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Exogenous versus endogenous dynamics in price formation

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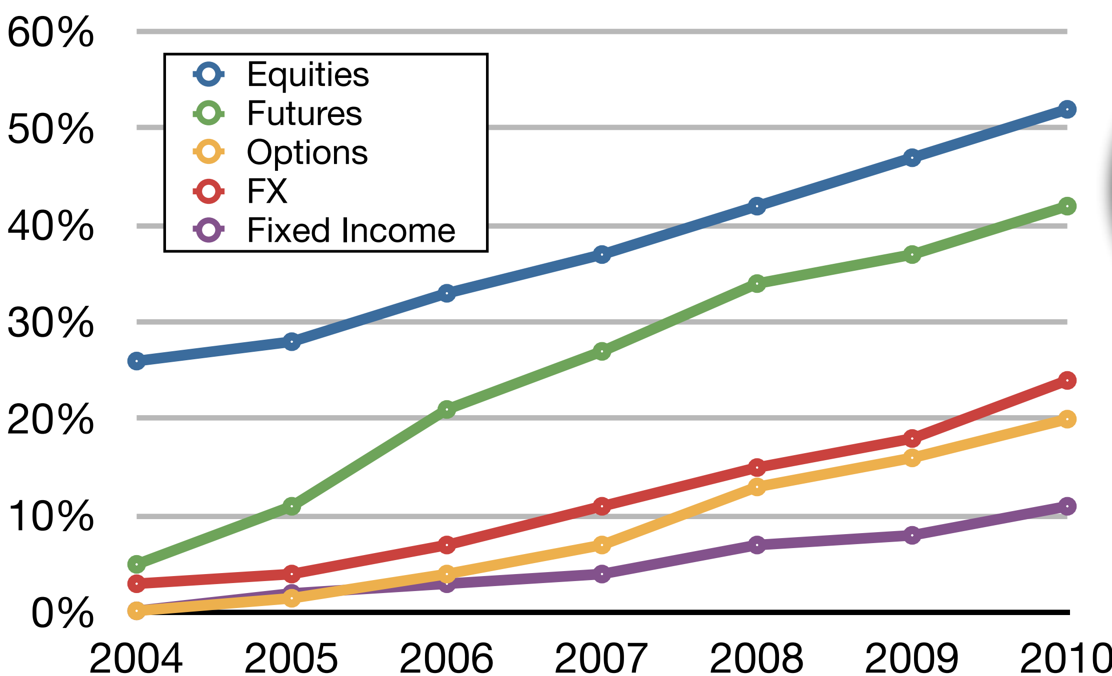
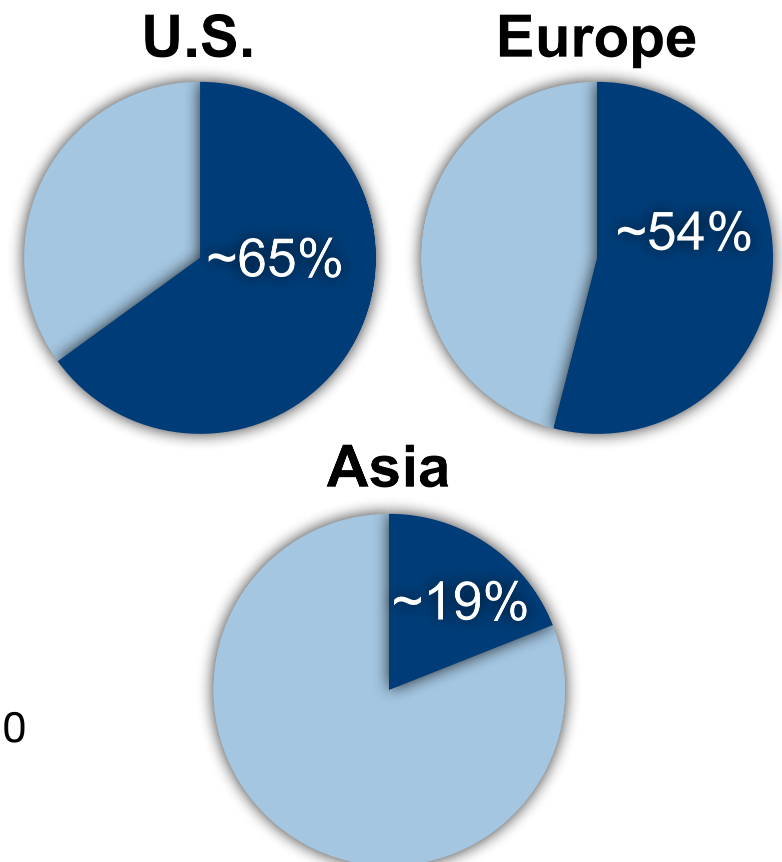
Algorithmic and High-Frequency Trading

Adoption of algorithmic execution by asset classes



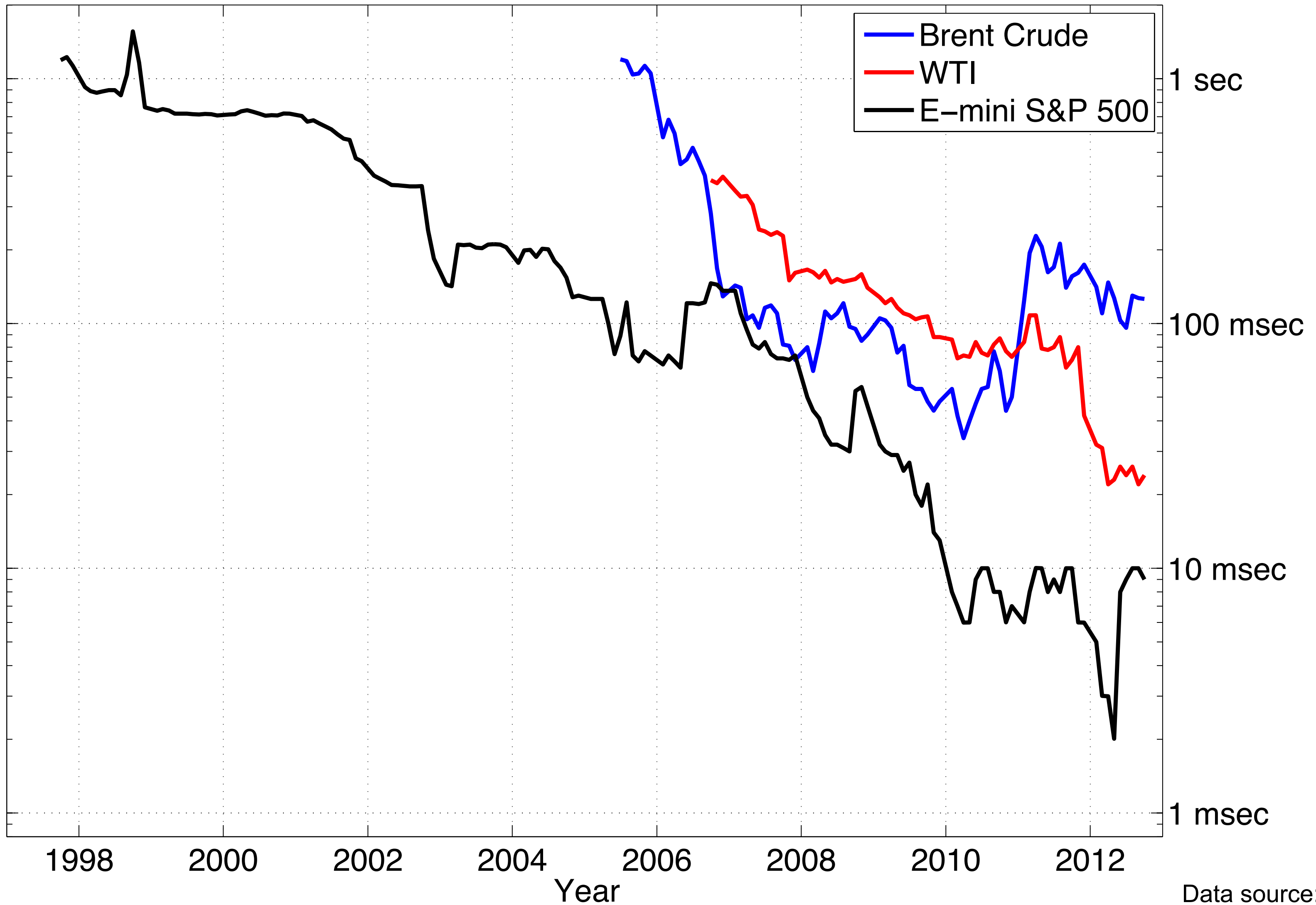
Source: Aite group

HFT trade volume as % of total market



Source: Aite group

Typical market makers' reaction time



Data source: TRTH

- Filimonov V., Sornette D. (2014) La vie èconomique

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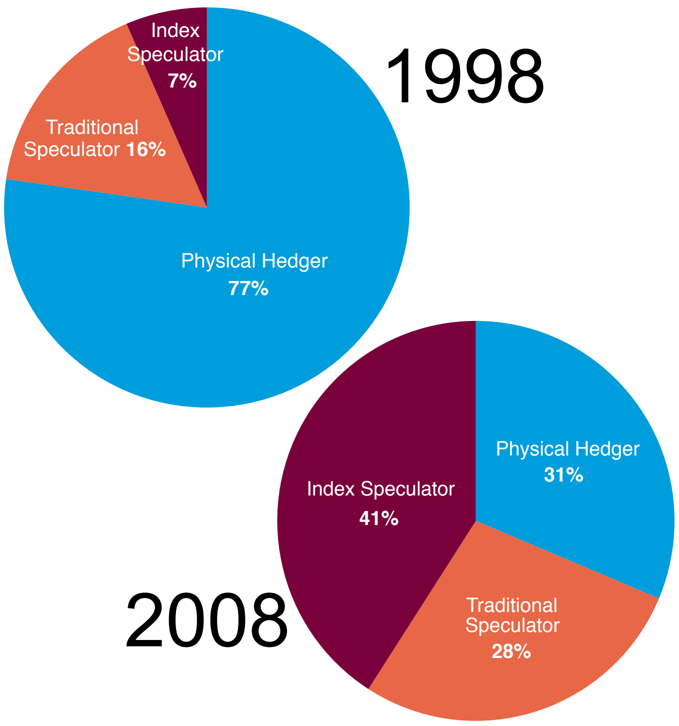
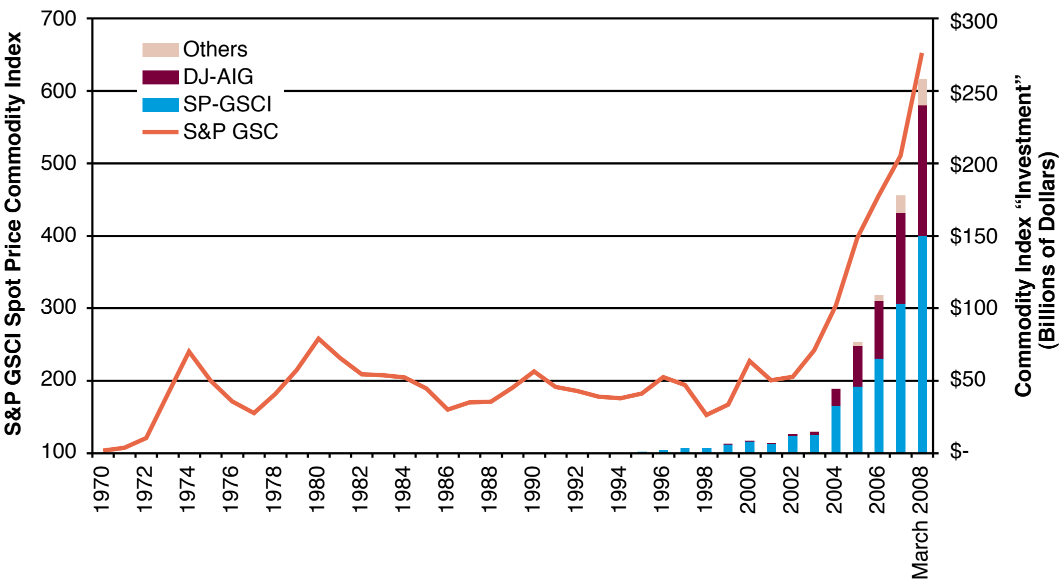
Financialization of commodities

Increasing market share of commodity speculators



Source: CFTC figures
charts by Mike Masters, Better Markets.

