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# How is the Continued Proliferation of HFT Impacting Financial Markets?

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**PRINCETON UNIVERSITY QUANT**

# Presentation Roadmap

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## Outline

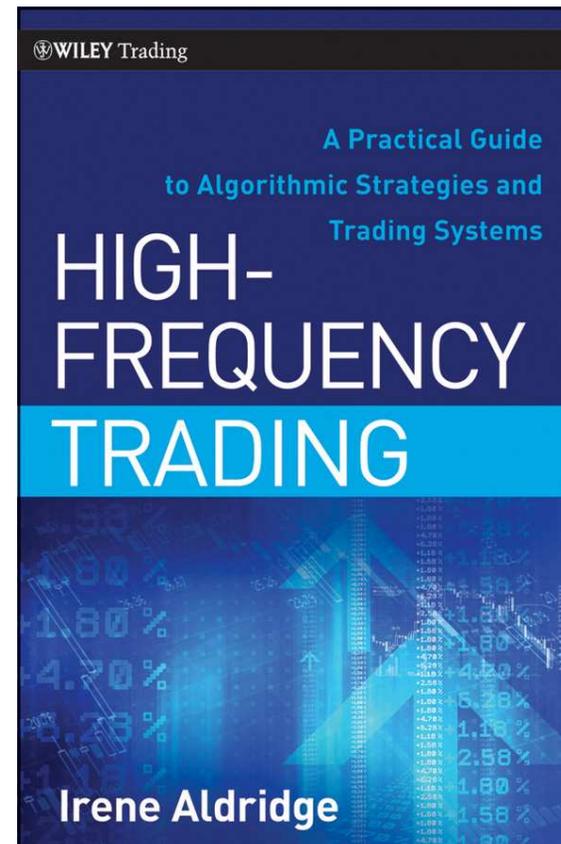
- 1. Developments in modern securities markets**
2. How to measure impact
3. How to detect adverse HFT impact
4. HFT Impact: case study
5. Implications and further research

# Reference

“Can High-Frequency Traders Game Futures?”, *forthcoming, Journal of Trading*

Aldridge, Irene. High-Frequency Trading: A Practical Guide to Algorithmic Strategies and Trading Systems. Wiley & Sons, 2009, Chapter 5. ISBN: 0470563761. Available on Amazon.com.

New edition of the book is forthcoming later this year.

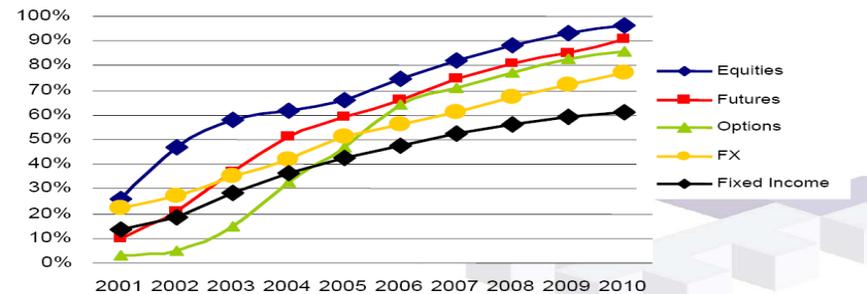


# 1. Developments in modern securities markets

## Evolution of trading

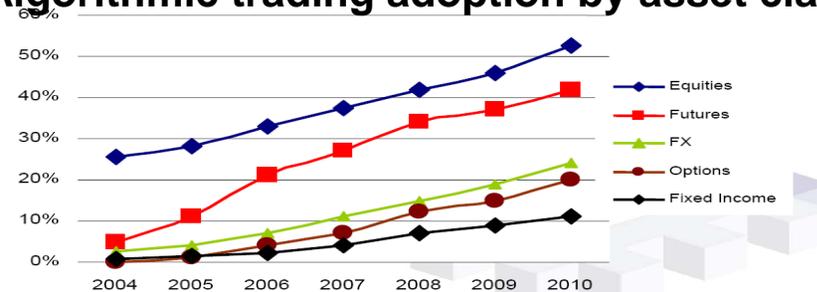
- Open outcry method of trading
- Virtual trading floor electronically
- Disintermediation
- Market booms and crashes
- Shorter settlement cycles
- Standardization using FIX protocol
- Program trading
- Digitalization of trading – Algorithmic trading

## Adoption of electronic trading



Source: Aite Group Estimates

## Algorithmic trading adoption by asset class



Source: Aite Group estimates

Electronization of markets is relentless

# 1. Developments in modern securities markets

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## High-frequency defined

- High-frequency trading is an umbrella term
- Industry consensus: high-frequency trading means
  - Systematic,
  - Quant-based models
  - With holding periods from a fraction of a second to 1 day (no positions held overnight)

## Core strategies

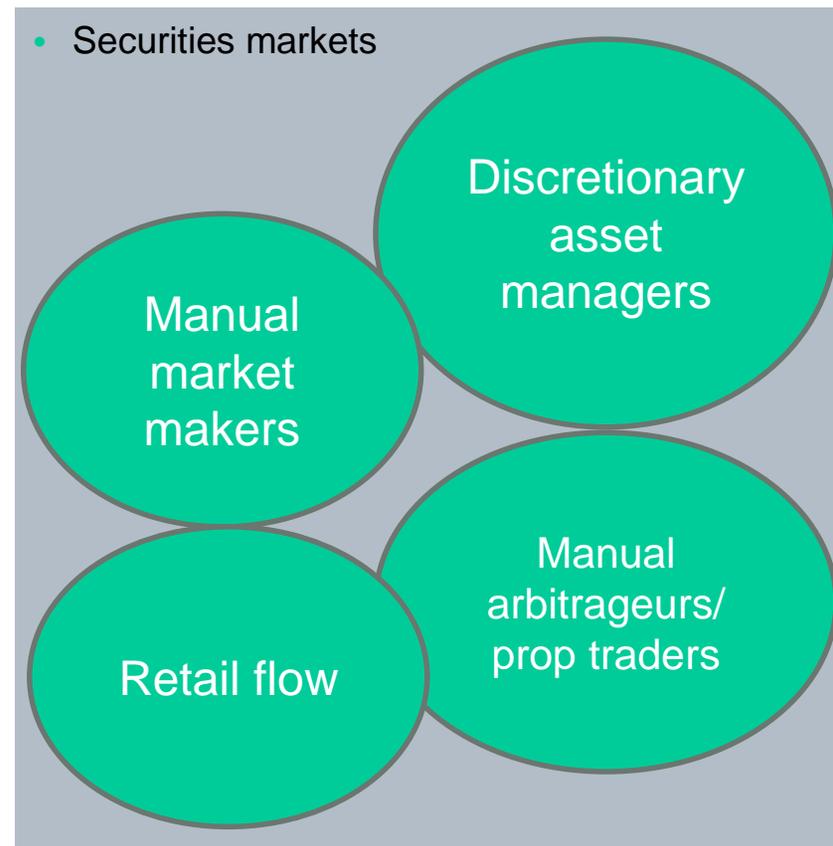
- Automated liquidity provision = “Inventory market microstructure”:
  - Quantitative algorithms for optimal pricing and execution of market-making position
  - Position holding time: < 1 minute
- Information microstructure trading:
  - Identifying trading party order flow through reverse engineering of observed quotes
  - Position holding time: < 10 minutes
- Event trading:
  - Short-term trading on macro events
  - Position holding time: < 1 hour
- Statistical Arbitrage
  - Arbitraging deviations from equilibrium: triangle trades, basis trades, etc.
  - Position holding time: < 1 day

# 1. Developments in modern securities markets

## Traditional market participants

- Traditional players:
  - Discretionary asset managers
    - Pension funds, mutual funds and hedge funds
  - Manual market makers
    - Broker-dealers
  - Manual speculators
    - Broker-dealer proprietary trading
  - Retail flow
    - Mom-n-pop
- Key characteristics
  - High transaction costs
    - => low turnover of securities
  - Manual processing
    - => high degree of error
    - => high risk (traders judgment may fail)
  - High margin businesses

