Lecture 6

March 4, 2020

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Lecture 6 Agenda

1. Administrative
2. Final Project Proposals
3. Incorporation of Tick Forecast into VWAP
4. MACD
5. Market Making – Basic Logic
6. Transaction Cost Analysis

Administrative

- Group Project – Proposals Assigned today
- Guest Lectures coming up
  - March 25: Q. Ethan McCallum
    - Time Series Analysis methods
  - April 15th: Michael Clarke
    - Operational Risk Management
    - E-trading Risk Management and Controls
- HW2 is live

Final Project

- A project of your choice, relevant to the material covered in class
- Exhibit understanding of theory and application
- You will submit a proposal for your project (counts as 1 assignment, due date TBA)
- The last two weeks of lecture will be reserved for group project presentations

Final Group Project: Proposal

Submit a one-page summary of your project. It should include the following:

- What is your objective, i.e. what do you hope to learn?
- What product (stocks, FX, futures, etc.) and what markets will you be analyzing?
- What sort of market data do you need? Do you have a source for market data or do you need assistance finding some?
- Sources for any papers / research you will reference.
- The purpose of this proposal is not to lock you into your project, but to a) get you started thinking about it and b) give me a chance to provide feedback on your proposal.
- Please submit one proposal per group using the text entry function for this assignment.
- Please reach out if you have any questions.

VWAP with Tick Forecast

Signal Factor Example: Tick Test

How do we use the theoretical value in trading decisions?

1. Consider a simplified conceptual version of a tick test signal T_j
2. Derive a signal from autocorrelation of trade directions:
   - State 1: Next tick predicted up
   - State 2: Next tick predicted down
   - State 3: Next tick indeterminate
3. Assume for the moment we want to trade immediately based on that signal
4. For a stock *j*, define price s_j to be the midpoint within the current quote.

   We can then express our three states as:
   - State 1: Next tick predicted up (buy): FV = the offer price = midpoint + spread/2
   - State 2: Next tick predicted down (sell): FV = the bid price = midpoint – spread/2
   - State 3: Next tick indeterminate: FV = midpoint

Signal Factor Implementation: Tick Test

Once again, we can express this the signal as a continuous function:

$$FV = midpoint_j + b_{jF} F_{tick}$$

Where

b_{jF} = loading of the tick signal factor

F_{tick} = tick signal factor described as buy: 1, sell: -1

Calculate the exponential moving average of the tick value, something like this:

$$F_n = \frac{1}{\tilde{\tau}_w} f_n + w_n F_{n-1}$$

Where the weighting factor is defined as a function of a volume window $\tilde{\tau}_w$:

$$w_n = e^{-(t_n - t_{n-1})/\tilde{\tau}_w}$$

In practice you would calibrate the decay factor once and store the value.

f_n is by construction in {-1,1}, so multiply by $\frac{spread_{avg}}{2}$ to scale the factor.

Source: Derived from Michael Sotiropoulos BAML Lecture on trading models

Determining Volume Window

For the volume window, we want trade time, not clock time.

During simulation we can count trades tick by tick and construct a rolling window of *n* trades.

But if you want to convert to clock time:

$$\tilde{\tau}_w = max\left(\tau_{min}, \left(\tau_{max}, \frac{T_{day}}{N_{trd}} n\right)\right)$$

Where:

τ_{min}, τ_{max} are user defined min and max values

T_{day} = length of the trading day (390 minutes for the US stock exchanges)

N_{trd} = avg number of trades per day

n = target number of trades to include

Source: Derived from Michael Sotiropoulos presentation on trading models

Our Two Factor Model

So now we have:

$$FV_j = midpoint_j + b_j F_{tick} + b_j F_{schedule}$$

Where:

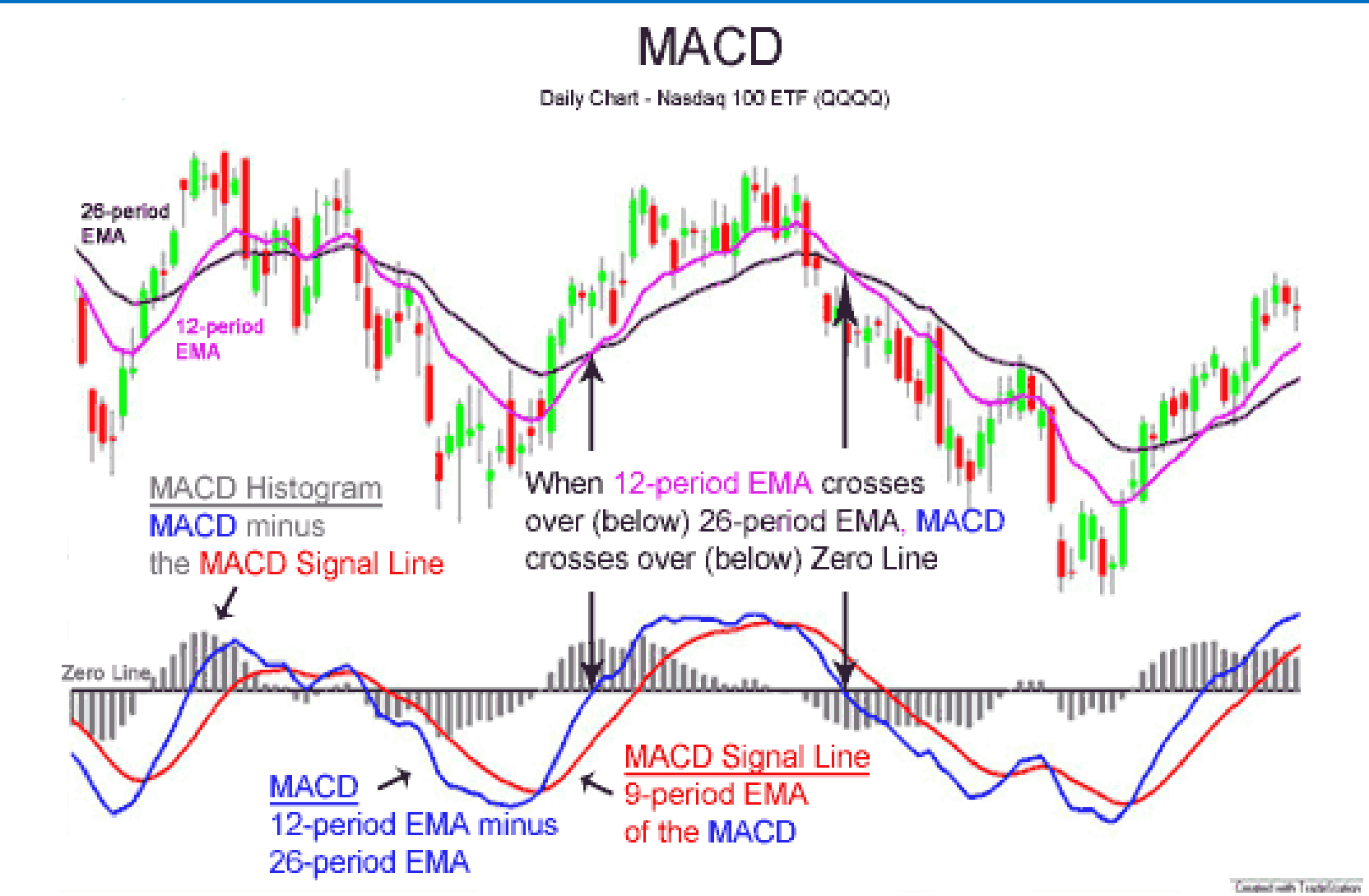
F_k = factors for each signal or adjustment

b_{jk}= stock *j's* sensitivity to factor F_k

See VWAP v2 – Tick Forecast.ipynb

MACD Factor

MACD



Source: Wikipedia. See MACD.ipynb

MACD as a Factor

In MACD.ipynb we make a simple 2 state signal:

State 1: Signal = 1 if buy

State 2: Signal = -1 if sell.

We could apply a similar EMA function to this signal, but the signal itself is a result of multiple EMA applications. Given that, let's keep it simple and just apply it directly:

- State 1 (buy): FV = midpoint + signal * spread/2 = the offer price

- State 2: (sell): FV = midpoint + signal * spread/2 = the bid price

MACD as a Factor

Once again, we can express this the signal as a continuous function:

$$FV = midpoint_j + b_{jF} F_{MACD}$$

Where

b_{jF} = loading of the tick signal factor

F_{tick} = tick signal factor described as buy: 1, sell: -1

f_n is by construction in {-1, 1}, so multiply by $\frac{spread_{avg}}{2}$ to scale the factor.

Market Making

Market Making

Objective: Provide liquidity by buying and selling passively (buy on or near the bid, sell on or near the offer) while minimizing market exposure and inventory

Why?

- Spread capture ("buy low, sell high)
- Rebate capture
  - Many markets will pay a fractional commission to passive liquidity providers
  - They also charge a larger fee to take liquidity

Challenges

- Inventory Management (minimize absolute inventory / minimize holding period)
- Adverse Selection
- Competition for liquidity

Market Making - Scenarios

When do market makers make money?x

- Stationary markets (benefit from bid ask bounce)
- Rebate capture

When do they lose money?

- trending markets – buy low, sell lower, or buy high, sell higher

The challenge, then, is to capture spread when you get, while defensively adjusting prices if you believe the market can trend against you.

Market Making – First Implementation

V1

Simple strategy

1. Simple buy on bid / sell on offer
2. Calculate P&L and exposure

V2:

Introduction of alpha signal to adjust pricing

Introduction of spread adjustment

See Market Making.ipynb

Transaction Costs

Transaction Costs

In this lecture we will present a fundamental overview of transaction costs involved in financial securities trading and portfolio management.

- We will present a classification system for various costs with respect to the nature (fixed or variable) and visibility (visible or non-transparent) of those costs.
- We will also review Perold's *implementation shortfall* as an objective measure of total transaction cost involved in portfolio transactions.

