SYSTEMATIC TRADING MTH9897
Lecture 2: Fixed Income
Quantitative Investment Framework

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Trading & Technology Landscape

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Trading mode (in order of complexity)

ATS Liquidity Taking (IBP, TMC, TWD, MTS, ALLQ)
- Hit bid/lift offer ➔
- ← Get trade or DNT

RFQ Taking (MKTX, IBP, TMC, TWD, ALLQ, BOLT)
- Send RFQ ➔
- ← Get Quote
- Accept or DNT (*auto-accept) ➔
- ← Get trade

Auction (TruMid, LiquidNet, GFI)
- Send Interest ➔
- ← Get matching interest
- ← Get trade

RFQ Providing anonymous (MKTX OT, IBP, TMC)
- ← Get RFQ
- Send Quote ➔
- ← Client accepts or DNT (* auto-accept)
- Get trade ←

Streaming Quotes Anonymous (MTS, IBP, TMC)
- Send Quote ➔
- Send Quote ➔
- Send Quote ➔
- ← Get trade

Technology

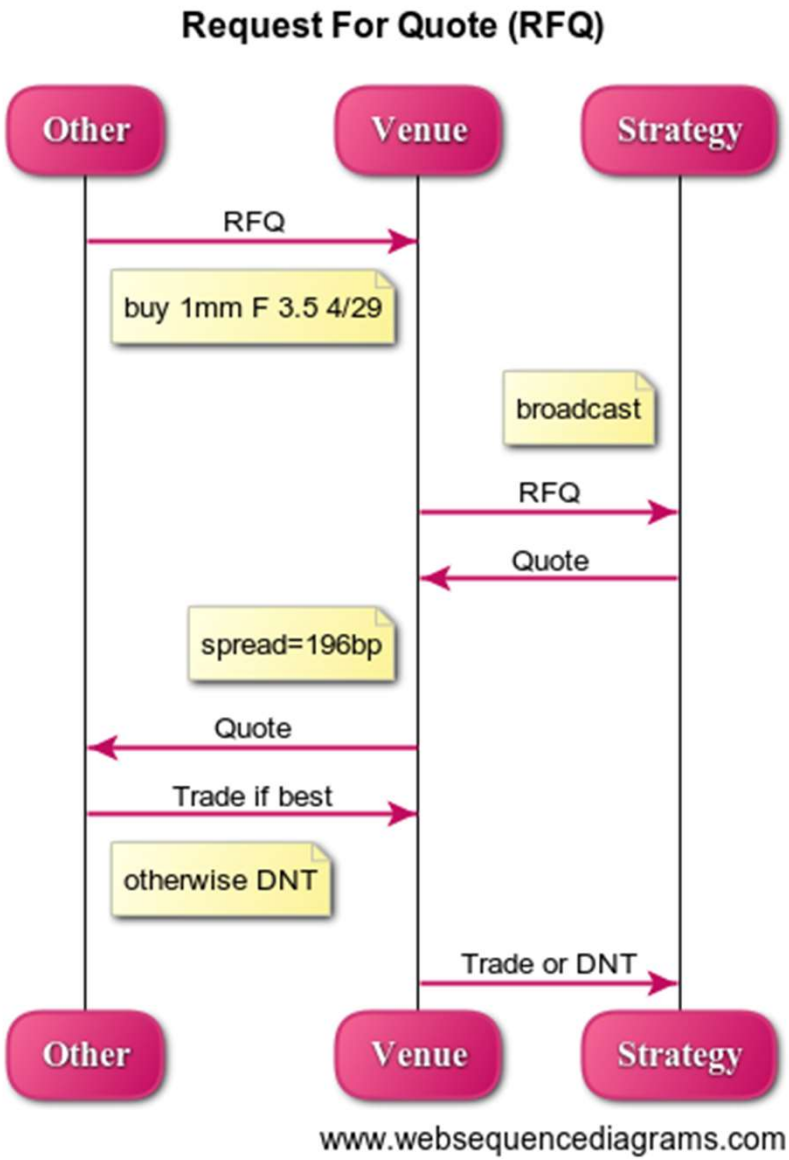
Connectivity (FIX)
- Logon/Logoff/Reconnect
- Normalization to message schema {Order, RFQ, Quote, Trade}.
- Kafka producer/Consumer

