What Does the VIX Actually Measure?

An Analysis of the Causation of SPX and VIX

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Road Map

- Main Take-Away
- What is VIX?
- Research Question
- Review of Relevant Literature
- Competing Hypotheses
- Research Methodology
- Data
- Some Interesting Observations Relating to the Data
- Main Results (including VECM)
- What does the daily data imply?
- Conclusions and Future Research

Main Take-Away

1. SPX significantly and robustly "granger causes" the VIX.

   This causality test is supported and is evident not only in any sample examined and robustness checks

2. we observe a pattern in the minute returns/level time series and especially in the VIX time series.

   - The SPX seems to strongly and positively relate to its first lag.
   - The VIX, however, is significantly related to all lags estimated in the model and follows a pattern which can be interpreted as a correction followed by a momentum

Main Take-Away

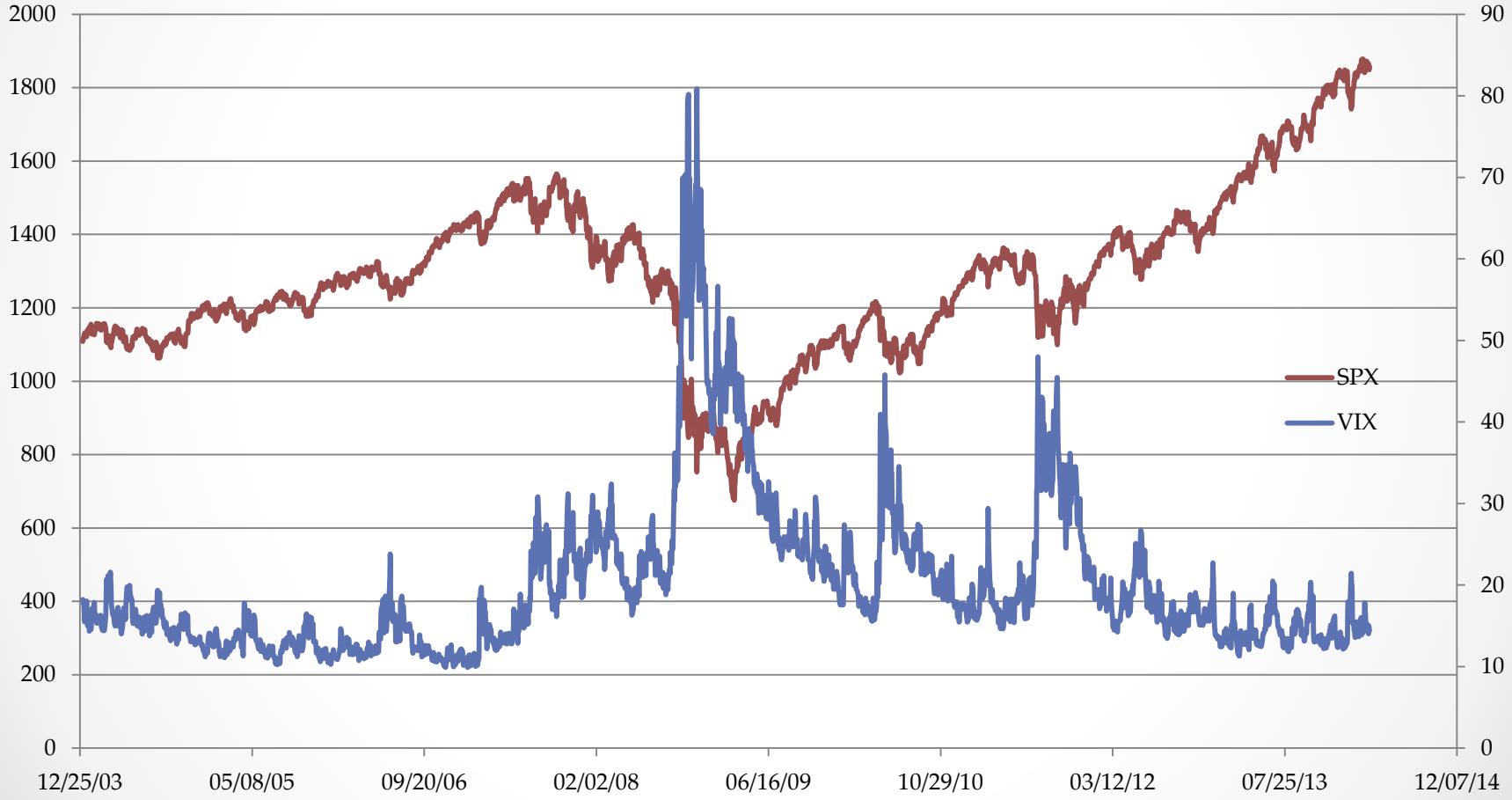
3. the VIX time series is much more autocorelated than the SPX. Any shock to the SPX will die relatively quickly, while the VIX will carry on the impact of a shock for a relatively long period of time.
   - In Market Microstructure literature, we can refer to that as a "permanent" market impact – VIX has a "permanent" market impact whereas the SPX market impact seems to be more transitory.
4. There is a cointegration relationship of first order between the VIX and the SPX time series.
   - The main finding when analyzing the VECM model lies in the Variance Decompositions.
     - variance for the VIX is 30% - 70%, explained by the VIX and SPX respectively.