Overview

The implementation of a financial decision is *not* free.

- It has an associated cost and usually results in *reduced* portfolio returns.
- If managers don't properly manage these costs during all phases of the investment cycle (as seen in Figure 1) many of the fund's superior investments will become only moderately profitable and other higher-quality investments will become unprofitable.
- As a result traders and investment managers need to be more proactive in managing transaction costs in order to achieve their benchmark and provide investors with competitive portfolio returns.

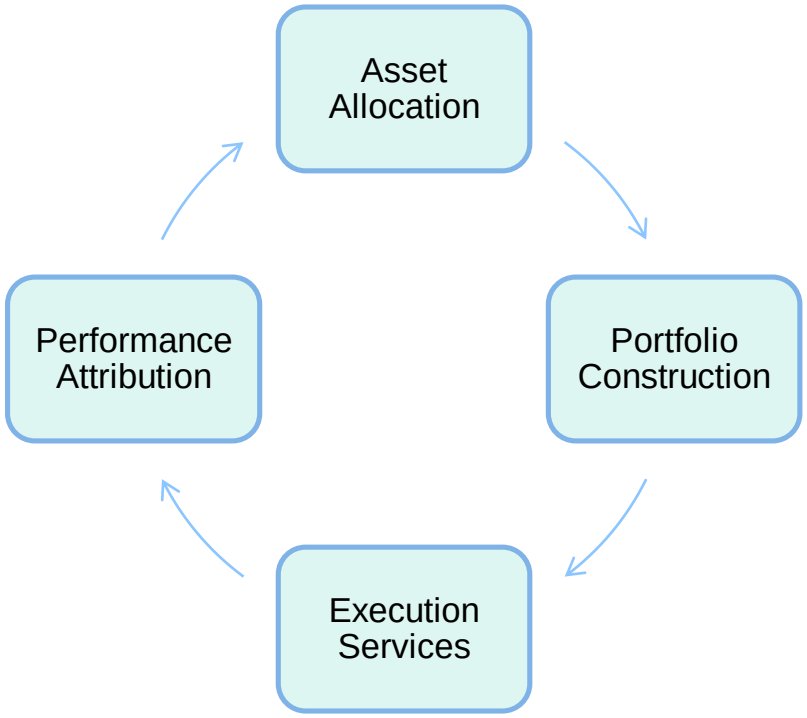


Figure 1: Phases of the Investment Cycle

Back to the Pyramid

Figure 2 shows our pyramid of costs associated with investment and portfolio management (as briefly discussed in an earlier lecture). Each of these costs adversely impact returns in different ways and by various degrees.

- The cost components most visible from a distance contribute the least to the total transaction cost.
- Costs *least* visible (non-transparent) from a distance contribute most to the total transaction costs.

Fortunately, these non-transparent cost components provide the greatest opportunity for cost reduction.

- A skilled trader or investment manager can add value to the investment cycle and reduce portfolio slippage by effectively managing these costs.
- Unfortunately, however, it is *not* possible to reduce all cost simultaneously.
- Careful transaction cost management is required to *balance* the impact of various costs.

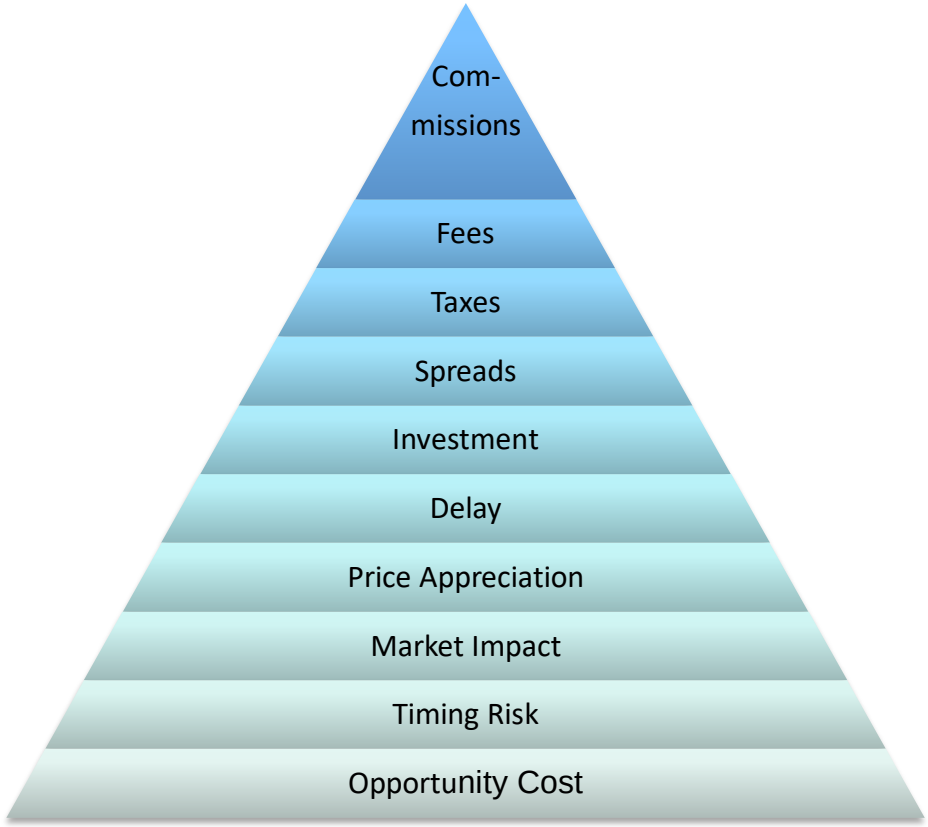


Figure 2. The Transaction Cost Pyramid

The Nature of Transaction Costs: Review

- Transaction costs are costs associated with implementing business decisions that are *incremental* to the cost of goods or services purchased or sold.
- In economic terms, transaction costs refer to costs paid by buyers and not received by sellers and/or paid by sellers but not received by buyers.
- Transaction costs consist of both fixed and variable costs, and transparent (visible) and non-transparent (hidden) costs.
  - **Fixed** components are those costs that are *independent* of the actual implementation strategy.
  - **Variable** costs are those costs that depend on the implementation strategy, and thus can be controlled and reduced during implementation.
  - **Transparent** (visible) costs refer to the costs whose structure is *known* in advance (such as commission fee or tax rate).
  - **Non-transparent** (non-visible) costs are those costs whose amount or structure is *not known* in advance (such as market impact); thus, structures must be inferred or estimated from market observations.
- Generally, it is the **variable non-transparent** costs that account for the largest percentage of transaction costs.

Transaction Cost Classification System

Transaction costs can be classified into *three* broad categories: *investment related*, *trading related*, and *opportunity cost related*, as shown in Figure 3.

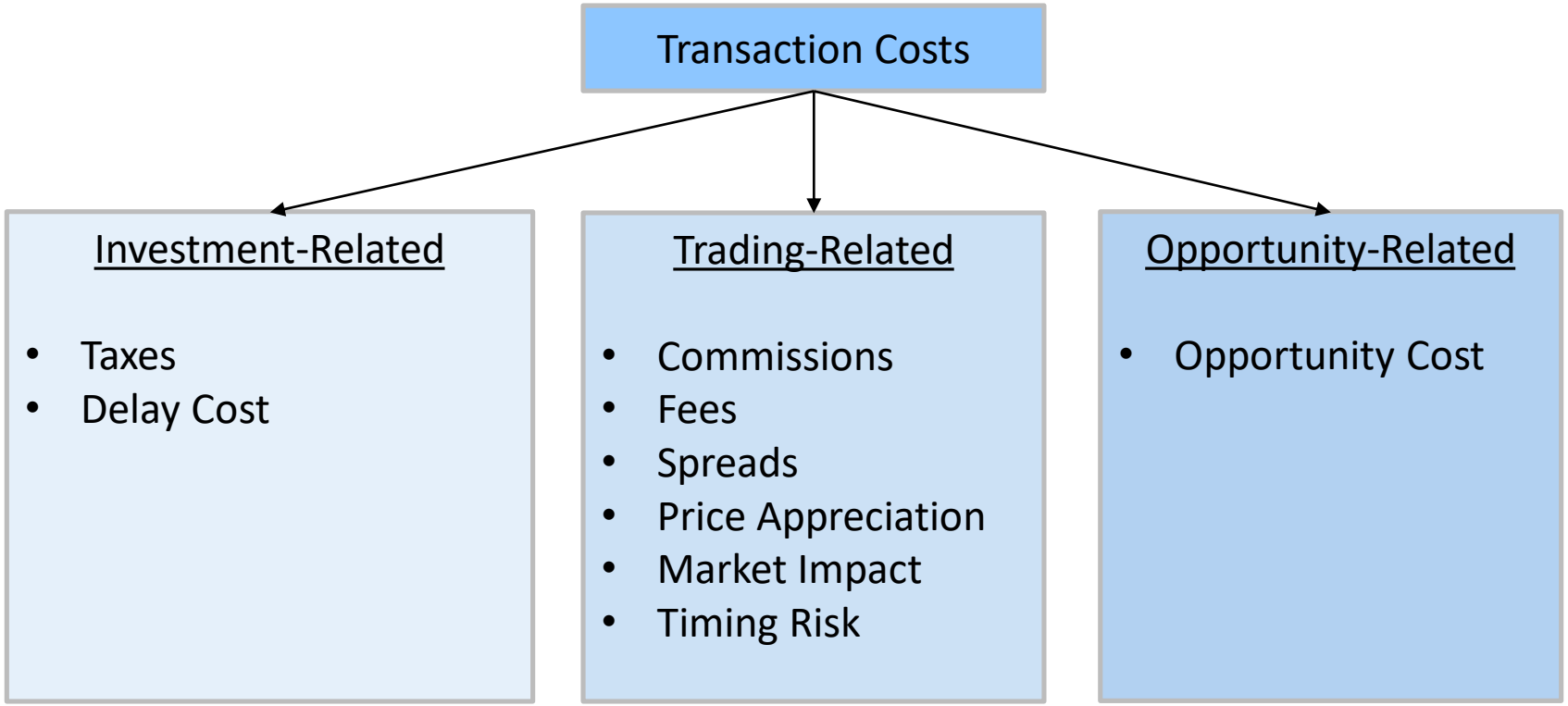


Figure 3: Transaction Cost Classification

Investment Related Costs

Investment-related transaction costs include manageable costs during the investment decision phase of the investment cycle and include taxes and delay cost.

