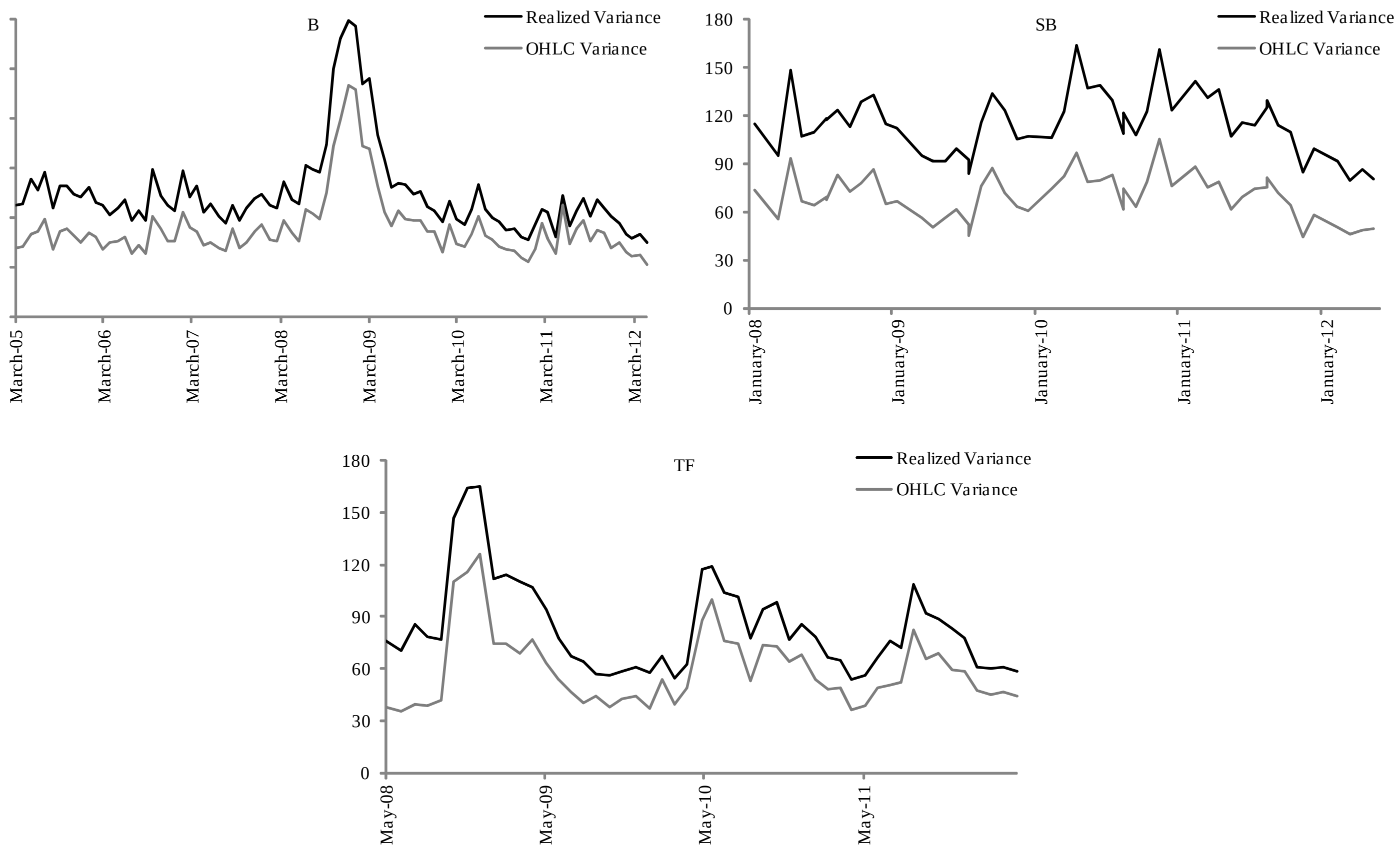


Figure 10. Realized Variance and OHLC Variance Comparisons – NYSE Liffe.