Trading engine -- real time event processor

Real time risk management
- e.g. outstanding orders
- trading controls

Load examples
- TRACE (bond trades) < 100K / day
- MSRB (muni trades) < 50K / day
- FI RFQ ~ 100K / day
- Runs/Axes ~ 200K / day
- Evaluated CP+ ~ 1000/second
- MarketData ~ 4000/second/venue
- Processed market data ~ 300/sec

Request For Quote



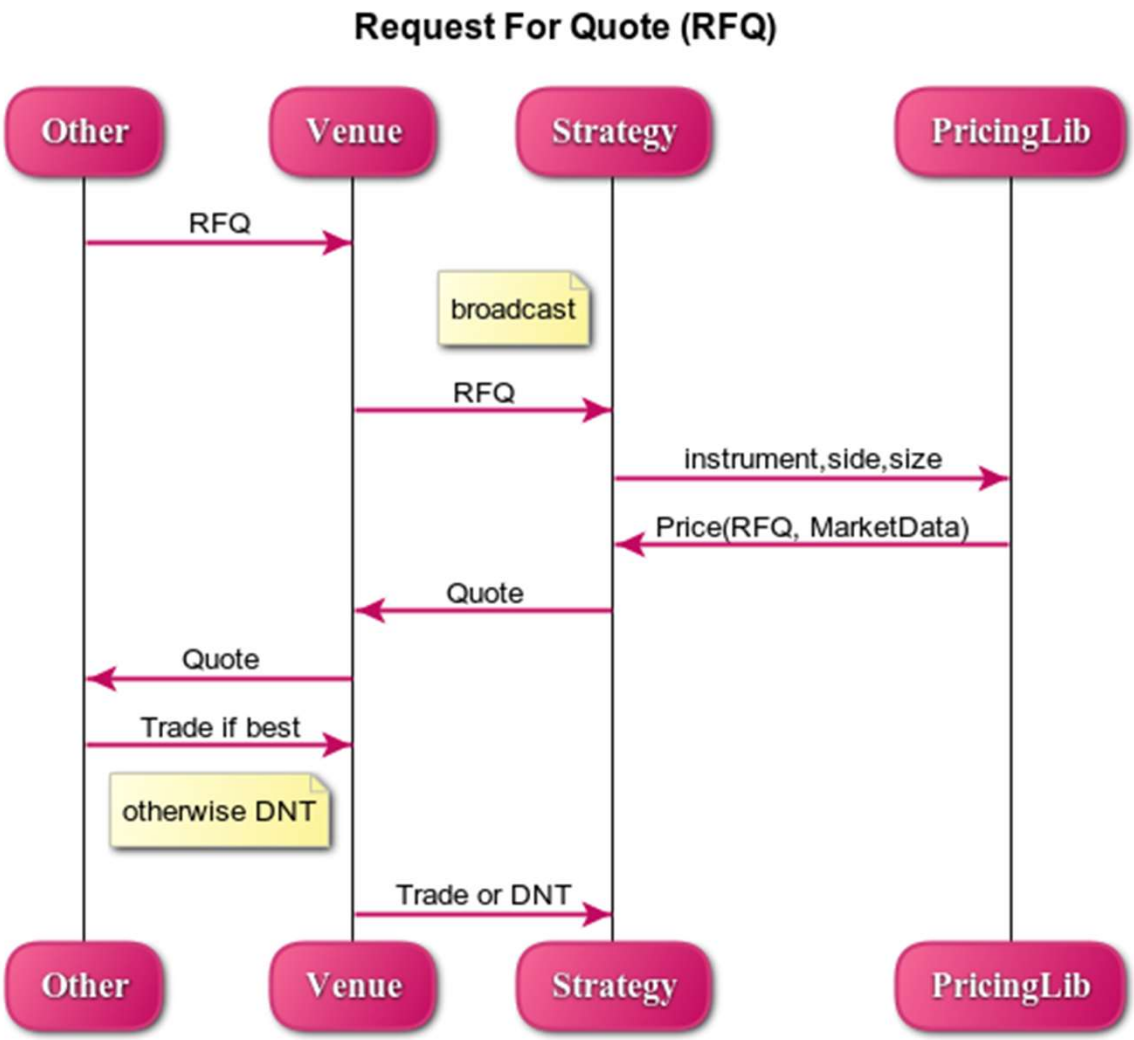
RFQ Attributes

- Symbol & Symbology
  - AltSymbol
- Side
  - From whose perspective?
- Size
- PricingProtocol
  - Pecentage, Yield, Spread
  - Benchmark if Spread
- HoldingBin | ASAP
  - Due Time
  - Firm Until
- RFQ ID
  - To be referenced
- [Sender]
- [# in competition]
- [PartialFillAllowed]