## Before Electronization



**Steady-state labor-intensive processes generated high margins**

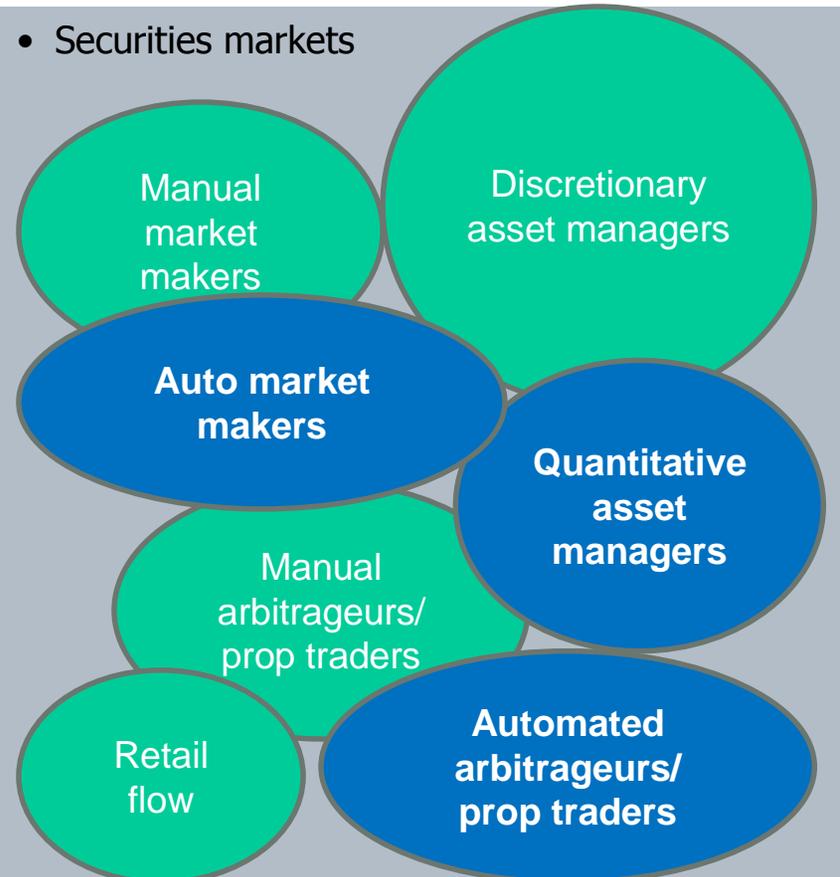
# 1. Developments in modern securities markets

## Modern markets

- New entrants:
  - Quantitative money managers
    - Mutual funds and hedge funds
  - Automated market makers
    - Broker-dealers and hedge funds
  - Automated arbitrageurs
    - Stat arb hedge funds, prop traders
- Key characteristics
  - Democratic access to markets
  - Lower transaction costs
    - Examples: retail cost per trade in 1998: \$70 with Merrill Lynch, retail cost per trade in 2008: \$7.00 with Schwab, \$0.70 with Interactive Brokers, a 100 times cost reduction over 10 years
    - Enables high turnover of securities
  - Automated trading, order routing and settlement
    - Low degree of error
  - Lower \$\$ margins for everyone

## Now: new entrants

- Securities markets



**Automation opens up access, reduces margins for all**

# 1. Developments in modern securities markets

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## Complaints against HFT:

- “HFTs are responsible for partial fills,” leading large investors on with market impact
  - A large institutional investor
- “HFTs drive prices away from fundamental values”
  - United Nations

“Traders placing large orders run the risk that [the mere size of their orders] signals they are a large buyer or seller – a process known as ‘information leakage’ – prompting the market to move against them, [causing the market reaction] known as ‘market impact.’”

- Financial Times

# 1. Developments in modern securities markets

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## **Academics are largely pro-HFT**

- High-frequency trading is mostly good
  - Gomber, Arndt, Lutat, and Uhle (2011) survey
- High-frequency trading assists the markets in:
  - Supplying liquidity
  - Reducing volatility
  - Both are key to healthy markets
- Studies include: Jarnecic and Snape (2010), Brogaard (2010), Hasbrouck and Saar (2010), and Groth (2011)

## **Traditional investors, media are against HFT**

- Media, traditional investor consensus:
  - HFT does not add value
  - HFT raises costs via market impact

# Presentation Roadmap

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## Outline

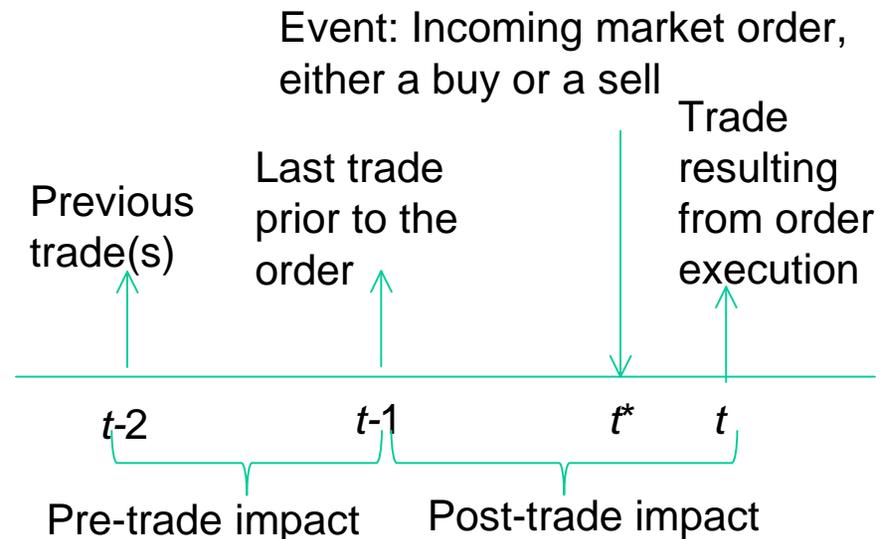
1. Developments in modern securities markets
- 2. How to measure impact**
3. How to detect adverse HFT impact
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## 2. How to measure impact

### Market impact

- Allows tick-by-tick analysis of market activity
- Easy to interpret results
- Here: assess post-trade market impact only
$$\Delta P_t = \ln(P_t) - \ln(P_{t-1})$$
- Can use event study methodology to estimate market impact

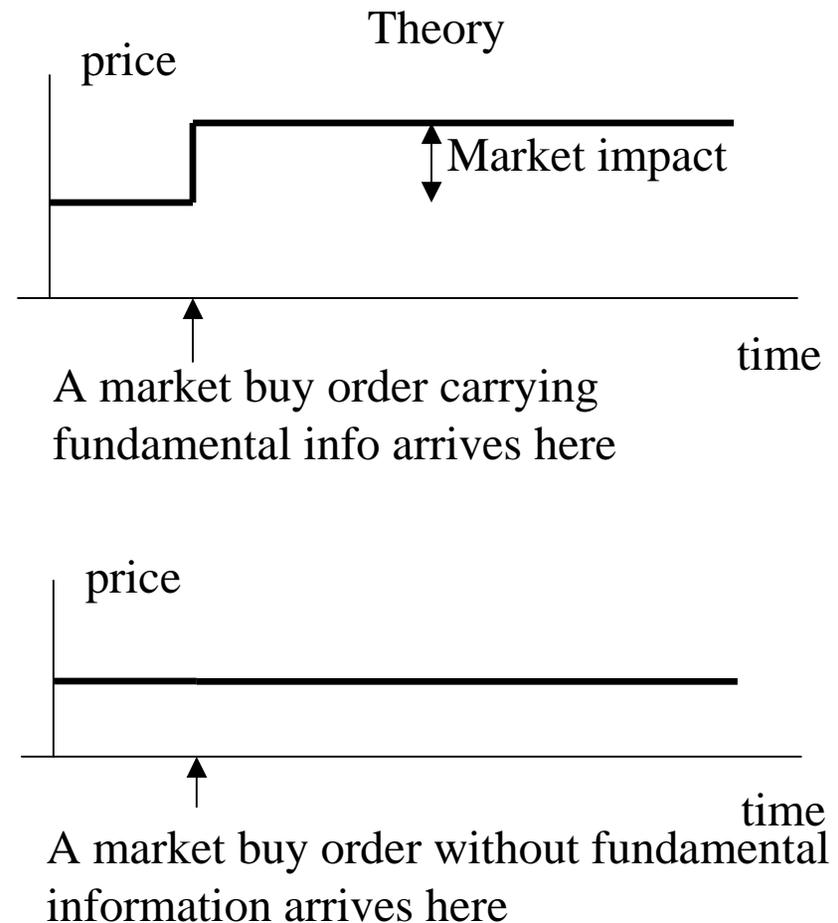
### Measuring market impact



## 2. How to measure impact

### Background

- Every order is a credible signal, transmits information (Bagehot, 1971)
- Information embedded in each order can translate into prices with varying speeds (Kyle, 1985)
  - To measure the speed, use Market Impact
  - Market Impact = price change in response to an order

