Toxic Arbitrage

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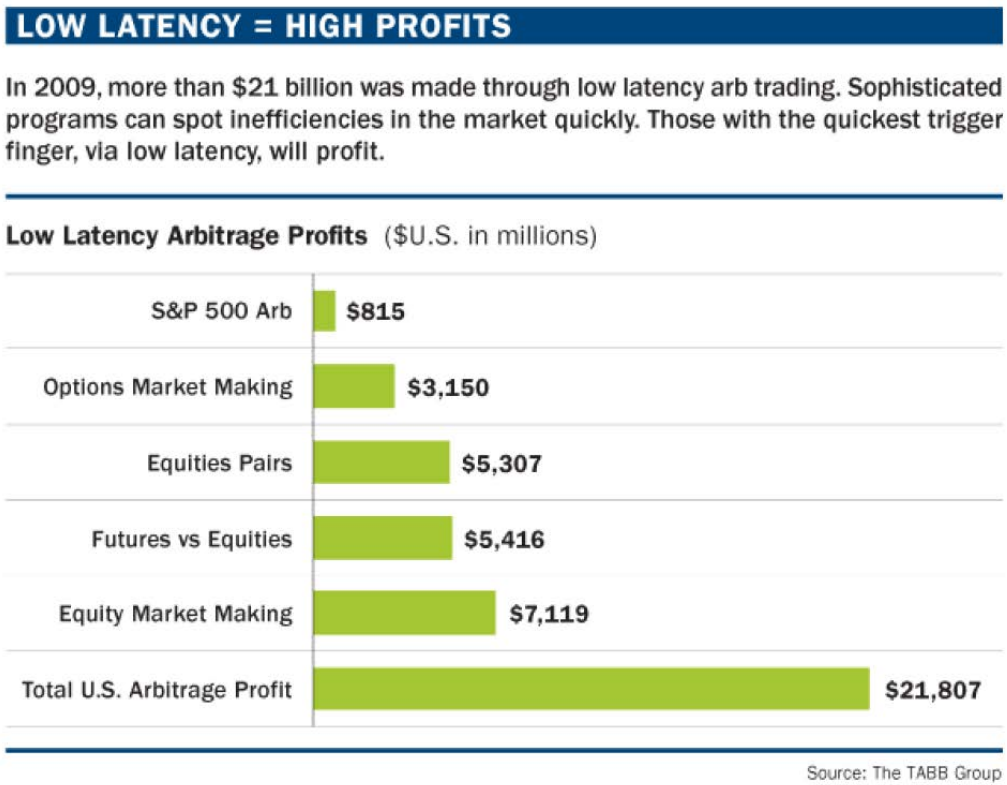
High Speed Arbitrage

- **Increased market fragmentation**
  1. 50^{+} trading platforms in U.S. equities markets
- **Proliferation of derivatives assets (ETFs, Options, Futures etc.)**
- **$\Rightarrow$ Large number of arbitrage opportunities at the high frequency**
  1. Examples: ETFs/undelying baskets, Futures/Cash, Options/underlyings, options/options, cross-listing stocks, stocks in different venues etc.
  2. Very short lived $\Rightarrow$ best exploited with machines and fast access to markets
  3. Almost riskless with tiny profits per opportunity.
- **$\Rightarrow$ A large fraction of high frequency trading is high speed cross-market arbitrage.**

Profits from High Speed Arbitrage.



High Frequency Arbitrage: Concerns

- **SEC (2010): "U.S. concept release on equity market structure."**

  " The Commission requests comment on arbitrage strategies and whether they benefit or harm the interests of long-term investors and market quality in general.[...]" (Securities Exchange Commission, 2010)

- **Yet no analysis of the effects of high frequency arbitrage because lack of data on cross-market trades by HFTs:**

  "The literature does not reveal a great deal about the extent of the HFT arbitrage strategies [...] " (Securities Exchange Commission, 2014)

Arbitrageurs: Heroes or Villains?

- **Economists tend to view arbitrage as a "good" thing:**
  1. **Arbitrageurs increase pricing efficiency:** they quickly correct mispricings due to noise/liquidity traders (Friedman (1953))
  2. **Arbitrageurs are like liquidity providers (literature on limits to arbitrage).** In correcting mispricing, they provide liquidity to noise/liquidity traders $\Longrightarrow$ "*Relaxing constraints should be desirable because arbitrageurs provide liquidity*" (Gromb and Vayanos (2012))

- **Our paper:** arbitrageurs can be a source of adverse selection $\Rightarrow$ they can make markets less liquid.
- **Why?**

Why is there a cause for concerns?