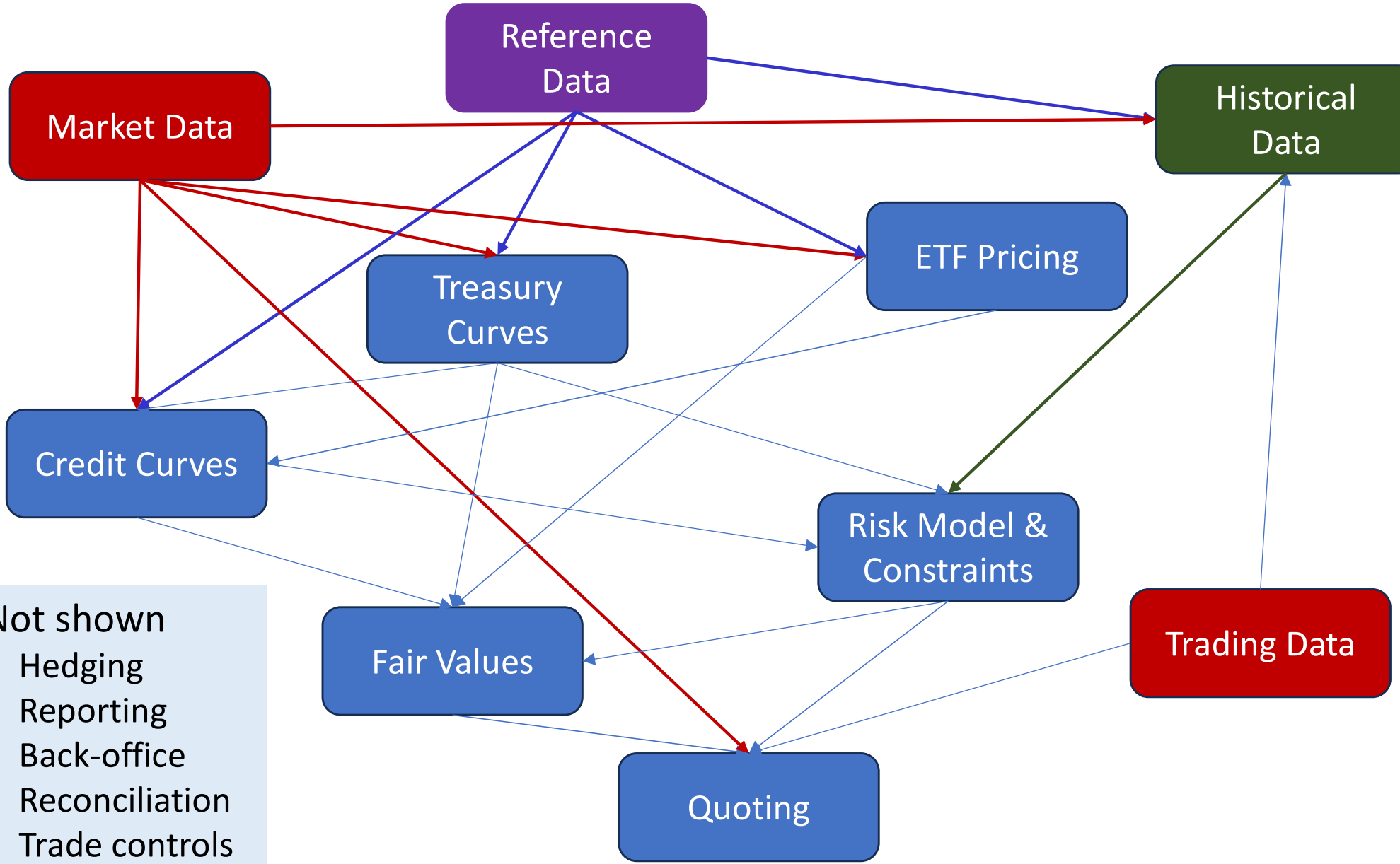
Venues and Data Vendors

VENUES		OrderBook	RFQ	Auction	Sweet spot	Data
MarketAxess Disclosed,OT			YES		>1M & <20K	RFQ, EvalPrice
Bloomberg ALLQ		YES	YES		[1 - 400]	Scraped
Bloomberg BOLT			YES			RFQ
ICE Bonds (TMC + Bondpoint)		YES	YES		[10 -200]	MD, RFQ
TradeWeb Direct		YES	YES		50-400	MD, RFQ
TradeWeb Institutional			YES			MD, RFQ, EvalPrice
MTS		YES			50K - 1M	MD
NYSE (ICE)		YES			0	MD?
Trumid				YES	6M	Mids, EvalPrice
Liquidnet				YES	3M	
GFI				YES	500+	
Chappy			YES		Muni	
JPM	Single Dealer		YES			MD
MS	Single Dealer	Quotes	YES			MD
Jane St	Single Dealer	Quotes				
Headlands	Single Dealer	Quotes			Muni	
DATA		TYPE				
NEPTUNE		IOI				
TRACE		TRADE			Corp, Treasury, Mtge	
CP+		EVALUATED				
MSRB		TRADE			Muni	
SOLVE		IOI				
CC&S		MUNI IOI				
IDC		EVALUATED				

Sequence of events



Incomplete* bond trading system



*Not shown
- Hedging
- Reporting
- Back-office
- Reconciliation
- Trade controls

Systematic Bond Trading

- Preparing Static Data
  - Acquisition (download, B-Pipe etc)
  - Filtering/Normalizing, preprocessing
  - Grouping
- Market Data Processing
  - Maintain current state of data (order book)
    - Data from corporate bond venues
    - Treasury pricing
    - Trades (TRACE/MSRB/Venues)
    - Requests for Quotes
    - New feeds
  - Fitting the Functional Form
- Curve Construction
  - Updating reference curve
  - Converting to *z*-Spread
  - Fitting the Functional Form
- Quantifying The Opportunity
  - Comparing bonds to the curve
  - Comparing to pricing implied by ETFs
- Monetizing The Opportunity
  - Use pricing in market/risk context
  - Short term tactical signals
  - Sending order/quotes/RFQ responses
- Hedging residual exposures
  - Treasuries
  - Treasury futures
  - Fixed Income ETFs (e.g. LQD for corporates, TLT, SHY rates)
- Classical Portfolio optimization
  - Implies ability to trade into desired portfolio
  - Getting different prices is a correction
  - Not getting into position is a correction
  - Has a baked in assumption about liquidity
- Credit trading
  - Multitude of correlated instruments
  - Trading cost could be comparable to returns on shorter horizon
  - Most instruments cannot be traded whenever you want
  - Opportunity-driven optimization is one approach