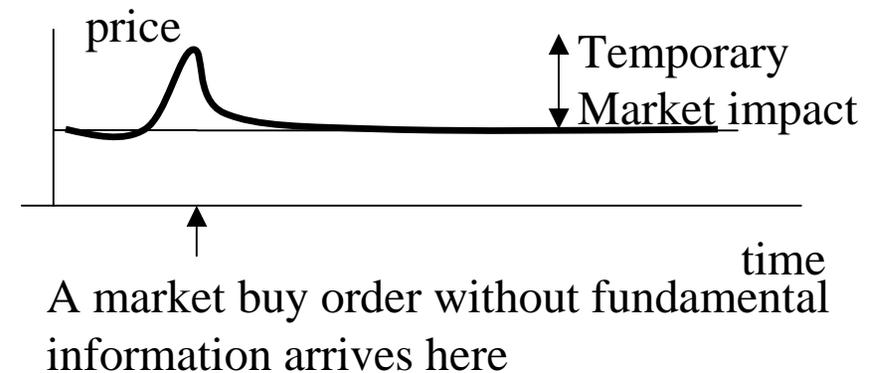
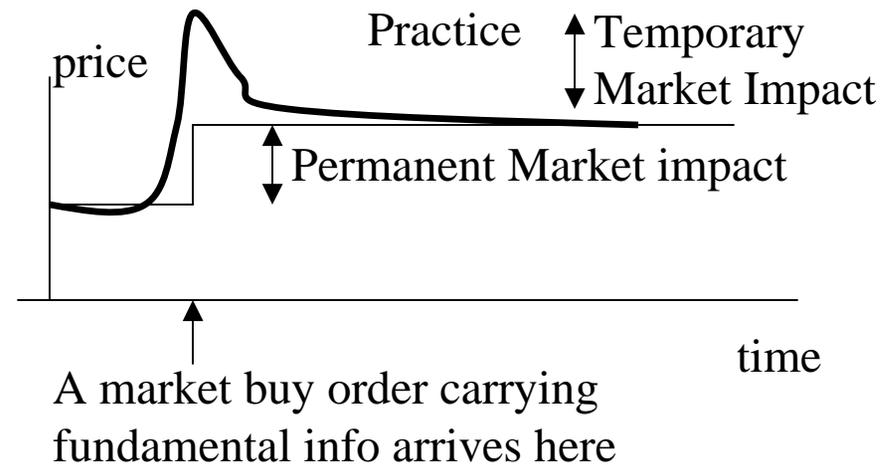


## 2. How to measure impact

### Market Impact Classification

(Glosten, 1987, and Easley and O'Hara, 1987):

- Permanent (impounds information into prices), consistent with market efficiency (Fama (1970))
- Temporary (noise)



## 2. How to measure impact

### Market Impact: functional specification

Total market impact function has been found to be:

- Linear with respect to order size

$$\Delta P_t \sim V_t$$

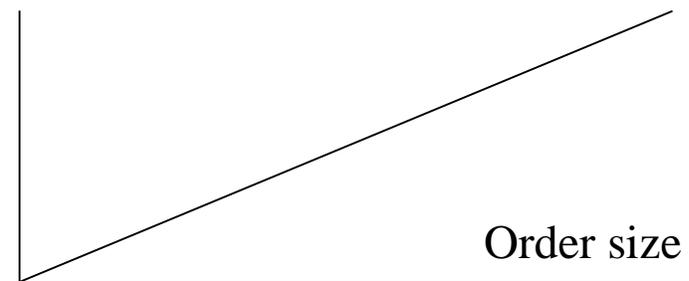
- Breen, Hodrick and Korajczyk (2002)
- Kissell and Glantz (2002)

- Power law function with respect to order size

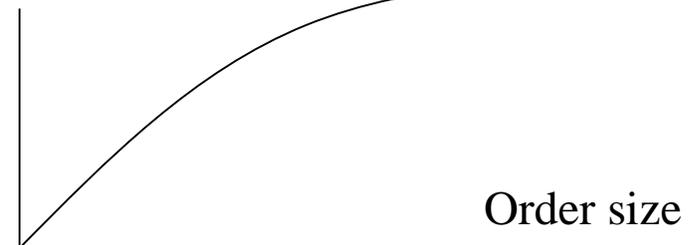
$$\Delta P_t \sim (V_t)^\beta$$

- Lillo, Farmer and Mantegna (2003)

Total market impact



Total market impact

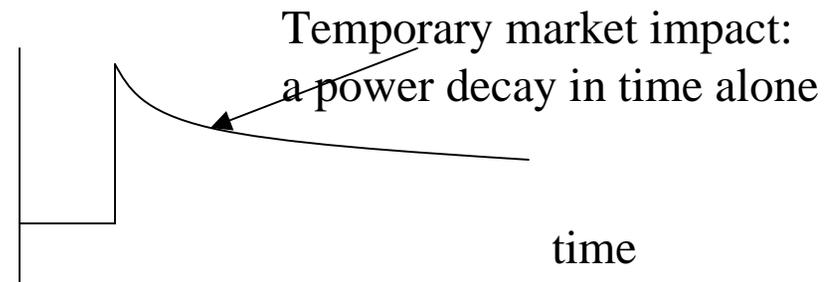
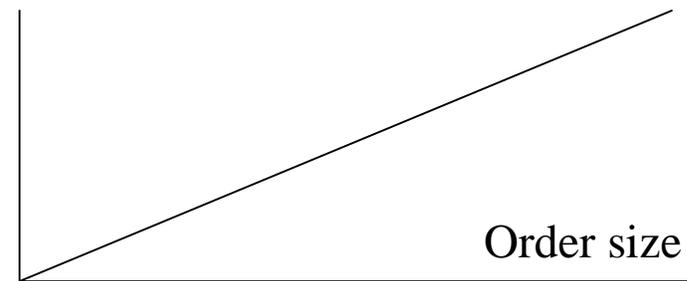


## 2. How to measure impact

### Latest research

- Permanent market impact has to be linear
  - If it were not linear, it would be easy to arbitrage until it is linear
  - Consistent with both  $\Delta P_t \sim V_t$  and  $\Delta P_t \sim (V_t)^\beta$  with  $\beta = 1$
  - See Huberman and Stanzl (2004), Gatheral (2009)
- Temporary market impact
  - Power-law decay in time
  - Gatheral (2009)

Permanent market impact



↑ Market buy order

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## 2. How to measure impact

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### **Market impact may depend on other variables**

- In futures:
  - Liquidity
    - Burghardt, Hanweck, and Lei (2006)

### **Market impact may depend on other variables**

- In equities:
  - Inter-trade durations
    - Dufour and Engle (2000)
  - Stock-specific characteristics
    - Breen, Hodrick, and Korajchyk (2002)
    - Lillo, Farmer and Mantegna (2003)
    - Almgren, Thum, Hauptmann, and Li (2005)
  - Volatility and spread in commercial models
    - Ferraris (2008)