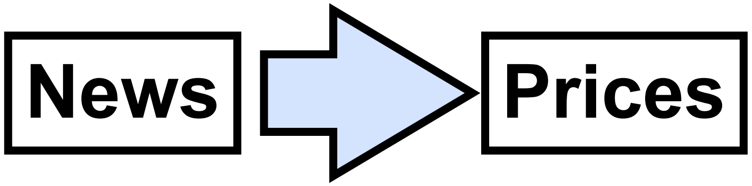
Increasing market share of commodity speculators

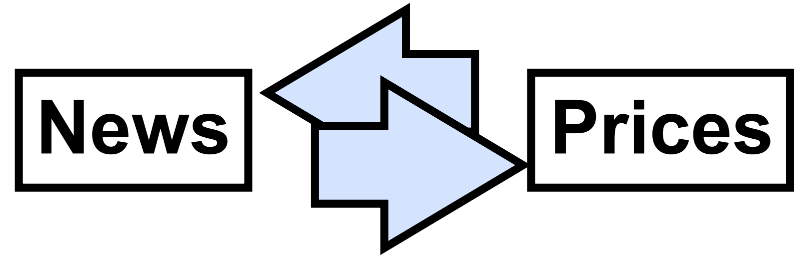


Source: Goldman Sachs, Bloomberg,
CFTC Commitments of Traders CIT Supplement

- How does introduction and adoption of algorithmic (including HFT) trading affect **price discovery mechanisms**?
- Is it possible to quantify the interplay between **exogeneity** (external impact) and **endogeneity** (internal self-excitation) in price formation?
- How **efficient** are financial and financialized commodity markets?

Two views on the price discovery mechanism





Efficient Markets (exogenous dynamics)

Prices are just reflecting news: the market fully and instantaneously absorbs the flow of information and faithfully reflects it in asset prices.

In particular, financial crashes are the signature of exogenous negative news of large impact.

"Reflexivity" of markets (endogenous dynamics)

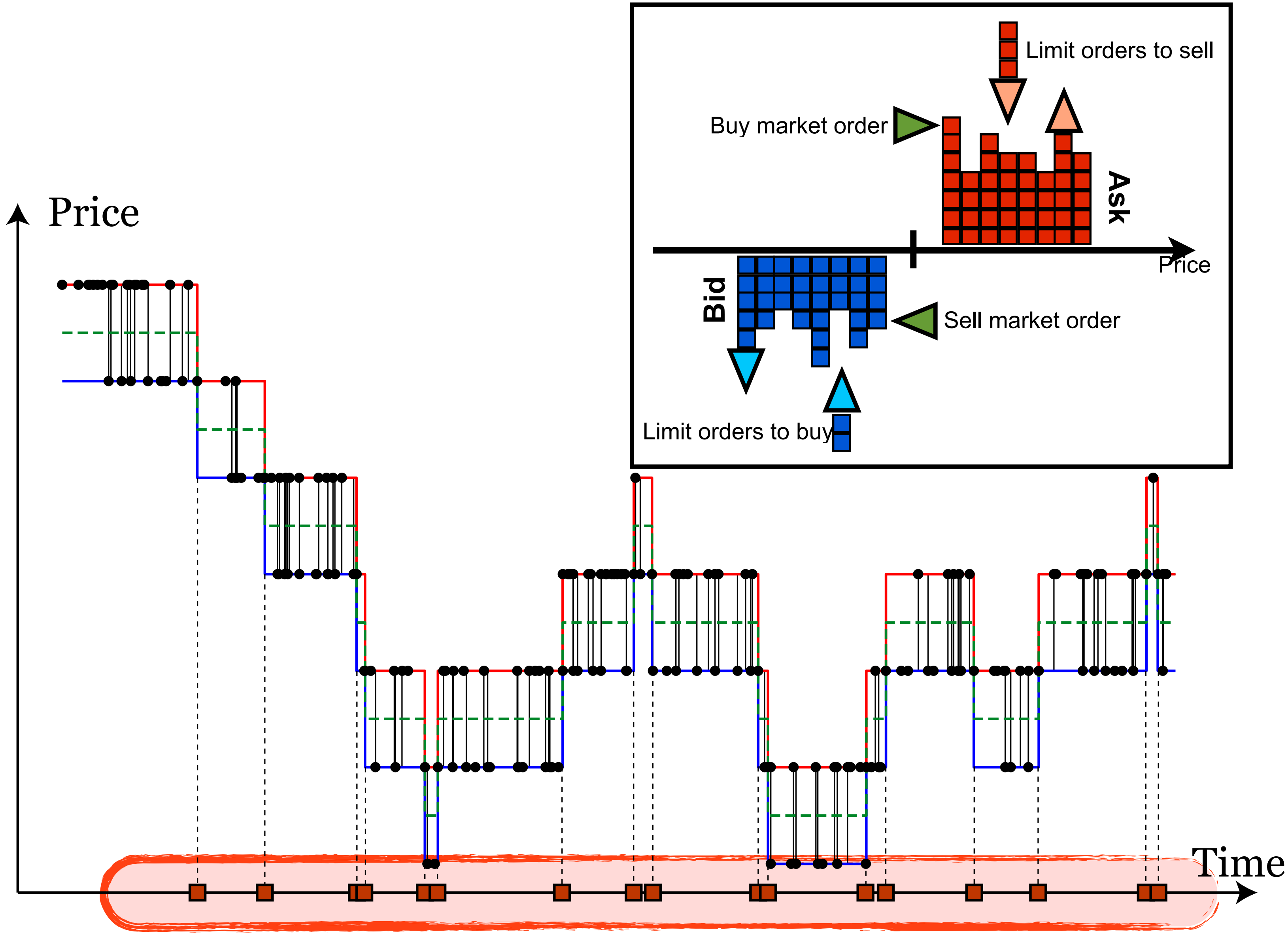
Markets are subjected to internal **feedback loops** (e.g. created by collective behavior such as herding or informational cascades).

Prices **do influence** the fundamentals and this newly-influenced set of fundamentals then proceed to change expectations, thus influencing prices.

Sources of reflexivity (endogeneity) in financial and financialized markets

- Behavioral mechanisms such imitation and informational cascades leading to **herding**;
- Speculation, based on technical analysis, including **algorithmic trading**;
- **Hedging** strategies (also increase cross-excitation between markets);
- Pricing of "**structured products**" such as ETFs (also contribute to cross-excitation)
- Methods of **optimal portfolio execution** and **order splitting**;
- Margin/leverage trading and **margin-calls**;
- **High frequency trading (HFT)** as a subset of algorithmic trading;
- **Stop-loss orders** and etc.

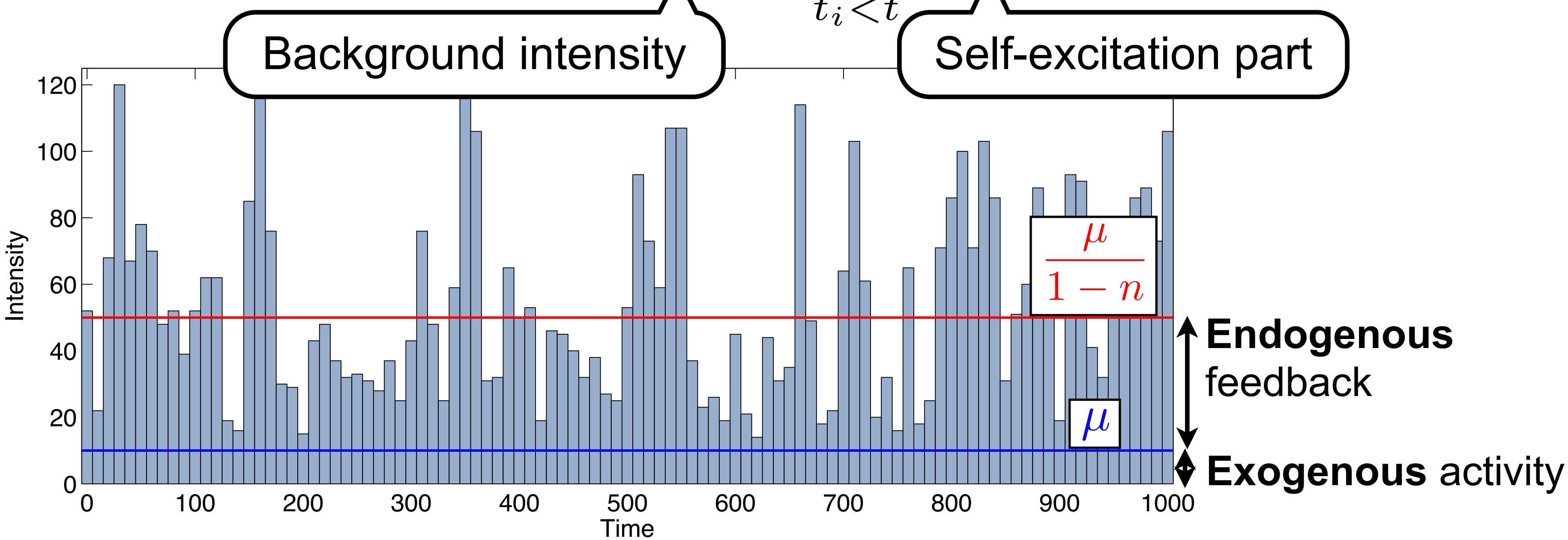
The test subject: HF price dynamics



The model: Self-excited Hawkes process

Self-excited Hawkes process is the point process whose intensity $\lambda_t(t)$ is conditional on its history:

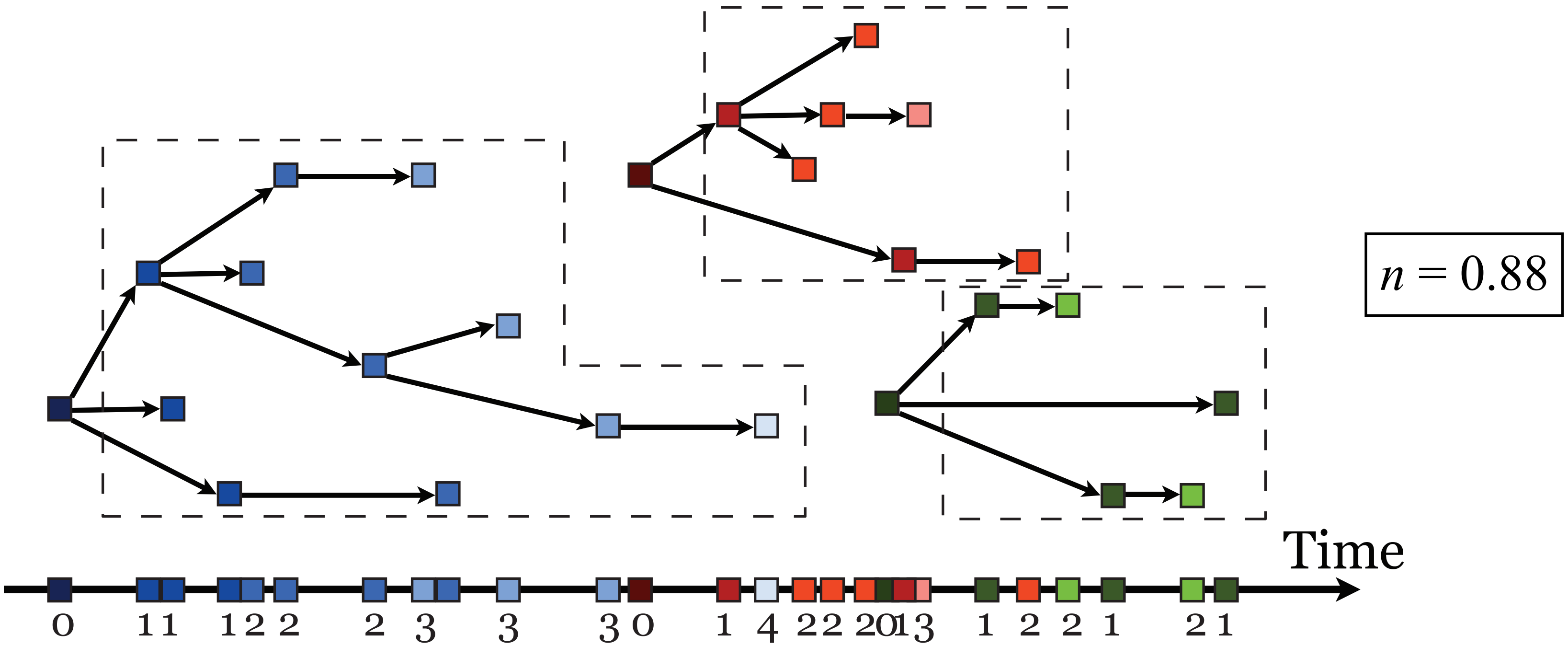
$$\lambda(t|\mathcal{F}_{t-}) = \mu + n \sum_{t_i<t} \phi(t - t_i)$$



Applications of the Hawkes model:

- High-frequency price dynamics
- Order book construction
- Critical events and estimation of VaR
- Default times in a portfolio of companies
- Triggered seismicity (earthquakes)
- Sequence of genes in DNA
- Epileptic seizures of brain
- Crime and violence propagation

Branching structure of Hawkes process



Crucial parameter of the branching process is the **"branching ratio" (*n*)**, which is defined as an average number of "daughters" per one "mother"

For ***n* < 1** system is **subcritical** (stationary evolution)
For ***n* = 1** system is **critical** (tipping point)
For ***n* > 1** system is **supercritical** (with prob.>0 will explode to infinity)

In subcritical regime, **the branching ratio (*n*) is equal to the fraction of *endogenously generated events* among the whole population.**

Calibration of the model

- **Maximum Likelihood method**

  Estimation of the parameters can be performed by maximizing log-likelihood function, which is given by the expression:

$$\log L(t_1, \dots, t_N) = -\int_0^T \lambda(t|\mathcal{F}_{t-})dt + \sum_{i=1}^{N} \log \lambda(t_i|\mathcal{F}_{t_i-})$$

- **Residual analysis**

  Under the null hypothesis that the data ($\{t_i\}$) was generated by the Hawkes process with given parameters, the following transformed point process ($\{\tau_i\}$) should be Poisson with unit intensity:

$$\tilde{t}_i = \int_0^{t_i} \lambda(t|\mathcal{F}_{t-})dt$$

Calibration issues. Kernel

- **Exponential kernel**

$$\phi(t) = \frac{1}{\tau} e^{-t/\tau} \chi(t)$$

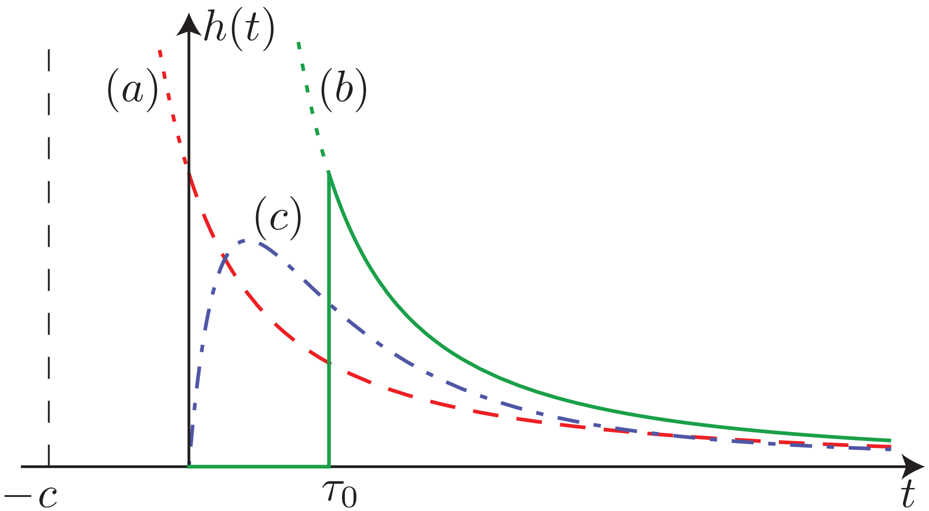
- **Power law kernels**

(a) Omori-type kernel

$$\phi(t) = \frac{\theta c^{\theta}}{(t+c)^{1+\theta}} \chi(t)$$

(b) Power law kernel with cut-off

$$\phi(t) = \frac{\theta c^{\theta}}{t^{1+\theta}} \chi(t-c)$$



(c) Approximate power law kernel

$$\phi(t) = \frac{1}{Z} \left[\sum_{i=0}^{M-1} \frac{1}{\xi_i^{1+\theta}} \exp\left(-\frac{t}{\xi_i}\right) - S \exp\left(-\frac{t}{\xi_{-1}}\right) \ , \right] , \ \xi_i = c m^i$$

Calibration issues. Kernel: sensitivity to outliers

Empirical quantiles of inter-quote durations in E-mini S&P 500 Futures Contracts within RTH

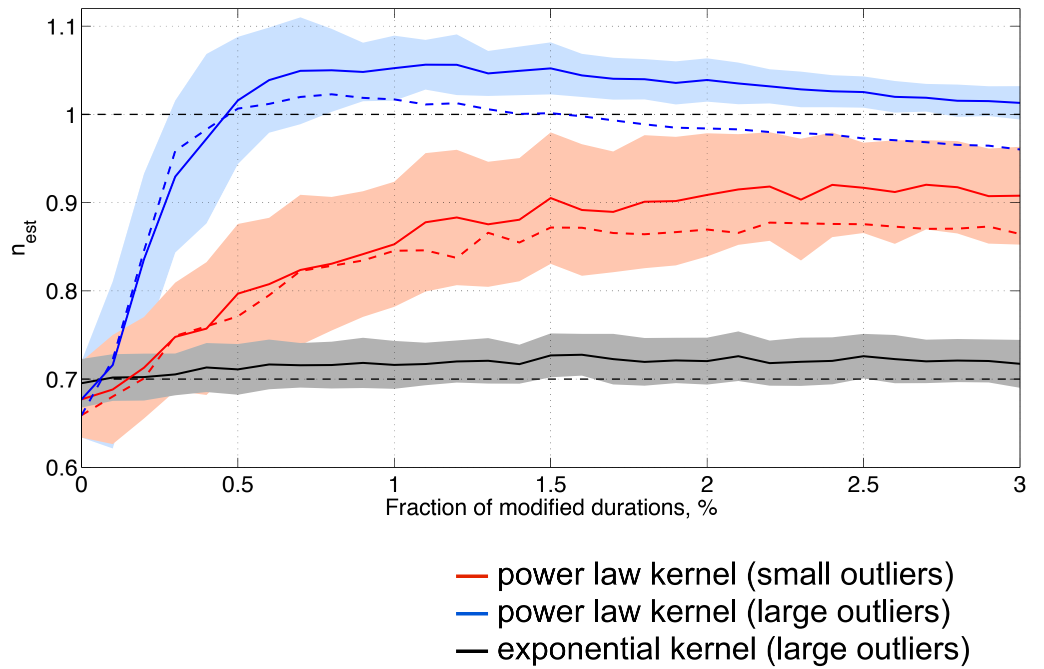
Date from	Date to	Q_{90}	Q_{95}	Q_{99}	Max
01-02-2002	01-04-2002	13.7	20.6	41.7	458.9
01-02-2006	01-04-2006	23.3	39.6	90.4	933.1
01-02-2009	01-04-2009	5.1	8.7	19.4	329.9
01-02-2011	01-04-2011	4.2	10.8	38.7	888.0

Data source: TRTH

Theoretical quantiles of inter-event durations for Hawkes process with exponential kernel and μ=1 and n=0.7

τ_0	Q_{90}	Q_{95}	Q_{99}	Max
1.0	0.7	1.1	2.2	5.4
0.1	1.0	1.6	3.2	7.2
0.01	1.1	1.9	3.5	8.3

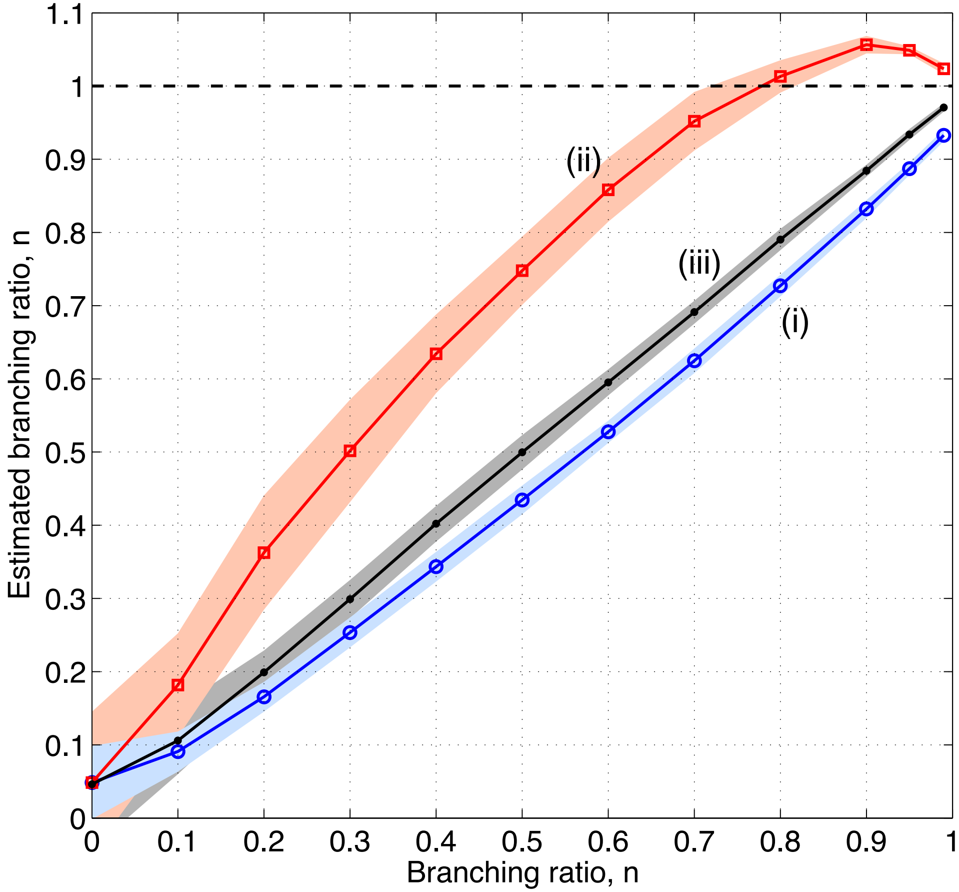
Sensitivity of the estimation of branching ratio (n) to "outliers" in inter-event durations



• Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. Kernel: regularization

Sensitivity of the estimation of branching ratio (n) to the mis-specification of the power law kernel



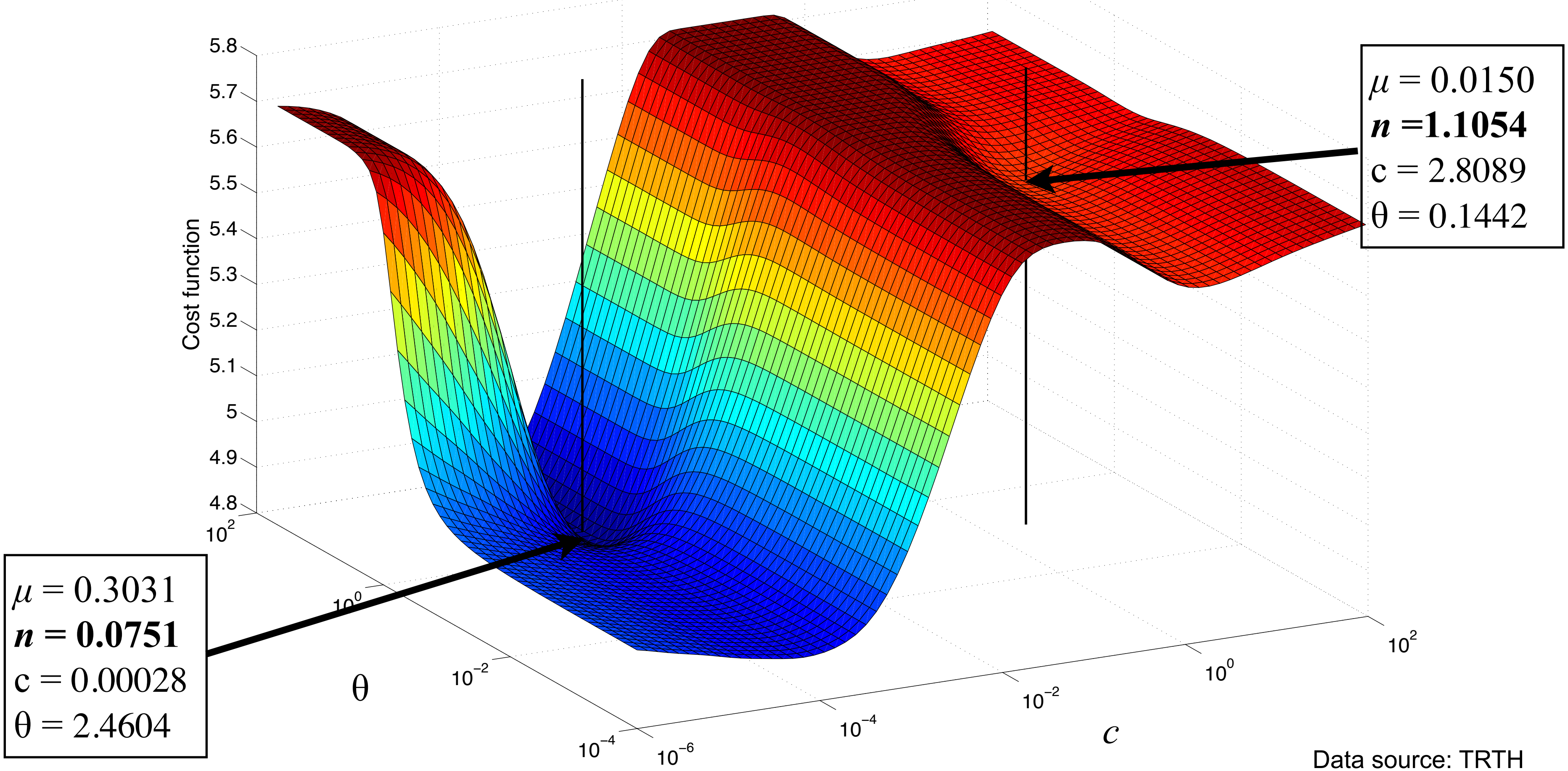
— Hawkes model with approximate power law kernel being calibrated on the data generated with Omori-type kernel

— Hawkes model with Omori-type kernel being calibrated on the data generated with approximate power law kernel

- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. Multiple extrema

Surface of the reduced cost-function used for calibration of the Hawkes model on the mid-price changes of E-mini S&P 500 Contracts in March 1 - April 30, 2001, using the data randomized within millisecond intervals (see paper for details)

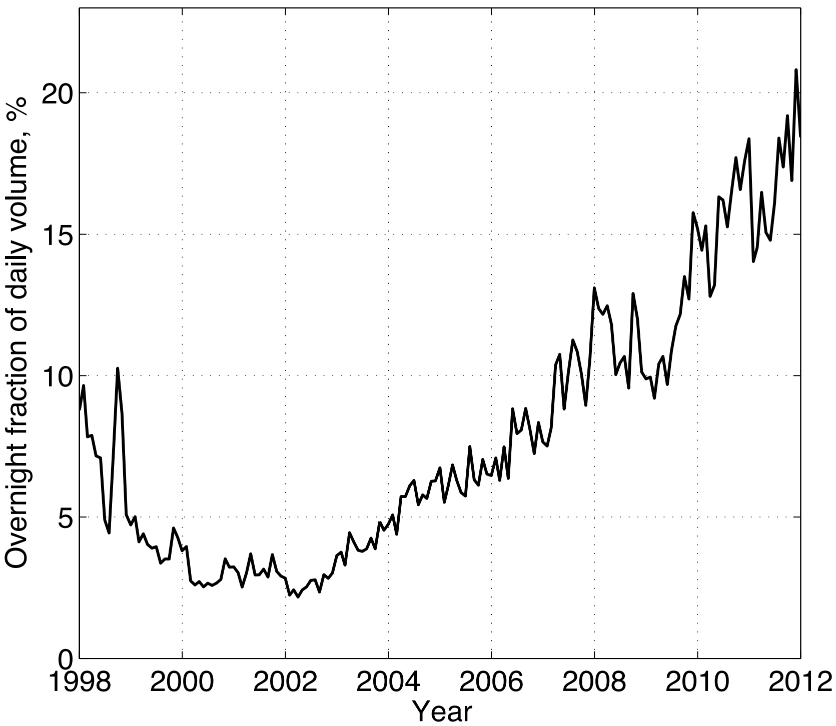


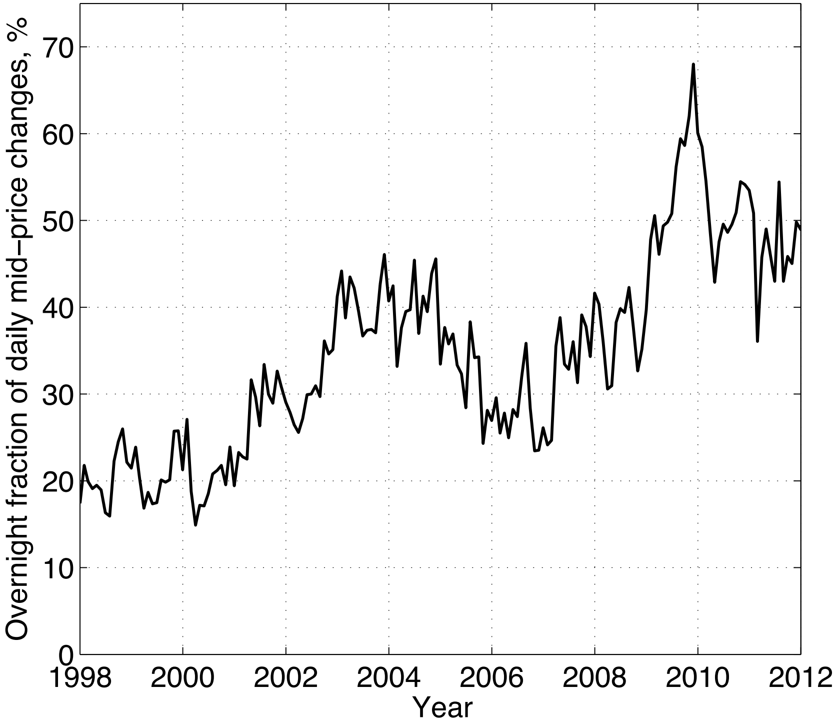
Data source: TRTH

- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. RTH and overnight trading

Fraction of total daily volume (left) and total daily mid-quote price changes (right) that is observed outside of Regular Trading Hours (9:30 to 16:15 CDT) on E-mini S&P 500 Futures Contracts.