Depicted are monthly estimates of volatility for the four NYSE Liffe futures contracts. Realized Variance is the sum of squared five-minute returns using the last trade price within each five-minute interval. Each day's realized variance is scaled to reflect trading in all 288 intervals. OHLC Variance uses the Rogers and Satchell (1991) range-based estimator each trading day. Variance measures are standardized by averaging across the days in the month and then annualizing assuming a 252-trading day year.

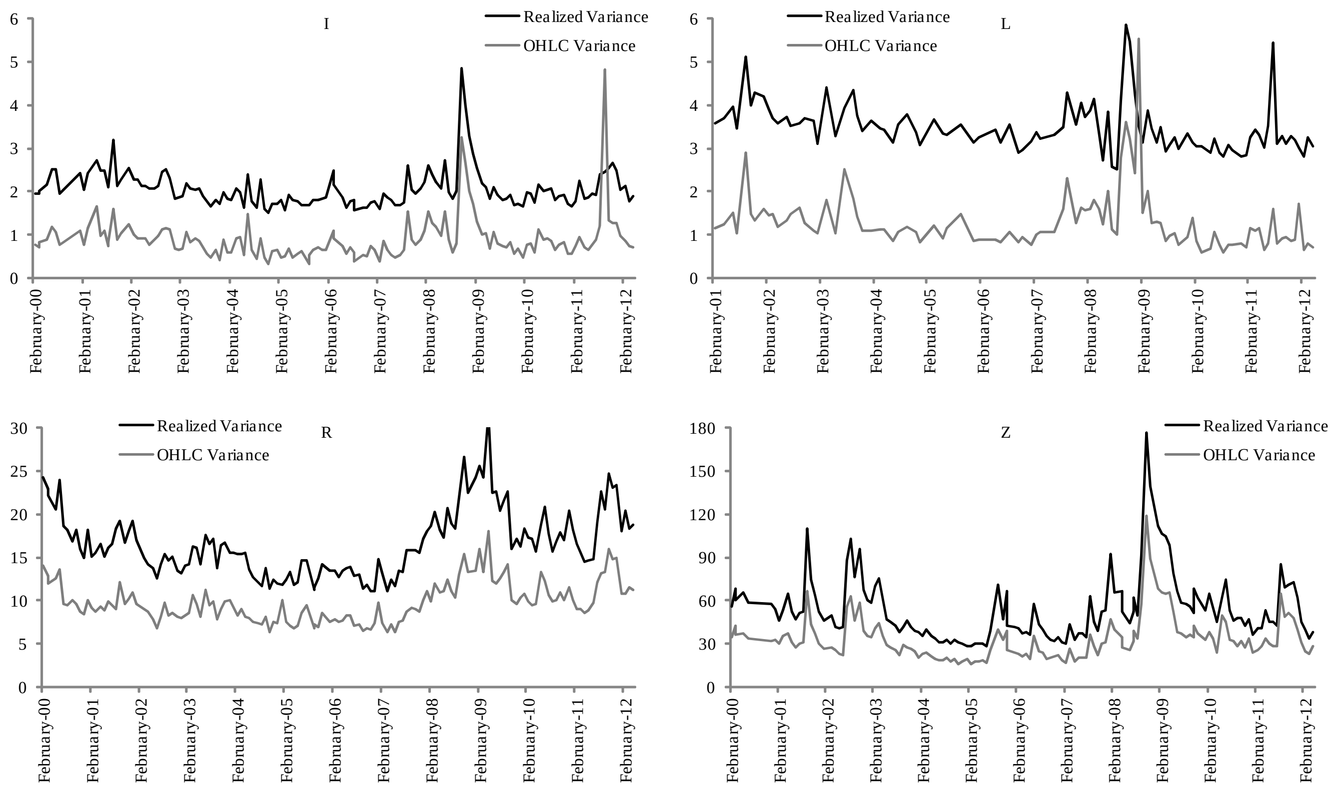


Figure 11. E-mini S&P 500 futures realized volatility vs. VIX volatility index.