Taxes

- Although taxes generally depend on specific portfolio transactions (e.g. capital gains tax), and is hence a variable cost component, since tax rates are in most cases known in advance, taxes generally form a visible transaction cost component.
- Treatment of taxes is generally complicated and best if incorporated in the investment decision process *from the beginning*.

Delay Cost

- On the other hand, delay cost is a *non-transparent variable* transaction cost component generally associated with indecisiveness or waiting to trade.
- This cost can arise due to *lack of proper communication* between investment managers and traders in specifying implementation *goals* of investment decisions.
- The longer it takes for traders and managers to resolve proper implementation objectives (often exacerbated by the lack of proper analytical tools), the more potential there is for price movement making investment decisions more costly.

Trading Related Costs

- Trading-related transaction cost components comprise the largest subset of transaction costs. These costs include those that arise during the implementation phase of investment decisions and can be effectively managed during proper execution of the list.

- While these costs cannot be eliminated, they can be dramatically reduced via a trading strategy that best meets the objectives of the fund.

- These costs consist of both **fixed** and **variable** costs and **transparent** (visible) and **non-transparent** (non-visible) costs.
  - The associated trading-related costs of *commission*, *fees*, and *spread*, can be further categorized as transparent *trading service* cost components associated with working with brokers, locating liquidity, negotiating prices, and clearing and settlement.
  - Non-transparent variable cost components consist of *price appreciation*, *market impact*, and *timing risk*.

Trading Related Costs

Traders can affect cost and risk of implementation through selection of trading strategies.

- For instance, price appreciation and timing risk are *minimized* via implementation with an *aggressive* trading strategy.
- Market impact, however, is *increased* with an aggressive strategy and lowest with a passive strategy.
- This implies that traders need to *balance* trade-off between these cost components.
- Trading costs are generally dependent upon the *trade list*, *order size* and *liquidity*, *volatility*, and other market conditions (e.g. volume correlation across all names in the list), and specified implementation strategy.

Opportunity Cost

Opportunity cost represents the foregone profit of not being able to fully implement an investment decision.

- Opportunity cost exists because insufficient market liquidity prevents completion of the order or the price moves outside a specified range.
- It combines the price change over the trading horizon and number of unexecuted (residual) shares.
- Opportunity cost can arise because traders are unable or unwilling to transact at existing market prices, or because of insufficient market liquidity.
- It can also arise because investment managers specify orders that are too large to be absorbed without producing adverse price movements.

One way to reduce opportunity costs is proper *pre-trade* analysis and *cost estimation* of the trade list.

- If managers determine that the market cannot readily absorb the desired quantity of shares, managers can modify the order to one that can be easily absorbed by the market and then invest surplus funds in the next most attractive investment vehicle.
- The net result is decreased opportunity cost and increased portfolio returns.

Transaction Cost Formulation

Let's now use this classification scheme to formulate a definition of transaction cost:

$$TC = \underbrace{\left\langle \begin{matrix} Taxes \\ Delay\ Cost \end{matrix} \right\rangle}_{\text{Investment Related}} + \underbrace{\left\langle \begin{matrix} Commisions \\ Fees \\ Spreads \\ Price\ Appreciation \\ Market\ Impact \\ Timing\ Risk \end{matrix} \right\rangle}_{\text{Trading Related}} + \underbrace{\langle Opportunity\ Cost \rangle}_{\text{Opportunity Related}} \qquad \textit{(EQ 1)}$$

Transaction Cost Formulation

If we incorporate the concept of visibility, an alternative cost categorization would be the following (equivalent) formulation of transaction costs:

$$TC = \underbrace{\langle Delay\ Cost \rangle}_{\text{Investment Related}} + \underbrace{\left\langle \begin{matrix} Price\ Appreciation \\ Market\ Impact \\ Market\ Timing \end{matrix} \right\rangle}_{\text{Trading Related}} + \underbrace{\langle Opportunity\ Cost \rangle}_{\text{Opportunity Related}} + \underbrace{\left\langle \begin{matrix} Taxes \\ Commisions \\ Fees \\ Spreads \end{matrix} \right\rangle}_{\text{Visible/Transparent Costs}}$$

Non-transparent Costs

(EQ 2)

This latter formulation provides the basis for our transaction cost measurement and transaction cost estimate framework described below.

Cost Measurement

The measurement of transaction costs can be written in the form of Perold*'s *implementation shortfall* measure, where we distinguish these non-transparent costs as investment, trading and opportunity cost as follows:

$$TC = \underbrace{\underbrace{X(P_d - P_0)}_{\text{Investment–related}} + \underbrace{\sum x_j (P_j - P_0)}_{\text{Trading–related}} + \underbrace{\left(X - \sum x_j\right)(P_n - P_0)}_{\text{Opportunity cost}}}_{\text{Non–transparent CostComponent}} + Visible$$

(EQ 3)

Perold, Andre F. (1988), "The implementation shortfall: paper vs. reality", Journal of Portfolio Management, 14 (Spring), 4–9.

Cost Measurement

$$TC = \underbrace{\underbrace{X(P_d - P_0)}_{\text{Investment–related}} + \underbrace{\sum x_j (P_j - P_0)}_{\text{Trading–related}} + \underbrace{\left(X - \sum x_j\right)(P_n - P_0)}_{\text{Opportunity cost}}}_{\text{Non–transparent CostComponent}} + Visible$$

where

X = total number of shares, $X > 0$ indicates a buy, and $X < 0$ indicates a sell

x_j = number of shares executed in j-th trade

$\sum x_j$ = total number of shares executed

$X - \sum x_j$ = number of unexecuted shares

P_d = manager's decision price

P_0 = stock price when order was released to market

P_j = price of j-th trade

P_n = stock price at end of trading

Visible = visible costs of commission, fees, taxes and spreads

Cost Measurement

$$TC = \underbrace{\underbrace{X(P_d - P_0)}_{\text{Investment-related}} + \underbrace{\sum x_j (P_j - P_0)}_{\text{Trading-related}} + \underbrace{\left(X - \sum x_j\right)(P_n - P_0)}_{\text{Opportunity cost}}}_{\text{Non-transparent Cost Component}} + Visible$$

- Usually prices for P_d, P_0 and P_n are taken as the midpoint of the bid-ask spread at the corresponding time.
- Therefore, spread cost is included in the trading related component. The price of the trade P_j, however is taken at its exact transaction price.
- The cost specification given above distinguishes those non-transparent transaction cost components from visible cost components.
- This classification scheme is essential for understanding transaction costs and developing estimation methodologies.

Discussion: Investment Costs

The *investment-related cost* classification is measured as the *change* in the value of the portfolio *between* the time managers make the investment *decision* and the time traders are prepared to *trade*. This is computed simply as the number of shares in the order multiplied by the price change, that is, $X(P_d - P_0)$. In the majority of situations, managers purchase stocks that are rising, and sell stocks that are falling. Thus, the associated *delay* reflects a *cost* to the fund. This component constitutes a *substantial* cost and their estimates show the cost to be in the order of 30–50 bp per transaction.

However, as traders practice proper transaction cost management, the time between the decision time t_d and order release time t_0 becomes small causing the *delay cost* to become effectively zero, that is,

$$P_d - P_0 \to 0 \quad as \quad t_d - t_0 \to 0 \qquad \text{(EQ 4)}$$

$$TC = \underbrace{X(P_d - P_0)}_{\text{Investment–related}} + \underbrace{\sum x_j (P_j - P_0)}_{\text{Trading–related}} + \underbrace{\left(X - \sum x_j\right)(P_n - P_0)}_{\text{Opportunity cost}} + Visible$$

$$\text{Non–transparent Cost Component}$$

Discussion: Trading Costs

The *trading-related cost* classification φ is measured as the difference between the total transaction dollars and the value of that number of shares evaluated at the price of order release P_0, that is:

$$\varphi = \sum x_j \left(P_j - P_0\right) \qquad \text{(EQ 5)}$$

- Since the price of order release P_0 is evaluated at the midpoint between the bid and the ask, the spread cost is already included in the trading cost calculations and does not need to be incorporated as its own separate component.
- The trading-related cost comprises the greatest portion of transaction costs but can effectively be reduced if proper transaction cost management techniques are put into effect.

$$TC = \underbrace{\underbrace{X\left(P_d - P_0\right)}_{\text{Investment-related}} + \underbrace{\sum x_j \left(P_j - P_0\right)}_{\text{Trading-related}} + \underbrace{\left(X - \sum x_j\right)\left(P_n - P_0\right)}_{\text{Opportunity cost}}}_{\text{Non-transparent Cost Component}} + Visible$$

Discussion: Opportunity Cost

The *opportunity cost* classification represents the missed profiting opportunity that results from *not* being able to completely implement investment decisions. It is measured as the number of *unexecuted shares* multiplied by the price change between the time of order release P_0 and the price at the end of trading P_n. This measure is intended to represent the change in portfolio value that is not enjoyed by funds. The cost of unexecuted shares over the *entire* implementation horizon t_d to t_n can be decomposed as:

$$OC = \left(X - \sum x_j\right)\left(P_n - P_d\right) = \underbrace{\left(X - \sum x_j\right)\left(P_d - P_0\right)}_{\text{Investment–related}} - \underbrace{\left(X - \sum x_j\right)\left(P_n - P_0\right)}_{\text{Trading–related}} \quad \text{(EQ 6)}$$

Thus, managers identify opportunity cost as both investment related and trading related. Since managers typically buy stocks that are rising and sell stocks that are falling (as well as exert an imbalance in the market supply demand equilibrium of the stock causing adverse price movement), this component generally reflects a *cost* to investors.

$$TC = \underbrace{\underbrace{X\left(P_d - P_0\right)}_{\text{Investment–related}} + \underbrace{\sum x_j\left(P_j - P_0\right)}_{\text{Trading–related}} + \underbrace{\left(X - \sum x_j\right)\left(P_n - P_0\right)}_{\text{Opportunity cost}}}_{\text{Non–transparent Cost Component}} + Visible$$

Discussion: Opportunity Costs, cont'd.