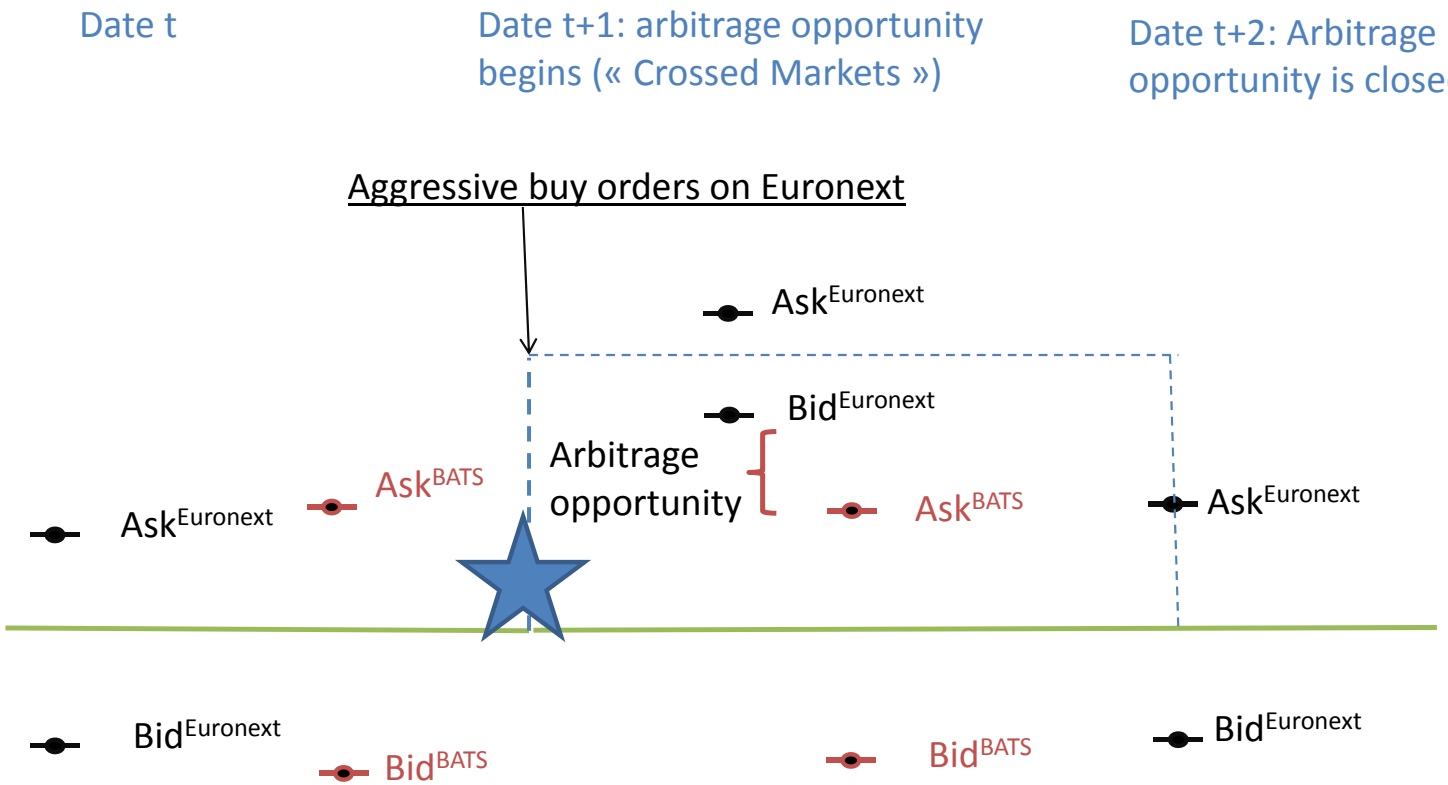
- **Where do arbitrage opportunities come from?**

1. **Transient price pressure effects:** deviations from non arbitrage relationships between assets X and Y due to a transient demand shocks in asset X.

2. **Delayed adjustments to new information:** ("stale quotes"): the price of asset Y reflects new information more quickly than the price of asset X.

Arbitrage 1: Stale Quotes.

Arbitrage 2: Transient Price Pressures.



Toxic arbitrage opportunities

- Arbitrage opportunities due to stale quotes are a **source of adverse selection** ("Picking off" or "sniping" risk) for market makers.
- $\Longrightarrow$ Arbitrage opportunities coming from asynchronous price adjustments are toxic:
  1. **They do not generate gains from trade**: the arbitrageurs' gains are his/her counterparties' losses.
  2. **They consume resources:** money spent in getting faster (e.g., hardware and infrastructure costs) is not used elsewhere.

