Toxic Arbitrage

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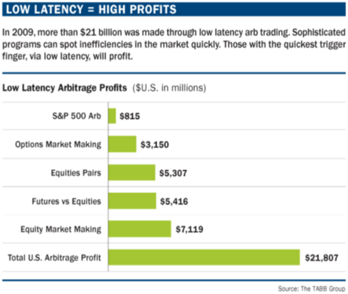
Goal of the paper

- What is the effect of high speed arbitrage on liquidity?
- Why is this question important and interesting?

Highly Profitable



- What is the value of these trades for arbitrageurs' **counterparties**?

Regulatory 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)

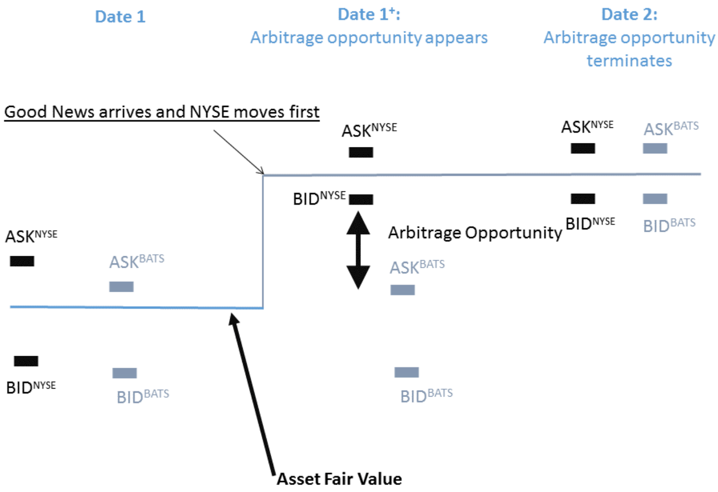
- **Yet no analysis of the effects of high frequency arbitrage because lack of data on cross-market trades by HFTs:**

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

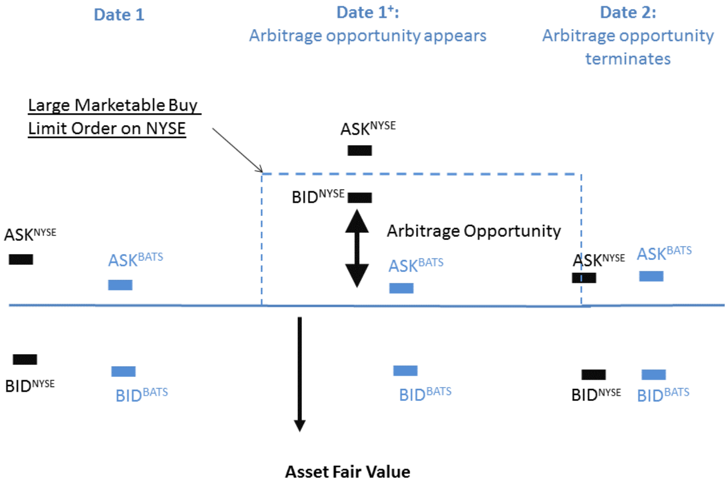
Arbitrage = Cornerstone of Financial Economics

- **"To make a parrot into a learned financial economist, he only needs to learn the single word: "arbitrage" (Ross (1987, American Economic Review)**
- **What is the social value of high speed arbitrage?**
- **Traditional view:**
  1. **Arbitrageurs increase pricing efficiency:** they quickly correct mispricings due to noise/liquidity traders.
  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:** Some arbitrage opportunities (**not all**) raise adverse selection costs $\Rightarrow$ they can make markets less liquid.
- **Why?**

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 risk; cf Copeland and Galai (1983)) for liquidity suppliers ⇒ They are **toxic.**

- They make the market less liquid.
- They do not generate gains from trade: the arbitrageurs' gains are his/her counterparties' losses.
- They consume resources: money spent in getting faster (e.g., hardware and infrastructure costs) is not used elsewhere.