Depicted are daily closing levels of "VIX," the VIX volatility index, and "E-mini," an annualized measure of realized volatility computed daily from 5-minute returns of the CME E-mini S&P 500 futures contract. Realized volatility is the square root of the sum of squared five-minute returns using the last trade price within each five-minute interval. Figures A and B show daily and monthly measures of realized volatility, respectively. The data run from January 3, 2000 through May 15, 2012.

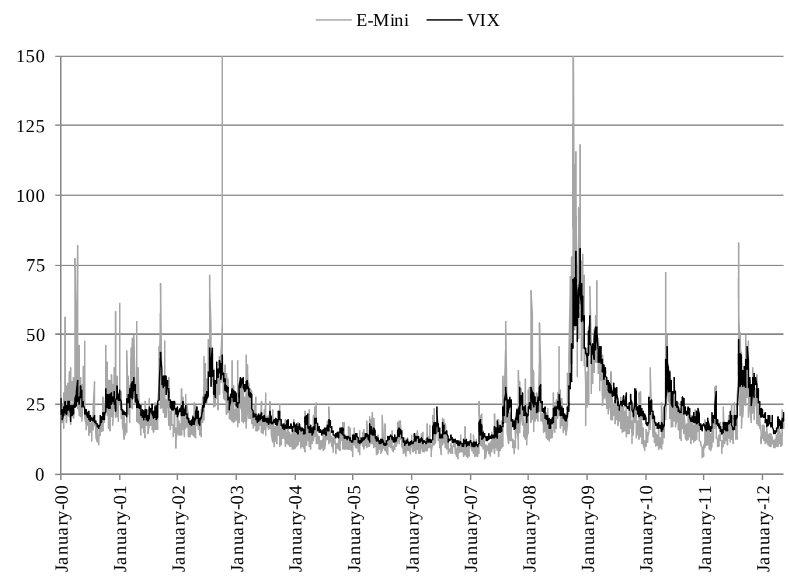


Figure A. Daily Realized Volatility

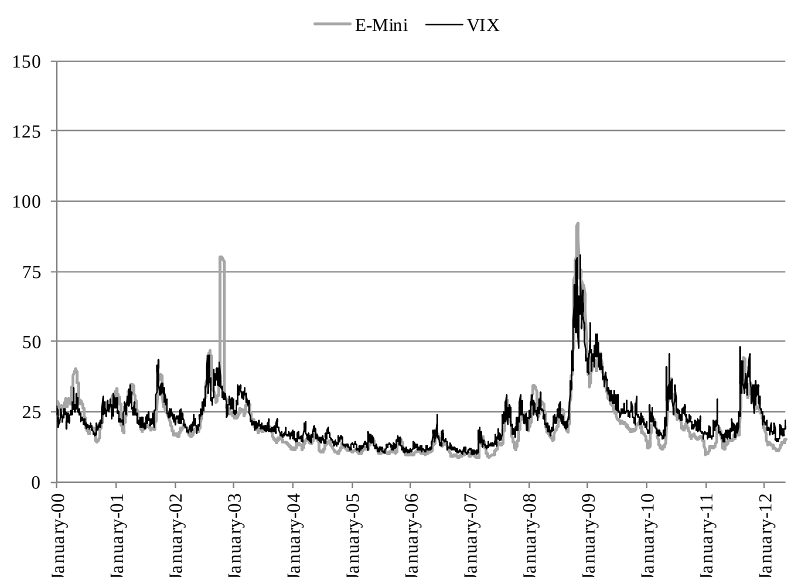


Figure B. Monthly Realized Volatility

Figure 12. FDAX futures realized volatility vs. VDAX volatility index.

Depicted are daily closing levels of "VDAX," the VDAX (new) volatility index, and "FDAX," an annualized measure of realized volatility computed daily from 5-minute returns of the Eurex DAX futures contract. Realized volatility is the square root of the sum of squared five-minute returns using the last trade price within each five-minute interval. Figures A and B show daily and monthly measures of realized volatility, respectively. The data run from October 24, 2006 through May 15, 2012.