It is quite possible to effectively *reduce* opportunity cost to *zero* through proper transaction cost management techniques; there the gap between investment decisions and order release should ultimately be *minimal*. Trading-related opportunity cost exists because of inadequate *liquidity conditions* and/or substantial *adverse price movement*. But if managers and traders work together they could *assess* liquidity conditions and estimate execution costs to determine the appropriate *order size* that can be readily absorbed by the market. Within managers' specified price range the number of unexecuted shares will effectively fall to zero. Thus,

$$OC \to 0 \quad as \quad X - \sum x_j \to 0 \qquad \text{(EQ 7)}$$

The *visible cost* classification consists of commissions, spreads, taxes, and any other fee charged to investors (e.g., ticket charge, clearing and settlement fee). Many times, however, brokers *bundle* these fixed costs (visible *excluding* spreads and taxes) into the *commission rate* charged by the broker and investors never see the costs. For the most part, these visible costs represent the *smallest* portion of the total transaction cost and *cannot* be affected or controlled by proper transaction cost management practices (i.e., selection of implementation strategy).

$$TC = \underbrace{\underbrace{X(P_d - P_0)}_{\text{Investment-related}} + \underbrace{\sum x_j (P_j - P_0)}_{\text{Trading-related}} + \underbrace{\left(X - \sum x_j\right)(P_n - P_0)}_{\text{Opportunity cost}}}_{\text{Non-transparent Cost Component}} + Visible$$

Basics of Cost Estimation

Our discussion of the proper analytical framework for estimating transaction costs and developing and evaluating appropriate trading strategies focuses on the *non-transparent*, *variable*, *trading-related* transaction costs since these are the costs that can be *controlled* during implementation. Subsequently, these pre-trade transaction costs will be appropriately referred to as trading costs. In short, the pre-trade costs are estimated based on the following price trajectory formulation:

$$p_t = p_{t-1} + \mu_t + \kappa_t + \varepsilon_t \qquad \text{(EQ 8)}$$

where,

p_t = price of the t-th trade

μ_t = natural price appreciation from time t-1 to t

κ_t = market impact of the t-th trade

ε_t = white-noise price innovation

Basics of Cost Estimation

This price process is a simplification of reality because it does not distinguish between temporary and permanent market impact nor account for the dissipation of temporary impact over time.

- It is shown here to demonstrate the need for a complete understanding of the non-transparent trading related transaction costs, namely, price appreciation, market impact, and timing risk.
- We need to thoroughly examine each cost component in order to gain insight into its mechanics and provide the means for measuring and forecasting each cost component based on a specified strategy.
- The ultimate goal would be to provide a quantitative framework for determining an "optimal trading strategy", that minimizes trading costs for a specified level of risk, in a manner that best meets its investment goals and objectives.

Basics of Cost Estimation

In summary, these trading costs are:

- Measured as the *difference* between the execution price and the price at the time of order entry.
- Estimated as a *distribution* of costs that consists of an expected cost and a risk parameter, not as a single (or constant) cost estimate.
- Dependent upon the *size*, liquidity, volatility and the correlation of price movement across all names in the trade list, and the actual market conditions over the trading period, and corresponding to a specific trading strategy.

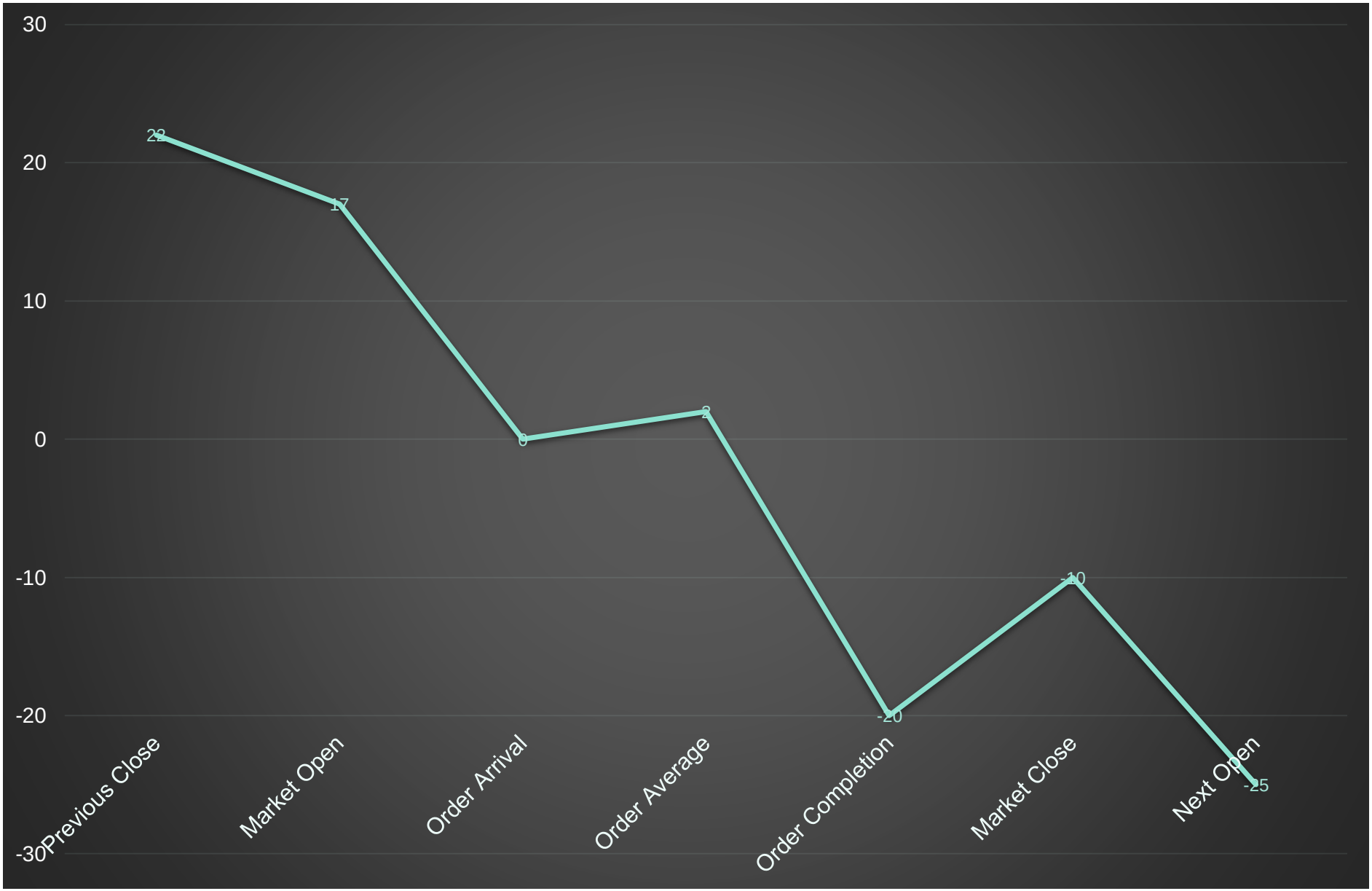
Common Performance Benchmarks

Metrics and Benchmarks	Definition
P_{avg} Volume weighted average price of *order*	Given an order of quantity Q, with executions of quantity q at price p, : $\frac{\sum(q_i \times p_i)}{Q}$
TWAP Time-weighted *market* average	1. For each bin i, mean($open_i$, $high_i$, low_i, $close_i$) 2. Calculate the mean across all bins
VWAP (or $VWAP_{mkt}$) Volume-weighted *market* average	$= \frac{\sum(qty_{@price} \times price)}{total\ market\ qty}$
Performance vs. TWAP	$= P_{TWAP} - P_{avg}^{*}$
Performance vs. VWAP	$= P_{VWAP} - P_{avg}^{*}$
Performance vs. Arrival/IS	$= P_{arrival} - P_{avg}^{*}$
Performance vs. Open	$= P_{OPEN} - P_{avg}^{*}$
Performance vs. Close	$= P_{CLOSE} - P_{avg}^{*}$