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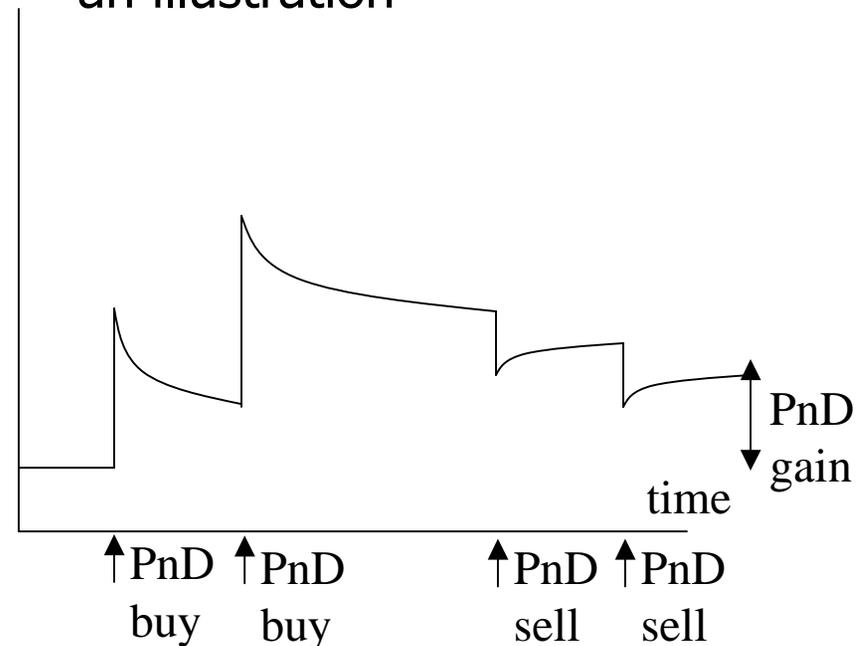
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# 3. How to detect adverse HFT impact

## High-frequency “pump-and-dump”

- AKA “bear raid”
- A specific case of potential HFT manipulation
- An Pump-and-dump (PnD) strategy would
  - Pump: place buy (sell) orders in a rapid sequence
    - Create an impression of high (low) permanent impact, artificially inflating (deflating) prices
  - Dump: sell (buy) security once the price has substantially departed from fundamentals

HFT “pump-and-dump” (PnD), an illustration

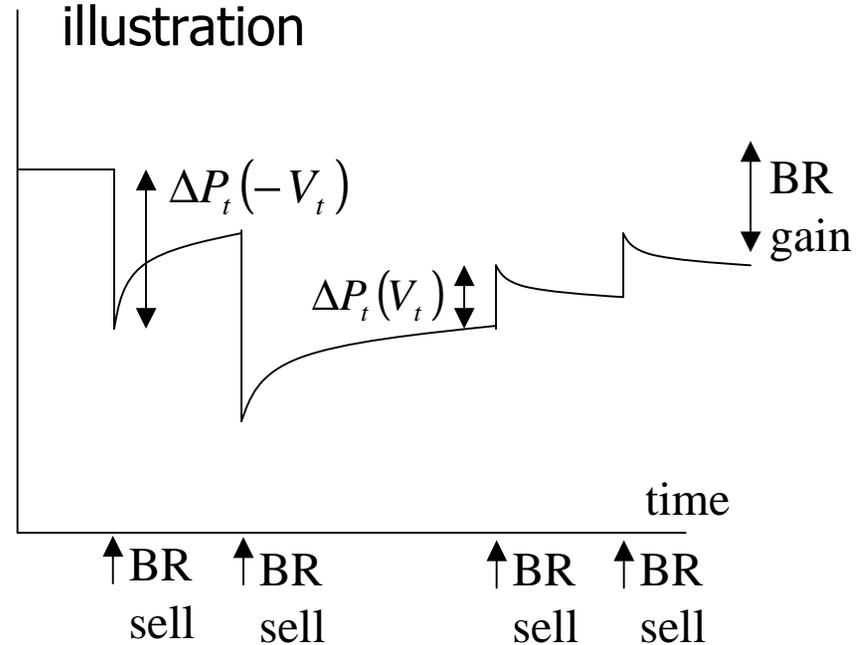


# 3. How to detect adverse HFT impact

## Pump-and-dump feasibility

- Pump-and-dump (bear raids) are only feasible under one specific market condition
  - Permanent market is NOT symmetric between buys and sells
  - Gatheral (2009)
- Notation:
  - Trade size:  $V_t$
  - Market impact:  $\Delta P_t(V_t)$

HFT "bear raid" (BR), an illustration



In the example, BR is profitable because  $\Delta P_t(V_t) < -\Delta P_t(-V_t)$

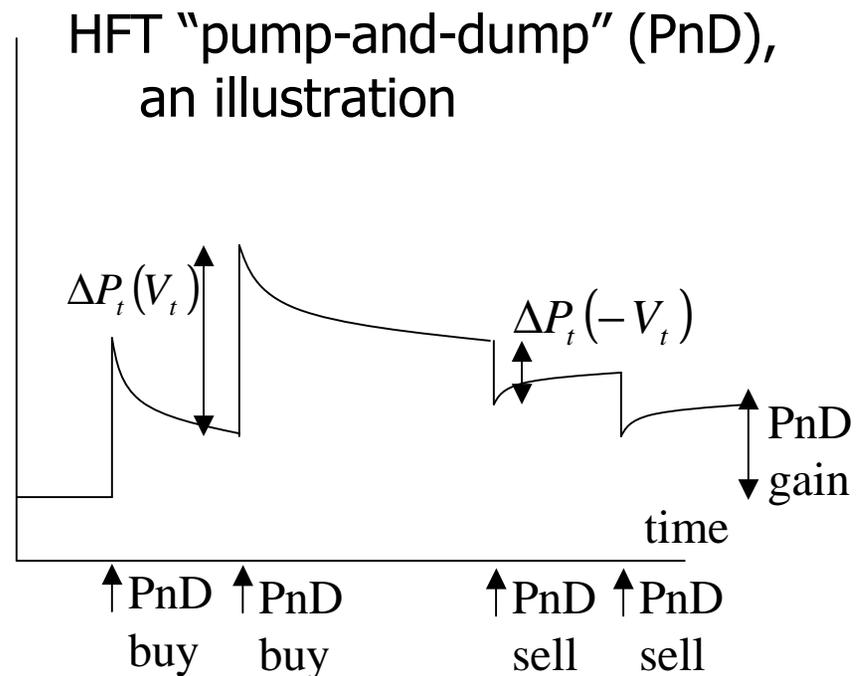
### 3. How to detect adverse HFT impact

“If  $\Delta P(v) > -\Delta P(-v)$ , we could manipulate the market price by buying then selling

at the same rate and conversely if  $\Delta P(v) < -\Delta P(-v)$ , we could manipulate

the market price by selling then buying at the same rate.”

—Gatheral (2009)



In the example, pump-and-dump is profitable because  $\Delta P_t(V_t) > -\Delta P_t(-V_t)$

### 3. How to detect adverse HFT impact

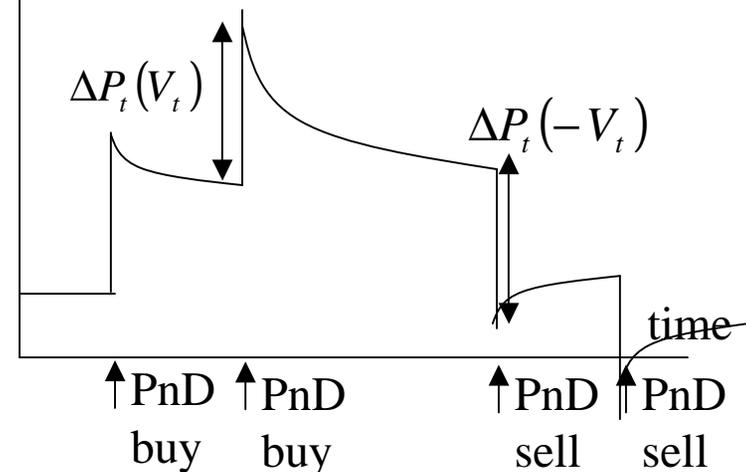
#### No pump-and-dump condition:

$$\Delta P_t(V_t) = -\Delta P_t(-V_t)$$

#### What about temporary impact?

- Temporary Impact (power-law decay) is only time-dependent
- Has no impact on pump-and-dump feasibility

When market impact is symmetric for buys and sells, pump-and-dump (or a bear raid) is NOT feasible



Testable hypothesis: Is  $\Delta P_t(V_t) = -\Delta P_t(-V_t)$  ?