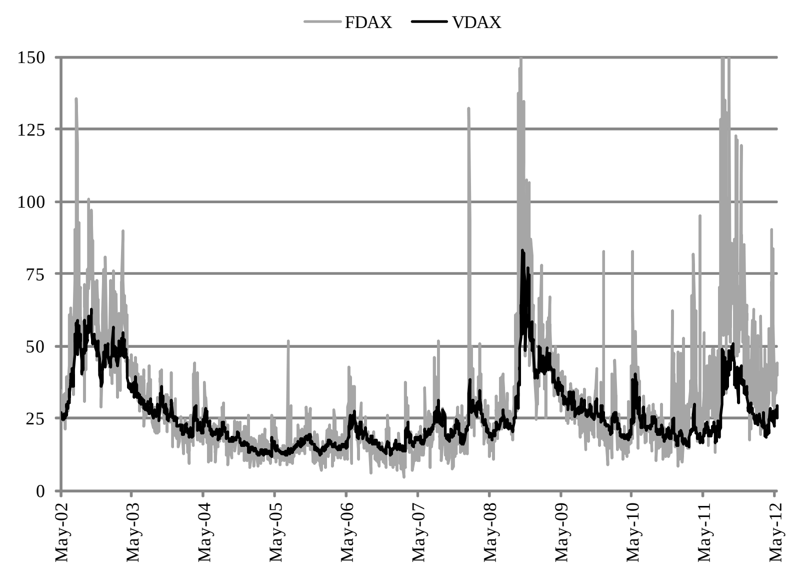


Figure A. Daily Realized Volatility

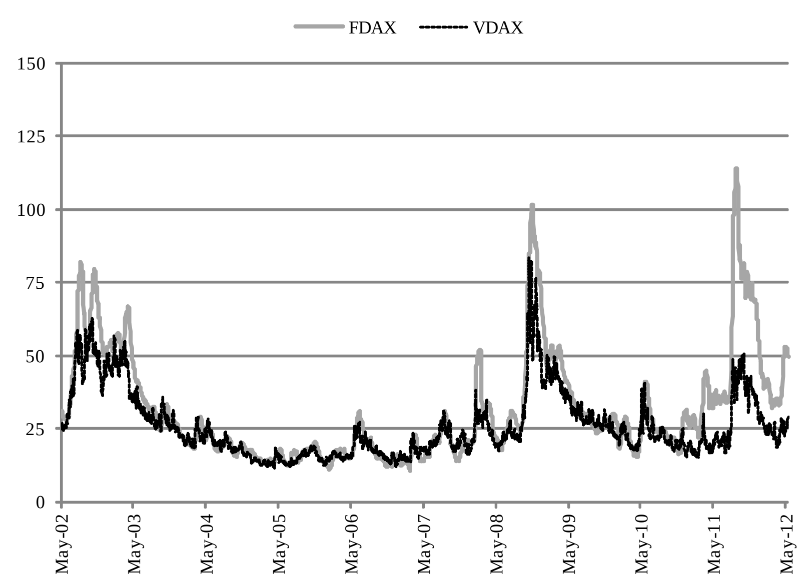


Figure B. Monthly Realized Volatility

Figure 13. FTSE futures realized volatility vs. VFTSE volatility index.

The top graph compares daily closing level of "VFTSE," the VFTSE volatility index, and "FTSE," an annualized measure of realized volatility computed daily from 5-minute returns of the NYSE Liffe FTSE 100 Index futures contract. Realized volatility is the square root of the sum of squared five-minute returns using the last trade price within each five-minute interval. Figures A and B show daily and monthly measures of realized volatility, respectively. The data run from January 4, 2000 through May 15, 2012.