The Volatility Index (VIX)

Volatility Index (VIX), originally designed to measure the market's expectation of 30-day volatility, implied by at-the-money S&P 100 Index option prices. In 2003, a new measure was introduced based on the S&P500 .

Principally, the VIX supposed to capture the future volatility of the SPX, and hence predict the future movement of the S&P500.

VIX vs. SPX


2000
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12/25/03
05/08/05
09/20/06
02/02/08
06/16/09
10/29/10
03/12/12
07/25/13
12/07/14
SPX
VIX

Research Question

Primary:

Does the VIX actually represent the future direction of the SPX in current market conditions?

Secondary:

Can we find evidence of "cause and effect" between the VIX and the S&P500?

Review of Relevant Literature

- Doran, Goldberg and Ronn (2008)
- Bekaert and Hoerova (2013)
- Hao and Zhang (2013)
- Lui and Qiao (2012)
- Zheng (2012)
- Brener, Shu and Zhang (2010)
- Carr and Wu (2006)
- Whaley (2008)

Competing Hypotheses

Hypothesis 1:

VIX is a forward looking measure of the S&P500 future volatility, we would expect a leading relationship, meaning the VIX movement leads the S&P 500 and hence, we would expect that VIX "granger causes" the S&P 500 Index

Hypothesis 2:

The VIX measure is a function of the S&P 500, and hence implicitly determined by the values of the S&P 500 Index. Therefore, this type of relationship implies that the S&P 500 "granger causes" the VIX

Competing Hypotheses

Secondary Hypothesis to the main hypotheses:

A third hypothesis states a bi-directional causality relationship between the VIX and the SPX(but also postulating that the impact of the S&P 500 Index (SPX) is the stronger and the more significant of the two.)

Research Methodology

The form of the VAR model is:

$$Y_t = C + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + \epsilon_t$$

For this model:

$$RetSPX_t = C_1 + f_1\left(RetSPX_{t-1,}, RetSPX_{t-2}, \ldots, RetSPX_{t-p,}\right)$$
$$+g_1(ChangeVIX_{t-1}, ChangeVIX_{t-2}, \ldots,$$

And

$$ChangeVIX_t = C_2 + f_2\left(RetSPX_{t-1,}, RetSPX_{t-2}, \ldots, RetSPX_{t-p,}\right)$$
$$+g_2(ChangeVIX_{t-1}, ChangeVIX_{t-2}, \ldots, ChangeVIX_{t-p})$$

Also, Vector Error correction Model (VECM)