Research questions

- **Conjectures:**
  1. **Illiquidity is higher when toxic arbitrage opportunities on days or in pairs of related assets (ETFs/Underlying basket) are more frequent**
  2. **Illiquidity is higher when arbitrageurs react faster to toxic arbitrage opportunities.**

Model

- **Two assets X and Y with payoffs $\theta_X = \sigma\theta_Y$ at $t = 2$.**
- **An arbitrage portfolio:**
  1. A Long position for σ shares of Y
  2. A short position for 1 share of X is riskless.
- **Assets X and Y's expected payoff at date $t = 0$**

$$v_X = \sigma \times v_Y$$

- **3 types of participants**
  1. **Two risk neutral market makers:** one specialized in asset X and one specialized in asset Y.
  2. **One risk neutral arbitrageur**
  3. **Liquidity traders who buy or sell asset X or Y with equal probabilities.**

Market Makers' Quotes

- **Market makers: at $t = 1$, they simultaneously post their bid-ask spreads: S_X and S_Y and post quotes for the asset**:

$$\text{Ask Price in asset } j : a_j = m_j + \frac{S_j}{2}$$

$$\text{Bid Price in asset } j : b_j = m_j - \frac{S_j}{2}$$

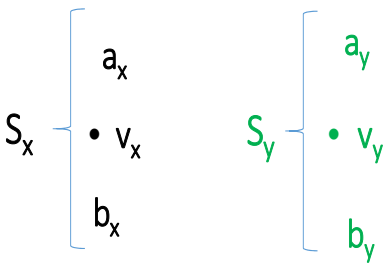
- $m_X = v_X$.
- Just before date 1 news arrives about the payoff of asset Y with probability $\alpha \Rightarrow$ In this case, the expected payoff of Y increases or decreases by $1/2$ with equal probabilities:

Possible Cases

Date t = 1
(σ=1 for the presentation)

