Assessing VPIN Measurement of Order Flow Toxicity Using Perfect Trade Classification

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- **VPIN** = Volume-synchronized Probability of INformed trading, Variation and Extension to Concept of PIN

- Developed in three recent papers by Easley, López de Prado and O'Hara (ELO):

  (1) "**The Microstructure of the "Flash Crash": Flow Toxicity, Liquidity Crashes, and the Probability of Informed Trading**," *J. of Portfolio Management*, 2011.

  (2) "**The Exchange of Flow Toxicity**," *J. of Trading*, 2011.

  (3) "**Measuring Flow Toxicity in a High-Frequency World**," SSRN Working Paper, February, 2011.

- ELO find
  - VPIN is **Proxy for "Toxicity" of Order Flow**
  - VPIN **Signaled Flash Crash** on May 6, 2010, as early as several Hours Ahead
  - VPIN provides **Superior and more Timely Indicator of Future Market Volatility** than celebrated Option-Implied Volatility measure, VIX, the so-called "Fear Gauge"
  - **VPIN leads VIX**, not otherwise

Recent ELO Developments include:

(1) "**Flow Toxicity and Liquidity in a High-Frequency World**,"
Review of Financial Studies, 2012.

(2) "**Bulk Classification of Trading Activity**,"
SSRN, March 2012 & November 2012.

(3) "**The Volume Clock: Insights into the High Frequency Paradigm**,"
J. of Portfolio Management, 2012.

(4) "**Optimal Execution Horizon**,"
forthcoming *Mathematical Finance*, 2013.

Suggested Applications of VPIN

- For Traders, Market Makers: Tool to **Gauge Risk of Liquidity-induced Crash**
- To Manage and Hedge this Risk: **Traded Futures on VPIN ?**
- For Regulators and Exchanges: Tool to **Monitor Market Conditions**
- **Circuit Breaker** based on VPIN: May Help **Prevent some Future Crashes ?**
- Joint CFTC-SEC Advisory Committee on **Emerging Regulatory Issues** to Address Challenges raised by the Flash Crash
- **Patent for VPIN** submitted to US Patent and Trademark Office

"**'Toxic' Orders Can Predict Likelihood of Stock Market Crashes, Study Says**" (**Bloomberg**, October, 29, 2010):

"The measure would have been able to anticipate two hours in advance there was a high probability of a liquidity-induced event on May 6," said Lopez de Prado, head of high-frequency futures at Tudor. "It measures order toxicity, or the probability the market is going to have persistent order imbalances that are going to damage market makers."

"This would be much more effective than a circuit breaker," he said. U.S. stock markets and the Securities and Exchange Commission instituted curbs in June that briefly halt trading in a security when its price moves rapidly. "That stops the infection after the infection is already widespread," he said.

Media Quotes

"**'Flow Toxicity' Metric May Help Avoid Another Flash Crash: Study**" (**Wall Street Journal**, November 5, 2010):

> *"Complementary to circuit breakers based on price action, they could have circuit breakers based on our metric," said Marcos Lopez de Prado.*
>
> *As a measurement of risk, the VPIN metric could help market participants "anticipate a rise in volatility and estimate the risk of a liquidity-induced crash".*

"**'Flash' Crashes now Predictable, Thanks to Cornell-Developed Metric**" (**Cornell University Chronicle**, December, 1, 2010)

DATA

- E-mini S&P 500 Futures Contract (CME Globex)
- Best Bid & Offer Files, CME Group DataMine
- February 10, 2006 – March 12, 2011 (Over 5 Years)
- Transaction i represented by Triplet (t_i, p_i, s_i), where
  - t_i is Time (in Seconds),
  - p_i is Price, and
  - s_i is Trade Size.
- Quote i Contains
  - Time Stamp in Second,
  - Bid Price, Ask Price,
  - Bid Depth, Ask Depth,
- When many Events Occur in Same Second, we **Know Correct Sequence**

Descriptive Trading Statistics

	Regular	Overnight	Holiday
# Days	1285	1285	30
Volume (1 min)	3973	208	69
# Trades (1 min)	285	23	9
# Order Book Changes (1 min)	1730	175	60
# BBO Changes (1 min)	26	8	4
Notional Value, $Mln (1 min)	235	12	4
Trade Size	13.9	8.9	7.3
Order Book Changes per Trade	6.1	7.5	6.4
Trades per BBO Changes	10.9	3.0	2.4

Order Size: Average Daily Percentiles

	Min	10%	50%	75%	90%	99%	99.9%	Max
All	1.0	1.0	2.1	7.5	30.5	233.4	643.5	1683.5

Sequence Indicator Allows for "Perfect" Classification.

Time	Sequence	BidPrice	BidSize	AskPrice	AskSize	TradePrice	TradeSize
17:02:58	5770	1289.50	125	1289.75	98		
17:02:58	5780	1289.50	125	1289.75	99		
17:02:59	5790					1289.75	5
17:02:59	5800	1289.50	125	1289.75	94		

Split Volume at Opening Auction equally to Buy and Sell.

If Trade Price between Quotes, Allocate equally to Buy and Sell.

Positive Identification of Direction over 99.95% of Time.

First Look at Flash Crash

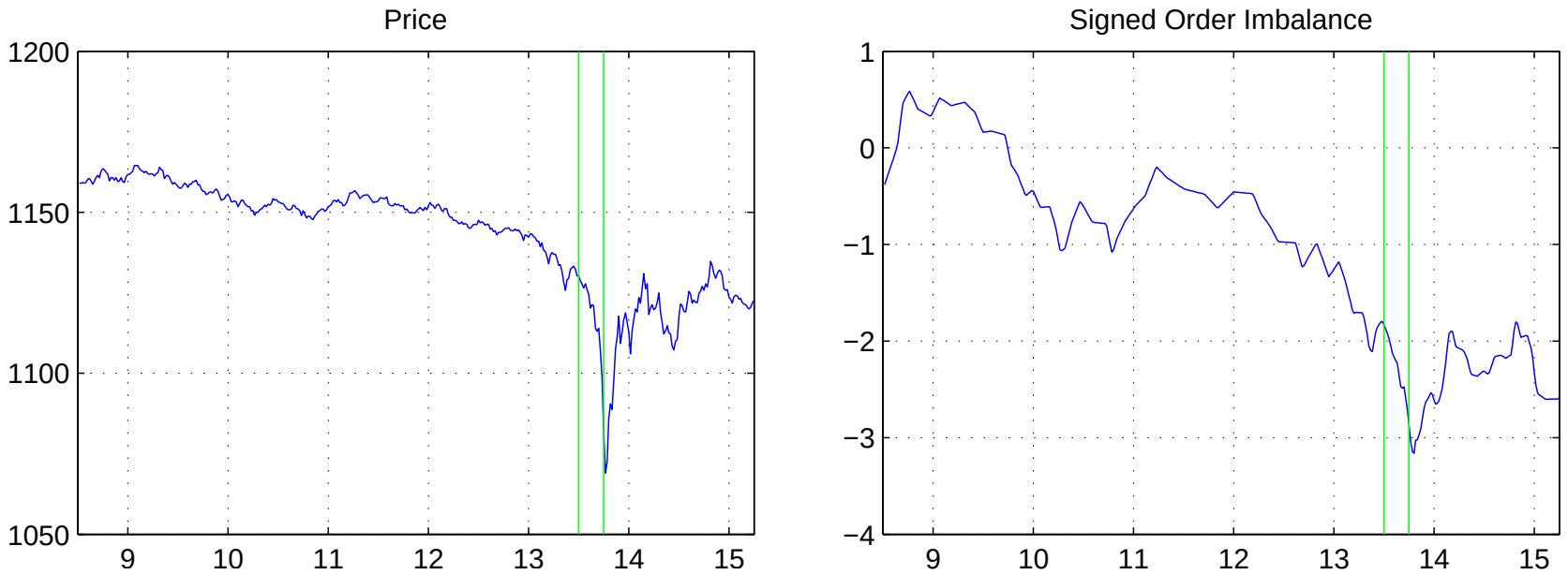


FIGURE : This figure plots the price and cumulative signed order imbalance for May 6, 2010. The solid vertical lines indicate the official CTFC report timing of the "flash crash."

1. Establishing the Transaction Sequence

- Fix Sample Period for the Analysis in Calendar Time, $[0, T]$.
- Each Individual Traded Contract represented by $(t_i\,, p_i\,)$.
- Trade of $v > 1$ Contracts $\leftrightarrow$ v trades of One Contract at Identical Price.
- $0 = t_0 \leq t_1 < \ldots \leq t_I \leq T$: Timing of Consecutive (One Unit) Trades.
- This Establishes Complete Transaction Record for Asset over $[0, T]$.
- In Total, I contracts Traded over $[0, T]$, indexed $i = 1, \ldots, I$.

2. Defining the Volume Bucket

- Define V to Indicate a Fixed Increment to Cumulative Volume.
- Leading Choice by ELO is $(1/50)^{\text{th}}$ of Daily Average Volume over Sample.
- Days with High Volume contain more Buckets than Days with Lower Volume.
- Measuring Time in Buckets represents **Event** or **Business Time** Transformation.
- Let T_ℓ Indicate Time when Bucket ℓ has just been Filled.
- Let P_ℓ be Last Transaction Price within Bucket ℓ.
- Let $\mathcal{L}$ be Number of Full Volume Buckets in $[0, T]$.
- (T_ℓ, P_ℓ), $\ell = 1, \ldots, \mathcal{L}$, Summarizes Transaction Record for Buckets.

3. Computing VPIN from Order Imbalances

- For each Bucket, ℓ, we need associated Order Imbalance Measure, OI_ℓ .
- VPIN is Moving Average over Last L OI Measures:
- $$VPIN_t = \frac{1}{L}\sum_{j=0}^{L-1} OI_{\ell-j}\,, \qquad t = T_\ell.$$
- VPIN is Computed when a Volume Bucket is Filled, so Random Timing.
- ELO Leading Choice is $L = 50$.
- VPIN, on average, Uses One Trading Day for VPIN Measurement.
- The MA(50) Filter implies fairly Aggressive Smoothing.
- Current Large OI Innovation has only (1/50) Weight in VPIN.
- On the other hand, Things Move Quicker, when Activity is Elevated.