Testable Predictions

- **"Composition effect:" This is <u>not the number</u> of arbitrage opportunities that matters but <u>the nature</u> of these opportunities. Illiquidity is higher**
  1. On days in which toxic arbitrage opportunities are more frequent;
  2. In pairs of related assets (ETFs/Underlying basket) in which toxic opportunities are more frequent.

- **"Speed effect": Illiquidity is higher when arbitrageurs react faster to toxic arbitrage opportunities.**

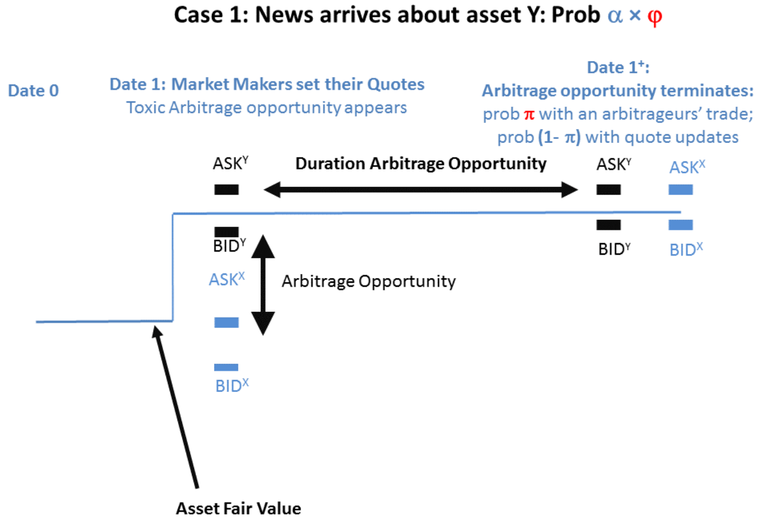
Model

- **Similar to Foucault, Röell and Sandas (2003, RFS) with two assets X and Y.**
- **Payoffs $\theta_X = \sigma\theta_Y$ at t=2.**
- **Assets X and Y's expected payoff at date t=0**

$$v_X = \sigma \times v_Y$$

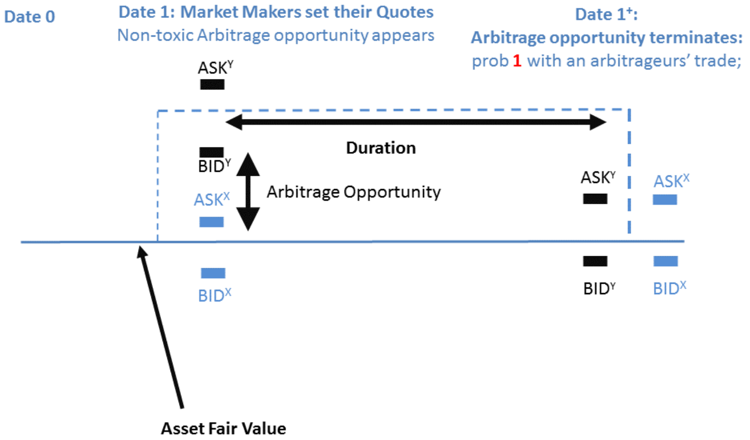
- **An arbitrage portfolio:**
  1. A Long position for σ shares of Y
  2. A short position for 1 share of X is riskless.
- **3 types of participants**
  1. **Two risk neutral market makers:** One **specialized** in asset X and one specialized in asset Y. They set bid-ask quotes in each asset.
  2. **One risk neutral arbitrageur**
  3. **Liquidity traders who buy or sell asset X or Y with equal probabilities.**

Case 1: Stale Quotes.