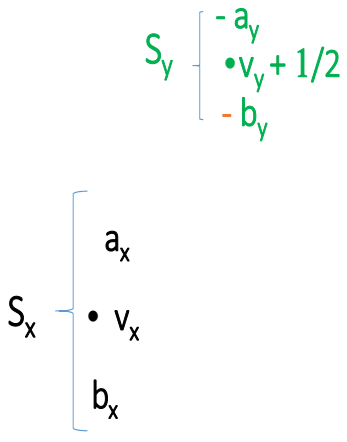
CASE1: NO JUMP

Probability (1-α): No Arbitrage



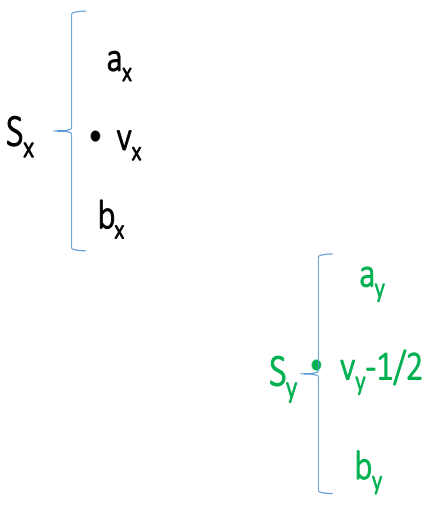
CASE2a

Probability (α/2): Arbitrage



CASE2b

Probability (α/2): Arbitrage

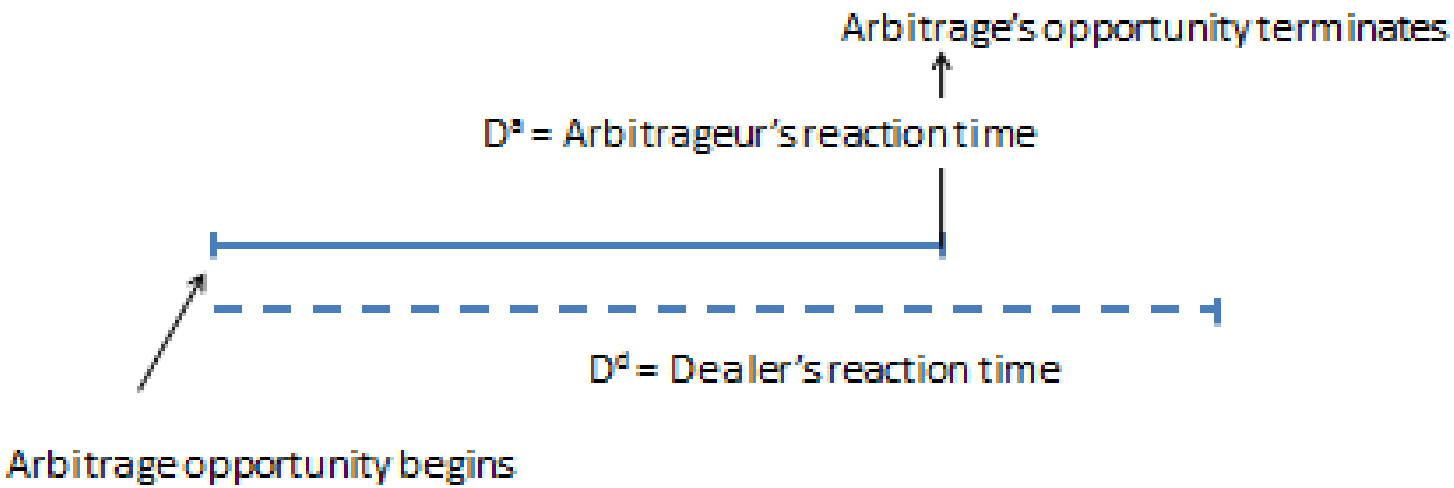


Profits: Arbitrageur and Market Maker X

Profits			
	Case 1	Case 2a	Case 2b
Trader		(Arb first, X first)	(Arb first, X first)
Arb	0	$\left(\frac{1}{2}(\sigma - S_X - \sigma S_Y/2), 0\right)$	$\left(\frac{1}{2}(\sigma - S_X - \sigma S_Y/2), 0\right)$
X	$S_X/2$	$\left(-\frac{1}{2}(\sigma - S_X), 0\right)$	$\left(-\frac{1}{2}(\sigma - S_X), 0\right)$

Racing for arbitrage opportunities

- **Traders' reaction times:** exponentially distributed with intensities λ (dealers) and γ (arbitrageurs); intensities = speeds.
- **Traders control their average speed of reaction ("latency") to arbitrage opportunities** (λ^{-1} or γ^{-1}).
- **Being fast is costly:** marginal costs of speed are c^a and c^m.



How do arbitrage opportunities terminate?

- **Likelihood of termination of an arbitrage opportunity with a trade by the arbitrageur:**

$$\pi = Prob(D^a < D^d) = \frac{\gamma}{\gamma + \lambda},$$

  1. Increases in arbitrageurs' relative speed$= \frac{\gamma}{\lambda}$
  2. can be measured empirically

- $\pi =$ **A measure of dealers' exposure to toxic arbitrage due to arbitrageurs' speed.**
- Not a standard adverse selection problem because π depends on speeds choices, which in turn depend on the bid-ask spread $\Longrightarrow$ **Spreads, speed and π are determined simultaneously.**

Equilibrium

- **In equilibrium:**

$$S_X^* = \frac{\alpha\pi^*(2-\pi^*)\sigma}{\alpha\pi^*(2-\pi^*)\sigma + (1-\alpha)}.$$

$$\pi^* = \gamma^*/(\lambda^* + \gamma^*) = \frac{\frac{c^m}{c^a}}{1+\frac{c^m}{c^a}}$$

- **The average duration of an arbitrage opportunity, D, is a measure of pricing/informational efficiency:**

$$E(D_t) = E(Min\{D_t^a, D_t^d\}) = \frac{1}{\lambda^* + \gamma^*}.$$

Accounting for non toxic arbitrage opportunities

- **Non toxic arbitrage opportunities.** The jump in the value of Y is permanent with probability φ and transient (reverts) otherwise.
- **Arbitrageur's problem: unchanged.**
- **Dealer in asset X: does not make a loss on non toxic arbitrage opportunities and even make a profit since arbitrage trades are then uninformed** $\Longrightarrow$ (i) the dealer has less incentive to be fast and (ii) the equilibrium bid-ask spread is:

$$S_X^* = \varphi \times \pi^* \times \frac{\alpha(2-\pi^*)\sigma}{\alpha\pi^*(2-\pi_t^*)\sigma + (1-\alpha)}.$$

Testable implications

- **Imp.1a**: An increase in the fraction of arbitrage opportunities that are toxic (φ) causes an increase in illiquidity.
- **Imp.1b:** An increase in arbitrageurs' speed relative to dealers' speed (π) causes an increase in illiquidity.
- **Imp.2:** A decrease in the cost of speed (a reduction in c^d or c^a) reduces the duration of arbitrage opportunities.
- **Imp.3:** An increase in the fraction of arbitrage opportunities that are toxic (φ) causes a reduction in the duration of arbitrage opportunities.