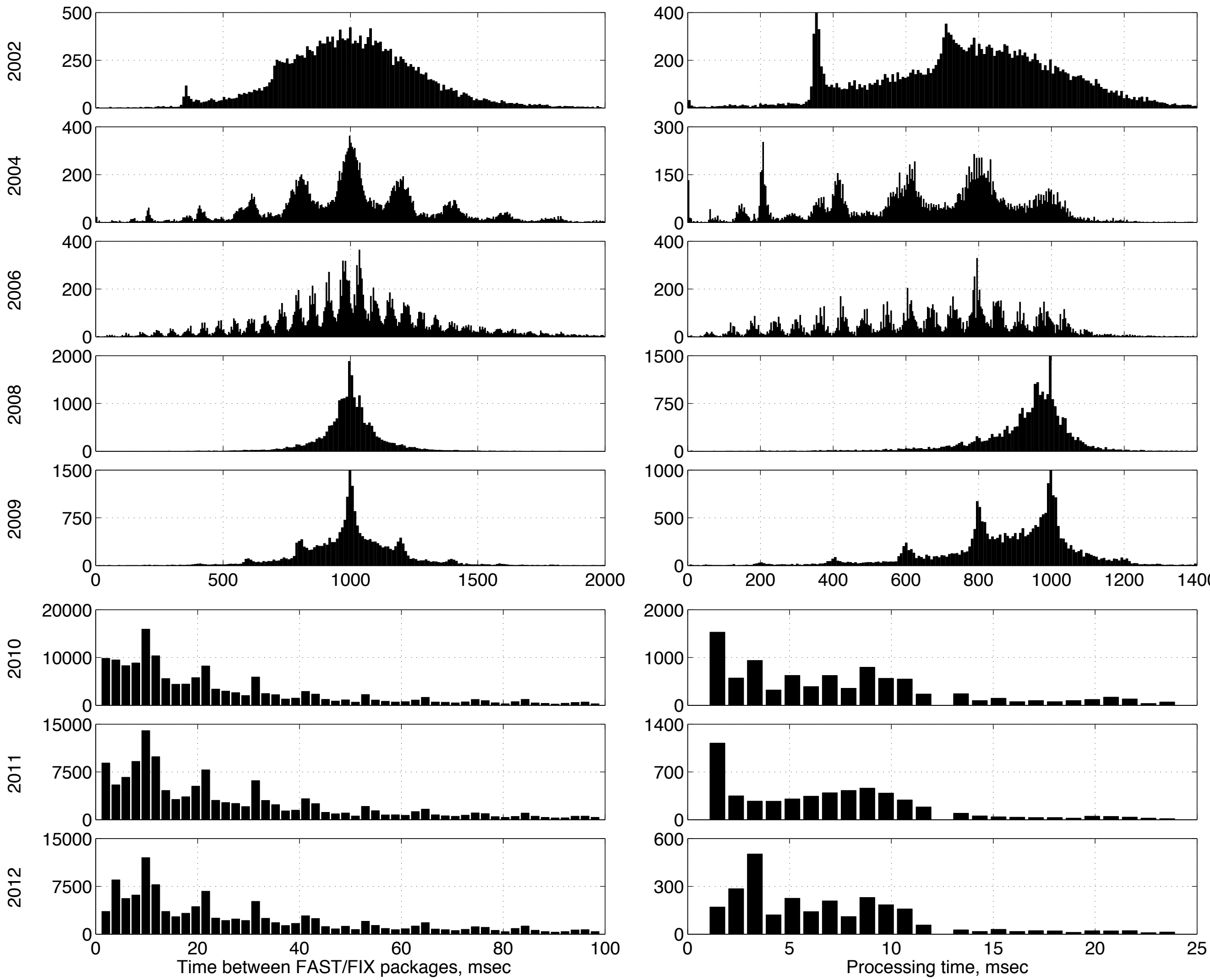




Data source: TRTH

- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. Resolution of timestamps (I)



Histograms of the time between consecutive FAST/FIX packages (left panels) and overhead for the data processing (right panels) for E-mini S&P 500 Futures Contracts over RTH

Data source: TRTH

• Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

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Calibration issues. Resolution of timestamps (II)

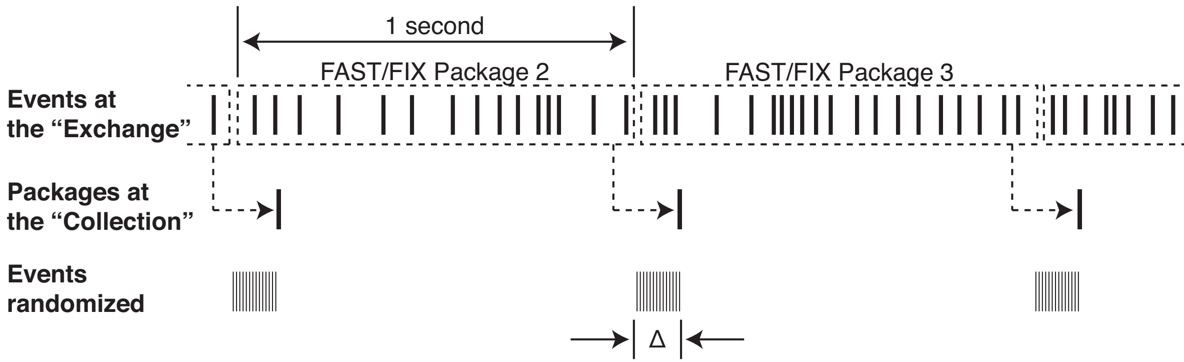
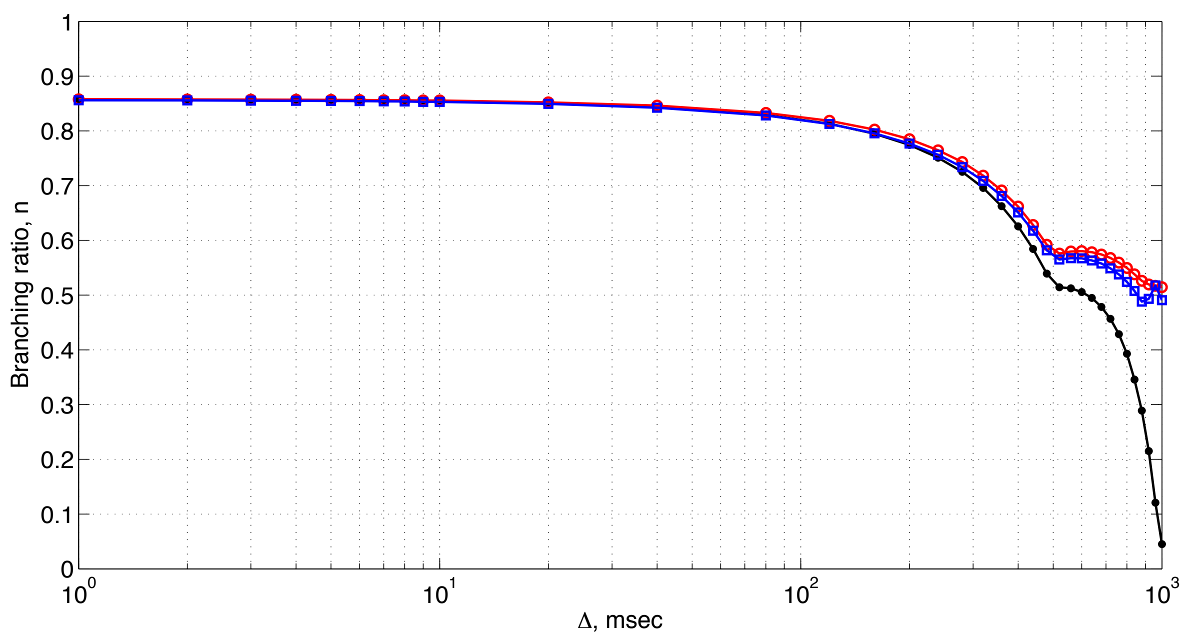


Illustration of the randomization procedure, when the resolution of timestamps is mis-specified.

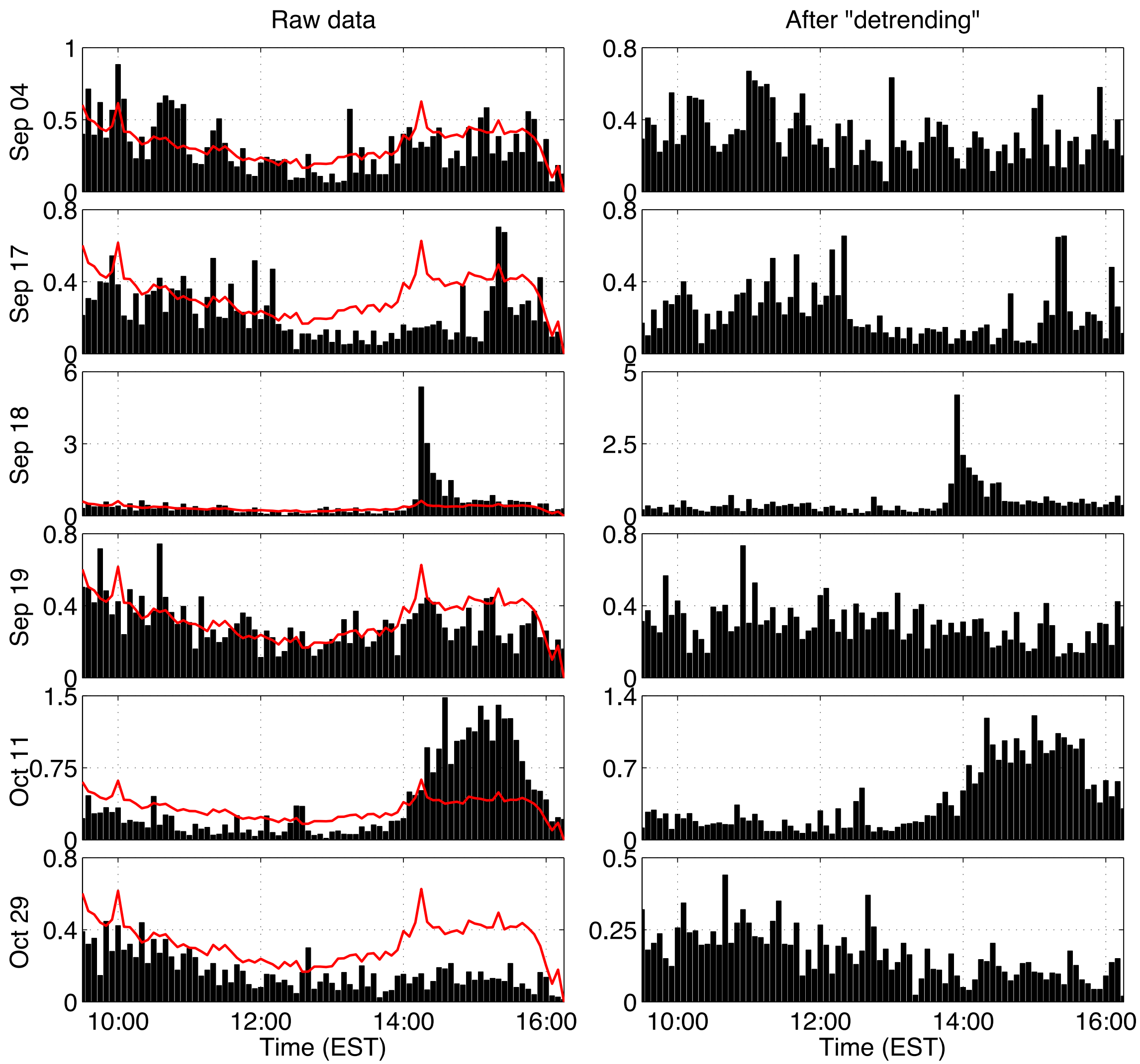


Bias in estimation of the branching ratio (n) that results from improper assumptions on the duration Δ of randomization intervals, when real inter-packet time is 1 second.

— exponential kernel (n=0.5)
— power law kernel (n=0.5)
— Poisson process (n=0)

• Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. Intraday trends



Unconditional intensity of flow of mid-quote price changes of E-mini S&P 500 Futures Contracts on some dates of September–October, 2007.

Left panels present the raw data (black bars) and the average intensity over the period of September 1–October 30, 2007 (red line).

Right panels present the unconditional intensity after “detrending” using the average intensity.