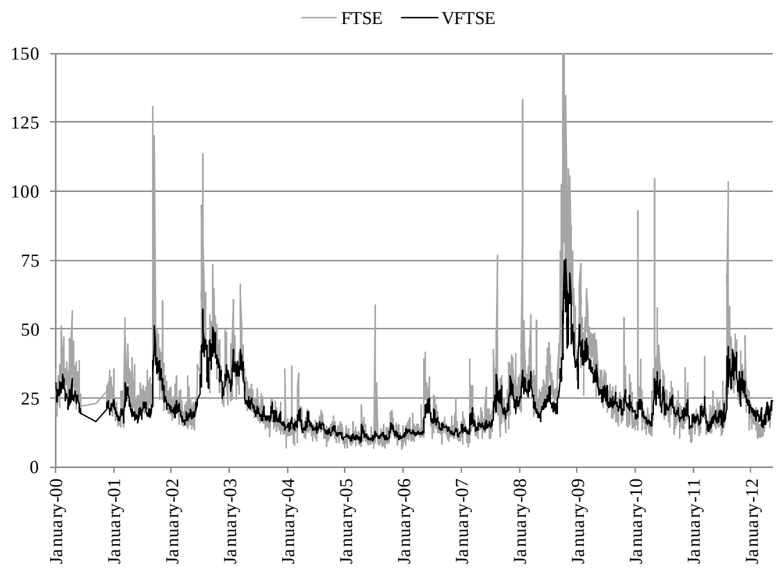


Figure A. Daily Realized Volatility

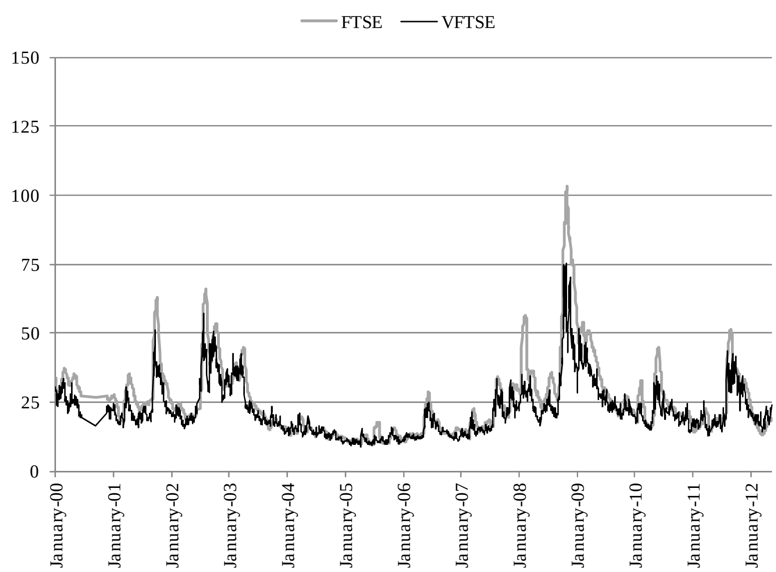


Figure B. Monthly Realized Volatility

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Appendix 1:
Contract roll dates and contract specifications