$\rightarrow$ Faster arbitrageurs' reactions to toxic arbitrage opportunities make the market less liquid but always more price efficient.

Data

- Tick-by-tick data (2003-2004) from Reuters D-3000: an interdealer limit order book in the FX market.
- Three currency pairs: \$/€, \$/£ and €/£
- All orders: limit, market, cancellations etc.
- Time-stamped accuracy at the one-hundredth of a second.

Triangular arbitrage opportunities

- **Two ways to buy euros with dollar:**
  1. Direct: Buy €1 at $A^{\$/€}$, the ask price in dollar for euros.
     Cost: $A^{\$/€}$
  2. Indirect: Buy $A^{£/€}$ units of pounds at $A^{\$/£}$ and then €1 at $A^{£/€}$ in the euro/sterling market.
     Cost: $\widehat{A}^{\$/€}=A^{£/€}\times A^{\$/£}$.
- **Two ways to sell euros against dollar:**
  1. Direct: Sell €1 at $B^{\$/€}$, the bid price in dollar for euros.
     Revenue: $B^{\$/€}$
  2. Indirect: Sell €1 at $B^{£/€}$ in the euro/sterling market and then sell $B^{£/€}$ units of pounds at $B^{\$/£}$.
     Revenue: $\widehat{B}^{\$/€}=B^{£/€}\times B^{\$/£}$.

Triangular Arbitrage Opportunities

- A triangular arbitrage opportunity exists if:

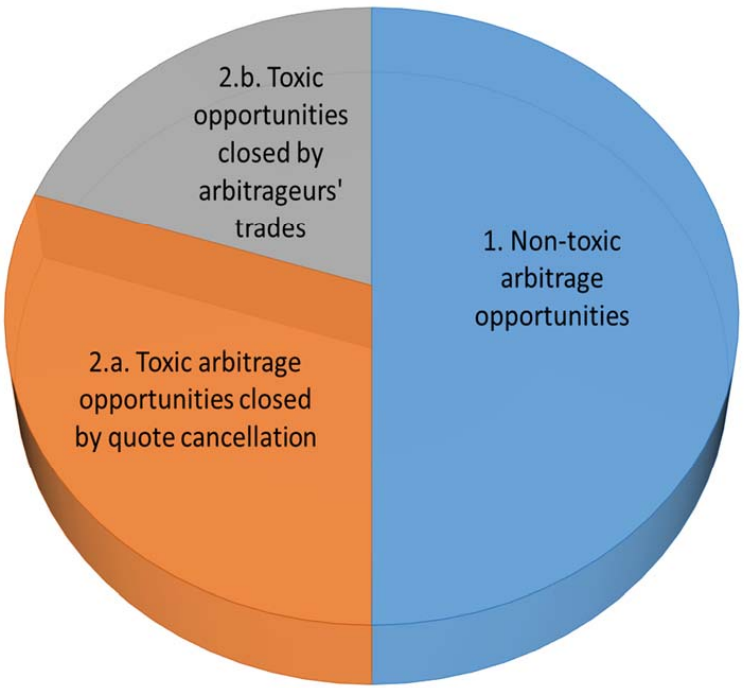
$$A^{\$/€} < \widehat{B}^{\$/€}$$

OR

$$\widehat{A}^{\$/€} < B^{\$/€}$$

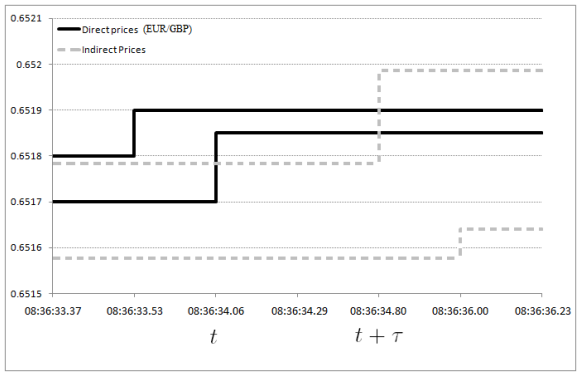
- Practically, we just focus on arbitrage opportunities that secure a profit before costs of at least 1bps.
- **# triangular arbitrage opportunities in sample:** 37,186 over two years.