Data source: TRTH

- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

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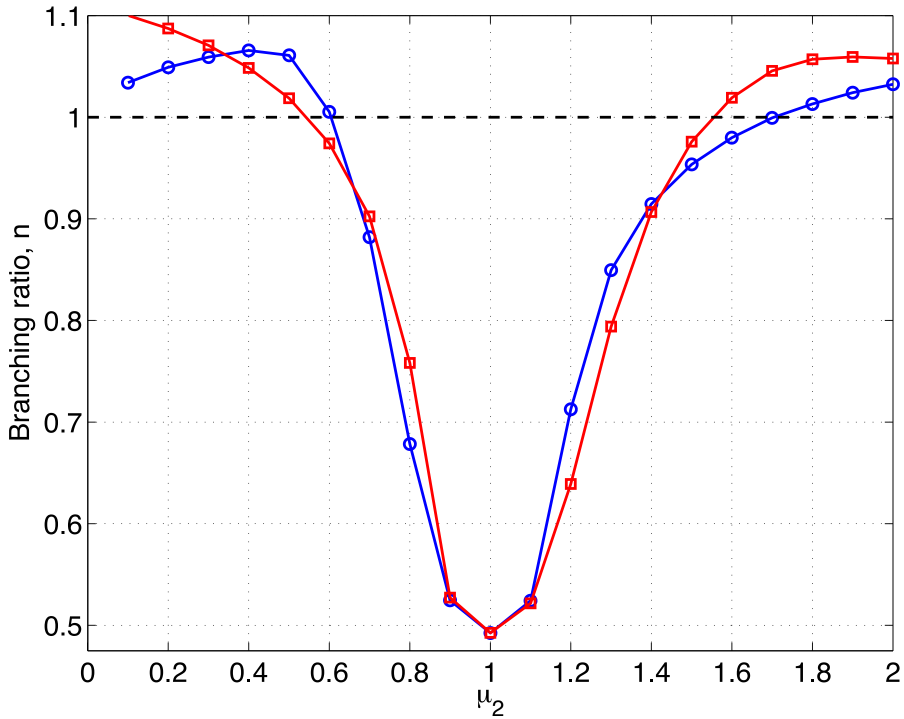
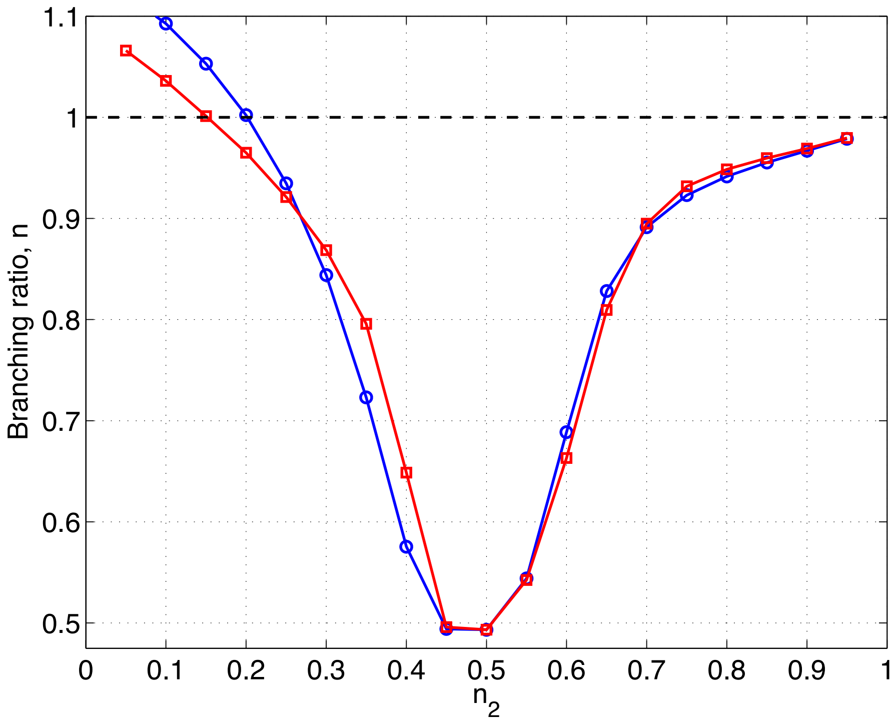
Calibration issues. Nonstationarity (I)

Bias of the estimation of the branching ratio (n) in case of *regime switch in background intensity* (concatenation of 2 independent samples with $\mu_1=1$ and μ_2, $n=1$)



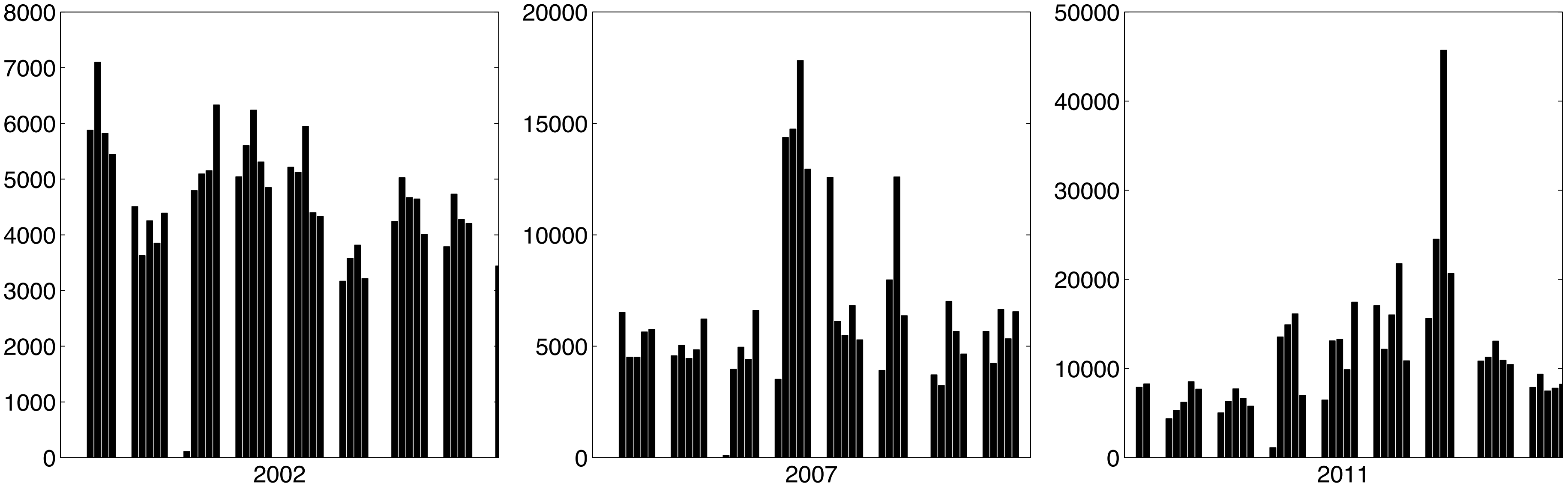
Bias of the estimation of the branching ratio (n) in case of *regime switch in branching ratio intensity* (concatenation of 2 independent samples with $n_1=0.5$ and n_2)



- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

Calibration issues. Nonstationarity (II)

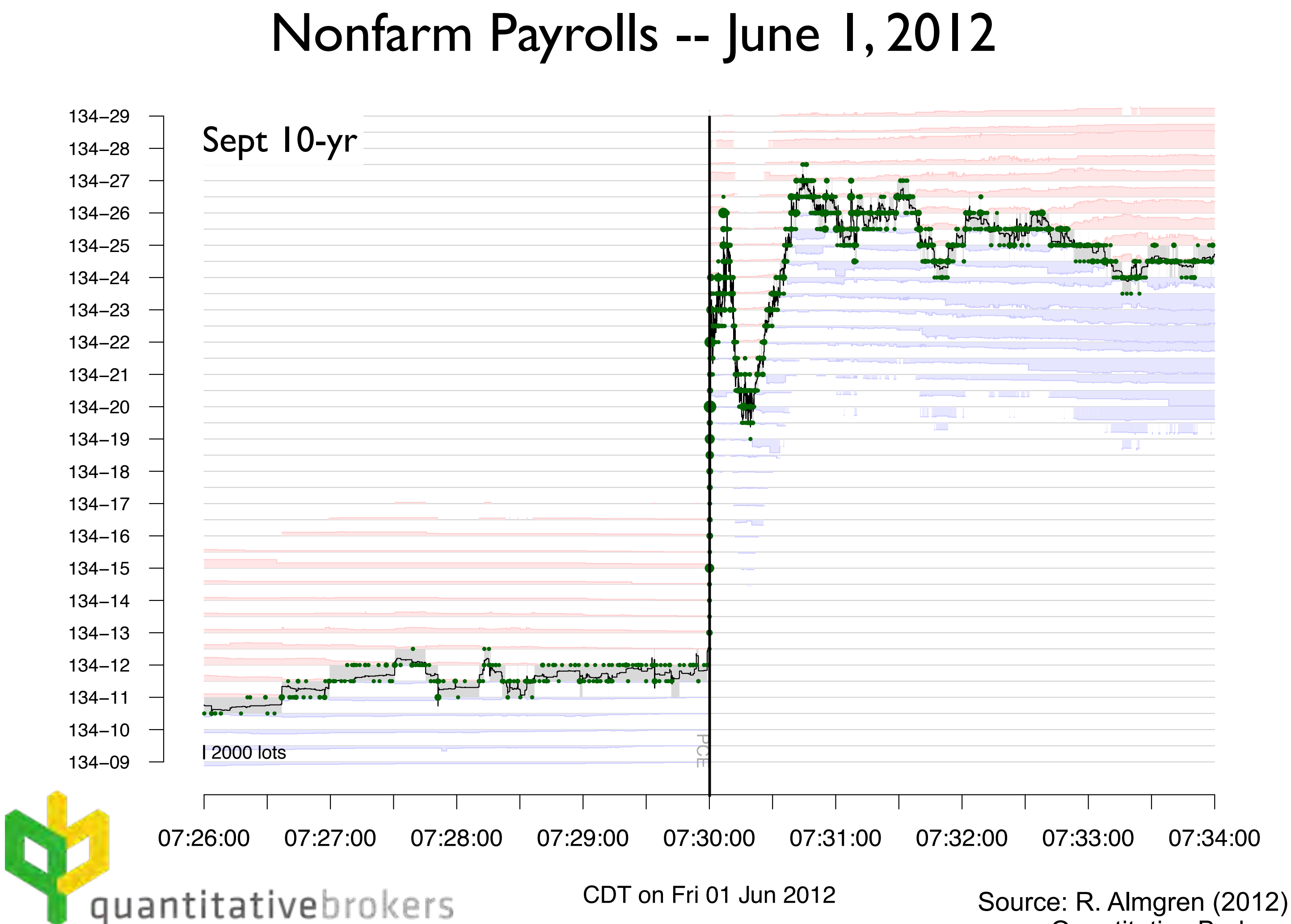
Dynamics of daily numbers of mid-quote price changes counted over RTH for the Front Month Contract of the E-mini S&P 500 Futures
(time period of February 1 to April 1 in three different years)



Data source: TRTH

- Filimonov V., Sornette D. (2013) Working paper. arXiv:1308.6756

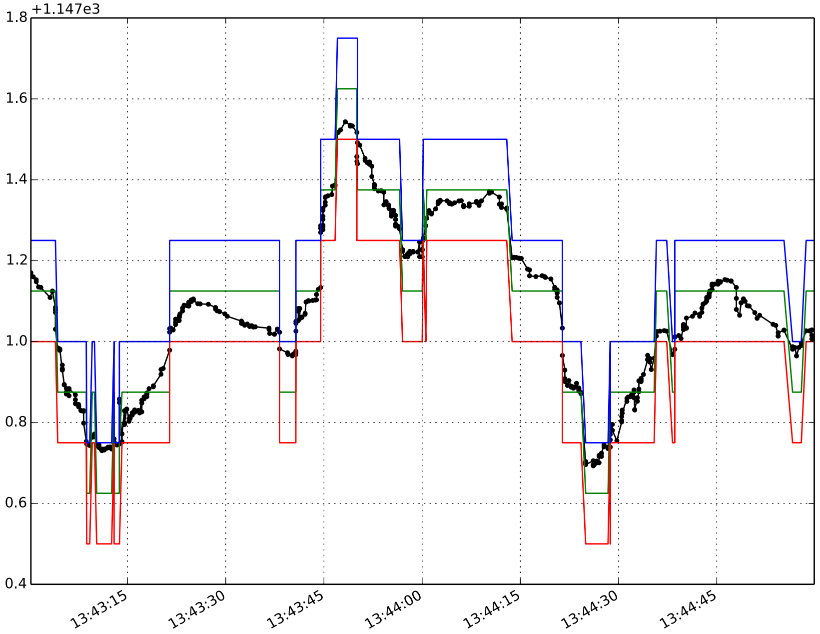
Calibration issues. Nonstationarity (III). Scheduled macroeconomic announcements