4. Defining Order Imbalances

- VPIN Requires Order Imbalance Measure for each Volume Bucket.
- Order Imbalance Determined via Trade Classification Scheme.
- Any given Scheme must Deliver $b_\ell = \frac{V_\ell^B}{V}$.
- We have, $V = V_\ell^B + V_\ell^S$, and $0 \leq b_\ell \leq 1$.
- *Signed* Order Imbalance, SOI: $\gamma_\ell = \frac{V_\ell^B - V_\ell^S}{V} = 2\,b_\ell - 1$.
- $OI_\ell = \frac{|\,V_\ell^B - V_\ell^S\,|}{V} = |\,\gamma_\ell\,| = |\,2\,b_\ell - 1\,|$.
- Trade Classification determines V_ℓ^B, and thus, in turn, b_ℓ, γ_ℓ, and OI_ℓ.
- Clearly, $0 \leq OI_\ell \leq 1$.

5. Computing (Bucket) SOI from Smaller "Bars"

- Given Bucket (drop subscript ℓ), Split into Q units, or "Bars."
- $V = V_1 + \ldots + V_Q$, and $\nu_q = V_q / V$.
- $b_q = V_q^B / V_q$, and $\gamma_q = 2\, b_q - 1$.
- $$OI_\ell = \frac{\left| \sum_{q=1}^{Q_\ell} \left(V_{q,\ell}^B - V_{q,\ell}^S \right) \right|}{V} = \left| \sum_{q=1}^{Q_\ell} \gamma_{q,\ell} \cdot \nu_{q,\ell} \right|.$$
- OI is Absolute Value of Volume-Weighted SOI over Bars in Bucket.
- Ultimately, Trade Classification performed over the Bars.

6. Defining Time and Volume Bars

- Bars defined via Fixed Increments in Calendar Time are labeled **Time Bars**.
  - Let δ be Fixed Length of Calendar Time Interval in Seconds.
  - Volume Buckets Contain Randomly Varying Number of Time Bars.
  - In Time Bars, Q Reflects (Inversely) the Trading Intensity.
- Bars defined as Fixed Increment in Trading Volume are labeled **Volume Bars**.
  - Let ν be (Fixed) Proportion of Volume Bucket represented by Volume Bar.
  - Volume Bar contains $\nu \cdot V$ Traded Contracts.
  - $\frac{1}{V} \leq \nu \leq 1, \quad \text{and} \quad 1 \leq Q \leq V.$

7. Volume Aggregation Prior to Trade Classification

- Classification from More (Less) Aggregated Volume if Bar is Longer (Shorter).
- Large δ or ν Increases VPIN Measure.
- Diversification of SOI Measures within Bucket is Critical for OI Measure.
- Variation in Number of Bars Systematically Impact/Distort Properties.
- For Volume Bars, Direct Control over Diversification (Event Time Measure)
  - Contract-by-Contract Classification: $\nu = \frac{1}{V}$ and $Q = \frac{1}{\nu} = V$.
  - Bucket-Wide Classification: $\nu = 1$ and $Q = 1$.
  - Regular (Interim) Scenario: $\frac{1}{V} < \nu < 1$ and $1 < Q < V$.
  - $OI = \frac{\left| \gamma_{1,\ell} + \ldots + \gamma_{Q,\ell} \right|}{Q}$.

8.B Tick Rule Classification (on Bulk Volume)

- Each Time Bar Classified as *Buyer* or *Seller* Initiated, using "Tick" Rule
- The j^{th} Time Bar is *Buy* $(\boldsymbol{b_j = 1})$, if either
  - (I) $\boldsymbol{P_j > P_{j-1}}$, or
  - (II) $\boldsymbol{P_j = P_{j-1}}$ **and** Previous Transaction is Buy
- Otherwise, Transaction is *Sell* $(\boldsymbol{b_j = 0})$.
- Important: Entire Time Bar, rather than each Individual Transaction, Classified as Buy or Sell; Effectively, **Whole Time Bar Treated as Single Transaction**

8.C Bulk Volume Classification

Assign Buy Volume as Function of Price Change over Bar.

Letting $Z(\cdot)$ denote CDF of Standard Normal Variate,

$$\gamma_j \;=\; 2\,Z\left(\frac{\Delta P_j}{\bar{\sigma}}\right) \;-\; 1,$$

where $\bar{\sigma}$ is Sample (**Unconditional**) Standard Deviation of ΔP_j.

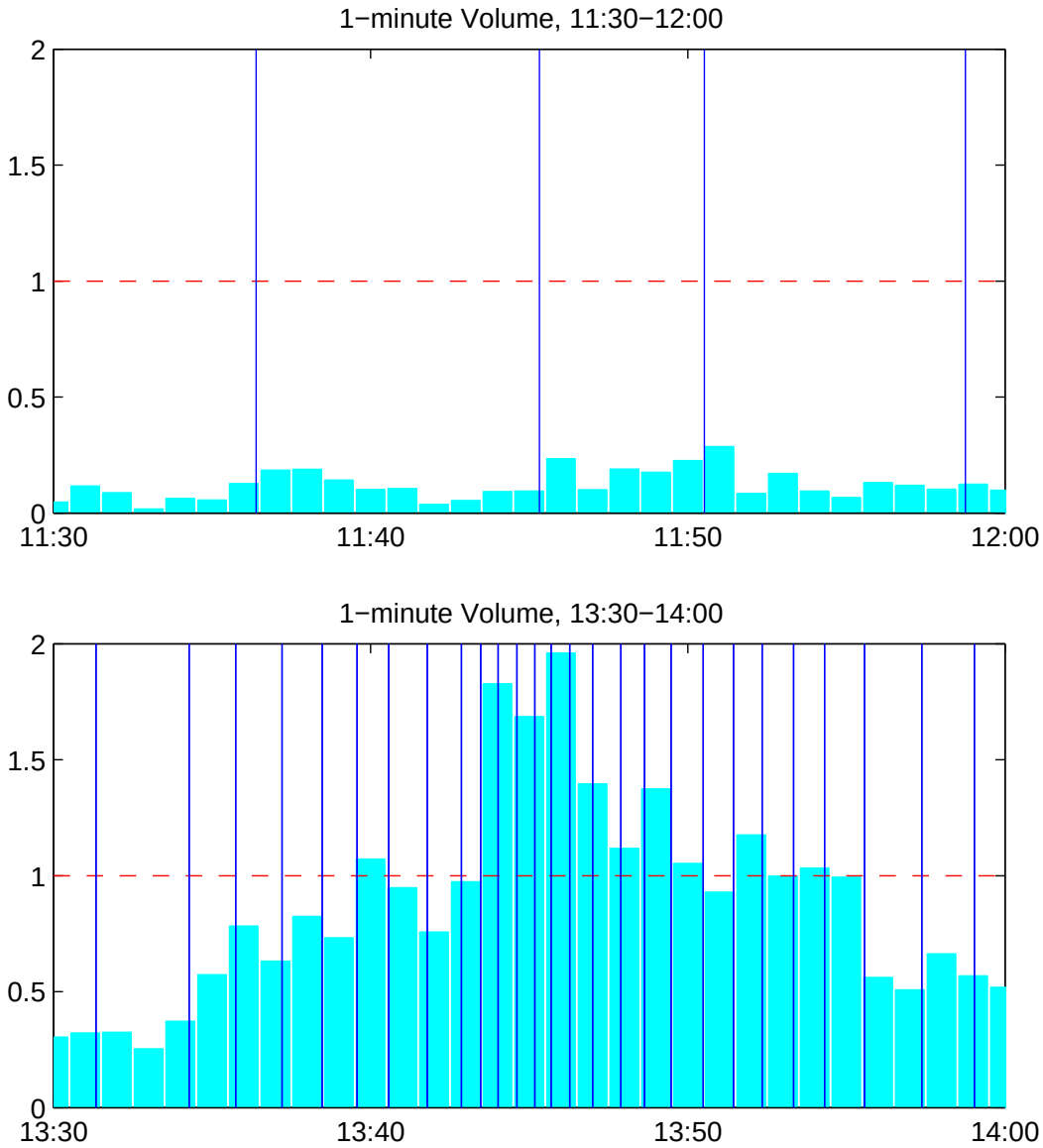
BVC interprets Zero Price Change as Balanced Trading: $\gamma_j = 0$.

Large Positive (Negative) Price Change Translates into
Large (Small) Proportion of Buy Volume, $\gamma_j \approx 1\,(-1)$.

Notice: When Volume and Volatility High, $\gamma_j \approx -1$ or 1

- **Main Features of VPIN**:
  - The Volume Bucket, V
  - The Moving Average Parameter, L
  - **Transactions, Time Bars, Volume Bars**
  - Data Aggregation, δ or ν
  - The Trade Classification Rule, b
  - Others
- **Implementation**: $V = (1/50)^{\text{th}}$ **of Average Daily Volume** and $L = 50$
- **We Investigate**:
  - Tick Rule on **Transactions**,
  - Time Bars, δ **= 1, 10, 60, 300 seconds**,
  - Volume Bars, ν **= (0.02, 0.10)** $\cdot$ **V**, (50 or 10 Volume Bars per Bucket)

Illustrating VPIN Bucketing



First Index Letter denotes **Type of Data Aggregation**:

(R) Individual "Real" Trades based on tRansaction level data;

(T) "Time bars" based on fixed increments to calendar time;

(V) "Volume bars" based on fixed increments to trading volume;

Second Index Letter refers to **Trade Classification** Rule:

(A) "True" Trade Classification, based on Trade at Bid or Ask;

(B) Tick Rule Classification, as in ELO (2011a, 2011b, 2011c);

(C) Bulk-Volume Classification, as in ELO (2012a); **Unconditional** $\sigma_{\Delta P}$;

(D) Same as C, but **Conditional** $\sigma_{\Delta P}$ (1 week rolling window);

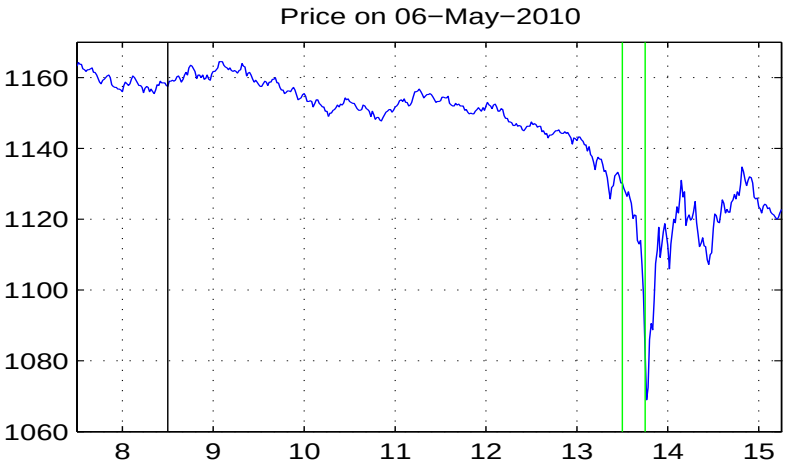
(E) Uninformative, using L_2 norm, U2-VPIN; using actual $v_{q,\ell}$.