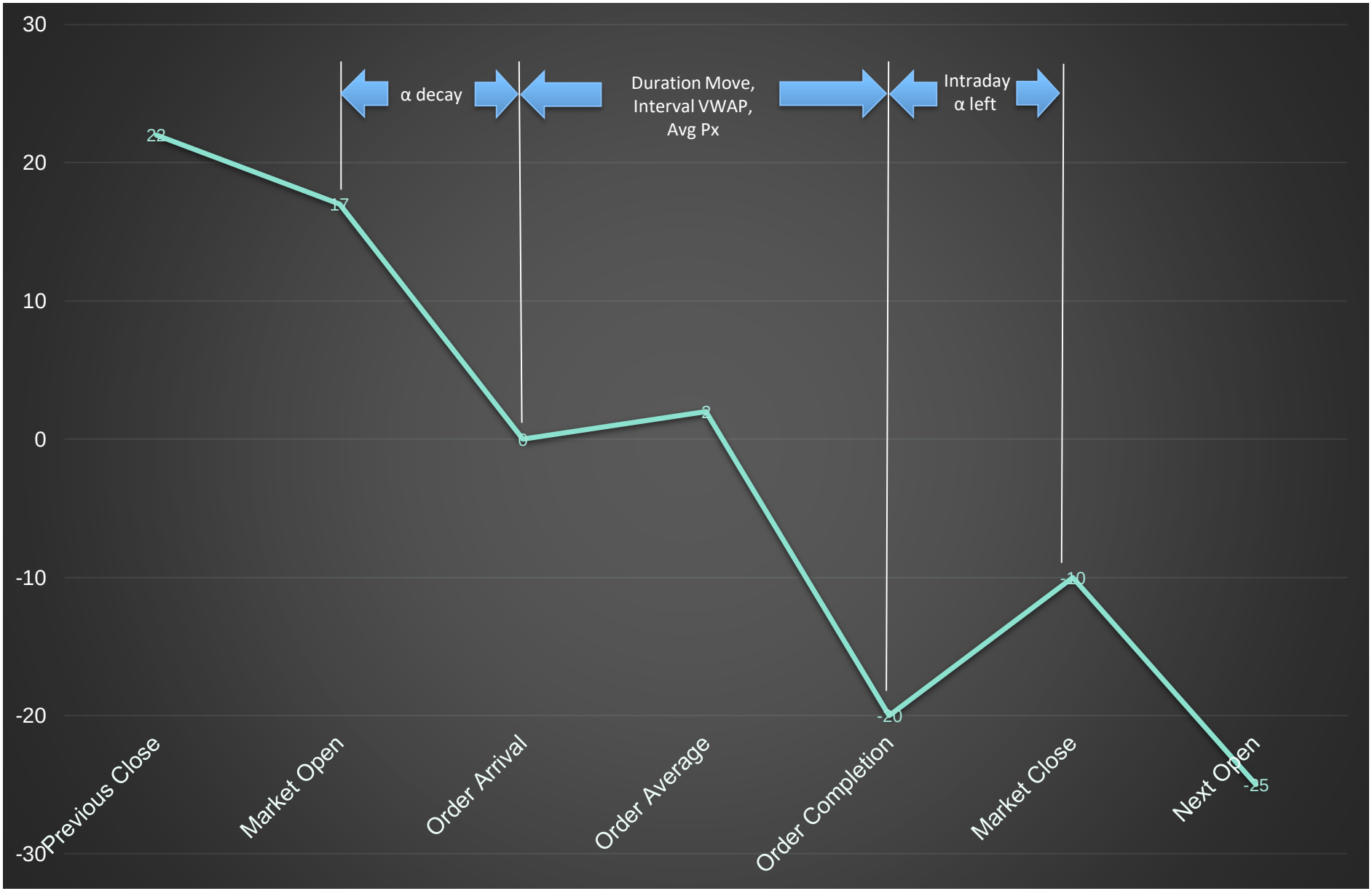
Key Points in the Transaction Lifecycle

Lifecycle Point	Definition
Previous Close	Last price of previous trading session
Market Open	Exit price of opening auction
Order Arrival	Price at the time an order (or the desire to trade) arrives. One of: • Last price (if instrument is open and liquid market) • Market midpoint (if instrument is not open or not sufficiently liquid) • Previous close (if instrument is not open and/or current market is insufficiently developed (e.g. no bid or offer or excessively wide spread)
Average Price	Volume-weighted average execution price
Order Completion	Last price at time of order completion
Market Close	Exit price of closing auction
Next Open	Exit price of next trading session's opening auction