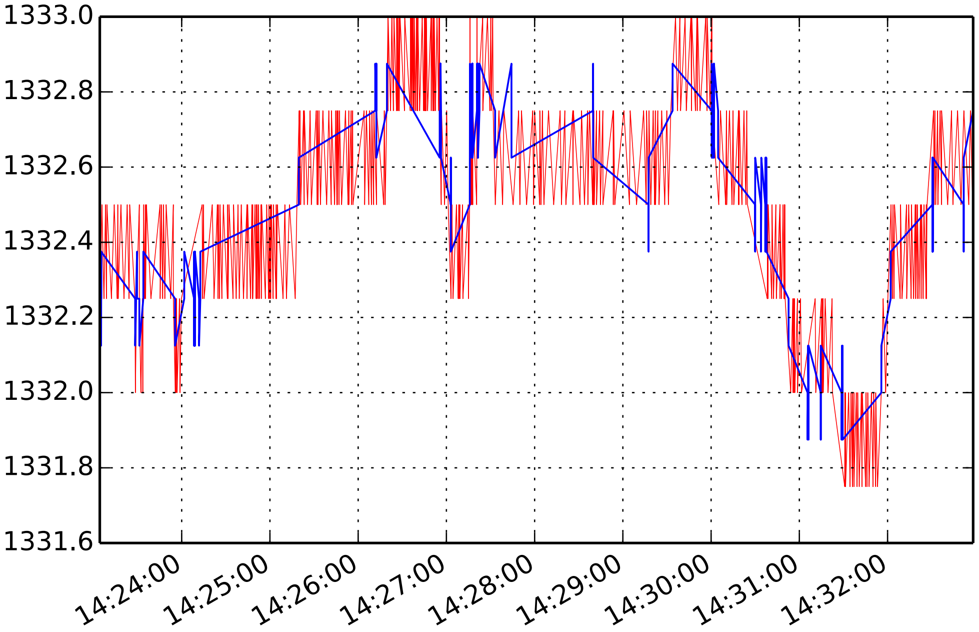
Source: R. Almgren (2012)
Quantitative Brokers

Calibration issues. The choice of proxy

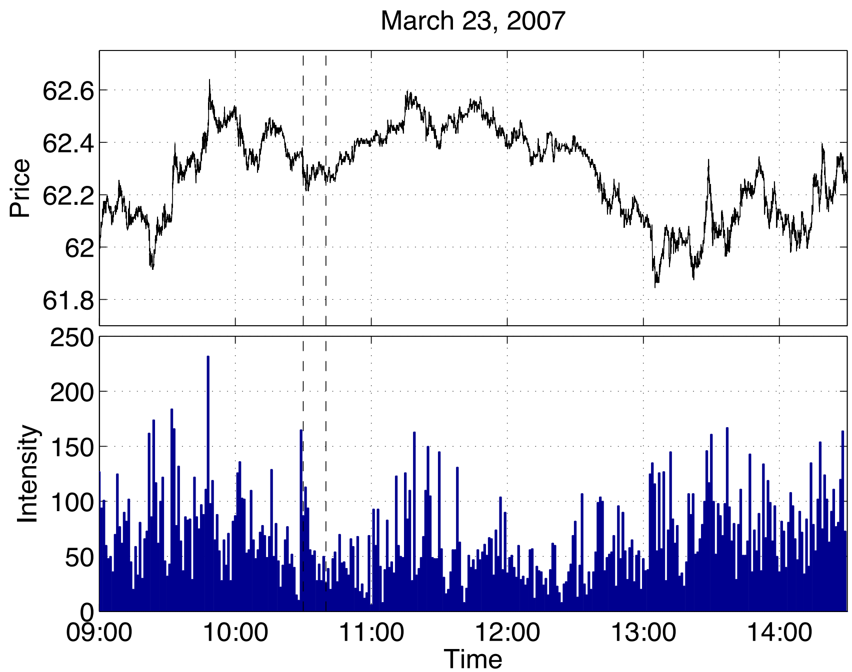
Dynamics of bid (red), ask (blue), mid-quote price (green) and micro-price (black)

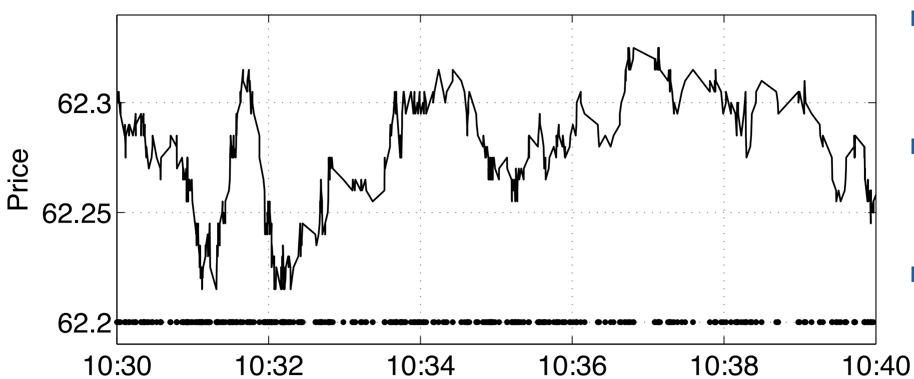


Dynamics of last transaction price (red) and mid-quote price (blue)



Methodology





n = 0.43

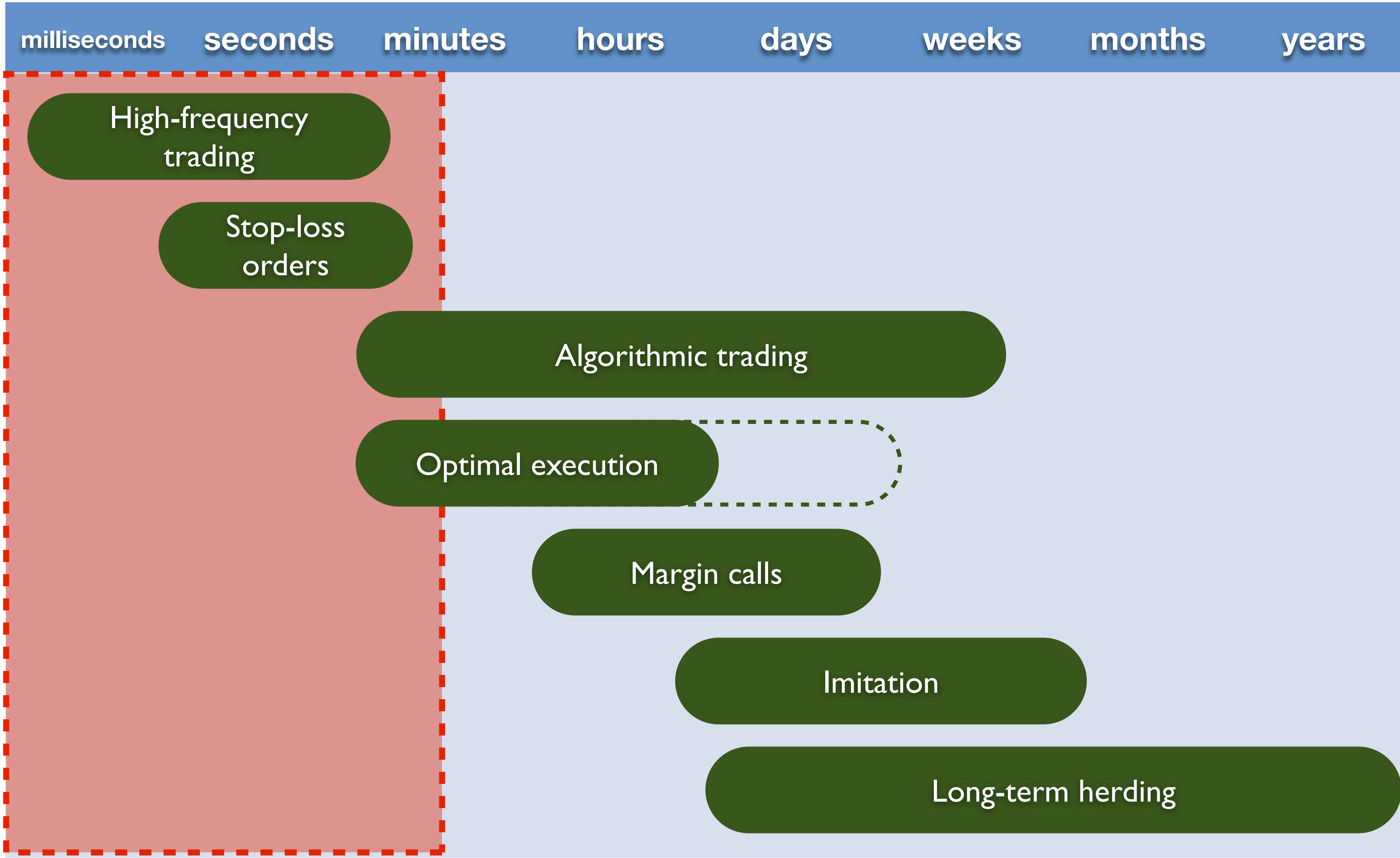
- We split the entire interval of the analysis (2005-2012) into **10 minutes** intervals, rolling them with a step of 1 minute within the RTH
- In each of these windows we have calibrated **the Hawkes model with the short-term exponential kernel**

$$\lambda_t(t) = \mu + \frac{n}{\tau} \sum_{t_i < t} \exp\left(-\frac{t - t_i}{\tau}\right)$$