Data

Data Type	Sample Period	Observations	Calendar Days	Trading Days (
Historical Intraday Tick	8/9/12-10/3/13	SPX: 1,415,935 VIX: 464,215	421	289
Historical Intraday Minute Bar	10/5/12-10/3/13	SPX: 100,323 VIX: 99,950	364	249
Inferred Intraday Minute Bar	8/9/12-10/3/13	SPX: 118,246 VIX: 116,101	421	289

Table 2: Dates Market Closed During the Sample Period

Sep 3 2012	Labor Day
Oct 29 2012	Hurricane Sandy
Oct 30 2012	Hurricane Sandy
Nov 22 2012	Thanksgiving
Dec 25 2012	Christmas
Jan 1 2013	New Year
Jan 21 2013	MLK Day
Feb 18 2013	Washington's Birthday
Mar 29 2013	Good Friday
May 27 2013	Memorial Day
July 4 2013	Independence Day
Sep 2 2013	Labor Day

Some Interesting Observations Relating to the Data

- Irregular number of ticks:
  - The number of irregular ticks in the SPX is more than 8 time of the number of irregular minutes within the VIX
  - concentrated in two particular month – August 2012 and October 2012
  - These phenomena might be explained by the very low volume (lowest in the past five years) the market has experienced in August 2012 and by the weak corporate results during the month of October 2012
- Outliers:
  - Significantly more outliers for the VIX than the SPX
  - for the VIX 34% of the outliers appear during the first half hour of the trading day and about 24% of the outliers appear during the last half hour of the trading day, which sum-up to about 58% of all outliers in the data sample
  - the second half hour of the trading day (i.e., 10am to 10:30am) which correspond to about 10% of all outliers in the sample

Some Interesting Observations Relating to the Data

- Outliers:
  - The number of VIX outliers per day has a negative correlation with both the SPX total return per day and the sign of its return.
    - Both of these observations imply that we should expect more outliers (i.e., irregularities) in the VIX when the SPX move down (i.e., negative returns)
  - size of the VIX outliers per day is negatively related to the sign of the previous minute return, which implies that if the SPX moved down in the previous minute it is likely that we would observe a large adjustment (i.e., change) in the VIX value.
  - These observations insinuate that our Hypothesis 2 may have merit