Filtering Bonds - example

Filter Level (usage)	Basic (store in history)	Tradable (publish prices)	High Quality (used in calibration)
Min Amount Issued	$50M	$50M	$250M
Min Amount Outstanding	$40M	$40M	$200M
Max Average Price Spread	Any	$3	$2
Other Conditions	• Not defaulted • Not matured	• Not called (if callable) • Avg daily volume of large trades ≥ 250K • Quotes with tight bid-ask spread are present > 40% of the day	• Matures at least 1Y away • Avg yield spread < 20 bps • 4+ high quality bonds per curve • Junior/Senior attribution

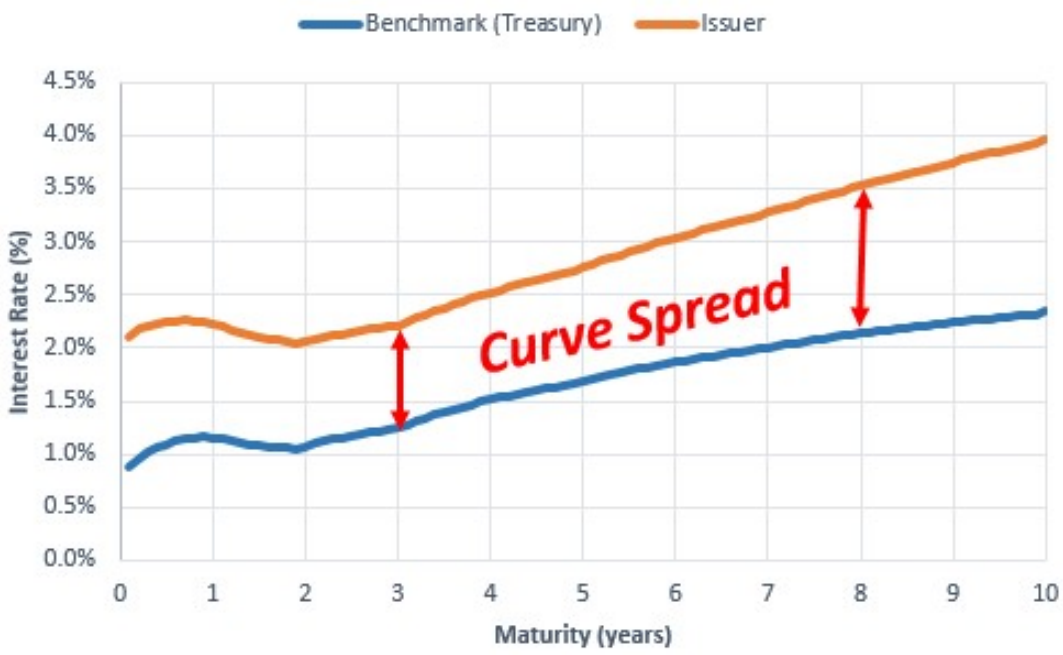
Grouping Bonds

To construct the curves, we need to arrange the bonds into logical units, related by common features:

- Grouping Characteristics
  - Issuer (e.g., AAPL, GS, MO)
  - Industry (e.g., Financials, Industrials)
  - Rating (e.g., A-, BB+)
  - Industry & Rating (e.g. Financials/BBB)

- Features
  - Distinguish between junior and senior bonds, if necessary
  - Spread from a relevant benchmark curve (called the reference curve)
  - Curve captures common risk of the entire group