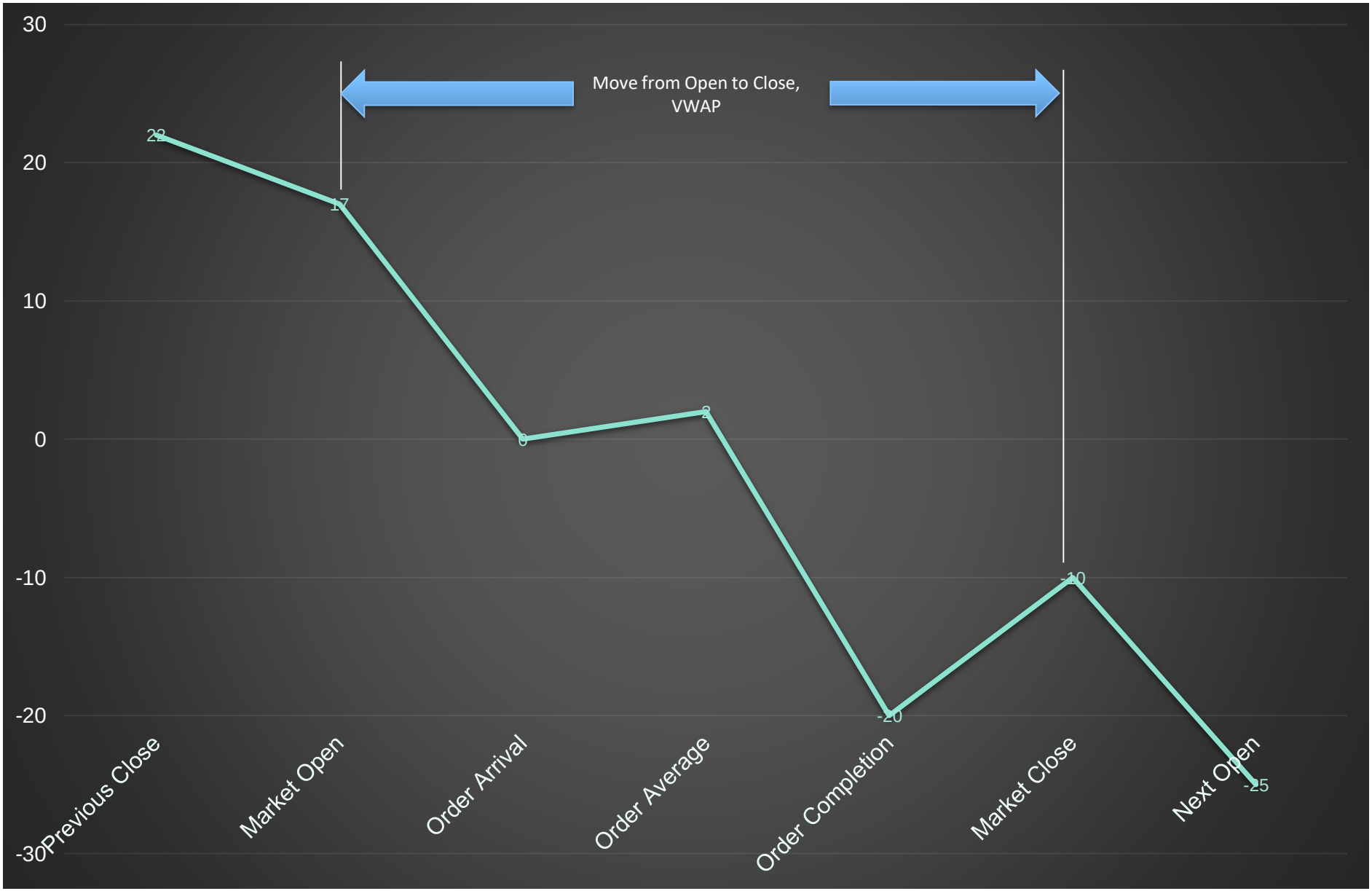
Performance vs. Points in Time



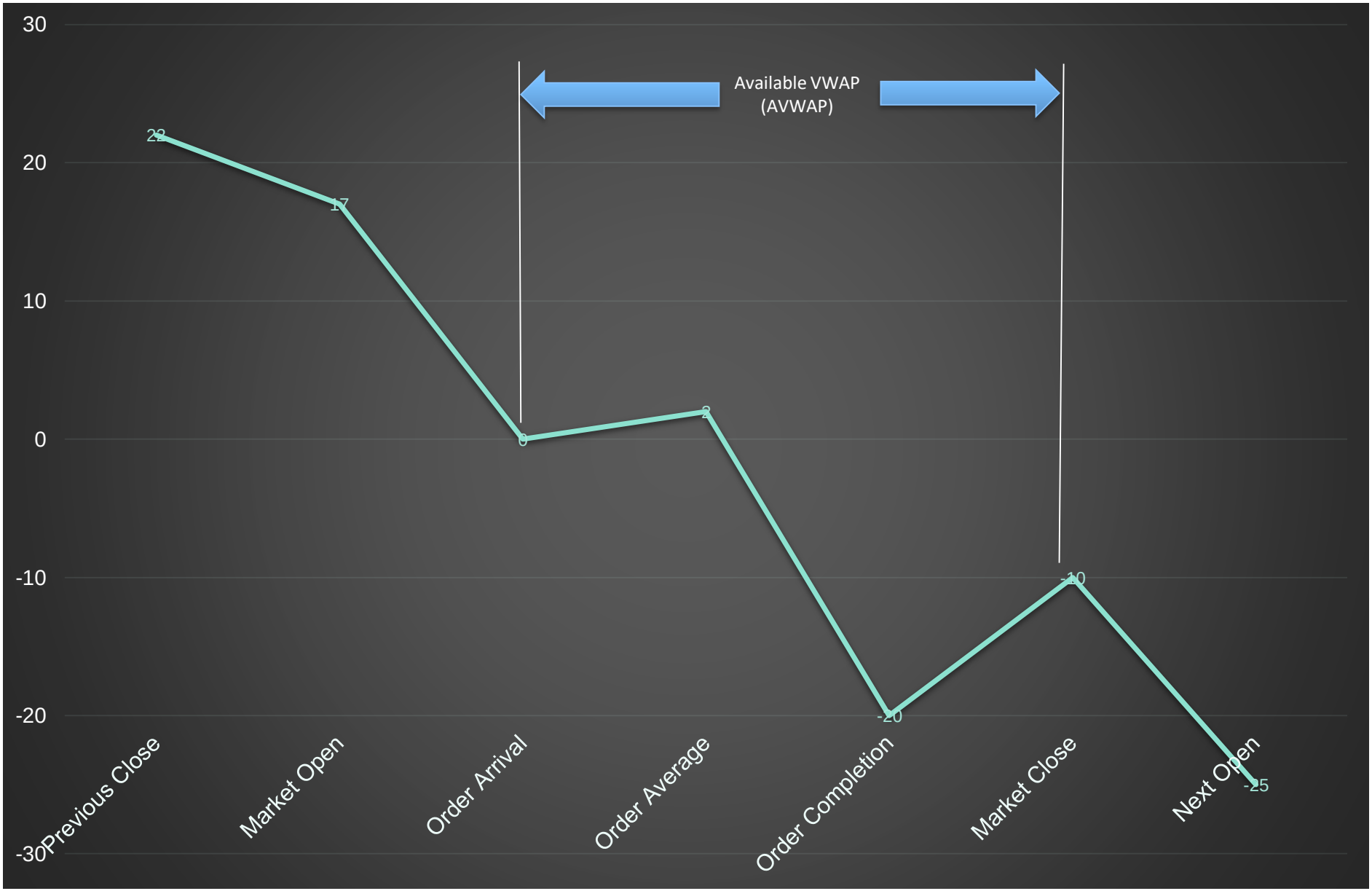
Order Life Span



Intraday Move, VWAP



Available VWAP



Post-Trade TCA – Examples

Post-Trade Analyses focus on <u>average performance of multiple trades</u> over time:

- By Algo (if applicable)
- By Benchmark
- By Trader
- By Duration
- By Sector
- Etc.

Single Stock TCA

- Outlier analysis (i.e. what went wrong!)
- Not as common for general trades

Trading Summary

Value Traded:	€3,053,204,896
(Bought):	€1,513,902,868
(Sold):	€1,539,302,028
Number Of Orders:	8,204
(Fills):	162,334
Average Order Size:	€372,160.52
(Average Fill Size):	€18,808.17
Book Spread (depth):	31.18 BPS
Book Spread (touch):	20.70 BPS
Average Duration:	0h 50m
Distinct Instruments:	519

Execution Style:

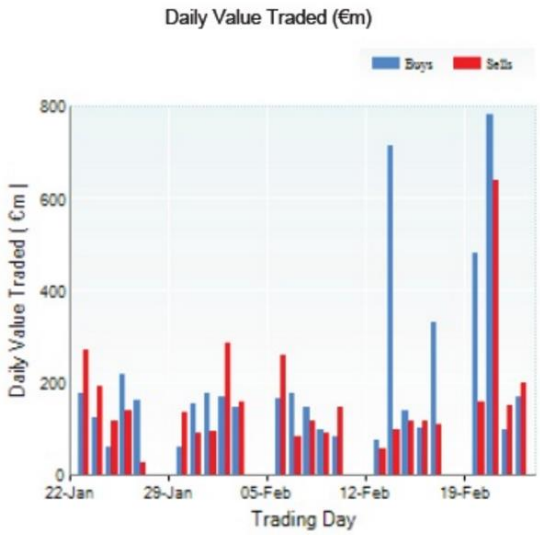
Aggr	Pass	Mid
99.3%	0.7%	0.1%

Venue Types:

Prim	MTF	Other
94.3%	0.0%	5.7%

Venues Traded:

XMAD: 71.51% XPAR: 7.02% XETR: 5.53% XHKG: 2.81% XNYS: 2.34% XSWX: 2.32% XAMS: 1.90% XMIL: 1.90% LSE2: 1.86% XLIS: 0.62% XSTO: 0.62% XHEL: 0.52% XNMS: 0.38% XOSL: 0.28% XBRU: 0.17% XSES: 0.11% XCSE: 0.03% XIOB: 0.02% XVIE: 0.02% XDUB: 0.01%

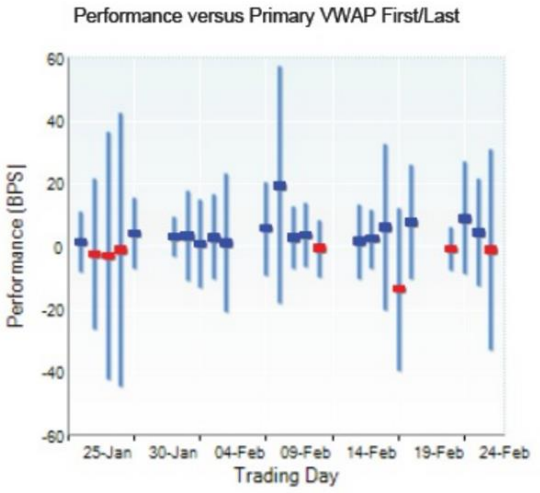


Performance Summary

Performance Benchmark	All	Buys	Sells
Market VWAP First/Last	1.88	-1.55	5.26
Primary VWAP First/Last	1.93	-1.40	5.22
Market Daily VWAP	7.46	-8.31	22.86
Primary Daily VWAP	1.93	-1.40	5.22
First Fill (mid)	-38.66	-93.43	26.46
Previous Closing Price	22.94	14.66	31.04
Closing Price	1.41	4.72	-1.82

Performance versus Primary VWAP First/Last

Average Improvement/Shortfall	1.93BPS
Standard Deviation	23.12BPS



COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Source: LiquidMetrix

Post-Trade TCA - Examples

Activity				Execution Quality		BPS	Performance		BPS	Timing					
	Total	Buys	Sells												
Count	4,710	2,654	2,056	IS	10,390,311	50	vs Interval VWAP	-6,125,763	-30	vs 3 Months Before	-21,608,390	-104	vs Next Day	-6,765,176	-32
Ordered Shares	981,927,686	664,780,333	317,147,353	Expected Cost	11,774,811	56	vs Open	-12,374,361	-59	vs 1 Month Before	5,755,420	27	vs 2 Days After	-5,514,169	-26
Ordered Amount	2,093,944,861	1,134,473,507	959,471,354	Performance	1,384,501	7	vs Close	-9,006,591	-43	vs 1 Week Before	-9,407,428	-45	vs 1 Week After	-8,195,449	-39
Executed Shares	981,927,686	664,780,333	317,147,353	Opportunity Cost	0	0	vs Price at End	-9,216,447	-44	vs 2 Days Before	-20,112,450	-95	vs 1 Month After	930,808	4
Executed Amount	2,130,533,949	1,153,471,350	977,062,599	Opportunity Cost 'End'	0	0	vs VWAP	-10,188,174	-49	vs 1 Day Before	-14,486,893	-69	vs 3 Months After	8,375,598	39
Order Life Average	388			Opportunity Cost 'Client'	0	0	vs Interval High	739,719	4						

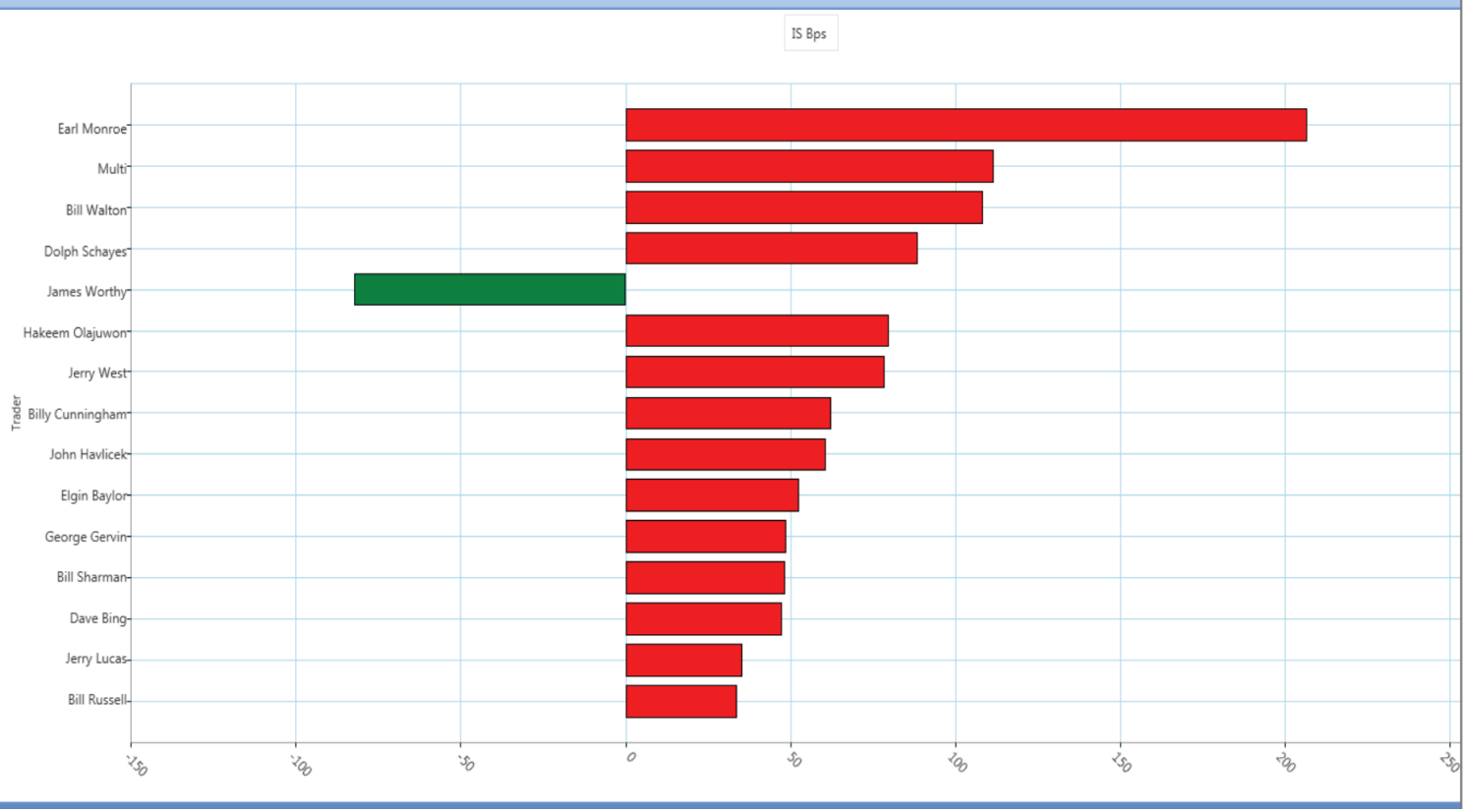
Comparison | Trade Timing | Date Range | XY Chart | Simple Alpha | Histogram | Participation | Spreadsheet