# Presentation Roadmap

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## Outline

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## 4. HFT Impact: case study

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### Hypotheses:

- Null hypothesis: pump-and-dump exists
- Alternative hypothesis: pump-and-dump does not exist

### Methodology:

- Estimate market impact function as a linear function of  $V$

$$\Delta P_{t+\tau} = \alpha_{\tau} + \beta_{\tau} V_t + \varepsilon_{t+\tau}$$

- Null hypothesis:

$$H_0 : \beta_{\tau} |_{\text{buyer-initiated trades}} \neq -\beta_{\tau} |_{\text{seller-initiated trades}}$$

- Alternative hypothesis:

$$H_A : \beta_{\tau} |_{\text{buyer-initiated trades}} = -\beta_{\tau} |_{\text{seller-initiated trades}}$$

# 4. HFT Impact: case study

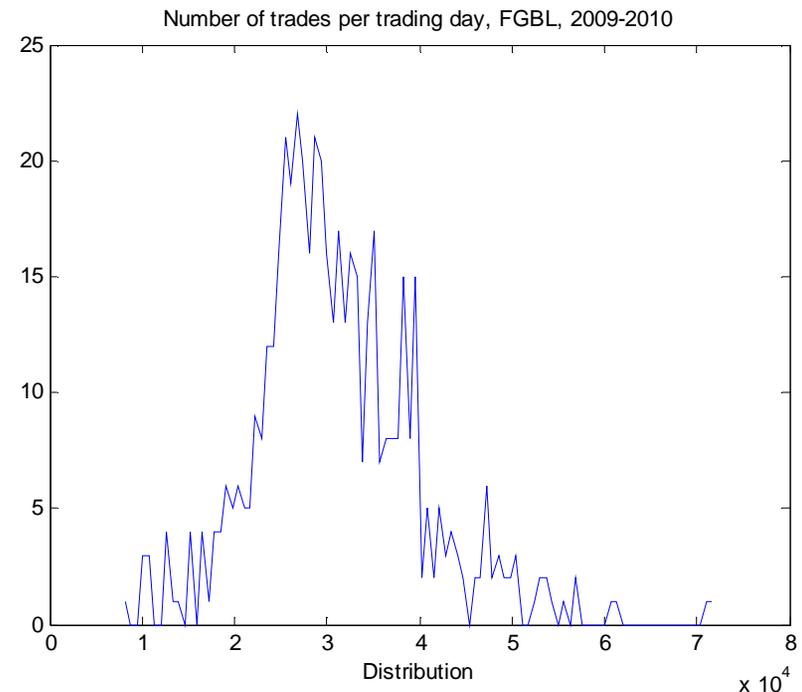
## Data: Eurobund futures (FGBL)

- Traded on Eurex
- All trade ticks 2009-2010
  - Timestamp
  - Trade price
  - Trade size
- No quote information
- No information on the identity of trade originators
- No information on whether the trade was buyer- or seller-originated.

## FGBL is very liquid:

10,000-80,000 trades per day

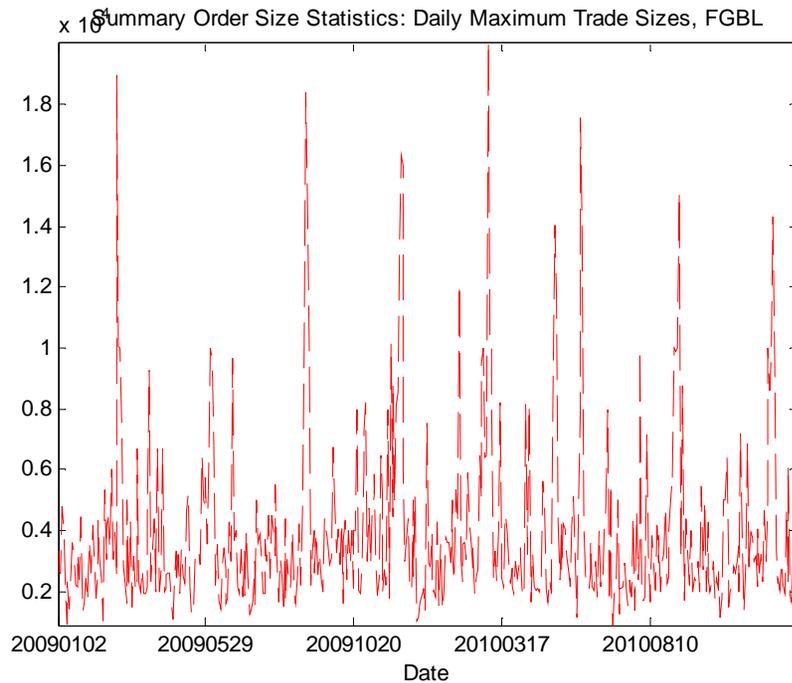
## Distribution of trades per day



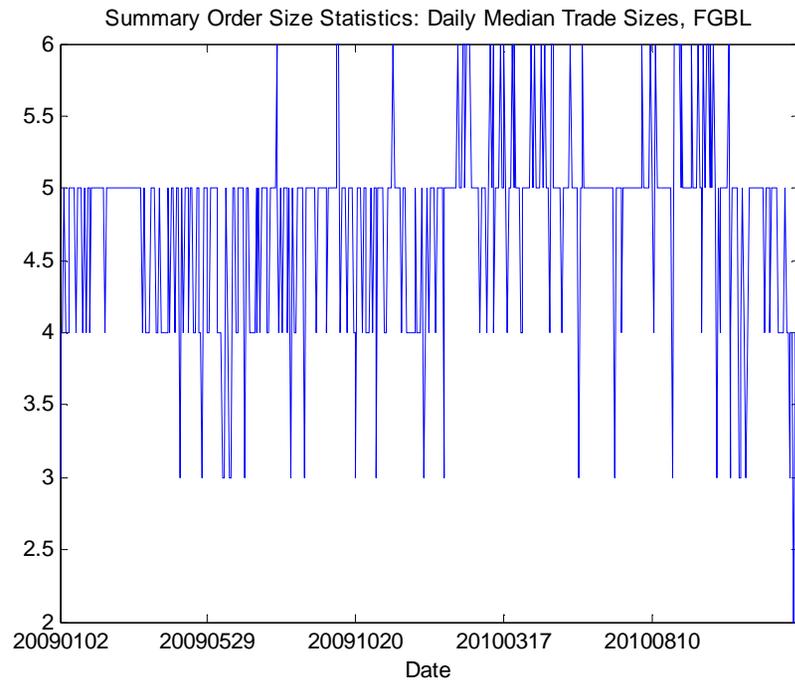
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# 4. HFT Impact: case study

Lots of large trades  
>20,000 contracts



Median trade size is small  
~ just 5 contracts

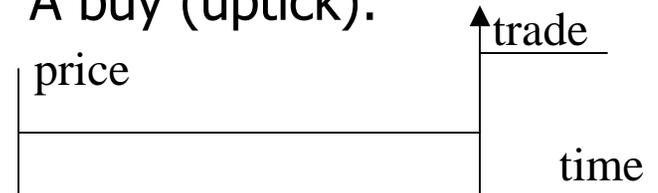


## 4. HFT Impact: case study

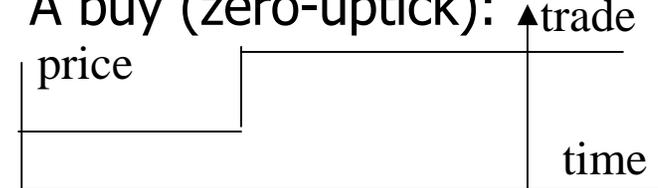
Use Tick Rule to separate buys and sells

- A trade is a buy if it occurred on an uptick or zero-uptick:
  - An uptick, if the trade price is higher than the price of the previous trade
  - A zero-uptick, if the price has not moved, but the last recorded move was an uptick
- A trade is a sell if it occurred on a downtick or zero-downtick:
  - A downtick, if the trade price is lower than the price of the previous trade
  - A zero-downtick, if the price has not moved, but the last recorded move was a downtick

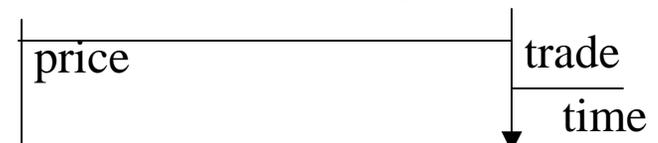
- A buy (uptick):



- A buy (zero-uptick):



- A sell (downtick):



- A sell (zero-downtick):