Some Interesting Observations Relating to the Data

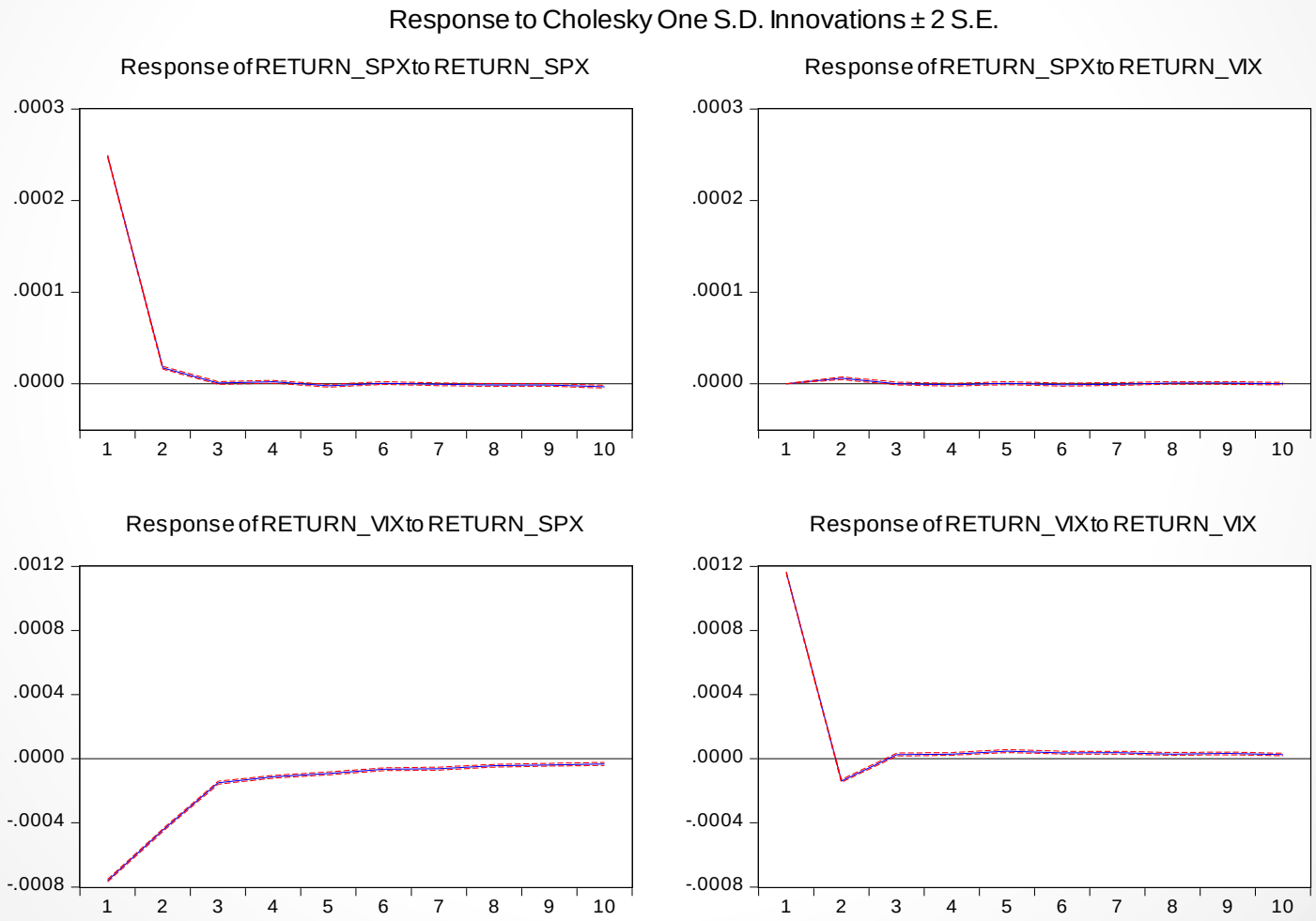
- Zero Returns
  - This phenomenon is prevalent every trading day for the VIX and in 49,439 minutes (out of the total 112,243 minutes in the sample). The effect of zero returns in the SPX sample data is quite negligible
    - which account for 1.7% of total observations for the SPX and 44% of total observations for the VIX
  - correlating either the daily number of zeros returns for the VIX or the percentage of minutes (with zero returns out of daily 391 minutes) **with the absolute SPX total returns per day, the direction is negative**
  - When correlating either the number of zero minute returns or the percentage of the daily zero minute returns (out of 391 daily minutes) **with the sign of the total SPX return per day, we observe positive correlation,**
  - These two observations are consistent with the documented **asymmetry in the equity markets, sometimes ascribed to as "leverage effect" or the "risk premium" effect** – in the equity market it is unlikely that positive and negative shocks have the same impact on the volatility.

Some Interesting Observations Relating to the Data

- Missing data
  - April 25, 2013, however, was an exceptional day. The CBOE experienced an outage that day since the opening of the trading day and resumed trading only at 1pm
  - On April 25th the CBOE had an internal system issue caused by software problem and "not the result of any outside influence" or cyber-attack. Trading resumed in the S&P500 options contracts at 12:50 pm and in all other equity and ETF options opened by 1pm.
  - The S&P 500 options and the options on the CBOE Volatility Index (VIX), exclusively trade on the CBOE so there was no trading in those contracts while the CBOE was shut