Contract roll dates

Exchange	Contract	Ticker	Begins	Ends	Roll date convention
CME Group (CME)					
	Eurodollar Futures	ED	1/1/2004	5/31/2112	45 days before quarterly contract expiration day
	E-mini S&P 500 Index Futures	ES	1/1/2000	5/31/2012	7 days before contract expiration day
	Light Sweet (WTI) Crude Oil Futures	CL	11/30/1999	5/31/2012	3 days before contract expiration day
	10-Year U.S. Treasury Note Futures	TY	1/1/2004	5/31/2012	22 days before contract expiration day
Intercontinental Exchange (ICE)					
	Brent Crude Futures	B	11/4/2004	7/9/2012	4 days before contract expiration day
	Russell 2000 Index Futures	TF	2/5/2007	7/9/2012	8 days before contract expiration day
	Sugar #11 Futures	SB	8/16/2007	7/9/2012	15 days before contract expiration day
Eurex					
	DAX Futures	FDAX	5/2/2002	5/15/2012	1 day before contract expiration day
	Euro-Stoxx 50 Index Futures	FESX	5/2/2002	5/15/2012	1 day before contract expiration day
	Euro-Bund Futures	FGBL	5/2/2002	5/15/2012	2 days before contract expiration day
	Euro-Bobl Futures	FGBM	5/2/2002	5/15/2012	2 days before contract expiration day
NYSE Liffe					
	FTSE 100 Index Futures	Z	1/4/2000	5/31/2012	1 day before contract expiration day
	Three Month Euro (Euribor) Futures	I	1/4/2000	5/31/2012	last day of month preceding quarterly expiration.
	Three Month Sterling (Short Sterling) Futures	L	1/2/2001	5/31/2012	last day of month preceding quarterly expiration.
	Long Gilt Futures	R	1/4/2000	5/31/2012	last day of month preceding quarterly expiration.

ED

Name	Eurodollar futures
Symbol	ED (Globex: GE)
Exchange	CME Group
Trading months	H,M,U,Z extending out 10 years (total of 40 contracts) plus the four nearest serial months (that are not in the quarterly cycle).
Trading hours	7:20-14:00 CT (5:00 PM - 4PM CT Sunday through Friday)
Quotation	100 minus rate of interest
Denomination	$1,000,000
Tick size	Quoted in IMM Index points. One-quarter of one basis point (0.0025 = $6.25 per contract) in the nearest expiring contract month; one-half of one basis point (0.005 = $12.50 per contract) in all other contract months. The “new” expiring front-month contract begins at 7:20 a.m., Central Time (CT) after the “old” expiring front-month contract ceases trading at 11:00 a.m. London time on the CME Globex electronic trading platform on the contract’s last trading day
Last day of trading	Second London business day prior to third Wednesday of the contract month.
Underlying instrument	Eurodollar time deposit having a principal value of $1,000,000 with a three-month maturity.
Final settlement	Cash settlement to 100 minus the British Bankers’ Association survey of 3-month LIBOR. Final settlement price will be rounded to four decimal places, equal to 1/10,000 of a percent, or $0.25 per contract.
Contract roll	**45 days before <u>quarterly</u> contract expiration day. NB: Non-quarterly serial**

ES

Name	E-mini S&P 500 futures
Symbol	ES
Exchange	CME Group
Trading months	Five months in quarterly expiration cycle.
Trading hours	MON-THURS: 5:00PM-3:15PM and 3:30PM-4:30PM (Daily maintence shutdown 4:30PM-5:00PM) SUN:5:00PM-3:15PM
Denomination	$50 times futures price
Tick size	0.25 index points = $12.50
Last day of trading	Trading can occur up to 8:30AM CST on the 3rd Friday of the contract month.
Underlying instrument	S&P 500 index
Final settlement	Cash settlement at special opening quotation at Friday open.
Contract roll	**7 days before quarterly contract expiration day.**

CL

Name	Light Sweet Crude Oil
Symbol	CL
Exchange	CME Group (NYMEX)
Price quote	Consecutive months extending out four years plus June and December contracts for another three years.
Trading hours	Electronic: Sunday-Friday 6:00pm-5:15PM ET; Pit: Monday-Friday 9:00am-2:30pm ET
Denomination	1,000 barrels (42,000 gallons)
Price quote	US dollars and cents per barrel
Tick size	One cent per barrel
Last day of trading	Trading ceases on 3rd business day prior to the 25th calendar of the month preceding the delivery month. If the 25th is not a business day, business day beforehand.
Delivery	Physical
Contract roll	**3 days before contract expiration day. NB: Expiration day is in previous month.**