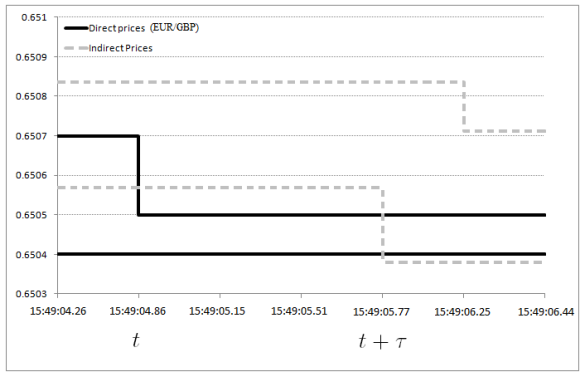
Arbitrage Opportunities Breakdown.



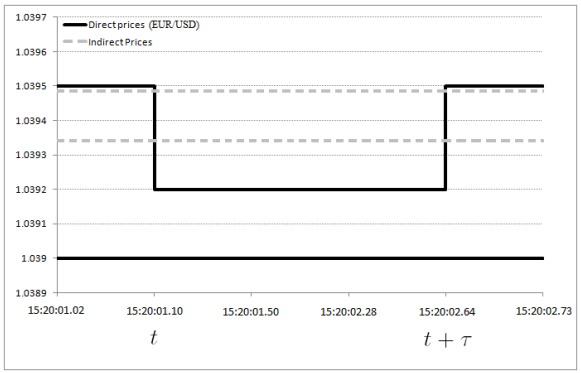
Toxic vs. Non-Toxic Arbitrage opportunities: Classification

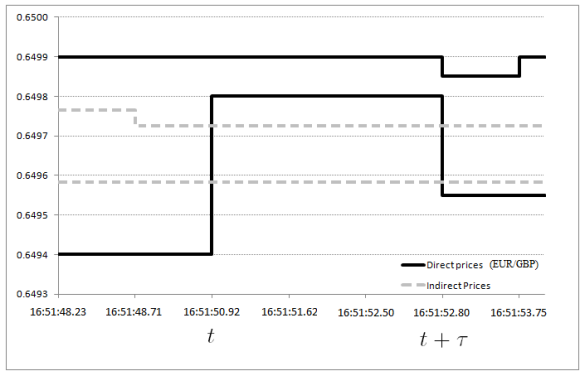
Panel A: Toxic arbitrage opportunities (permanent shifts in prices)





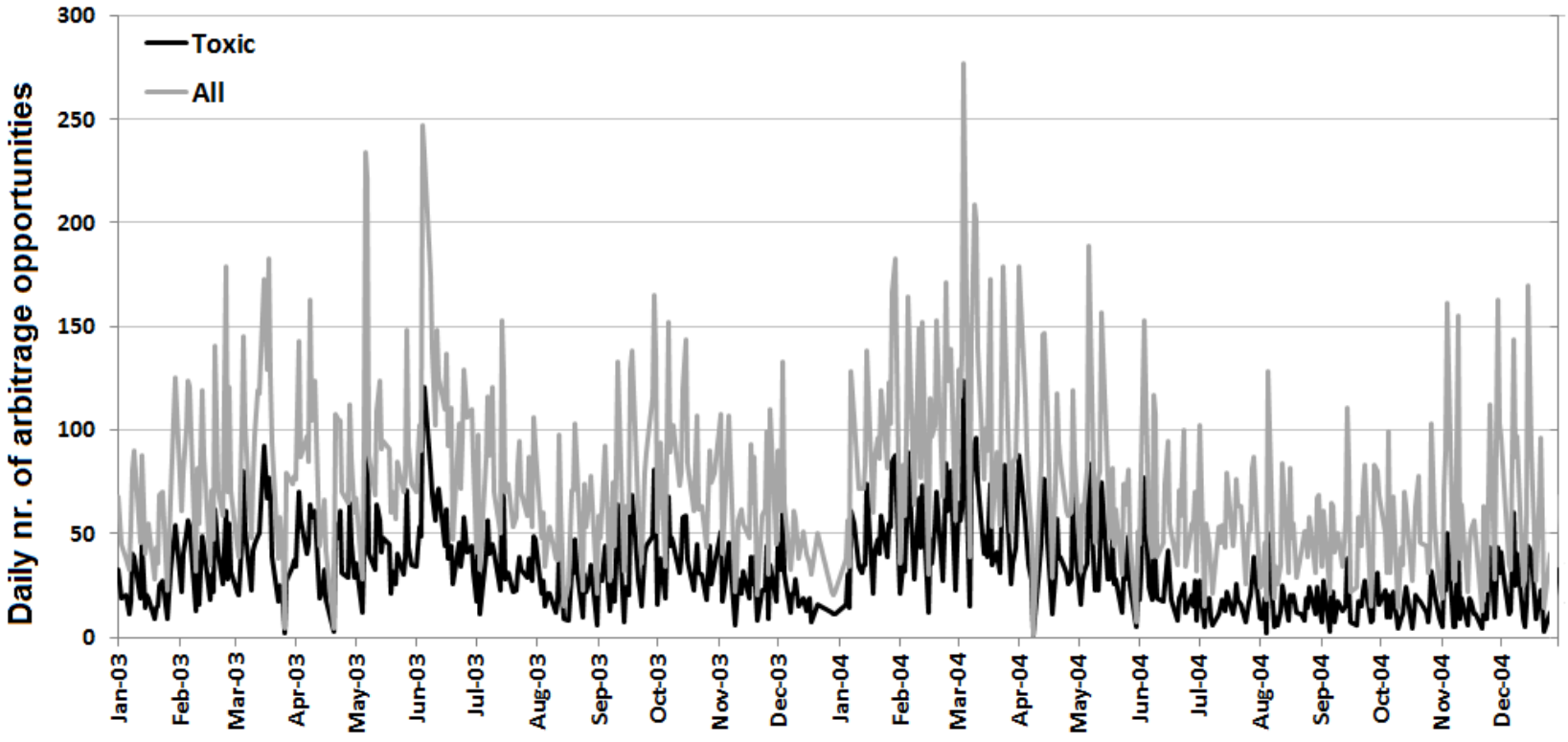
Panel B: Non-toxic arbitrage opportunities (price reversals)