Main Results

Impulse Response



Cointegration VECM

$$\Delta x_t = \alpha_1(\beta_1 y_{t-1} + \beta_2 x_{t-1}) + \varepsilon_t + v_t$$

$$\Delta y_t = \alpha_2(\beta_1 y_{t-1} + \beta_2 x_{t-1}) + u_t + v_t$$

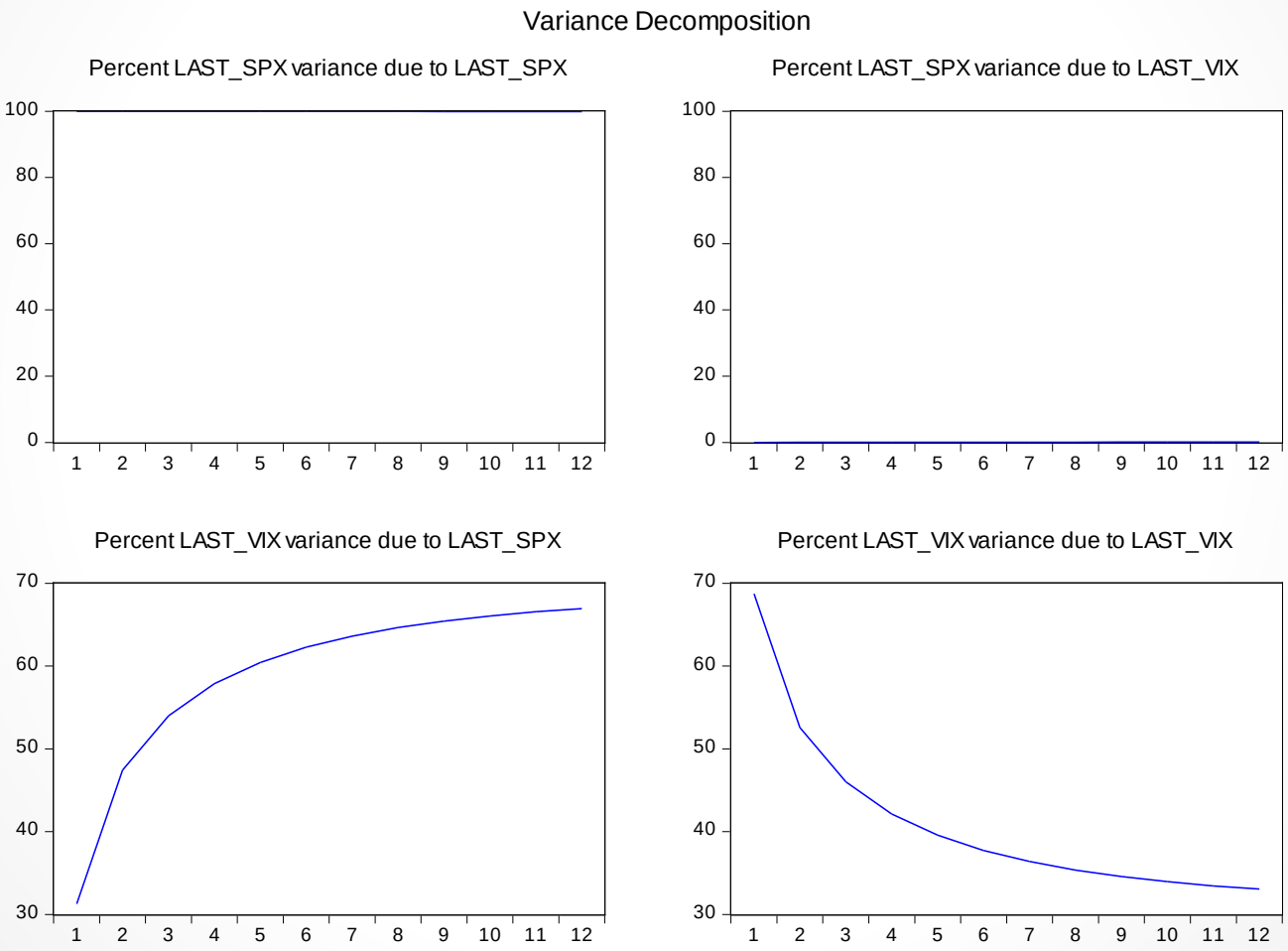
This is called a Vector Error Correction Model (VECM). The error correction comes from the cointegrating relationship. The betas contain the cointegrating equation and the alphas the speeds of adjustment