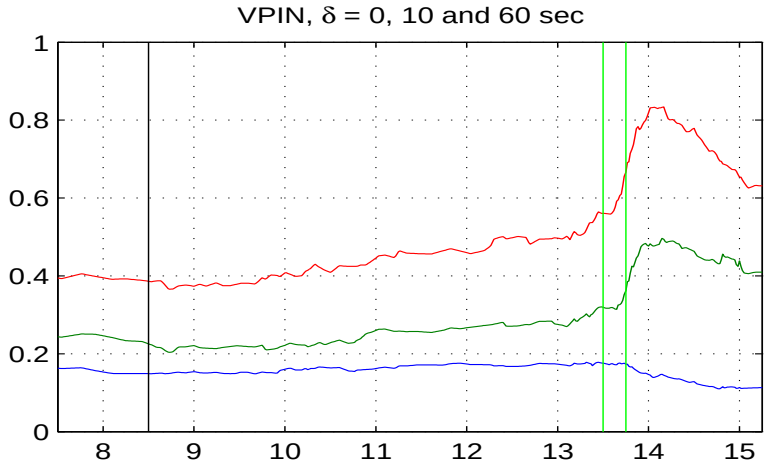
Third Index Letter for **Aggregation Level** (for δ or ν):

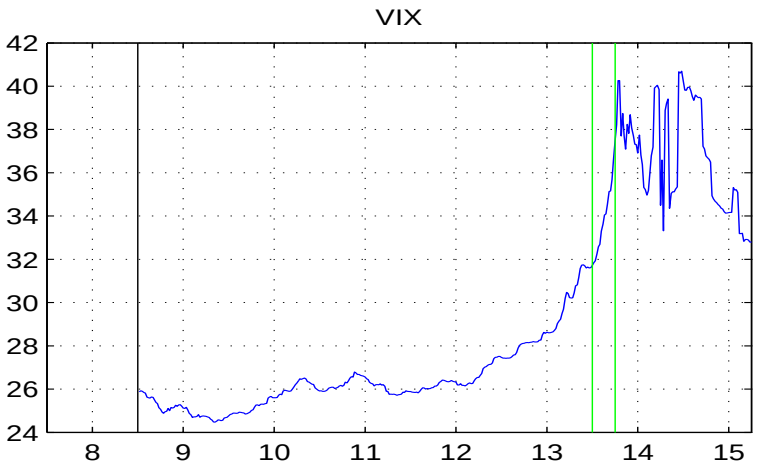
(1-4) For $\delta = 1, 10, 60, 300$ seconds;

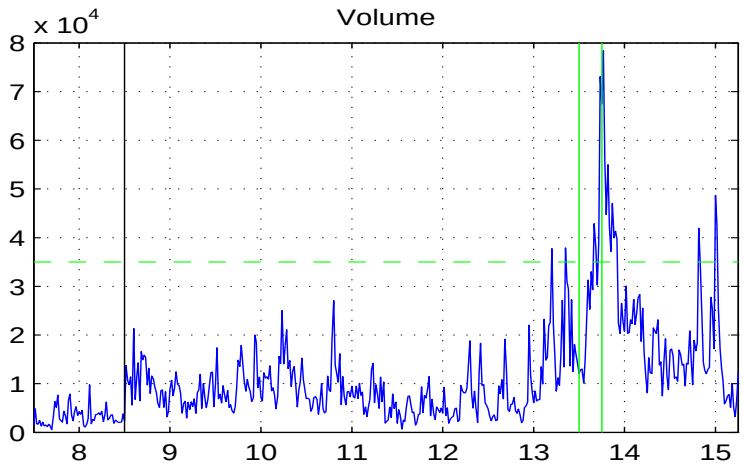
(1-2) For $\nu = 0.02$ or $0.10 \cdot \mathrm{V}$ contracts;

Tick Rule-VPIN and the Flash Crash









- Suppose there are $\boldsymbol{Q}$ Bars in Volume Bucket, with Number of Contracts Traded $\boldsymbol{V_1, \ldots, V_Q}$, so $V_1 + \ldots + V_Q = V$.

- Suppose these Q Bars are *Randomly* Classified as Buys or Sells. Specifically, let $\boldsymbol{\gamma_1, \ldots, \gamma_Q}$ be i.i.d. Trade Indicators, equal to ± 1 with same Probability

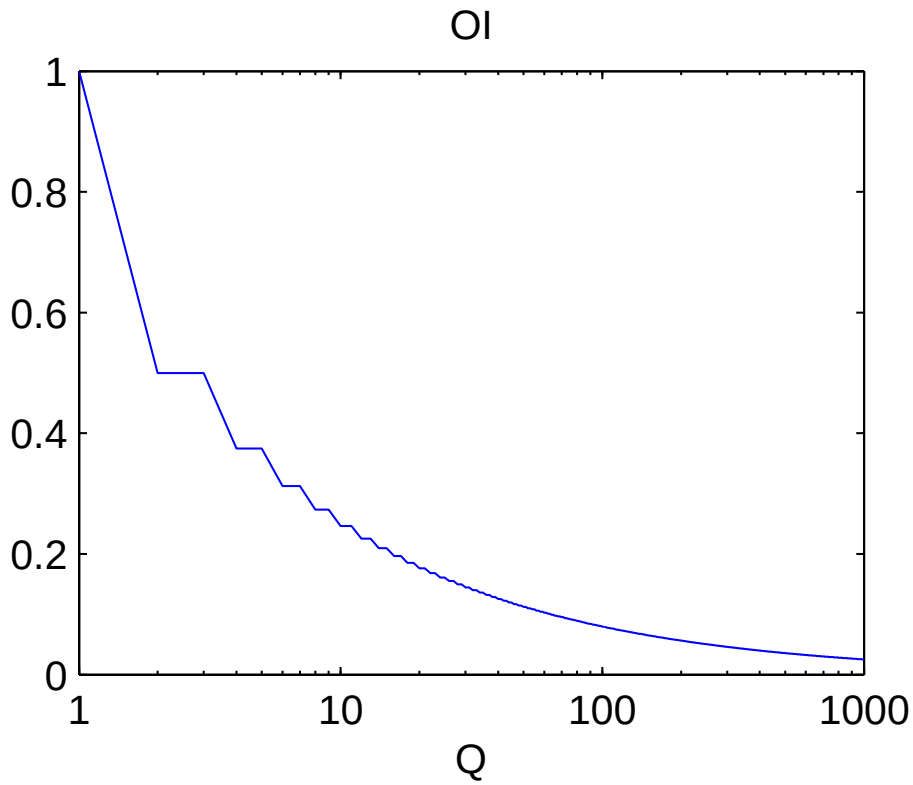
- Corresponding Order Imbalance is

$$\text{OI} = \left| \frac{V_1}{V} \gamma_1 + \ldots + \frac{V_Q}{V} \gamma_Q \right| = \left| \nu_1 \gamma_1 + \ldots + \nu_Q \gamma_Q \right| .$$

- Under Assumption of **Equal Volume Sizes**, $\nu_1 = \ldots = \nu_Q = \frac{1}{Q}$, Expected Order Imbalance $E[OI]$ can be derived Analytically,

$$\text{E}[\text{ OI }] = \text{F(Q)} = \frac{(2q)!}{2^{2q}\, q!\, q!}, \qquad \text{if} \quad Q = 2q, \quad \text{or} \quad Q = 2q+1 .$$

"Uninformed" VPIN Measures: U1-VPIN and U2-VPIN



Expected Order Imbalance Function $F(Q)$

$$E[OI] \equiv F(Q) = \frac{(2q)!}{2^{2q}\, q!\, q!}, \qquad \text{if} \quad Q = 2q, \quad \text{or} \quad Q = 2q+1.$$

$$F(Q) \sim \sqrt{\frac{2}{\pi Q}}, \qquad \text{for large } Q.$$

Uninformed VPIN Measures: U1-VPIN and U2-VPIN

- $F(Q)$ is Used to Construct the U1-VPIN Measure as:

$$\textbf{U1-VPIN}_t = \frac{1}{L}\sum_{\ell=1}^{L} F(Q_\ell),$$

  where Q_ℓ is Number of Bars included in Volume Bucket Ending at τ_ℓ.

- U1-VPIN is "Uninformed" - independent of Price Information
  Variation Cannot be Attributed to Order Flow "Toxicity."

- Of course, Trading Volume Related to Market Environment.

  Key Question: Does the Trade Classification provide Information beyond Observable Trading Pattern ?

- When the Weights $\nu_1, \ldots, \nu_Q$ are *not* equal, $E[OI]$ is Untractable. However, we can compute the L^2 Norm instead of the L^1 Norm:

$$\sqrt{E\left[OI^2\right]} = \sqrt{E\left[\left(\nu_1 b_1 + \cdots + \nu_Q b_Q\right)^2\right]} = \sqrt{\nu_1^2 + \cdots + \nu_Q^2} = |\boldsymbol{\nu}|.$$

- Therefore, we Construct the **U2-VPIN Metric** as:

$$\textbf{U2-VPIN}_t = \frac{1}{L}\sum_{\ell=1}^{L} |\nu_\ell|,$$

where ν_ℓ is Weight Vector in Volume Bucket ending at T_ℓ.