Click here to hide chart options

Select Grouping: Manager, Trading Team, Trader, Broker, Algorithm, Side, Strategy, Style, Sleeve, Account, Amount Order, Liquidity, Market Cap, Participation, PerformanceBt, Sector, Security, Country, Country of Risl, Region, Currency, Order Id, MKT/LMT, DAY/GTC, Order Type, Start Time, Cross/Non-Cro, Program/Non-, Program ID

Graph — Benchmarks (bps): 7.5% PWP, 10% PWP, 15% PWP, 20% PWP, 25% PWP, Close, Client, Custom, Interval Best, Interval High, Interval Low, Interval VWAP, Interval VWAP Overlapping, Interval Limit VWAP, Interval Worst, IS, IS Plus Opp Cost, Open, Opportunity Cost, Opportunity Cost 'End', Opportunity Cost 'Client', Performance, Index Performance, Previous Close, Price at End, TCA Used, VWAP, Generated to Close VWAP, Generated +5 min, Generated +30 min, Price at End +5 min

Build Report



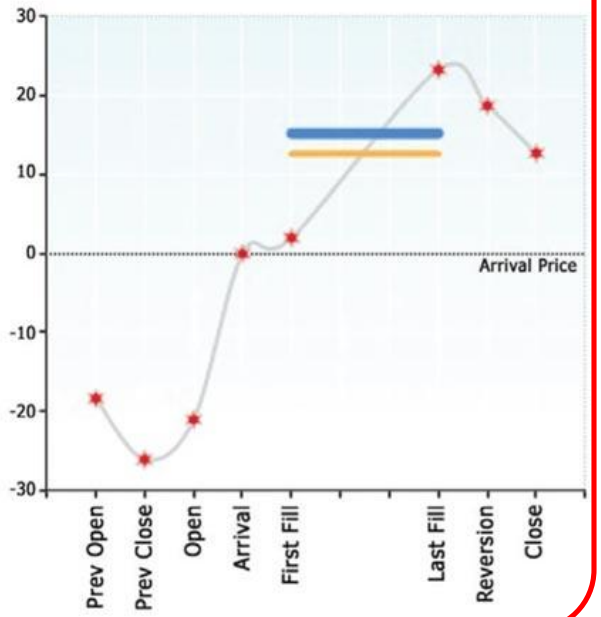
Source: Charles River

Post-Trade TCA – Examples

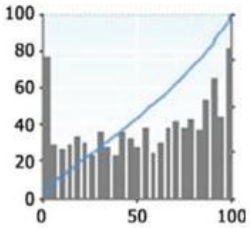
Figure 2:

Macro performance for 6-7 hours **Orders: 100** **Value: €83,344,193** **Avg duration: 06:24:42**

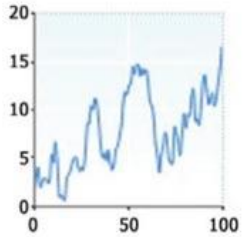
Macro chart:



Fill rate:



Price Impact:



Macro summary:

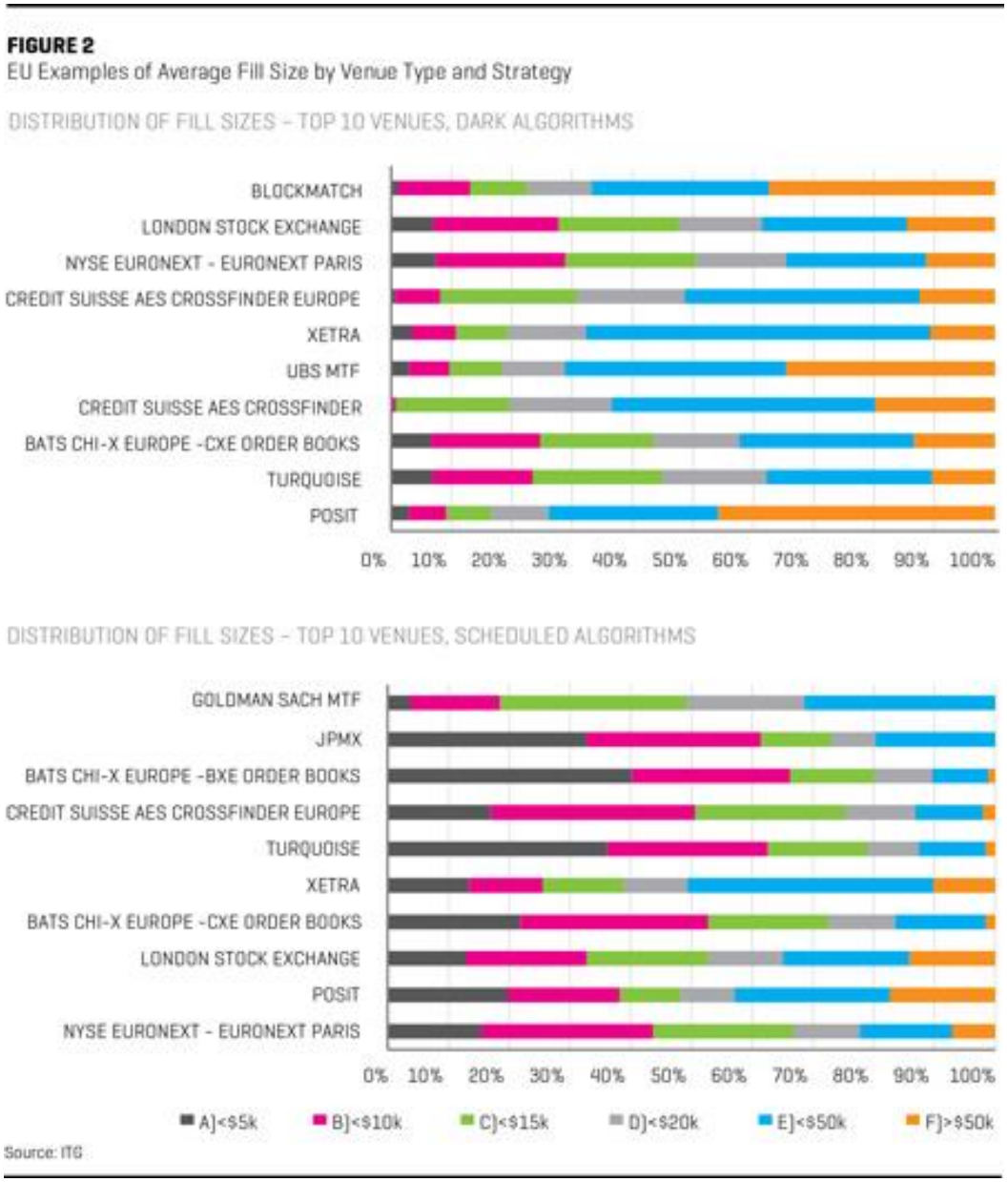
VWAP (First/Last):	**-2.62 BPS**
Spread Capture*contribution:	+0.09 BPS
Timing contribution:	-2.72 BPS
IS (Open)	**-35.95 BPS**
Opportunity Cost contribution:	-20.74 BPS
Delay Cost contribution:	-2.12 BPS
Spread Capture* contribution:	+0.09 BPS
Impact Contribution:	-13.18 BPS
Participation/Reversion	
Participation Rate:	19.07%
Reversion(15min):	-4.54 BPS
Front Loading:	24%-21%-24%-31%
Market Dynamics	
Alpha (Day of Trade):	+34.24 BPS
1 Day Momentum:	-9.69 BPS
5 Day Momentum:	+16.42 BPS

(*)Based on 50.77% spread capture and 11.92 BPS average spread.