Cointegration VECM

- The level values of the indexes are non-stationary (but the first difference is – that is the cointegration is of order $I(1)$).
- Using the Johansen Cointegration test (we find that there is one cointegration equation (in both cointegration test measures – Trace and max-eigenvalue.)
- The error correction term is only significant for the VIX time series (at 1% significance level) but with a very negligible magnitude,
  - which might be a result of the minute bar interval (i.e., there is not much of a disequilibrium "correction" within one minute. It could very well be that the disequilibrium "correction" may take longer.
- Moreover, this result is consistent with the long-period of autocorrelation that we observe with the VAR model

Main Results

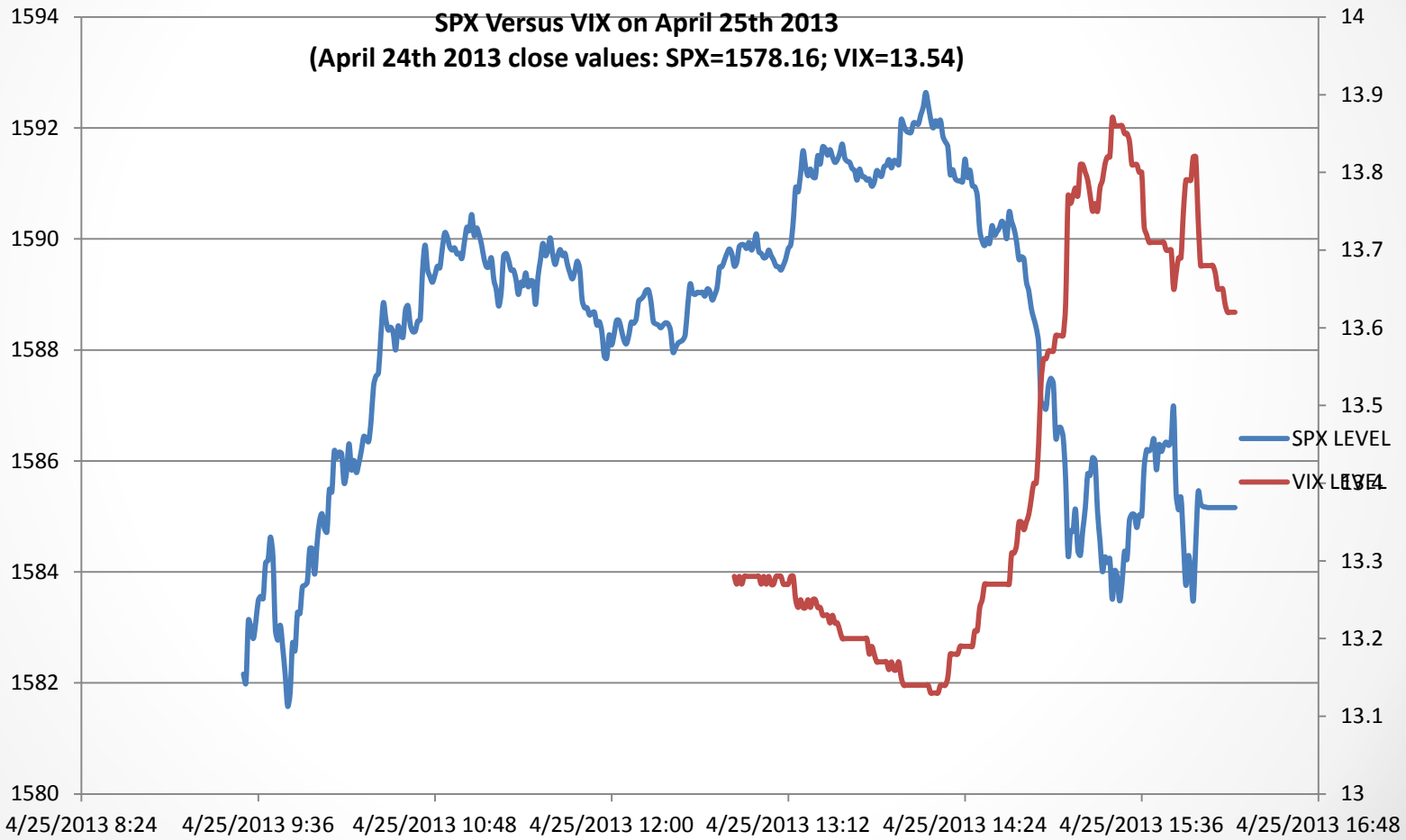
Variance Decomposition



Some Applications

- One way to show the applicability of the study's results is by looking at the special event on April 25th, 2013, when the CBOE had a major glitch and had to shut down the exchange for the first half of the trading day (the CBOE opened for regular trading at 1pm, whereas the S&P options contracts resumed at 12:50pm).
- The SPX closed the day earlier at 1578.16 and was moving up in early morning due to positive economic reports and then remained steady at a level of about 1589 (about 0.7% increase) until the opening of the trading at the CBOE. Since we know that the SPX negatively affects the VIX, we should expect that the VIX should open lower than its **close of 13.61 the day before**.

Some Applications



Some Applications

- If we use the VAR model estimates and knowing of a 0.7% change, we can calculate that this change will **result in a level of 13.32 for the VIX**
- If we use the VECM model estimates and knowing of about 11 point of an increase in the SPX level, the calculation will **result in approximately 13.29** for the VIX. These are quite good estimates considering that **the VIX opened at 13.28**.