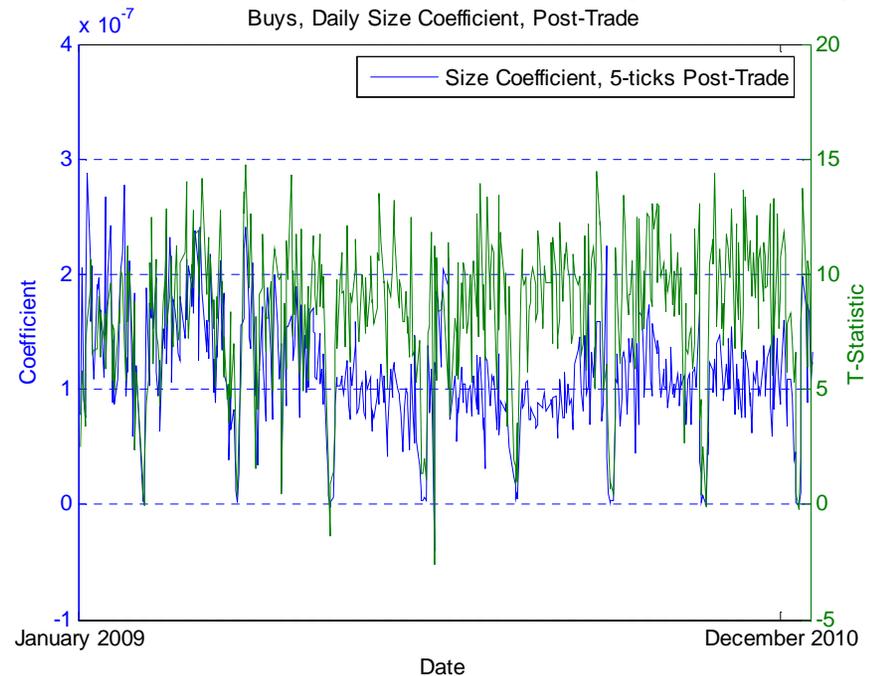
# 4. HFT Impact: case study

## Estimation on buyer-initiated trades

$$\Delta P_{t+\tau} = \alpha_{\tau} + \beta_{\tau} V_t + \varepsilon_{t+\tau}$$

- The post-trade size-dependent coefficient is positive, and of the order 10E-7
  - For every 100 contracts traded, the Eurobund futures price rises 0.001% five ticks after the trade, on average.
  - The results are extremely persistent: t-ratios of 10-15 (right axis)
- The results are also largely invariant on the day-to-day basis;
  - The regular dips in market impact persistence correspond to quarter ends
  - Passive traders and hedgers roll-over their positions to avoid taking physical delivery

## Buyer-initiated trades, Beta (size coeff.)



- Size-dependent impact (coefficient beta), post-trade impact 5 ticks after each trade

**Post-trade impact for buyer-initiated trades is positive and small:**

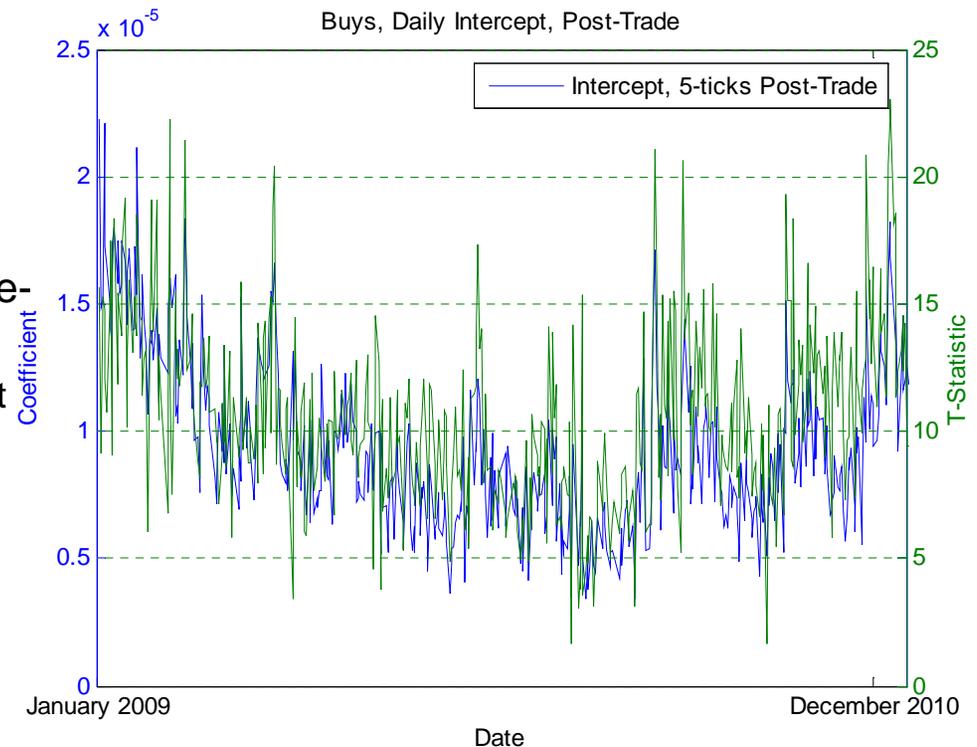
# 4. HFT Impact: case study

## Estimation on buyer-initiated trades

$$\Delta P_{t+\tau} = \alpha_{\tau} + \beta_{\tau} V_t + \varepsilon_{t+\tau}$$

- The intercept dominates the post-trade impact
- The intercept is on the order of 1E-5: one hundred times larger than the trade-size coefficient
  - The intercept is still statistically persistent (t-ratios on the order of 5-20).
  - **A trade with 1 or 100 contracts would incur approximately the same post-trade market impact!**
- The intercept is positive – leading to higher post-trade market impact
- The intercept captures factors unexplained by trade size

## Buyer-initiated trades, Alpha (intercept)



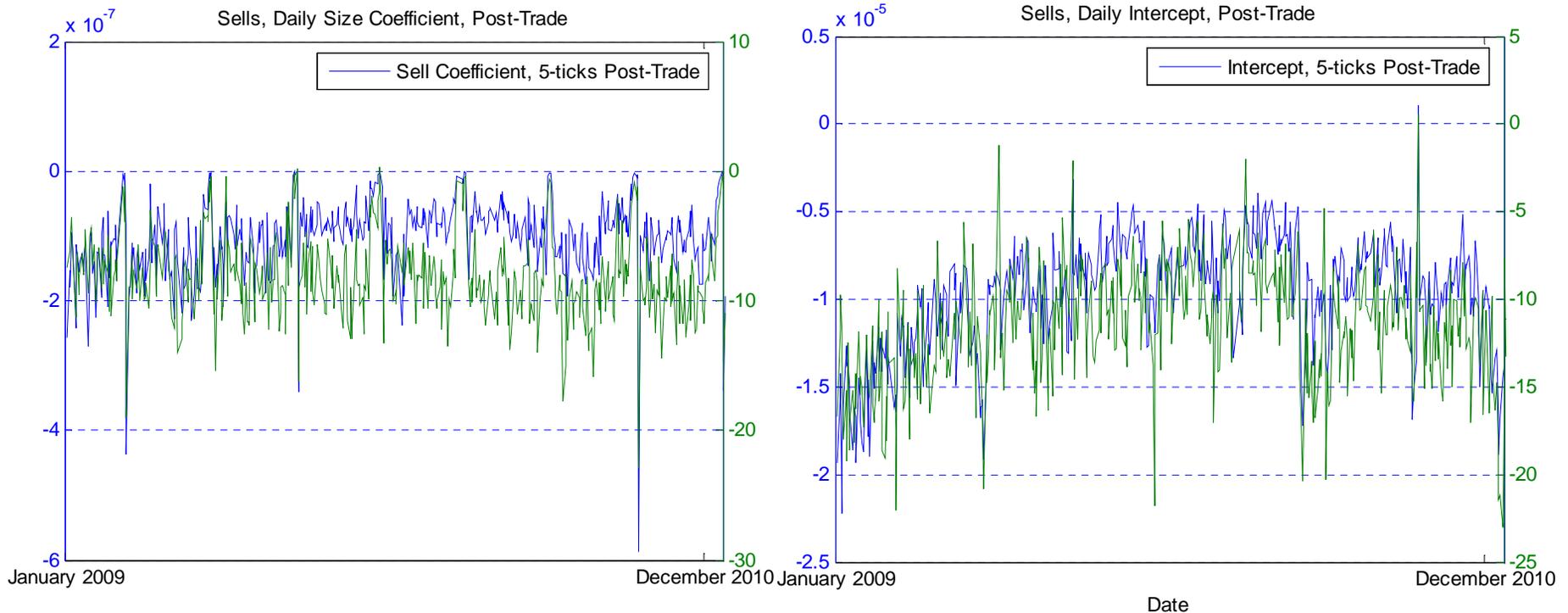
- Intercept, post-trade impact, 5 ticks after each trade