Source: LiquidMetrix

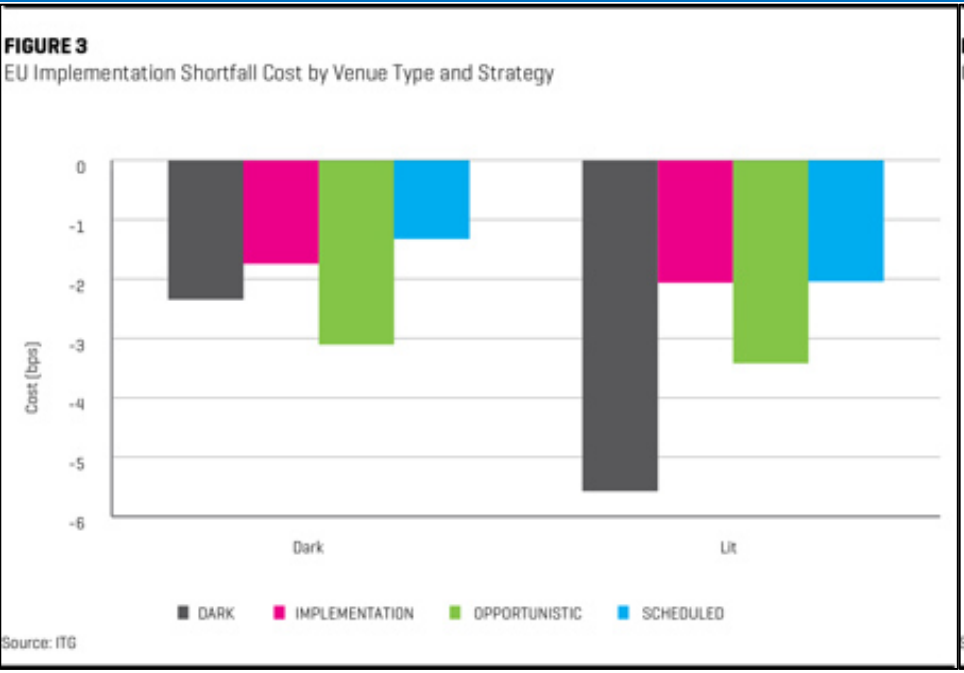
Execution Venue Analysis

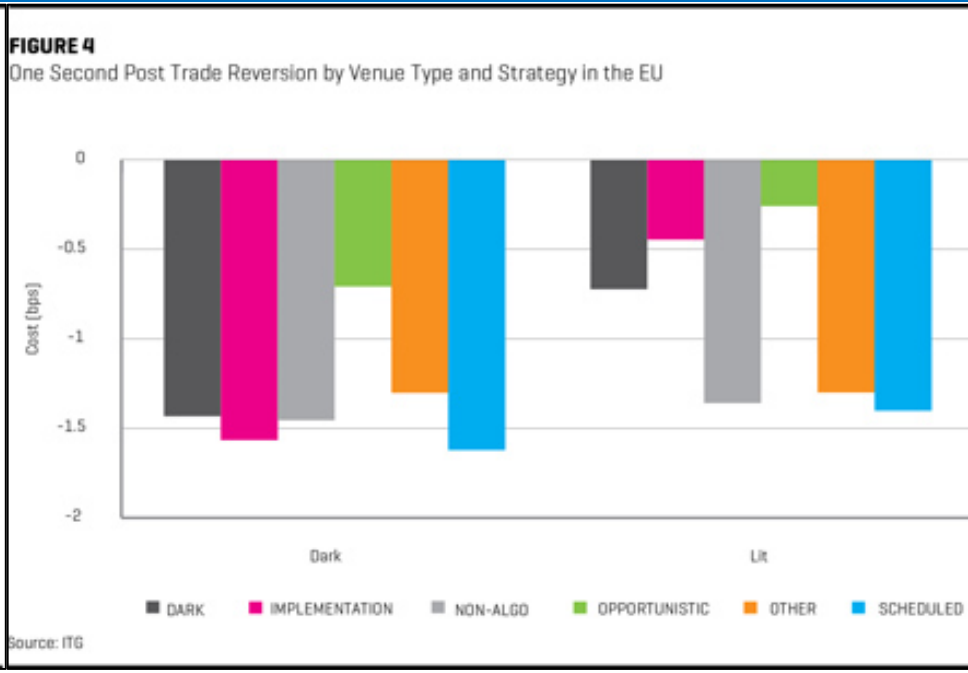
- Distribution of Executions between Venues
- Execution Size (bigger is better)
- Slippage (from what?)
- Adverse selection / Reversion



Source: ITG

Execution Venue Analysis cont'd.





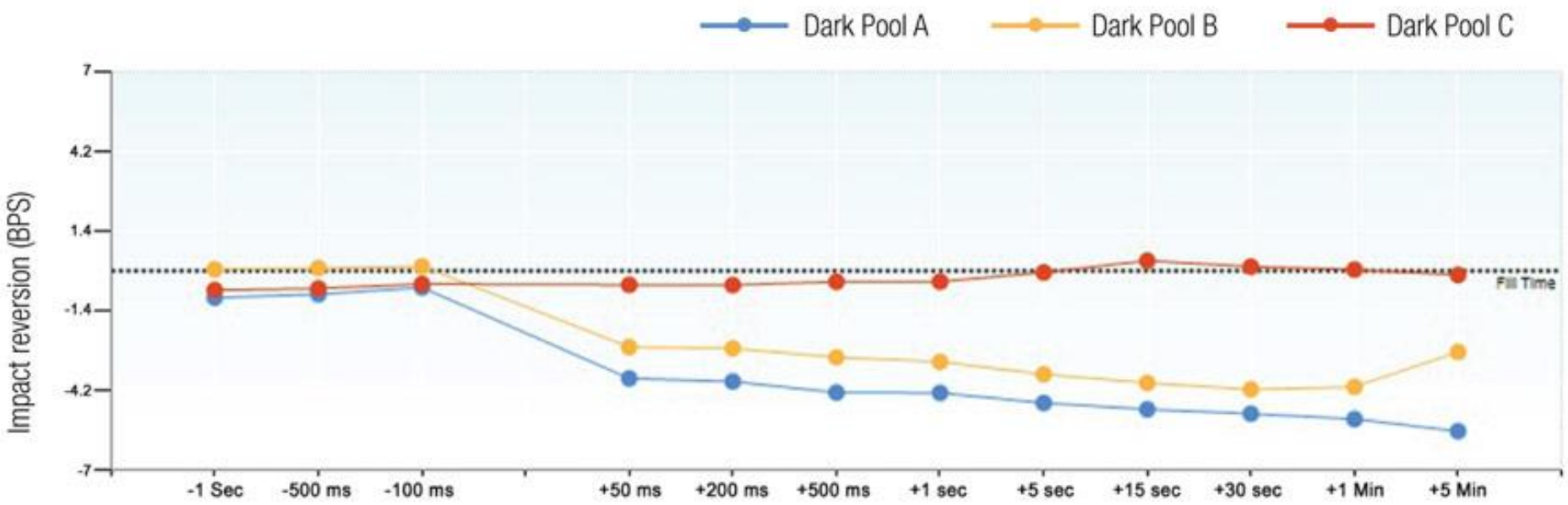
Source: ITG

- Slippage from arrival – causality?
  - Multiple venues
  - Overlapping orders
  - Decoupling timing from order placement is impossible

- Adverse selection / Reversion
  - What happened after the trade?
  - Excess Reversion is bad (could have traded better later)
  - Momentum = information leakage?

Adverse Selection

Figure 5: High frequency price movements just before and after fills



Source: LiquidMetrix

Spread Capture

Figure 3: Dark pools – spread capture histogram

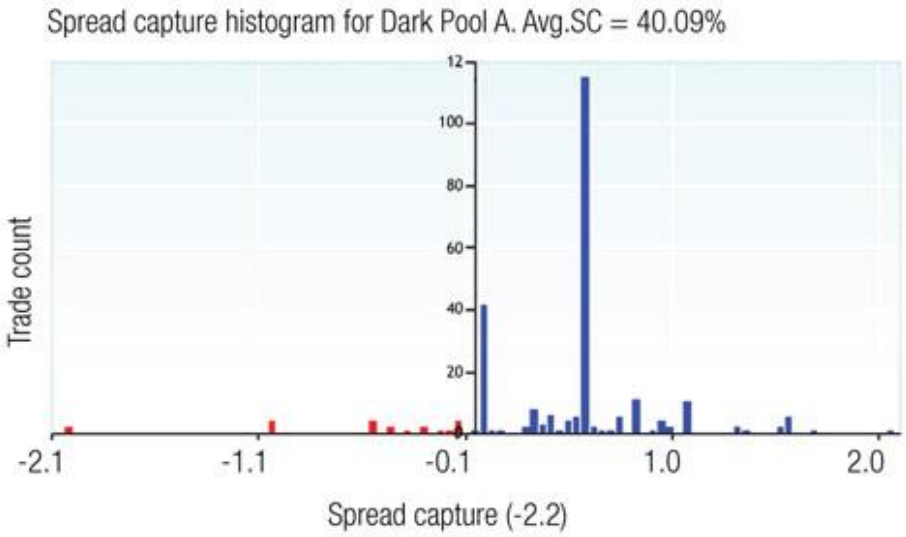
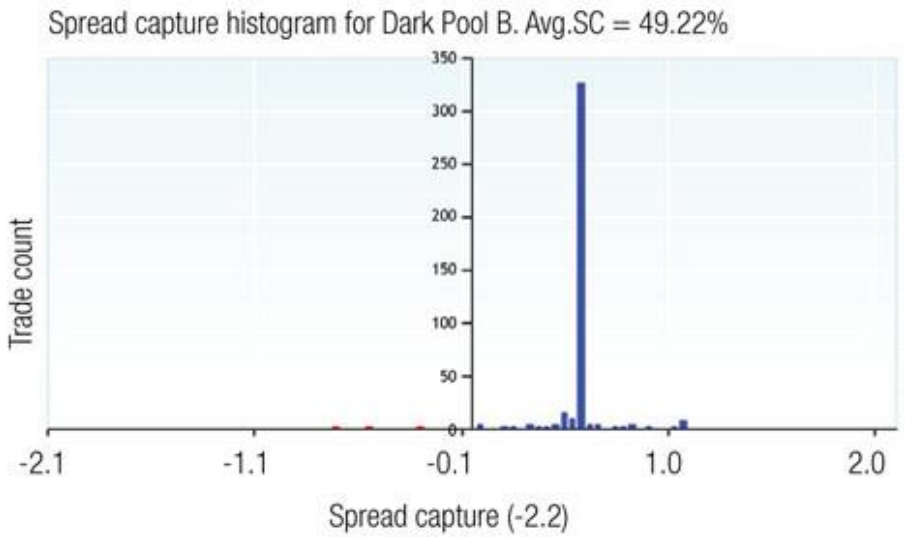


Figure 4: Dark pools – spread capture histogram



Source: LiquidMetrix

- For passive flow (market making, passive strategies)
- What is the impact of order placement?
- Peg Order Types:
  - Passive,
  - Mid,
  - Market / Aggressive

Questions?