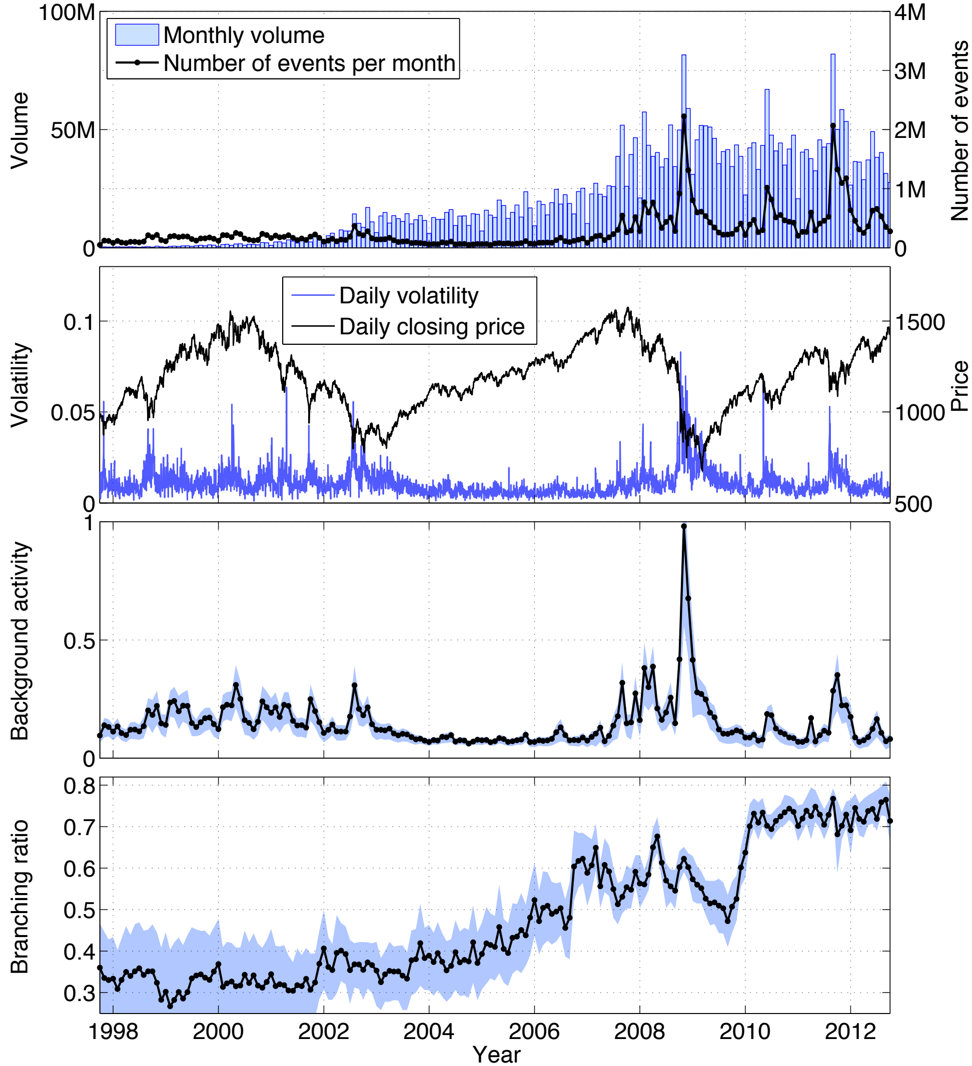
on the timestamps of mid-quote price changes

- Each calibration resulted in a single estimation of the **branching ration (n)**
- We have performed residual analysis and rejected “bad” fits (using KS-test)
- Collecting all estimates for each month (~6000-7000 estimates) we have averaged them to construct the **“endogeneity index”** for the given month

Mechanisms of self-reflexivity



Benchmark: Financial markets (E-mini S&P 500)



Trading activity
proxied by volume and
number of mid-price changes

Dynamics of **price** and **volatility**

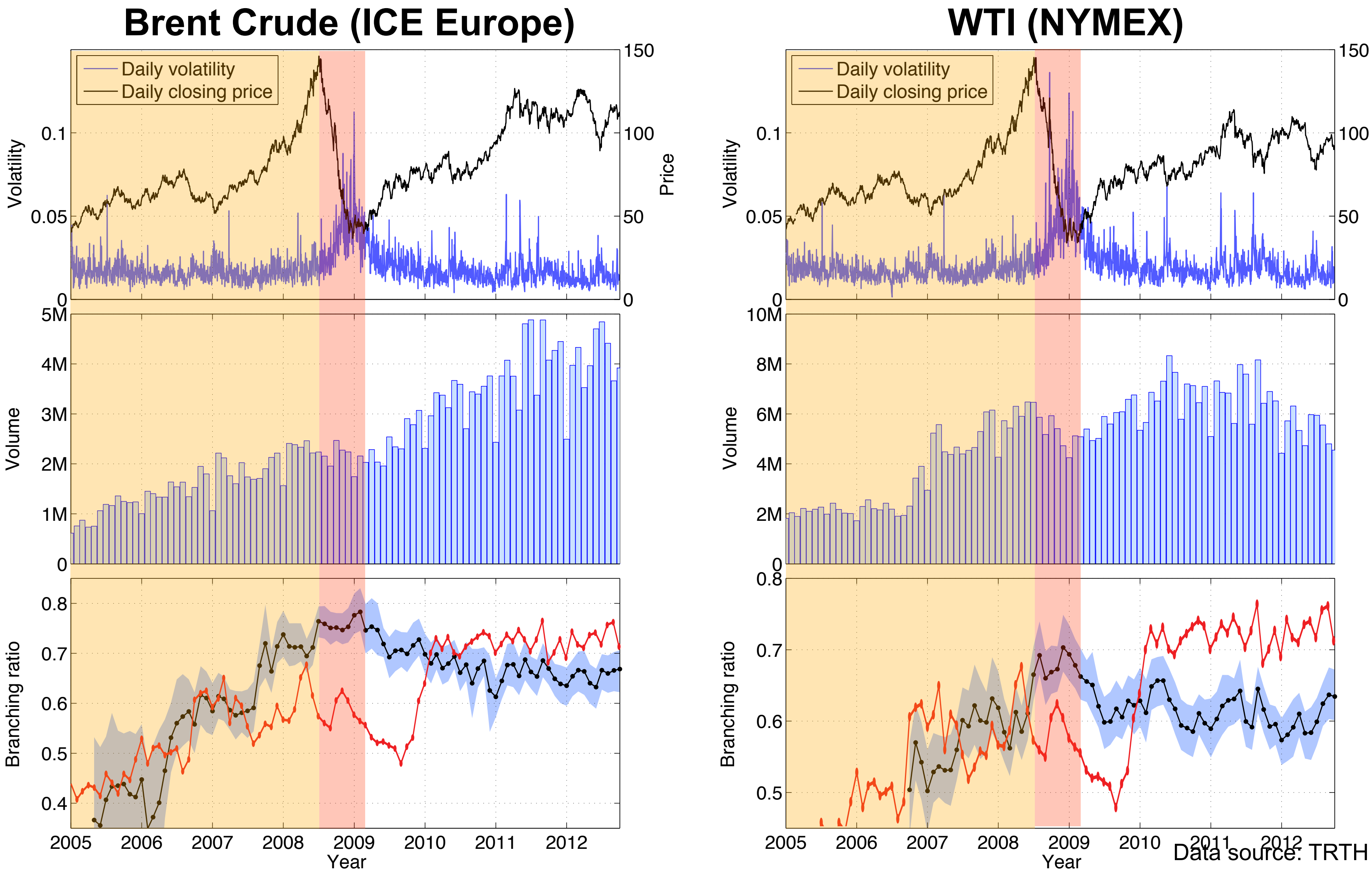
Rate of exogenous events
(triggered by **idiosyncratic**
"news")

Branching ratio that quantifies
endogeneity of the system
(fraction of endogenous events
in the system)

Data source: TRTH

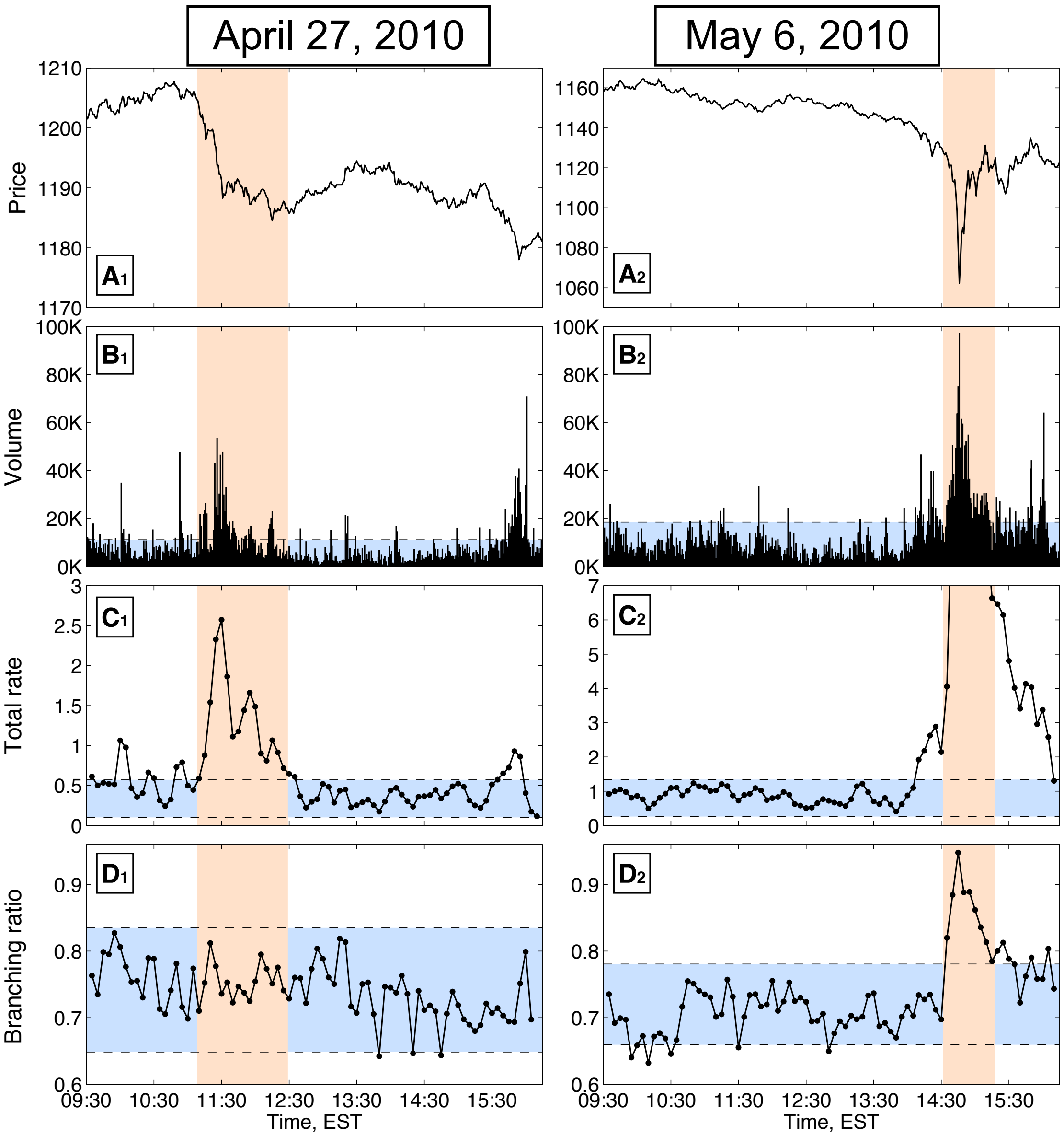
- Filimonov V., Sornette D. (2012) Physical Review E 85(5), 056108
- Filimonov V., Bicchetti D., Maystre N., Sornette D. (2014) J. of Int. Money and Finance, 42, 174-192

Crude Oil: Brent and WTI



• Filimonov V., Bicchetti D., Maystre N., Sornette D. (2014) J. of Int. Money and Finance, 42, 174-192

Exogenous vs endogenous shocks in HF



April 27, 2010:

Significant fall of most of US markets following the cut of the credit rating of Greece and Portugal

May 6, 2010 ("flash-crash"):

The activity of high-frequency traders of the S&P 500 E-mini futures contracts leaded to a dramatic fall in other markets

Volume and **Trading activity** behave similar in both cases

Branching ratio ("endogeneity index") reveals fundamental difference between two shocks

Source: V. Filimonov, D. Sornette (2012) PRE 85 (5): 056108.

References

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