TY

Name	Ten-year T-note futures
Symbol	TY (ZN electronic)
Exchange	CME Group
Trading months	H,M,U,Z (five consecutive contracts)
Trading hours	Open outcry: Mon - Fri 7:20am - 2:00pm
	Globex: Sun - Fri 5:00pm - 4pm
Denomination	$100,000
Tick size	One-half of one thrity-second of a point (1/64th)
Last day of trading	Seventh business day preceding the last business day of the trading month. Trading in expiring contracts closes at 12:01pm on the last trading day.
Last delivery day	Last business day of the delivery month.
Underlying instrument	US Treasury note with $100,000 face value
Contract roll	**22 days before contract expiration day.**

B

Name	Brent Crude Oil Futures
Symbol	B
Exchange	ICE Futures U.S.
Price quote	Consecutive months extending out four years plus June and December contracts for another three years.
Trading hours	20:00 (18:00 on Sundays) to 18:00 next day ET
Denomination	1,000 barrels (42,000 gallons)
Price quote	Dollars and cents per barrel
Tick size	One cent per barrel
Last day of trading	Trading shall cease at the end of the designated settlement period on the business day (a trading day which is not a public holiday in England and Wales) immediately preceding: (a) Either the 15th day before the first day of the contract month, if the 15th day is a business day, or (b) is such a day is not a business day the next preceding business day.
Settlement price	The weighted average of trades during a two-minute settlement period from 19:28: London time.
Underlying instrument	Cash settled
Contract roll	**4 days before contract expiration day. NB: Expiration day is in previous month.**

TF

Name	Russell 2000 Index Mini Futures
Symbol	TF (TS for block trades)
Exchange	ICE Futures U.S.
Trading months	H,M,U,Z
Trading hours	20:00 - 18:00 ET
Denomination	100 times index
Tick size	0.1
Last day of trading	Third Friday of contract month at 9:30 ET
Final settlement	SOQ on Friday morning
Underlying instrument	Russell 2000 Index

Contract roll **8 days before contract expiration day.**

SB

Name	Sugar No. 11 Futures
Symbol	SB
Exchange	ICE Futures U.S.
Trading months	H,K,N,V (Mar., May, Jul., Oct)
Trading hours	2:30-14:00 ET
Denomination	112,000 lbs.
Price quote	Cents and hundreths of a cent per pound
Tick size	1/100 cent/lb.
Last day of trading	Last business day of month preceding delivery month.
First notice day	First business day after last trading day.
Last notice day	First business day after last trading day.
Underlying instrument	Physical delivery of raw cane sugar.
Contract roll	**15 days before contract expiration day. NB: Expiration day is in previous month.**

FDAX

Name	DAX Futures
Symbol	FDAX
Exchange	Eurex
Trading months	H,M,U,Z
Trading hours	7:50-22:00 CET
Denomination	EUR 25
Tick size	0.5 index points
Last day of trading	3rd Friday of contract month
Underlying index	Deutsche Borse AG German Stock Index DAX (DAX)
Index composition	The German Stock Index is a total return index of 30 selected German blue chip stocks traded on the Frankfurt Stock Exchange. The equities use free float shares in the index calculation. The DAX has a base value of 1,000 as of December 31, 1987. As of June 18, 1999 only XETRA equity prices are used to calculate all DAX indices. The index represents 80% of the market capital authorized in Germany.
Contract roll	**1 day before contract expiration day**

FESX

Name	EURO STOXX 50 Index Futures
Symbol	FESX
Exchange	Eurex
Trading months	H,M,U,Z
Trading hours	7:50-22:00 CET
Denomination	EUR 10
Tick size	1.0 index points
Last day of trading	3rd Friday of contract month
Underlying index	EURO STOXX 50 Price EUR
Index composition	The EURO STOXX 50 Index, Europe's leading Blue-chip index for the Eurozone, provides a Blue-chip representation of supersector leaders in the Eurozone. The index covers 50 stocks from 12 Eurozone countries: Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain.
Contract roll	**1 day before contract expiration day**