**Large trades are executed with the same market impact as small trades!**

# 4. HFT Impact: case study

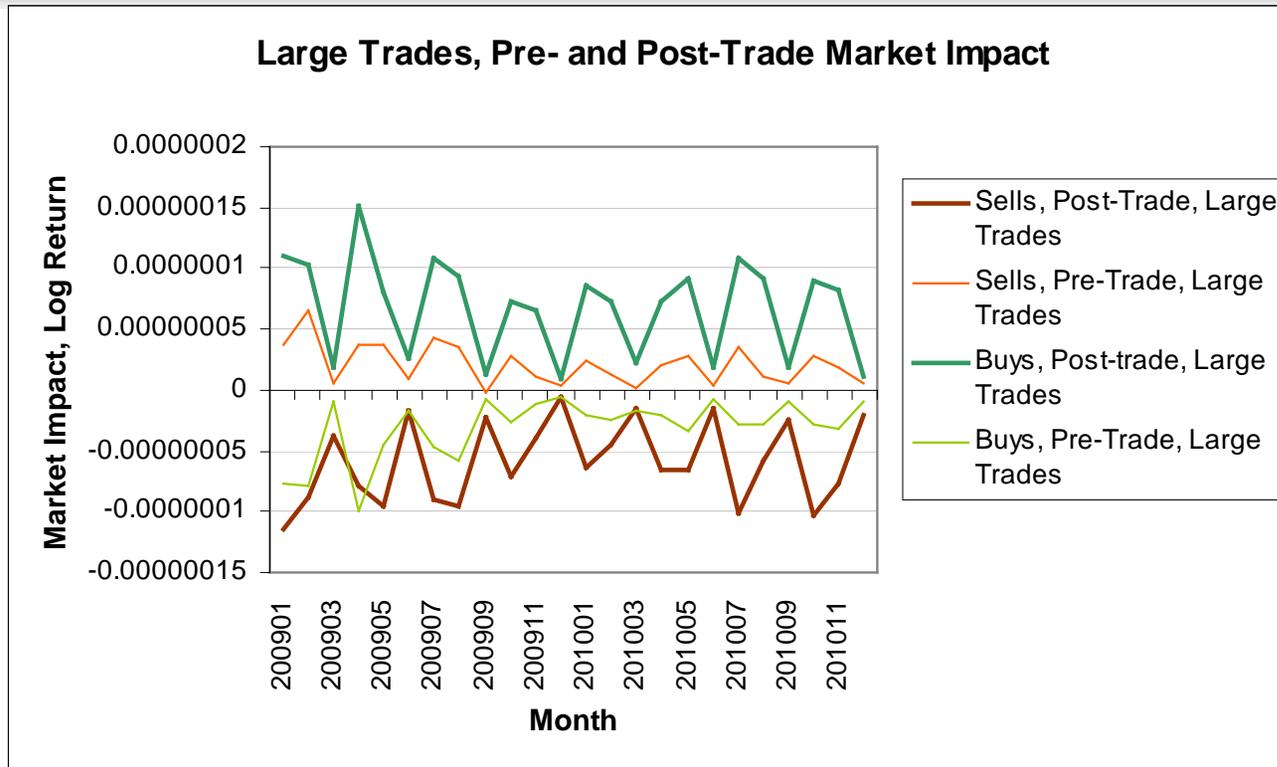
## Results for seller-initiated trades are similar in size, opposite in sign

- Sell post-trade size coefficient is negative and on the order of  $1E-7$
- Sell post-trade intercept is negative, on the order of  $1E-5$ , with t-ratios of -5 to -15



**Post-trade, size-independent characteristics dominate market impact**

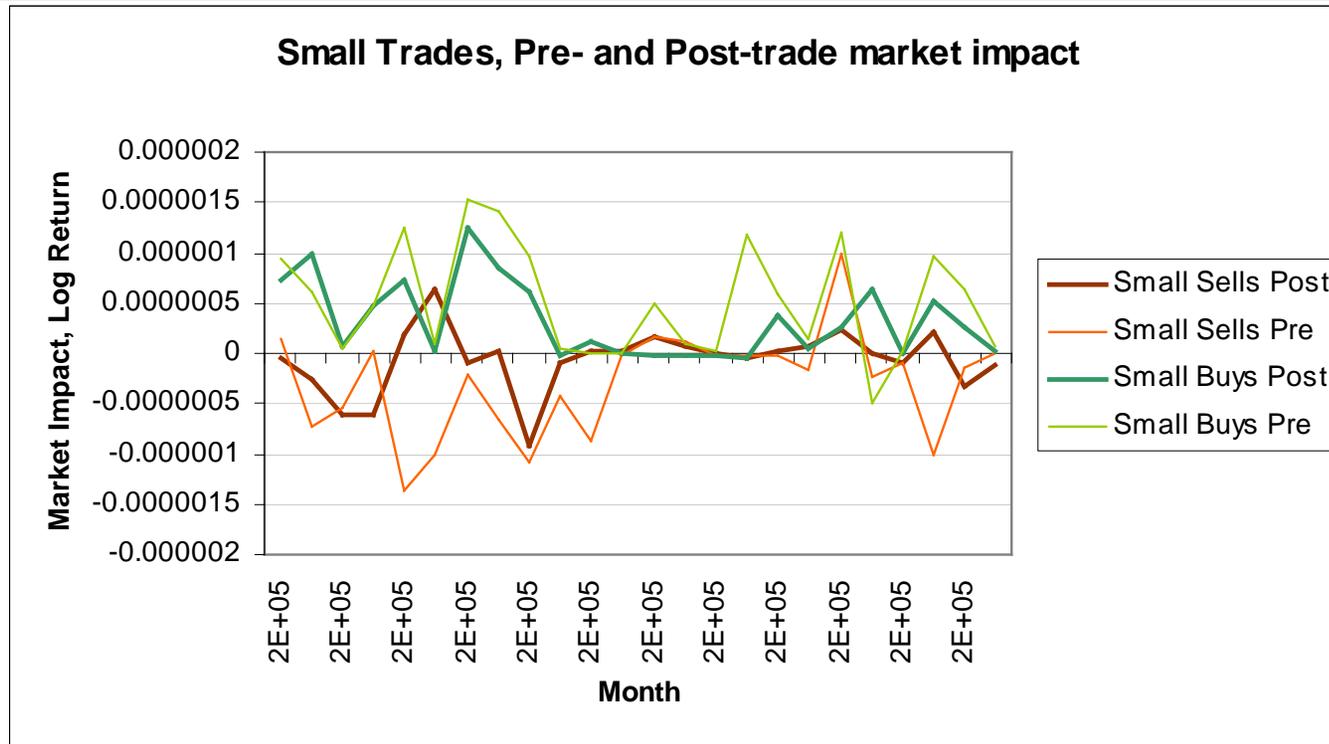
## 4. HFT Impact: case study



- Large trades: size > median (5 contracts)
- Following Huberman and Stanzi (2004) and Gatheral (2009): Symmetric market impact eliminates possibility of 'pump-and-dump'

**Pump and Dump is NOT feasible in large FGBL futures trades**

## 4. HFT Impact: case study



- Small trades: size ≤ median (5 contracts)
- Symmetry less clear cut, but the \$\$ amount gained dissipates after trading costs are taken into account

**Pump and Dump is NOT economical in small FGBL futures trades**

# 4. HFT Impact: case study

## Causality? Use VAR framework

- To measure the impact of trade size and the time of day, we used the Vector-Autoregressive (VAR) model proposed by Hasbrouck (1991) and then extended by Dufour and Engle (2000). The VAR model is specified as follows:

$$R_i = \sum_{j=1}^5 a_j R_{i-j} + \sum_{t=8}^{18} \gamma_t D_{t,i} + \sum_{j=0}^5 b_j Q_{i-j} + v_{1,i}$$

$$Q_i = \sum_{j=1}^5 c_j R_{i-j} + \sum_{t=8}^{18} \gamma_t D_{t,i-1} + \sum_{j=1}^5 d_j Q_{i-j} + v_{2,i}$$

$$b_j = \gamma_j + \delta_j \ln(V_{i-j})$$

$$d_j = \theta_j + \vartheta_j \ln(V_{i-j})$$

## Buyer-initiated trades, post-trade impact

- Q is the indicator of whether the trade  $i$  was buyer-initiated (  $Q=1$ ) or seller-initiated (  $Q=-1$ ).
- In the absence of quote data, we denote R to be the log change in trade prices from price attained at time  $i-1$  to trade time  $i$ .
- T is the time interval between trade recorded at time  $i-1$  and trade time  $i$ .
- $D$ s are the dummy indicators of the hour of the day.