Daily Data Analysis

Total data period since new VIX was introduced – Jan 2004 to April 2014

- According to SIC: SPX does not "Grander Causes" VIX; and VIX does not "Granger Causes" SPX
- According to AIC: SPX "Grander Causes" VIX; and VIX "Granger Causes" SPX

- VAR model with 20 lags reveals:
  - **SPX lags 7, 12 and 15 significantly affect the VIX time series**
  - **The sign of this lags affect the SPX series and the VIX series in opposite directions**
  - **SPX series does NOT relate to the VIX lags**
  - **About 60% of the VIX variance is due to SPX**

Daily Data Analysis

Looking a bit more closer at the daily data:

Recent Bull Market – 3/9/2009 to present:

- **SPX** significantly and robustly **"granger causes" VIX**, but
- **VIX** does **NOT** "granger causes" the **SPX**
- SPX does not relate to any of the VIX lags
- VIX significantly relate to SPX 5th lag
  - The relation is opposite to the relation of this lag to the SPX series.
  - SPX 5th lag negatively relate to the SPX series but positively to the VIX series. (weekly correction?)
  - Over 60% of the VIX variance is due to SPX

Daily Data Analysis

Looking a bit more closer at the daily data:

Last Bear Market – 10/8/2007 to 3/9/2009:

- SPX does not "Grander Causes" VIX; and VIX does not "Granger Causes" SPX
- VAR model with 20 lags reveals:
  - **SPX lags 9, 12 and 15 significantly affect the VIX time series**
  - **The sign of this lags affect the SPX series and the VIX series in opposite directions**
  - **SPX series does NOT relate to the VIX lags**
  - **About 70% of the VIX variance is due to SPX**

Main Take-Away

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   This causality test is supported and is evident not only in any sample examined and robustness checks

2. we observe a pattern in the minute returns/level time series and especially in the VIX time series.