FGBL

Name	Euro-Bund Futures
Symbol	FGBL
Exchange	Eurex
Trading months	H,M,U,Z (three nearest months)
Trading hours	8:00-22:00 CET
Denomination	EUR 100,000
Tick size	0.01 percent
Delivery day	Tenth calendar day of the respective quarterly month, if this is an exchange day; otherwise the exchange day immediately succeeding that day.
Last day of trading	Two exchange days prior to the delivery date of the relevant maturity month.
Underlying instrument	Notional medium-term debt instruments issued by the Federal Republic of Germany, with a remaining term of 8.5 to 10.5 years.
Contract roll	**2 days before contract expiration day**

FGBM

Name	Euro-Bobl Futures
Symbol	FGBM
Exchange	Eurex
Trading months	H,M,U,Z (three nearest months)
Trading hours	8:00-22:00 CET
Denomination	EUR 100,000
Tick size	0.01 percent
Delivery day	Tenth calendar day of the respective quarterly month, if this is an exchange day; otherwise the exchange day immediately succeeding that day.
Last day of trading	Two exchange days prior to the delivery date of the relevant maturity month.
Underlying instrument	Notional medium-term debt instruments issued by the Federal Republic of Germany, with a remaining term of 4.5 to 5.5 years.
Contract roll	**2 days before contract expiration day**

Z

Name	FTSE 100 index futures
Symbol	Z
Exchange	NYSE Liffe (London)
Trading months	H,M,U,Z (nearest four months)
Trading hours	1:00 - 21:00
Denomination	10 pounds times futures price
Tick size	0.5 (5 pounds)
Last day of trading	3rd Friday of contract month. Trading ceases at 10:15AM London time
Underlying index	FTSE 100
Index composition	The FTSE 100 is a market value-based index of the 100 companies on the London Stock Exchange with the market capitalization. The number of shares is adjusted by a free float adjustment factor (rounded to the nearest five percent) that eliminates restricted stocks such as those held by company insiders.
Contract roll	**1 day before contract expiration day**

I

Name	Three-month Euro (Euribor) interest rate futures
Symbol	I
Exchange	NYSE Liffe (London)
Trading months	H,M,U,Z and four serial months (non-quaterly expirations) such that 28 delivery months are available.
Trading hours	1:00-6:45, 7:00 - 21:00 (NB: Between 6:45 and 7:00 the market enters pre-open).
Quotation	100 minus rate of interest
Denomination	EURO 1,000,000
Tick size	0.005 or EURO 12.50
Last day of trading	10AM two business days prior to the third Wednesday of the delivery month
Settlement	Cash settlement based on the European Bankers Federations' Euribor Offered Rate
Contract roll	**Last day of trading in month preceding delivery quarterly month. NB: Non-**

L

Name	Three-month short sterling interest rate futures
Symbol	L
Exchange	NYSE Liffe (London)
Trading months	H,M,U,Z and two serial months (non-quarterly expirations) such that 26 delivery months are available.
Trading hours	7:30 - 18:00
Quotation	100 minus rate of interest
Denomination	500,000 pounds
Tick size	0.01 or 12.50 pounds
Last day of trading	11:00 on the third Wednesday of the delivery month
Settlement	Cash settlement based on the British Banker's Associations London Interbank Offered Rate (BBA LIBOR) for three month sterling deposits at 11:00 on the last day of trading.
Contract roll	**Last day of trading in month preceding delivery quarterly month. NB: Non-quarterly serial months have little volume**

R

Name	Long gilt futures
Symbol	R
Exchange	NYSE Liffe (London)
Trading months	H,M,U,Z such that nearest three months are available.
Trading hours	8:00 - 18:00
Quotation	100 minus rate of interest
Denomination	100,000 pound nominal value notional gilt with 4% coupon
Tick size	0.01 or 10 pounds
Last day of trading	Two business days prior to the last business day in the delivery month. On the last trading, trading in the front delivery month will cease at 11:00.
Underlying	Delivery of £100,000 nominal of a deliverable Gilt.
Maturities	8 years and 9 months to 13 years
Contract roll	**Last day of trading in month preceding delivery quarterly month. NB: Non-quarterly serial months have little volume**