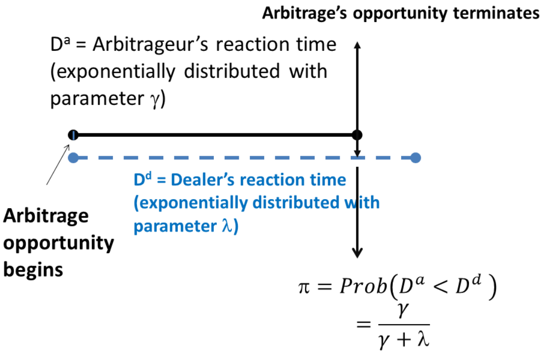


Case 2: Transient Price Pressures.

Case 2: Transient liquidity shock for market maker Y: Prob $\alpha \times (1-\varphi)$



The Arbitrage Race



- Traders choose their average speed of reaction ("latency") to arbitrage opportunities λ^{-1} or γ^{-1}) but being faster is costly.
- $\pi =$ **A measure of arbitrageurs' relative speed.**

Equilibrium

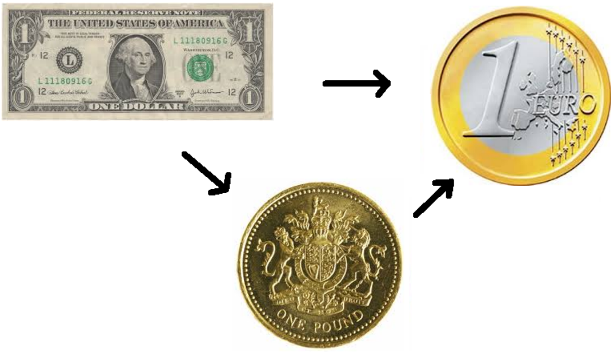
- Not a standard adverse selection problem because π depends on speeds choices, which in turn depend on the bid-ask spread
- $\Longrightarrow$ **Spreads, traders' speeds (π), and the duration of an arbitrage opportunity (a measure of pricing efficiency).**
- We solve for equilibrium spreads, speeds, duration of arbitrage opporunities and π^* and obtain 4 testable implications.

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.

Triangular Arbitrage



Triangular Arbitrage Opportunities

Two ways to buy euros with dollar:

- Direct: Buy €1 at $A^{\$/€}$, the ask price in dollar for euros
  Cost: $A^{\$/€}$
- 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:

- Direct: Sell €1 at $B^{\$/€}$, the bid price in dollar for euros
  Revenue: $B^{\$/€}$
- Indirect: Sell €1 at $B^{£/€}$ in the euro/sterling market and then sell $B^{£/€}$ units of pounds at $B^{\$/£}$
  Revenue: $\widehat{B}^{\$/€} = B^{£/€} \times B^{\$/£}$

A triangular arbitrage opportunity exists if:

$$Ask^{\$/€} < \widehat{Bid}^{\$/€} \quad \text{or} \quad \widehat{Ask}^{\$/€} < Bid^{\$/€}$$

Data

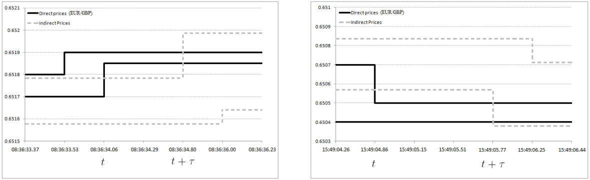
- Tick-by-tick data (2003-2004) from Reuters D-3000: an interdealer limit order book in the FX market
- Three currency pairs: $/€, $/£ and €/£
- All orders: limit, market, cancellations etc
- Time-stamped accuracy at the one-hundredth of a second

Triangular arbitrage in the FX market

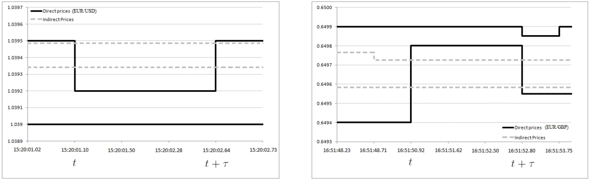
- short-lived (last for about 1 second and sometimes much less)
- almost riskless
- deliver a very small profit per opportunity
- large number of triangular arbitrage opportunities in our sample (37,689 over two years)
- similar in nature to opportunities exploited by HF arbitrageurs