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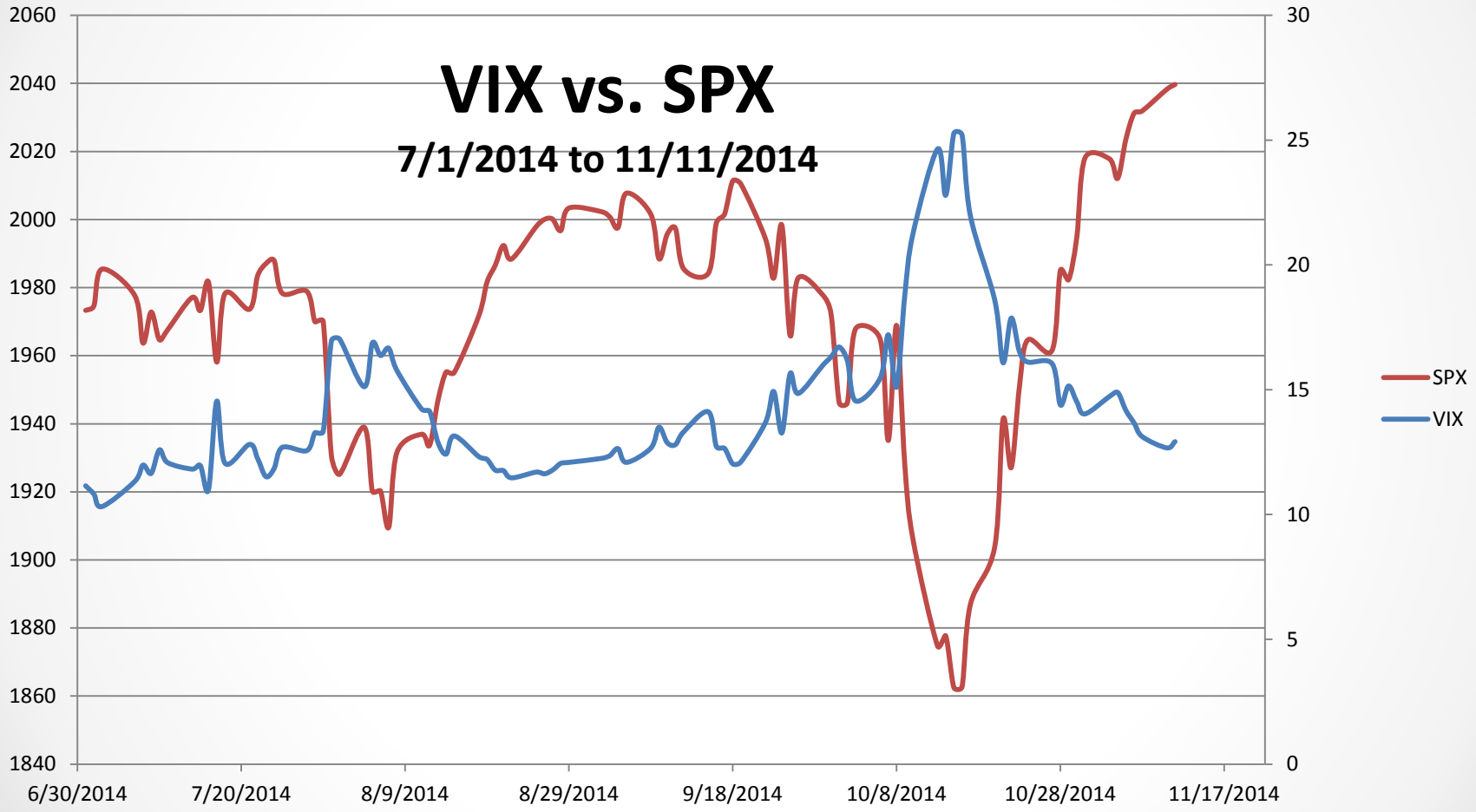
Future Research

- Assessing "permanent" and "transitory" market impact for both the SPX and the VIX (using for example the methodology developed by Almgren, Thum, Hauptmann and Li (2005), Almgren and Chris (2000) and Almgren (2003)).
- Further investigate whether the SPX indeed has a predictive power, which can then be applied for investment decision.


VIX vs. SPX
7/1/2014 to 11/11/2014
2060
2040
2020
2000
1980
1960
1940
1920
1900
1880
1860
1840
30
25
20
15
10
5
0
6/30/2014
7/20/2014
8/9/2014
8/29/2014
9/18/2014
10/8/2014
10/28/2014
11/17/2014
SPX
VIX

Models fit to S&P 500 options

minimizing modified sum squared pricing errors across strike prices (from McCulloch and Lee 2008)