VOLUME BAR VPIN, VX-VPIN

- T-VPIN Highly Sensitive to Trading Activity:

  As Trading Volume Rises, Number of Time Bars per Volume Bucket (Average Q) Decreases, **mechanically Increasing T-OI and T-VPIN**.

- Approach **Mixes** Two Types of Clocks: **Calendar Clock** for Time Bars and **Trade Clock** for Volume Buckets.

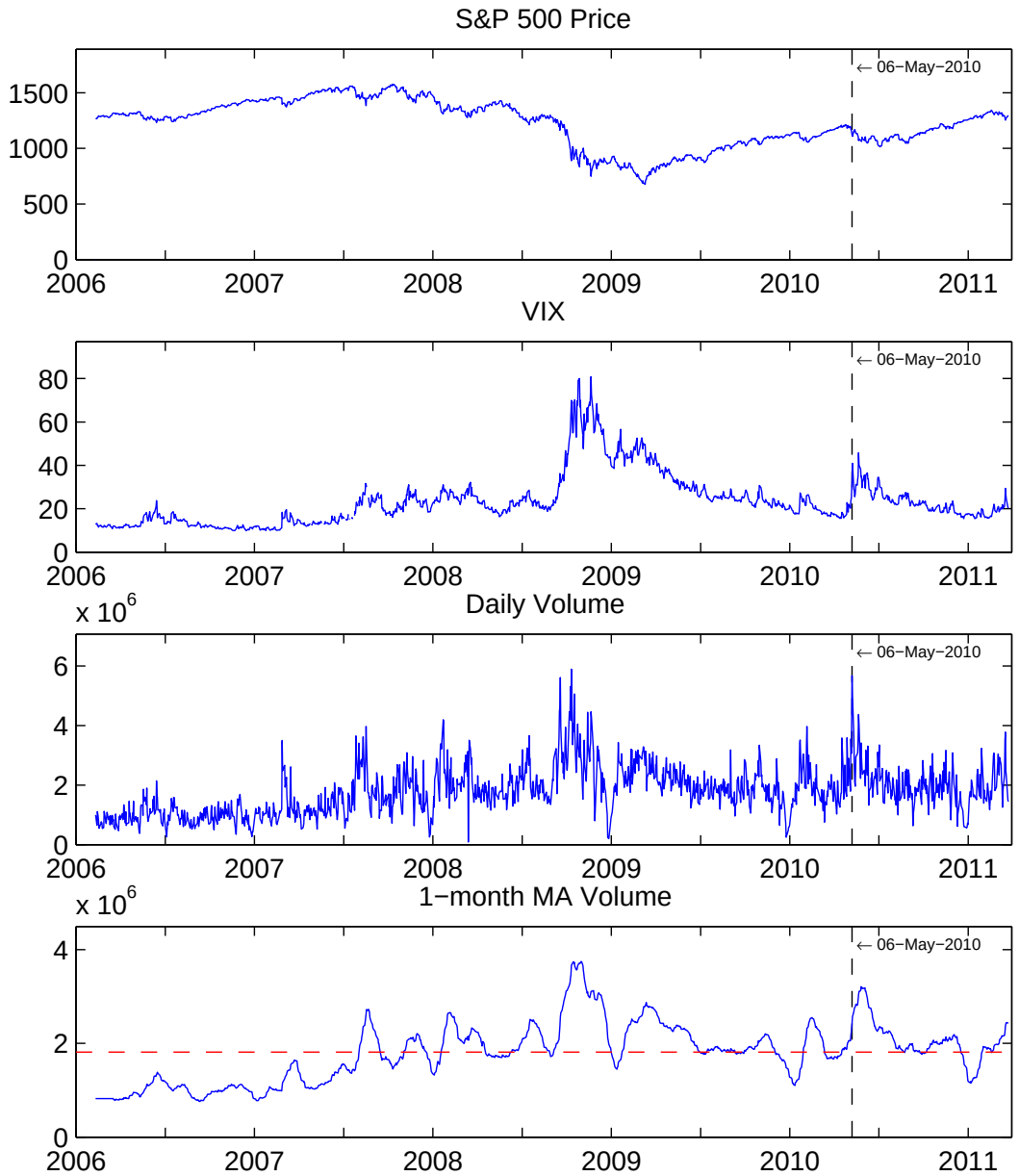
- To Break mechanical effect of Trading Activity, we Aggregate Transaction Data into **Equal-Sized Volume Bars**.

- Volume Bar Measures provide Control for **Volume Distortion**.

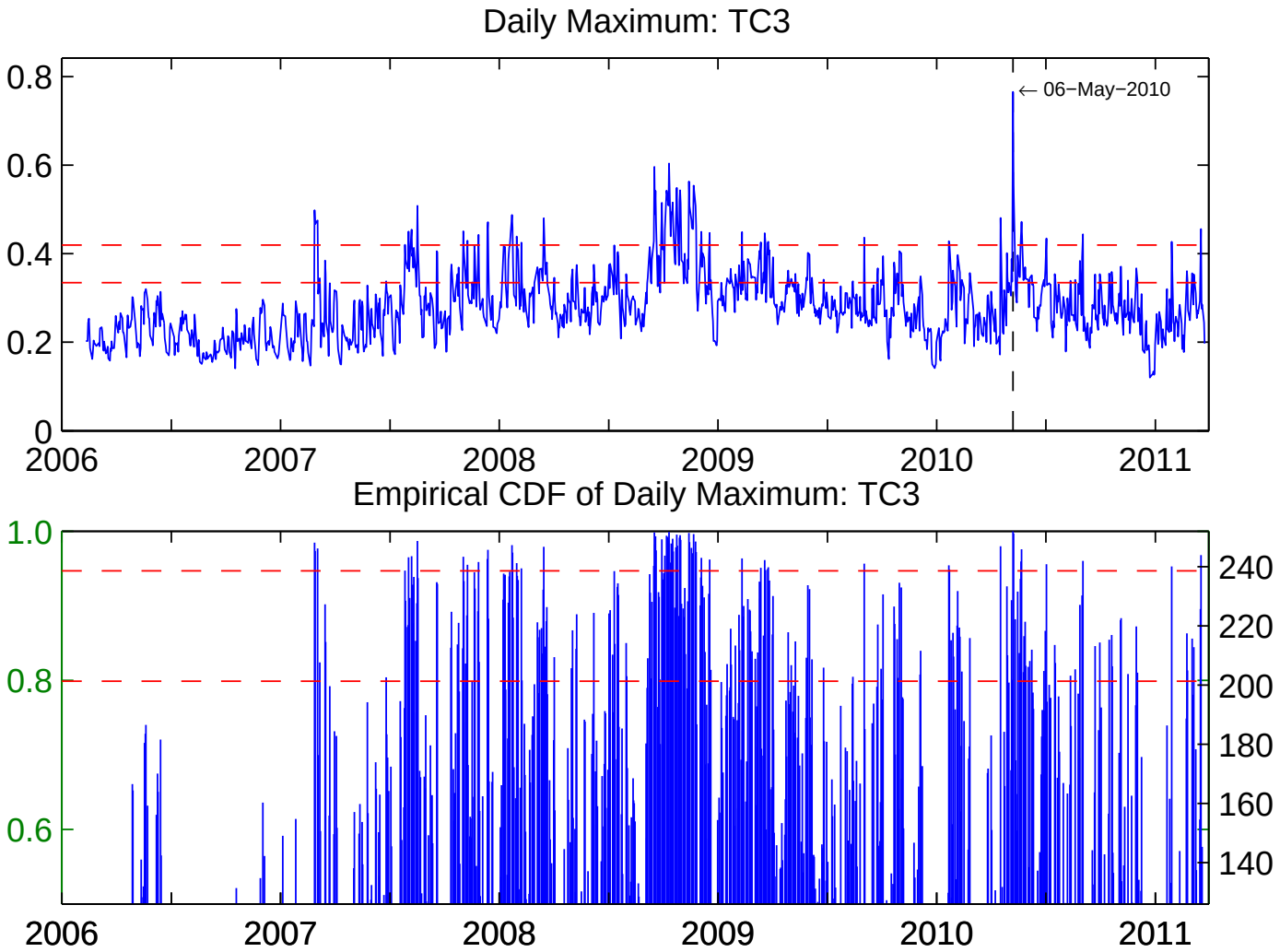
- Analogous to U-VPIN Control for **Impact of Trade Classification**.

  Key Question: Does the Trade Classification provide Information beyond Trading Intensity – Does It Work in Event Time?