- **# toxic triangular arbitrages in sample:** 15,908.

Toxic and Non Toxic Arbitrage Opportunities: Time-Series



Proxies for Dealers' Exposure to Toxic Arbitrage Trades

$$\hat{\varphi}_t = \frac{\#\text{ Toxic arbitrage opportunities on day t}}{\#\text{ Arbitrage opportunities on day t}}.$$

$$\hat{\pi}_t = \frac{\#\text{ Toxic opportunities closed by a trade on day t}}{\#\text{ Toxic Arbitrage opportunities on day t}}$$

- **Reminder:**
  1. If toxic arbitrage opportunities end up more frequently with an arbitrageur's trade, arbitrageurs tend to be faster.
  2. Thus, days in which π_t is high, are days in which arbitrageurs are relatively faster.

Toxic vs. Non-Toxic Arbitrage opportunities

	Toxic		**Non Toxic**	
Daily measures	**Median**	**SD**	**Median**	**SD**
Duration (msd)	890	0.30	510	0.2
Nbr Arb	32	20	45	38
$\hat{\varphi}(\%)$	41.5	10	59	11
Arb Size (bps)	3.53	0.75	3.53	0.84
Profit (bps)	1.42	0.27	1.61	0.57
π **(%)**	74	11	80	8.2

- Profit per opportunity are small but the total daily profit on triangular arbitrages (about \$5,000) is of the order of magnitude of that found for HFTs on Nasdaq (see Brogaard, Hendershott and Riordan (2012)).
- π for toxic and non toxic arbitrage opportunities have a zero correlation (0.08) $\Longrightarrow$ do not capture the same phenomenon.

Liquidity measures

Liquidity (daily averages)						
	\$/€		\$/£		€/£	
	Median	SD	Median	SD	Median	SD
Quoted Spread (bps)	2.53	0.50	2.74	0.3	1.35	0.25
Effective Spread (bps)	1.88	0.45	2.07	0.25	0.96	0.15
Slope	1.11	0.27	1.12	0.16	0.52	0.26

- Other control variables: daily realized volatility, daily average trade size in millions, daily number of trades.

Findings 1/2

- We estimate the following regression for the three currencies in our sample:

$$\begin{aligned} Ill_{it} &= \alpha_i + \beta_t + b_1 \hat{\pi}_t + b_2 \hat{\varphi}_t + b_3 Vol_{it} + b_4 Arbsize_t \\ &+ b_5 Trsize_{it} + b_6 \#Orders_{it} + b_7 Illiq_{it}^{EBS} + \epsilon_{it} \end{aligned}$$

Predictions: $b_1 > 0$ and $b_2 > 0$.