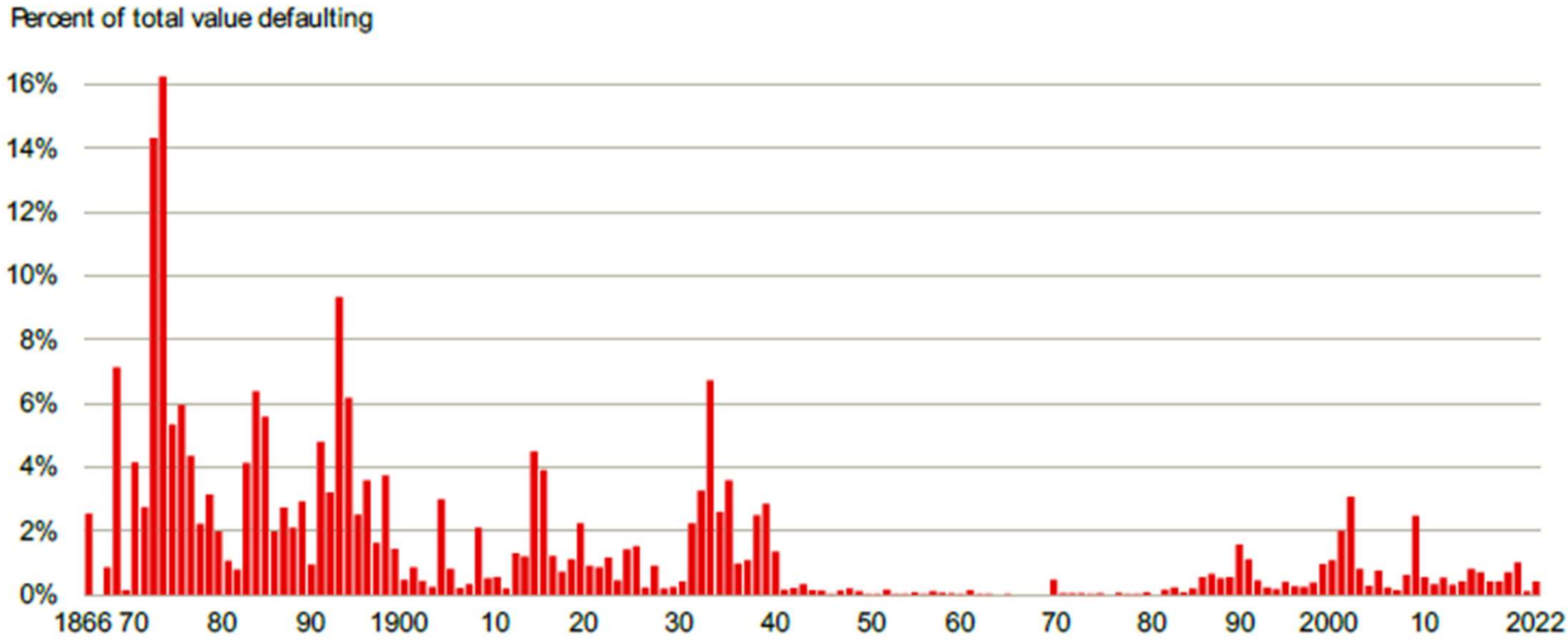
Converting Prices to Spreads



- Initialization
  - ➢ Prepare the structures
    - ✓ Construct cash flows, calendars, etc.
    - ✓ Construct bond objects
- Real-Time Processing
  - ➢ Obtain market prices
  - ➢ Calibrate the reference curves
  - ➢ Calculate the spreads for each bond
    - ✓ Imply yields from clean prices
    - ✓ Calculate the corresponding values from the base curve
    - ✓ Compute the spreads

Factor Investing in Credit

- Default rates cluster in time with a serial correlation of 0.63
- Average US credit premium ~1.80% after 1936 (1.35% IG and 3.35% HY)
- Average default rate 1.2% (0.1% for IG and 2.9% for HY)
- Annual loss rate it 1.0% (0.2% for IG and 2.7% for HY)