S&P 500, VIX and Trading Volume



TC3-VPIN – Daily Max



Volume-Standardized TC3-VPIN – Daily Max

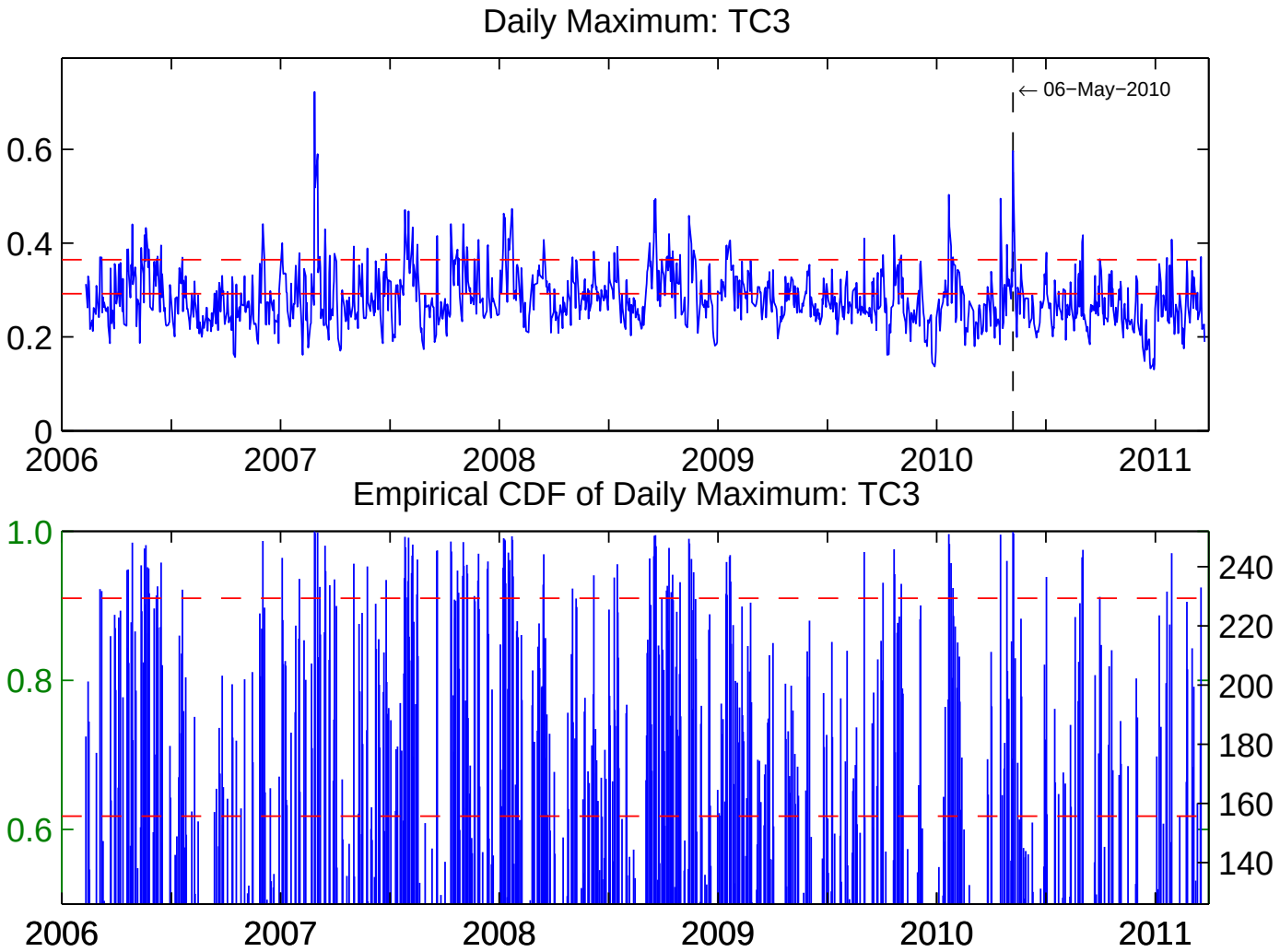


Illustration: Actual Trade Sequence: **BBBSSSSB**.

Actual Rule (A): $(1,1,1,0,0,0,0,1)$
Candidate Rule (K): $(1,0,1,0,1,0,1,0)$

For $\nu = 1/8$, 50% Misclassification.
For $\nu = 1/4$, 25% Misclassification.
For $\nu = 1/2$, 25% Misclassification.
For $\nu = 1$, 0% Misclassification.

Reflects **Diversification (Aggregation) Result**:

$$\sum_{q=1}^{Q} |\hat{V}_q^B - V_q^B| \leq \left| \sum_{q=1}^{Q} (\hat{V}_q^B - V_q^B) \right| .$$

Always **Compare Precision at Identical Aggregation Level!**

Volume Buckets

$$MVB_\ell = \frac{\sum_{q=1}^{Q} |\hat{V}_q^B - V_q^B|}{V} = \sum_{q=1}^{Q} |\hat{b}_q - b_q| \cdot \nu_q \,.$$

Simplification for Volume Bars: $$MVB = \frac{1}{Q} \sum_{q=1}^{Q} |\hat{b}_q - b_q| \,.$$

Sample-Wide Measure:

$$\underline{MVB} = \frac{1}{\mathcal{L}} \sum_{\ell=1}^{\mathcal{L}} MVB_\ell \,.$$

Contract-by-Contract

$$\underline{MCC} = \frac{1}{I} \sum_{i=1}^{I} |\hat{b}_i - b_i| \,.$$

Error Rates for Alternative Classification Schemes

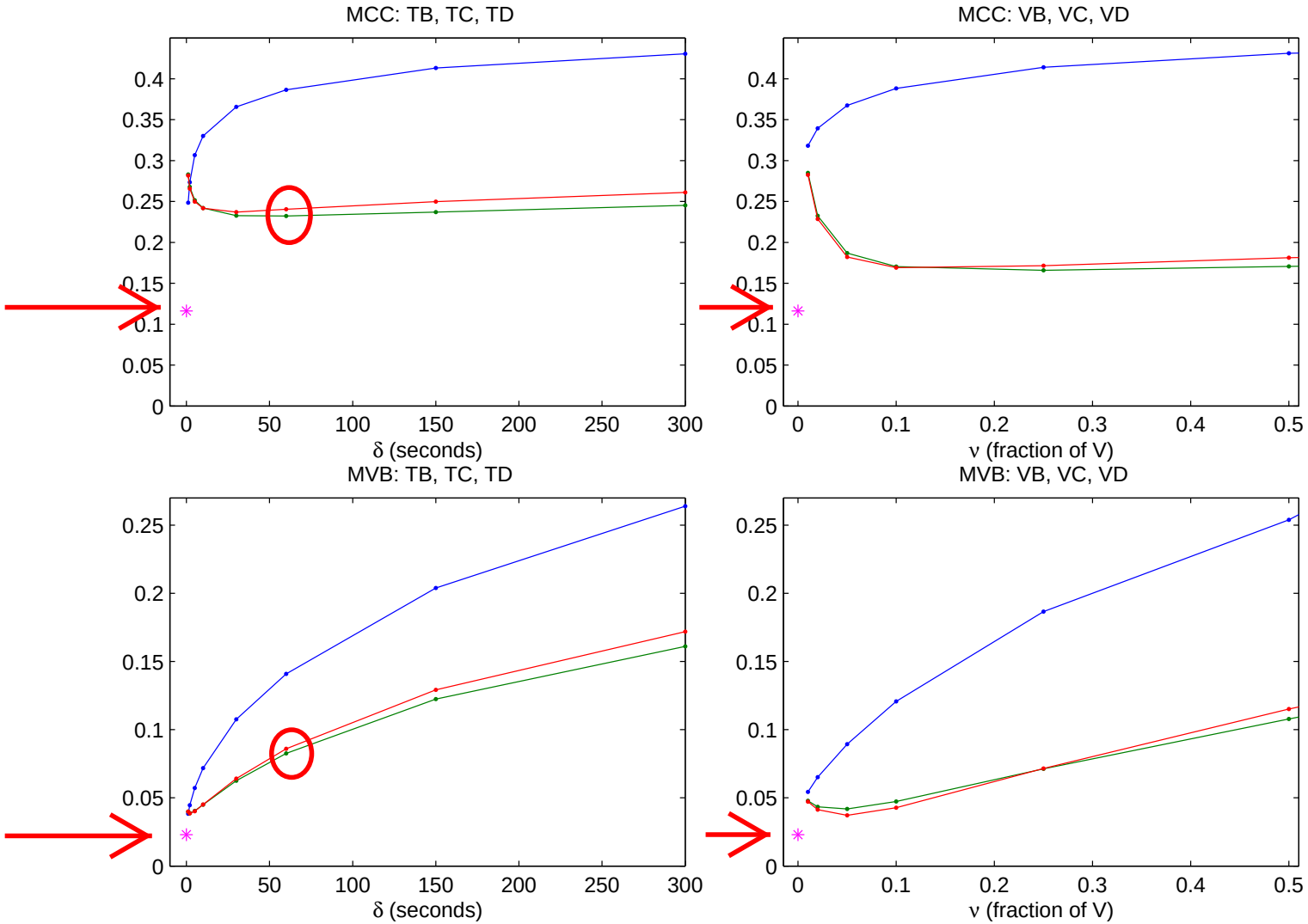
Panel A: MCC

Rule	R	T1	T2	T3	T4	V1	V2
A	0						
B	0.116	0.248	0.330	0.387	0.431	0.339	0.388
C		0.283	0.242	0.232	0.245	0.233	0.170
D		0.282	0.242	0.240	0.261	0.228	0.169