IV Approach

- **Reverse Causality Problem:** Illiquidity also affects π: Arbitrageurs have less incentive to be fast when trading costs are large.
- Proper econometric analysis requires an exogenous shock on π (an "instrument"), i.e., one that affects participants' speed **without directly** affecting liquidity.
- We use the introduction of "AutoQuote " (API) by Reuters D-3000 in July 2003 as an instrument.
- AutoQuote API (Application Programming Interface): Enable traders using Reuters D-3000 to automate order entry based on Reuters D-3000 datafeed $\Rightarrow$ onset of algo trading on Reuters.
- $\Leftrightarrow$ Increase in traders' speed. Should affect π **without** directly affecting illiquidity.

Findings

	spread		*espread*		*slope*	
	1^{st} stage	2^{nd} stage	1^{st} stage	2^{nd} stage	1^{st} stage	2^{nd} stage
$\hat{\pi}$		7.934 (3.91)		3.443 (3.70)		4.526 (3.96)
AD	0.040 (4.09)		0.042 (4.12)		0.040 (4.10)	
vol	-0.009 (-0.75)	0.374 (3.72)	-0.009 (-0.77)	0.401 (8.65)	-0.009 (-0.76)	0.220 (3.87)
$\hat{\varphi}$	-0.011 (-0.31)	0.691 (2.29)	-0.011 (-0.31)	0.511 (3.68)	-0.010 (-0.28)	0.445 (2.61)
$\hat{\sigma}$	-0.011 (-2.14)	0.238 (4.93)	-0.012 (-2.17)	0.221 (9.94)	-0.011 (-2.11)	0.120 (4.39)
trsize	0.002 (0.66)	-0.128 (-0.30)	0.001 (0.84)	-0.196 (-0.98)	0.001 (0.76)	-0.265 (-1.09)
nrorders	0.014 (0.27)	-0.004 (-0.77)	0.012 (0.22)	-0.006 (-2.62)	0.016 (0.30)	-0.003 (-1.01)
$illiq^{EBS}$	-0.003 (-3.88)	0.021 (0.79)	-0.003 (-3.85)	-0.002 (-0.43)	-0.003 (-3.89)	0.001 (0.08)
$Adj.R^2$	2.34%	34.40%	2.34%	62.18%	2.35%	25.56%
Fstat	16.7		16.9		16.8	
Currency pair FE	YES		YES		YES	
Month dummies	YES		YES		YES	

Economic size of the effects

- A 1% increase in the likelihood that a toxic arbitrage terminates with an arbitrageur's trade ($\hat{\pi}$) raises bid-ask spread by about 4% ($0.08 bps$).
- This effect translates in a quite large increase in trading costs given the trading volume for the currencies in our sample (average trade size of about 1.8 mio with about $2,500$ trades per day). We estimate that the increase in trading costs due to a 1% increase in:
  1. $\hat{\pi}$ is \$161,296 **per day**
  2. $\hat{\varphi}$ is \$14,047 (the daily standard deviation of $\hat{\varphi}$ is 10%) **per day**.

Arbitrage and Pricing Efficiency (Implications 3 and 4)

Dep.Var: $log(TTE)$	Toxic	All
AD	**-0.068** (-3.04)	-0.057 (-2.93)
vol	-0.084 (-3.15)	-0.105 (-4.53)
$\hat{\varphi}$	-0.248 (-2.95)	0.050 (0.68)
$\hat{\sigma}$	0.070 (6.59)	0.085 (9.22)
$trsize$	0.022 (0.18)	0.015 (0.14)
$nrorders$	-0.012 (-7.29)	-0.010 (-7.40)
$Adj.R^2$	21.24%	33.33%

- **The introduction of "Automated Order Entry" reduces by about 0.06 sd the duration of arbitrage opportunities (about 5.6% of the median duration of toxic arbitrage opportunity).**

Conclusions

- **Arbitrage and liquidity:**
  1. The mix of arbitrage opportunities matters: more arbitrage opportunities due asynchronous price adjustments are associated with less liquidity.
  2. Faster arbitrageurs' reaction to these opportunities $\rightarrow$ lower liquidity.
- **What is the social benefit of high speed arbitrageurs?**
  1. Faster price discovery? Do we care about prices being right 60 ms faster? Why?
  2. Faster response to transient liquidity shocks? Maybe...needs to be modeled and quantified, however.
- **Risk of excessive investment in speed (see Biais/Foucault/Moinas (2014), fthcoming JFE in a related context):** (i) speed is valuable to arbitrageurs but (ii) generate adverse selection costs and (iii) do not provide clear cut social benefits.