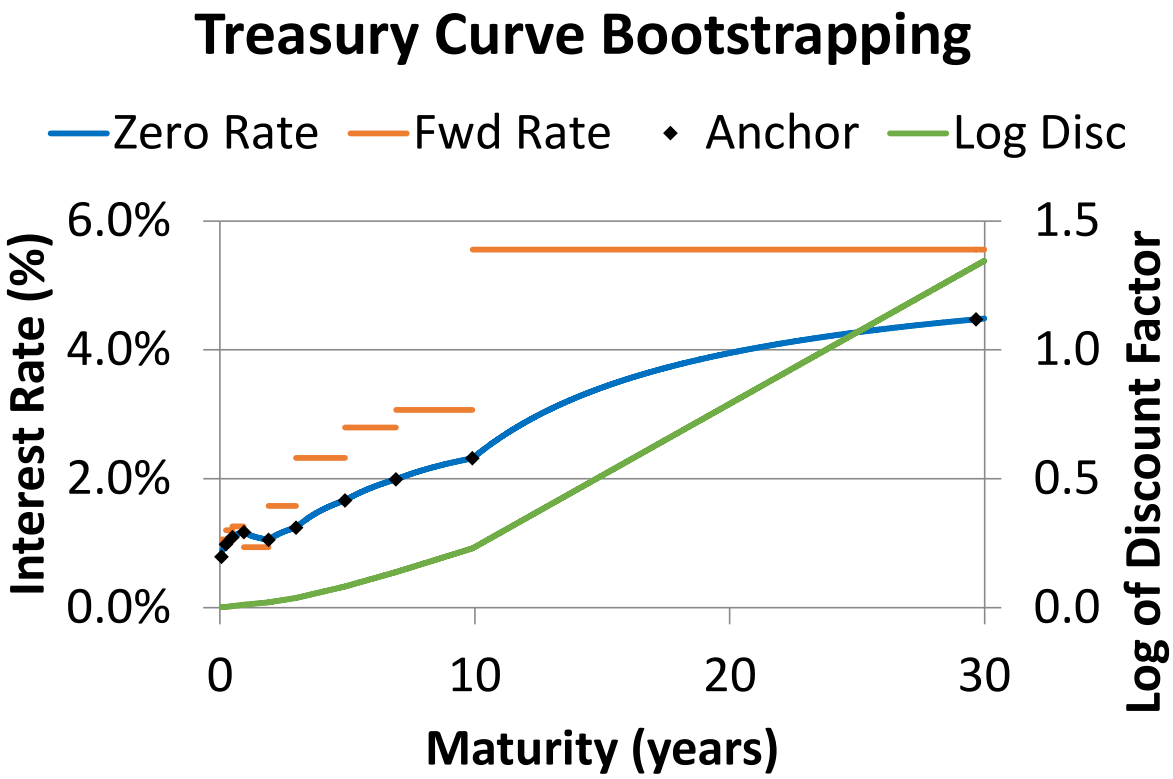
Source: Giesecke, Longstaff, Schaefer and Strebulaev (2011), updated to 2022 by Dimson, Marsh and Staunton using Moody's data.

Buy-sell asymmetry

- Most bonds not shorted and are held to maturity
  - munis are a good example
  - Corporates are expensive to short
- Buyer buys **a** bond (any in a group)
  - Chooses be best price among many nearly fungible bonds
- Seller can be motivated (he needs to close on a house, a yacht)
- Seller sells **the** bond (what he owns)
  - Seller sends bid-wanted (RFQ)
  - Dealers compete to buy “at bid”
  - Dealer turns around post liquidity on exchange
- May vary quoting logic between bidding and offering

Constructing the Treasury Curve

- Arrange instruments (anchors) by maturity
- Bootstrap the zero-coupon rates for each anchor
  - Find the (unique) zero-coupon rate to match the theoretical price of the anchor to its market price
  - Interpolate using
    - ✓ constant forward or
    - ✓ linear log of discount



https://www.atlantafed.org/-/media/documents/research/publications/economic-review/2004/vol89no3_fisher.pdf
http://gouthamanbalaraman.com/blog/quantlib-term-structure-bootstrap-yield-curve.html