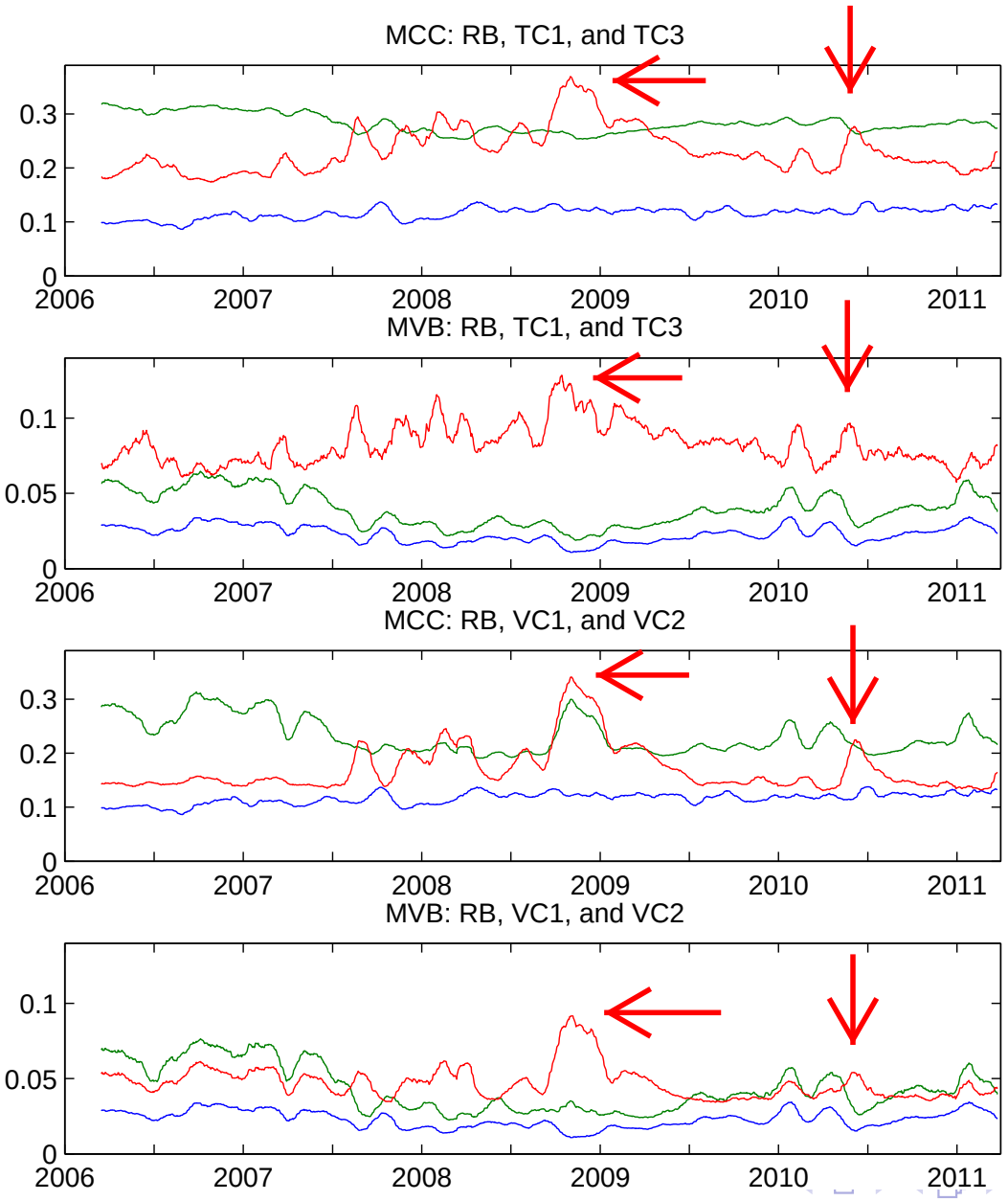
Panel B: MVB

Rule	R	T1	T2	T3	T4	V1	V2
A	0						
B	0.023	0.038	0.072	0.141	0.264	0.065	0.121
C		0.040	0.045	0.083	0.161	0.043	0.047
D		0.040	0.045	0.086	0.172	0.041	0.043

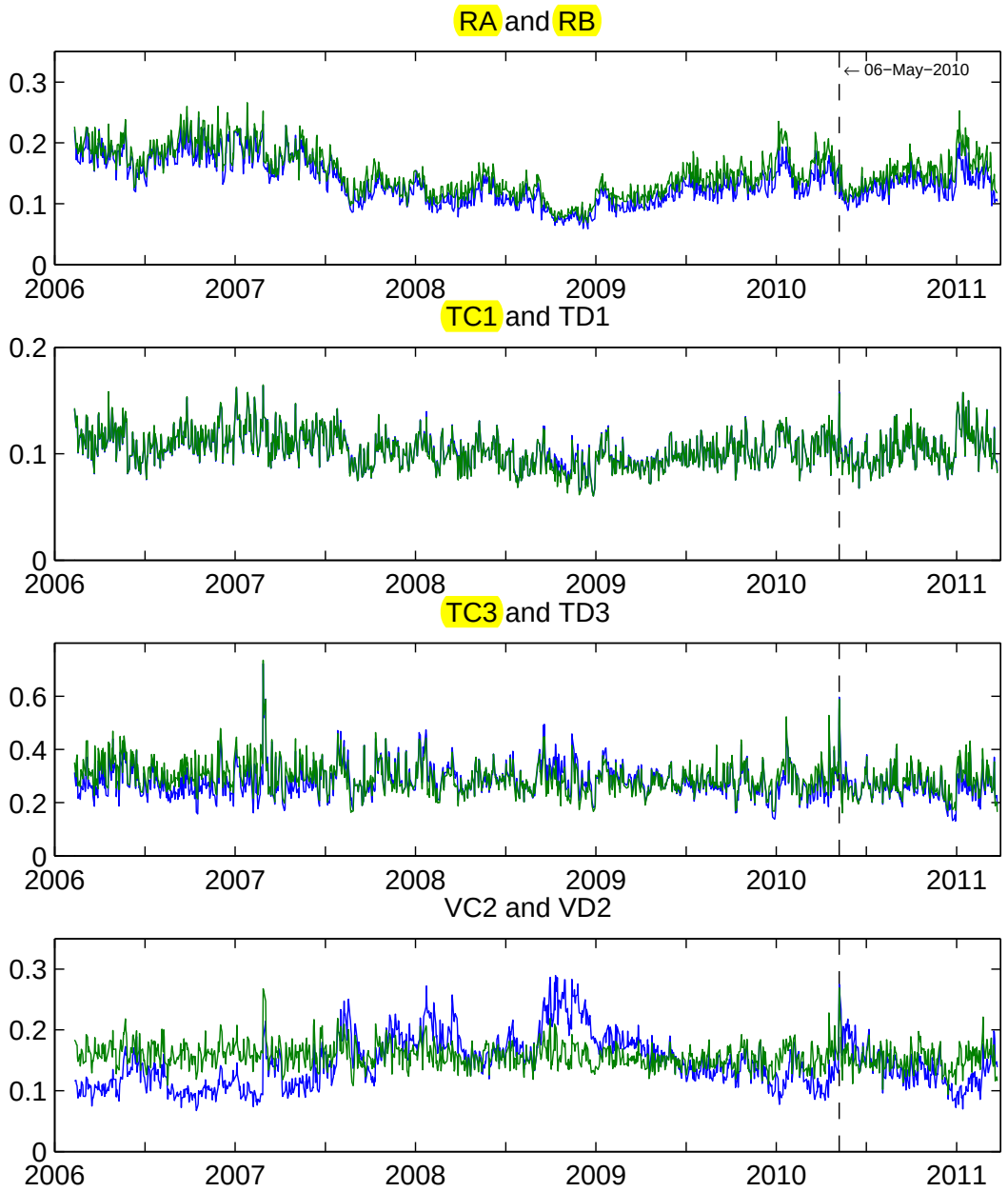
Error Rates for Alternative Classification Schemes



Time Variation in Error Rates (21-Day Moving Average)



Time Series of Daily Max VPIN Values



Transaction-Based Classification (R-VPIN)

	RA	RB	Volume	VIX	RV
RA	1.00		-0.53	-0.72	-0.62
RB	0.96	1.00	-0.53	-0.73	-0.64

Volume Bar-Based Classification (V-VPIN)

$\nu = 0.02$

	VB	VC	VD	RA	RB	Volume	VIX	RV
VB	1.00			0.84	0.86	-0.45	-0.63	-0.53
VC	-0.59	1.00		-0.66	-0.71	0.69	0.76	0.80
VD	-0.17	0.72	1.00	-0.20	-0.25	0.51	0.32	0.45

$\nu = 0.10$

	VB	VC	VD	RA	RB	Volume	VIX	RV
VB	1.00			0.65	0.66	-0.28	-0.44	-0.35
VC	-0.32	1.00		-0.65	-0.69	0.68	0.74	0.78
VD	0.36	0.42	1.00	0.22	0.17	0.25	0.01	0.19

Time Bar-Based Classification (T-VPIN)

$\delta = 1$

	TB	TC	TD	TE	RA	RB	Volume	VIX	RV
TB	1.00				0.90	0.92	-0.42	-0.66	-0.55
TC	0.71	1.00			0.63	0.62	-0.08	-0.39	-0.24
TD	0.74	1.00	1.00		0.66	0.66	-0.13	-0.44	-0.31
TE	0.85	0.58	0.62	1.00	0.83	0.87	-0.48	-0.72	-0.64

$\delta = 10$

	TB	TC	TD	TE	RA	RB	Volume	VIX	RV
TB	1.00				0.76	0.75	-0.16	-0.49	-0.34
TC	0.71	1.00			0.35	0.30	0.30	-0.04	0.15
TD	0.85	0.94	1.00		0.60	0.56	0.03	-0.30	-0.11
TE	0.84	0.59	0.76	1.00	0.76	0.76	-0.16	-0.53	-0.38

$\delta = 60$

	TB	TC	TD	TE	RA	RB	Volume	VIX	RV
TB	1.00				0.61	0.60	0.04	-0.34	-0.19
TC	0.65	1.00			0.06	0.01	0.55	0.21	0.38
TD	0.87	0.87	1.00		0.47	0.43	0.22	-0.16	0.01
TE	0.84	0.69	0.87	1.00	0.55	0.52	0.16	-0.28	-0.10

Why such High VC1- and VC2-VPIN (TC3-VPIN) Correlation with RV?

Only Possible Reason is Trade Classification (otherwise Identical to other indices)

$$\text{VC-VPIN} = \frac{1}{L}\sum_{\ell=1}^{L}\left|\frac{1}{Q}\sum_{q=1}^{Q}\gamma_{q,\ell}\right| = \frac{1}{L}\sum_{\ell=1}^{L}|\gamma_{\ell}|\,.$$

Cumulates Absolute Values of HF Increments Linked to Price Changes!

Resembles (Distorted) Realized Volatility Measure

Why such High VC1- and VC2-VPIN (TC3-VPIN) Correlation with RV?

In Fact, "Bulk Return" $r_\ell^b = \gamma_\ell$ **Highly Correlated with Log-Returns**.

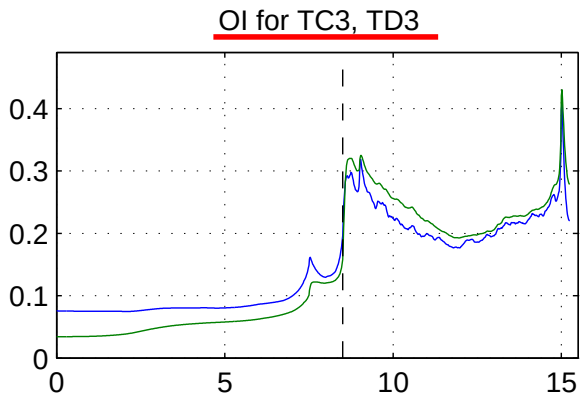
Average Correlation over Volume Buckets: **0.86**, **0.84** for VC1, VC2 Schemes.