Toxic vs. Non-Toxic Arbitrage opportunities: Classification

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

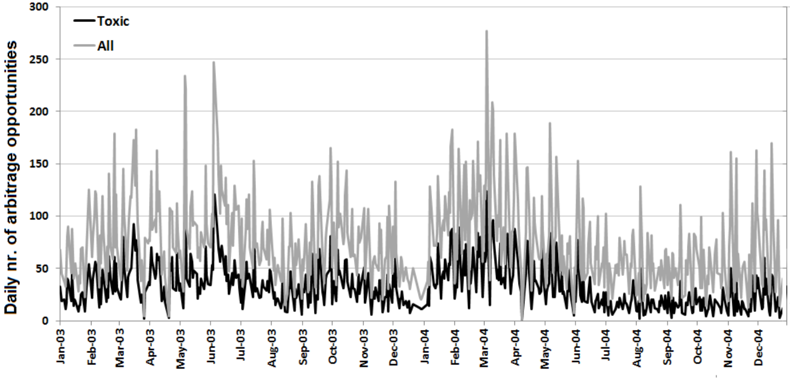


Panel B: Non-toxic arbitrage opportunities (price reversals)

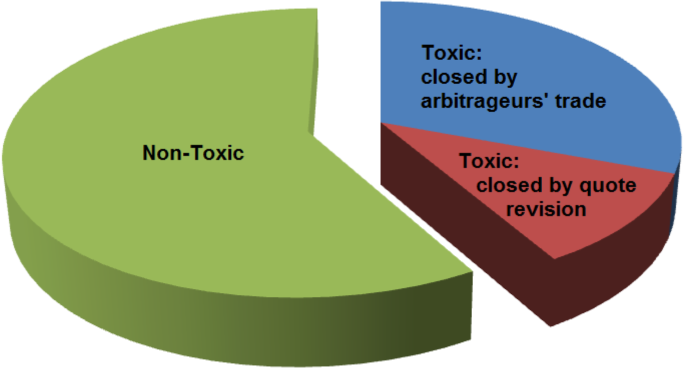


- **# toxic triangular arbitrages in sample:** 15,908.

Toxic and Non Toxic Arbitrage Opportunities: Time-Series



Arbitrage opportunities breakdown



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

	GBP/USD	EUR/GBP	EUR/USD
Quoted Spread	2.741 (0.309)	1.352 (0.259)	2.532 (0.509)
Effective Spread	2.073 (0.255)	0.966 (0.180)	1.886 (0.459)
Slope	1.120 (0.162)	0.541 (0.132)	1.111 (0.275)
Quoted Spread (EBS)	5.253 (1.157)	2.520 (0.807)	1.139 (0.046)
Effective Spread (EBS)	5.112 (3.467)	2.082 (1.847)	0.998 (0.065)
Slope (EBS)	3.860 (3.246)	1.833 (2.448)	0.296 (0.041)

- Other control variables: daily realized volatility, daily average arbitrage profit, daily average trade size in millions, daily number of orders, illiquidity on EBS platform

Main Test

- 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
AD	0.040 (4.09)		0.042 (4.12)		0.040 (4.10)	
$\hat{\pi}$		7.934 (3.91)		3.443 (3.70)		4.526 (3.96)
$\hat{\varphi}$	-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)
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)
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% (0.08bps)

- 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:
    - $\hat{\pi}$ is \$161,296 (about \$40 mio per year)
    - $\hat{\varphi}$ is \$ 14,047 (the daily standard deviation of $\hat{\varphi}$ is 10%)

- As a point of comparison: Naranjo and Nimalendran (2000) estimates at \$55 mio the annualized cost of German and U.S central banks intervention in the DM/\$ market

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 opportunities).**

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 → lower liquidity.

- **Future Work: 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.