**VAR captures cause and effect relationships:  
does the trade size influence market impact or vice versa?**

# 4. HFT Impact: case study

Estimate Causality using VAR, LHS = trade return

Lag trade return		Lag trade sign		Lag trade sign, lag size	
$a_1$	0.347 (71.1)	$\gamma_0$	4.1E-05 (67.4)	$\delta_0$	1.9E-07 (25.9)
$a_2$	0.151 (29.0)	$\gamma_1$	-1.3E-05 (-18.6)	$\delta_1$	8.5E-09 (1.0)
$a_3$	0.080 (15.2)	$\gamma_2$	-2.8E-06 (-3.9)	$\delta_2$	2.7E-08 (3.5)
$a_4$	0.061 (11.8)	$\gamma_3$	2.7E-06 (3.8)	$\delta_3$	2.5E-08 (3.2)
$a_5$	-0.306 (-62.5)	$\gamma_4$	7.7E-06 (11.0)	$\delta_4$	8.4E-09 (1.0)
		$\gamma_5$	-2.4E-05 (-37.6)	$\delta_5$	-1.1E-07 (-14.8)

- May 6, 2009, trade return equation
- Use five lags as in Dufour and Engle (2000) – turns out sufficient
  - Market impact is determined by:
    - Previous market impact (up to four lags),
    - Contemporaneous trade sign
    - Signed trade size up to four lags
  - The hourly dummy for the trade return equation was significant only at 10 GMT, shortly after European markets opened on May 6, 2009.
    - The coefficient accompanying the dummy was negative. This likely accompanied a macro-economic news release that had negative effect on trade returns at that hour.
  - **Adj R-sq: 46.25%!!!**

VAR captures cause and effect relationships:  
trade sign, size, lagged returns influence market impact

# 4. HFT Impact: case study

Estimate Causality using VAR, LHS = trade sign

Lag trade return		Lag trade sign		Lag trade sign, lag size	
$a_1$	-841.5 (-18.1)	$\gamma_1$	0.462 (75.8)	$\delta_1$	2E-04 (2.8)
$a_2$	-94.1 (-1.8)	$\gamma_2$	0.163 (24.6)	$\delta_2$	1.6E-04 (2.1)
$a_3$	184.5 (3.6)	$\gamma_3$	0.068 (10.1)	$\delta_3$	1.4E-04 (1.9)
$a_4$	55.7 (1.1)	$\gamma_4$	0.032 (4.7)	$\delta_4$	1.3E-04 (1.8)
$a_5$	-10.2 (-0.2)	$\gamma_5$	0.010 (1.7)	$\delta_5$	2.4E-04 (3.3)

• **Adjusted R-squared: 39.29%**

May 6, 2009, trade sign equation

- Trade sign is much less influenced by the preceding trade size
- Instead, trade sign is:
  - Positively influenced by previous trade sign (up to four lags)
  - Negatively influenced by lag 1 returns: if the price declined, the next trade is likely to be a sell, and vice versa
- The hourly dummy for the trade sign equation was only significant for 16 GMT (11 AM ET),
  - Was likely to have been a result of macro news announcements. The dummy coefficient was positive, indicating a predominance of buyer-initiated trades at that hour.

Trade size does not influence direction of the subsequent trades:  
HFTs do NOT “jump” on large traders

# 4. HFT Impact: case study

## Additional explanatory variables?

- Separate trades into buys and sells, run the following regressions:

$$R_{t,\tau} = \alpha_\tau + \beta_V V_{t+1} + \beta_{\tau,\Sigma} \hat{\Sigma}_{t,\tau} + \beta_{\tau,S} \hat{S}_{t,\tau} + \beta_{\tau,I} \hat{T}_{t,\tau} + \varepsilon_{t,\tau}$$

where

- $R_{t,\tau}$  is a log-return, measured relative to the earliest price point considered:

$$R_{t,\tau} = \begin{cases} \ln[P_t] - \ln[P_\tau], & \text{if } t > \tau \\ \ln[P_\tau] - \ln[P_t], & \text{otherwise} \end{cases}$$

- $S_t$  is the average spread observed during the event window measured as the absolute value of non-zero changes in sequential trade prices:

$$\hat{S}_{t,\tau} = \frac{1}{\tau - t} \sum_{i=t}^{\tau} \text{abs}(\ln[P_i] - \ln[P_{i-1}]), \text{ where } P_i \neq P_{i-1}$$

- $\Sigma$  is the range-based volatility observed during the event window estimated as the log return between the highest and the lowest prices during the window:
 
$$\hat{\Sigma}_{t,\tau} = \ln[P_{High[t,\tau]}] - \ln[P_{Low[t,\tau]}]$$
- The high vs. low intra-period price fluctuation has been shown to be a successful volatility measure by Garman and Klass (1980).
- $V_t$  is the size of the trade, recorded immediately subsequent to the pre-trade price  $P_t$
- $T$  is the readily-observable inter-trade durations,  $T$ , (Dufour and Engle (2000))

What explains the unexplained impact in the intercept?

## 4. HFT Impact: case study

### Additional explanatory variables do not change results

- Trade size dependency and sign hold with same statistical significance even in the presence of other variables
- Inter-trade duration results are consistent with those in equities by Dufour and Engle (2000): *shorter* intertrade durations incur *lower* market impact
- Pre-trade market impact rises with volatility for large trades, decreases with volatility for small trades.
  - Volatility coefficients are large, may help explain the entire pre-trade market impact

### Comparison with equities: market impact in FGBL is much smaller than in equities

- Overall, observed market impact in FGBL futures is much smaller than that documented for equities
- Eurex FGBL futures market impact is small, on the order of 0.02% per trade
- In equities, the ITG's Global Trading Cost Review (2010) reported:
  - The average cost of an equities trade in the U.S. in the first quarter of 2010 was 0.476%,
  - 0.089% was spent on commissions
  - the remaining 0.387% were due to market impact (the numbers were comparable to those in the E.U., the U.K., and Japan; emerging markets posted higher costs).

**Volatility is a key driver of market impact for large trades**

# Presentation Roadmap

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## Outline

1. Developments in modern securities markets
2. How to measure HFT impact
3. How to detect adverse HFT impact
4. HFT Impact: case study
5. Key results
6. Implications and further research

# Presentation Roadmap

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## Outline

1. Developments in modern securities markets
2. How to measure HFT impact
3. How to detect adverse HFT impact
4. HFT Impact: case study
- 5. Implications and further research**

# 5. Implications and further research

## Large trading coexists well with HFT

- Two commonly thought adverse actions by HFTs are not feasible, at least in FGBL futures
  - Pump-and-dump is infeasible for large traders, uneconomical for small traders
- Analysis in other markets is needed

## Further findings

- Large orders can execute in FGBL futures with little market impact
- Large traders seeking to reduce market impact costs further may choose to avoid high-volatility conditions
- Shorter intertrade durations are better market impact conditions
- FGBL futures compare favorably with equities: similar characteristics, but lower market impact costs

**HFT does NOT cause any problems for traders in FGBL futures**

# Presentation Roadmap

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## Outline

1. Developments in modern securities markets
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5. Implications and further research

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