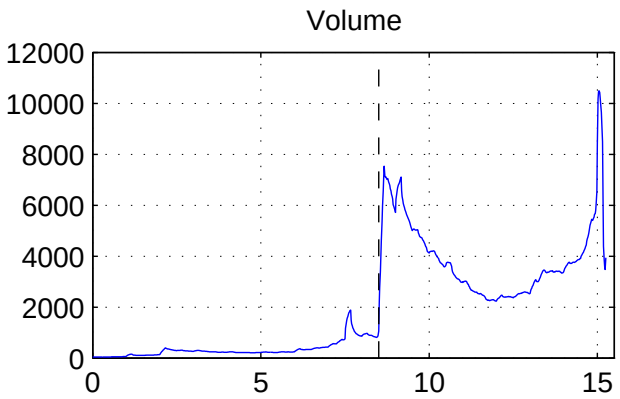
VC-VPIN Measures Trivially Strongly Correlated with RV (and Volume).

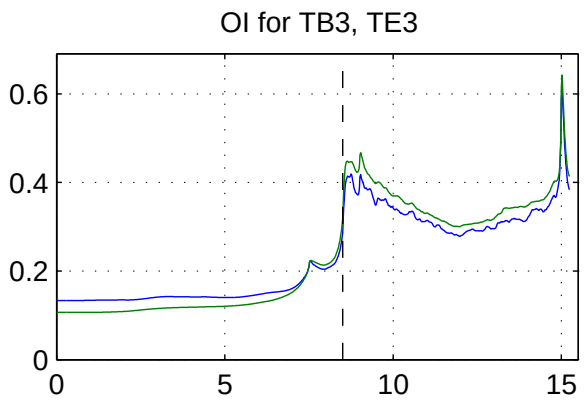
TC-VPIN Measures will be Correlated with both RV and Volume.

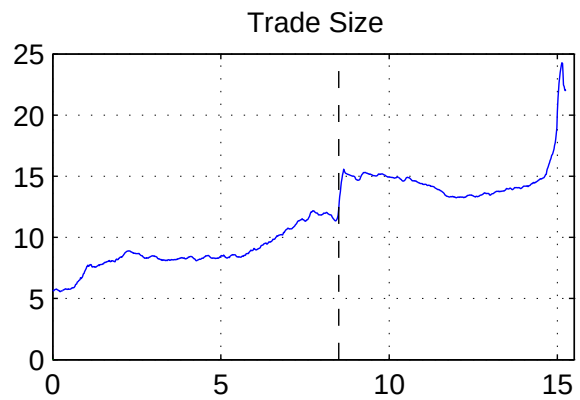
VD-VPIN Controls for Recent RV – only RV Innovations Matter.

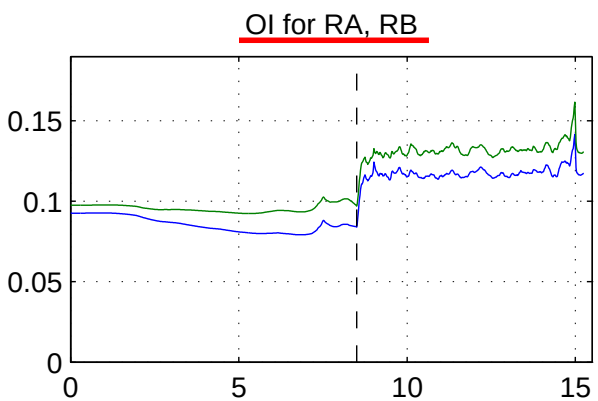
Intraday Order Flow Imbalances

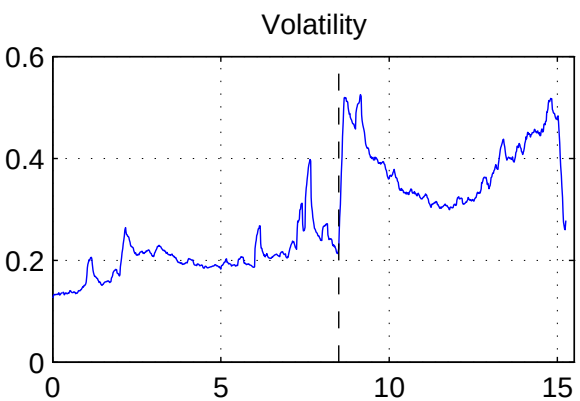










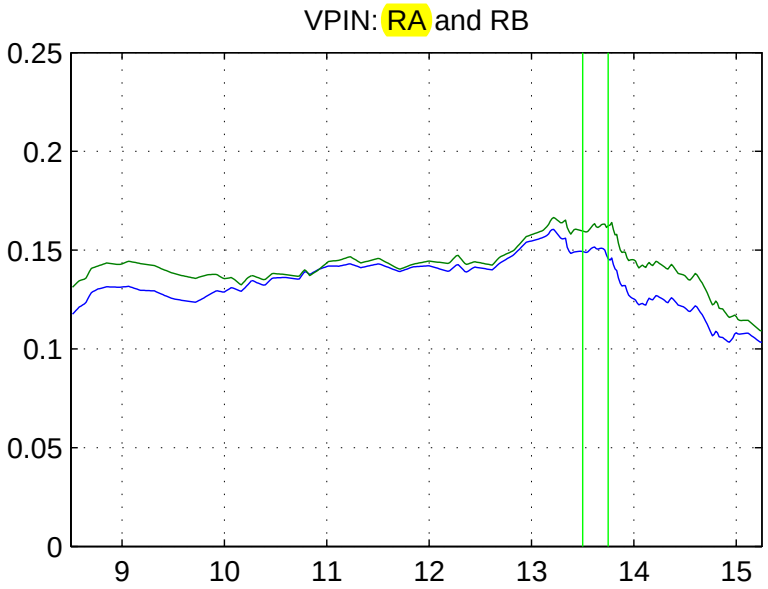


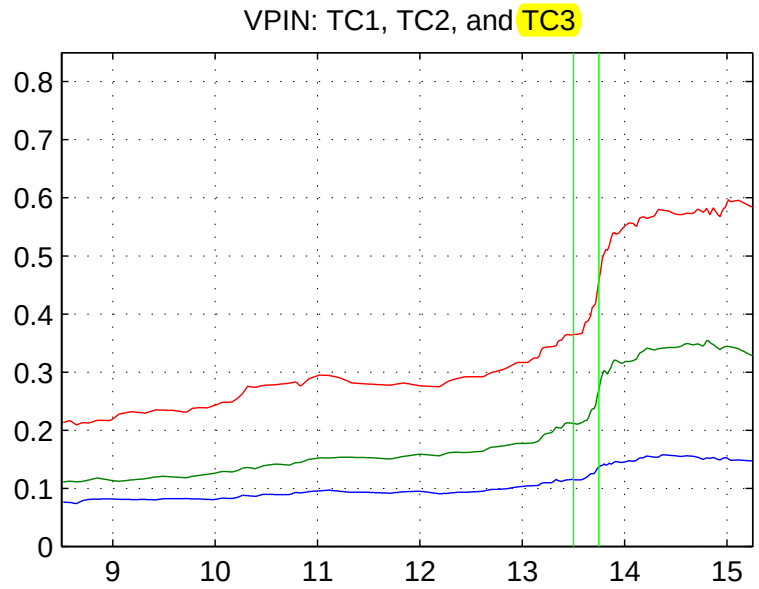
Panel A: 5-Minute Forecast

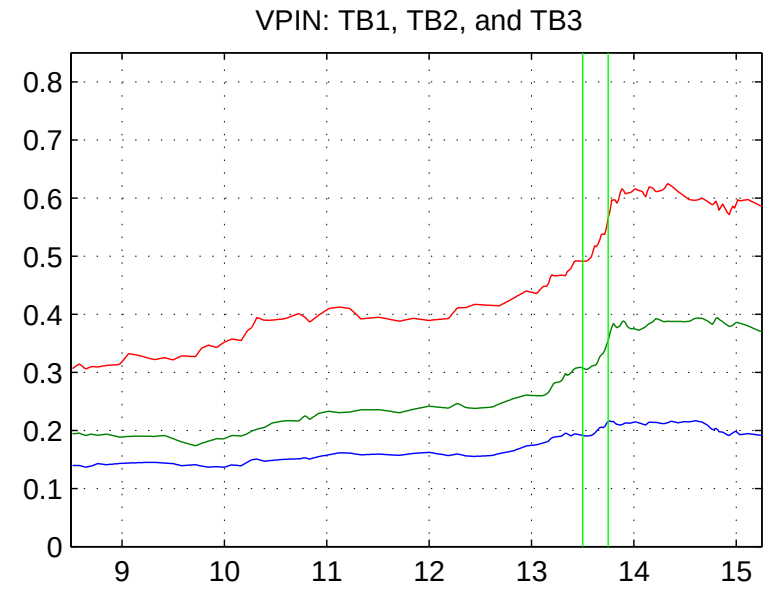
Reg	Const	RA	RB	TB3	TC3	TD3	TE3	Vol	VIX	RV	$\bar{R}^2$
(1)	0.10 (25.50)	-0.50 (-17.90)									19.71
(2)	0.11 (25.43)		-0.52 (-18.47)								22.35
(3)	0.06 (14.90)			-0.07 (-6.25)							1.32
(4)	-0.02 (-4.03)				0.22 (13.04)						9.91
(5)	0.03 (9.16)					0.03 (2.31)					0.19
(6)	0.05 (9.66)						-0.04 (-2.71)				0.27
(7)	-0.01 (-4.27)							0.26 (19.66)			33.42
(8)	-0.01 (-8.31)								0.22 (30.66)		48.42
(9)	0.00 (3.17)									0.13 (98.96)	61.35
(10)	0.00 (1.81)				0.00 (0.54)					0.13 (92.26)	61.35

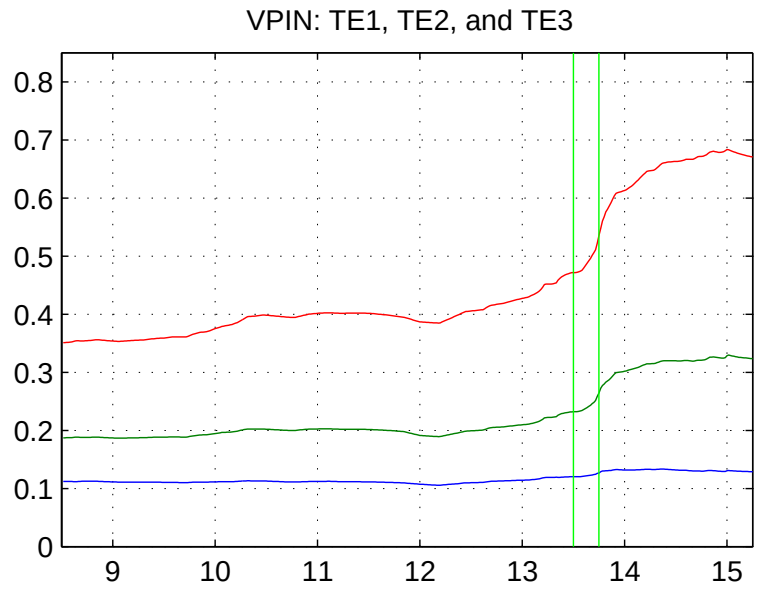
Panel B: 1-Day Forecast

Reg	Const	RA	RB	TB3	TC3	TD3	TE3	Vol	VIX	RV	$\bar{R}^2$
(1)	0.10 (26.14)	-0.50 (-18.34)									33.30
(2)	0.11 (25.98)		-0.52 (-18.84)								37.40
(3)	0.07 (16.27)			-0.08 (-7.82)							3.36
(4)	-0.01 (-1.94)				0.18 (12.14)						11.87
(5)	0.04 (12.06)					-0.00 (-0.20)					0.00
(6)	0.06 (11.48)						-0.06 (-4.49)				1.15
(7)	-0.01 (-2.66)							0.24 (18.97)			48.02
(8)	-0.01 (-8.33)								0.21 (32.87)		77.85
(9)	0.00 (0.56)									0.18 (26.33)	82.30
(10)	0.00 (0.06)				0.00 (0.46)					0.18 (24.60)	82.30

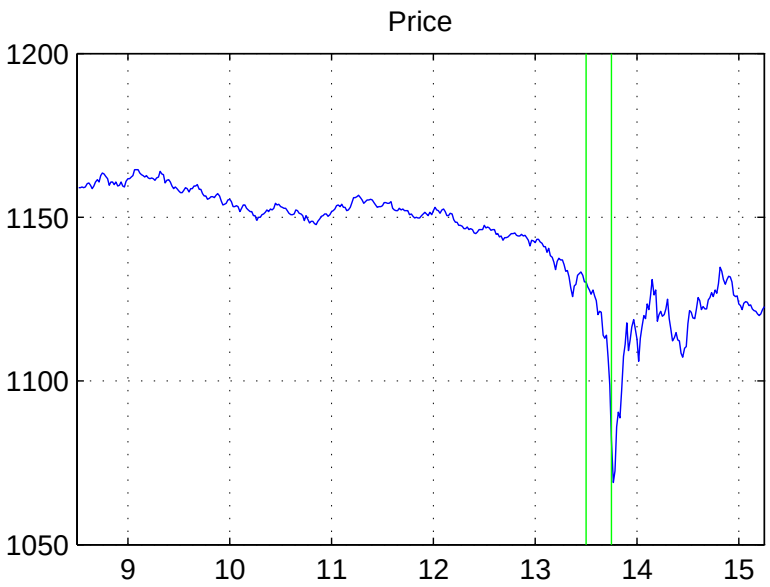

VPIN: RA and RB
0.25
0.2
0.15
0.1
0.05
0
9
10
11
12
13
14
15

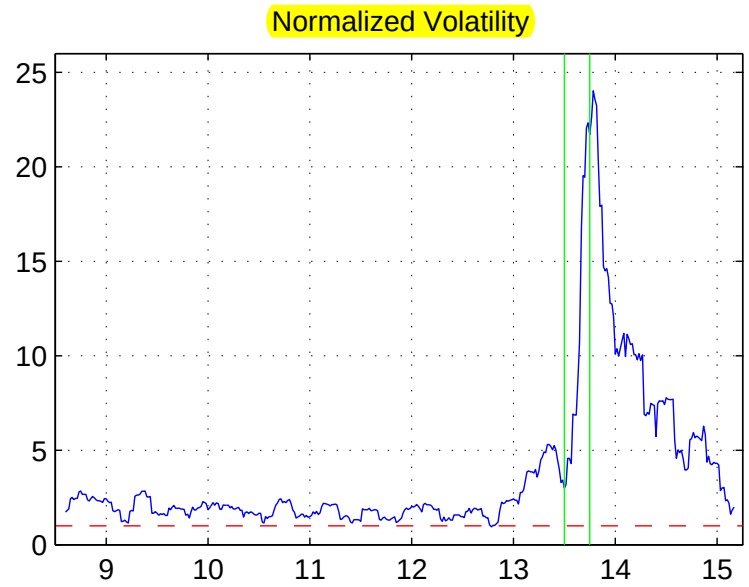

VPIN: TC1, TC2, and TC3
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
9
10
11
12
13
14
15

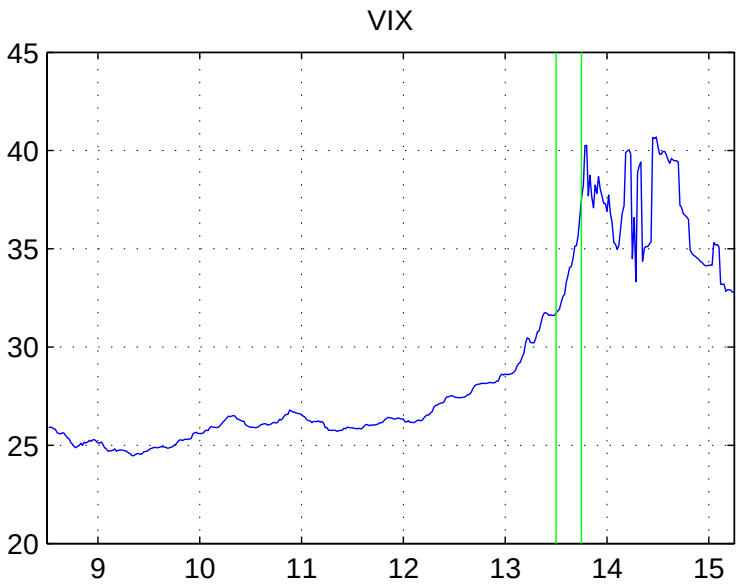

VPIN: TB1, TB2, and TB3
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
9
10
11
12
13
14
15

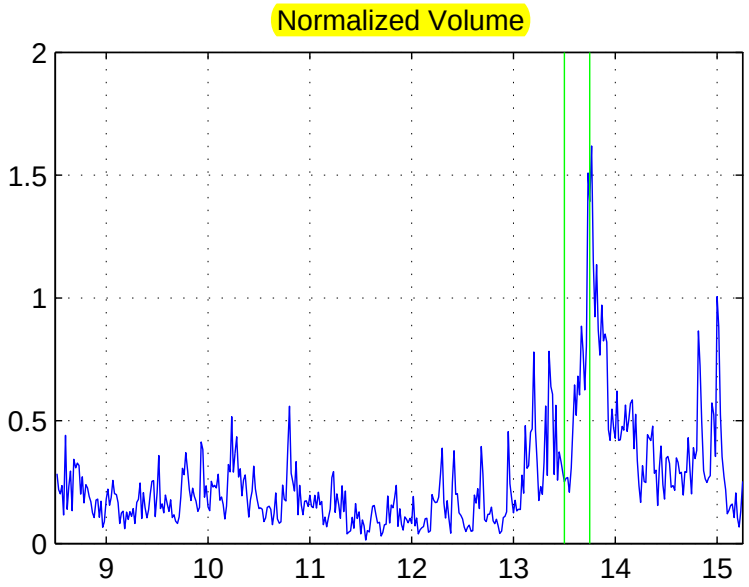

VPIN: TE1, TE2, and TE3
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
9
10
11
12
13
14
15

The Flash Crash









ELO Metric for Evaluating VPIN

- VPIN Signals Impending Market Turbulence – **NO, just reflects Volume, RV**
- VPIN Predicts Future Short Run Volatility – **NO, Subsumed by RV**
- VPIN Leads VIX – **NO, VIX Superior Volatility Predictor**
- BVC Accuracy Superior – **NO, Poor and Errors Correlate w/ Activity**

Features of VPIN Constructed from Ideal Classification (or RB):

- Negative Correlation with Volatility and Volume.
- High Uncertainty $\rightarrow$ Thinning Order Book, Smaller Trade Sizes.
- Negative Correlation with TC3-VPIN.
- No Signal Effect for Crashes.
- Information in RA-SOI Destroyed by VPIN-Transformation.
- Is Flat across Trading Day up to Closing.

Classification Errors of Bar-Based VPIN Correlated with Volatility.

Conclusions

- Take In-Depth Look at Performance of TB-VPIN and TC-VPIN Measures.
- Contrast Performance to VPIN under Perfect Trade Classification.
- Also Contrasting to U-VPIN, RB-VPIN, xD-VPIN, and Vx-VPIN.
- ELO VPIN Positively Correlated with Volatility by Construction.
- Classification Errors Correlate with Volume/Volatility.
- No Auxiliary Forecast Power beyond known Activity Variables.
- No Formal Metric used for Evaluation.
- Association to Actual Trade Direction Broken.
- By What Formal Metric Does VPIN Help with Anything?

Conclusions

- Level of VPIN prior to Flash Crash Not Extraordinary.
- Level of VPIN (near) Record High following Crash.
- Increase in VPIN driven by Concurrent Volume/Volatility Innovations.
- Volume Bar Tick-Rule (VB-) VPIN Annihilates Results.
- We hope the Battery of Tests Undertaken here will be Helpful in Identifying more Suitable and Robust Market Stress Indicators.