Constructing the Issuer Curve – Model

Nelson-Siegel 4-Parameter Model

- Assumes implied forward as Laguerre function with constant shift:

$$f_t = L + Se^{-tD} + CDte^{-tD} = L + e^{-tD}(S + CDt)$$

- Resulting zero curve is then

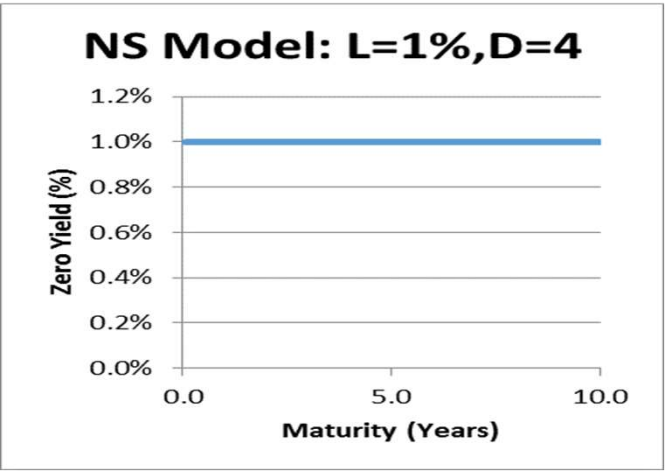
$$z_t = \frac{1}{t}\int_0^t f(s)ds = L + (S + C)\frac{e^{-tD} - 1}{tD} - Ce^{-tD}$$

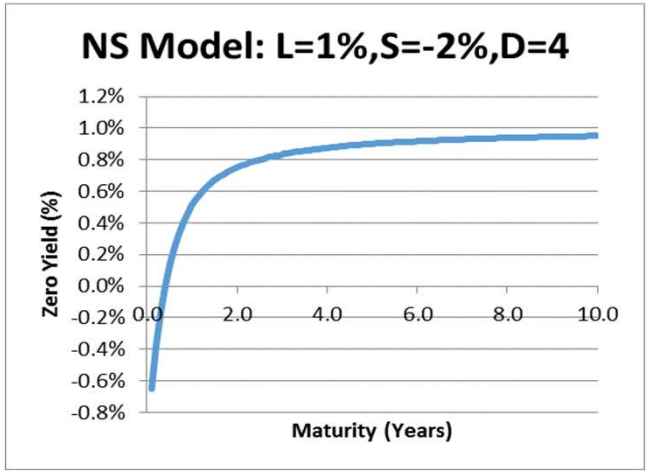
Nelson, C., & Siegel, A. F. (1987). Parsimonious modeling of yield curves. The Journal of Business, 60(4), 473-89.

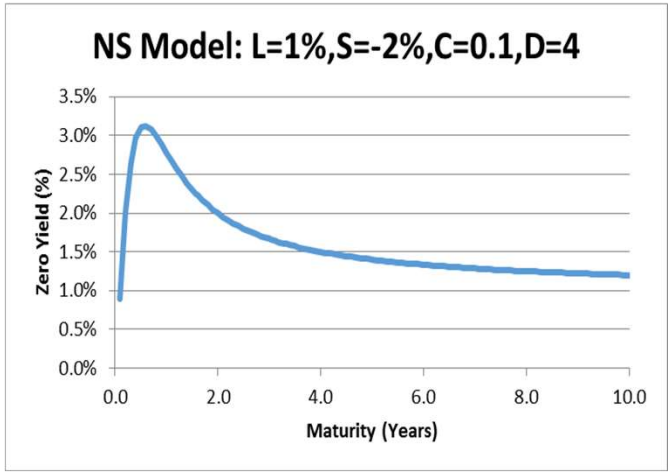
Constructing the Issuer Curve – Intuition

Geometric Interpretation of Parameters

- Level (z_∞), slope ($z_0 - z_\infty$), curvature and decay D
- L, $(S + C)$ and $-C$ are the top 3 principal component factors
- D determines the shape of the curve (location of hump/bend)





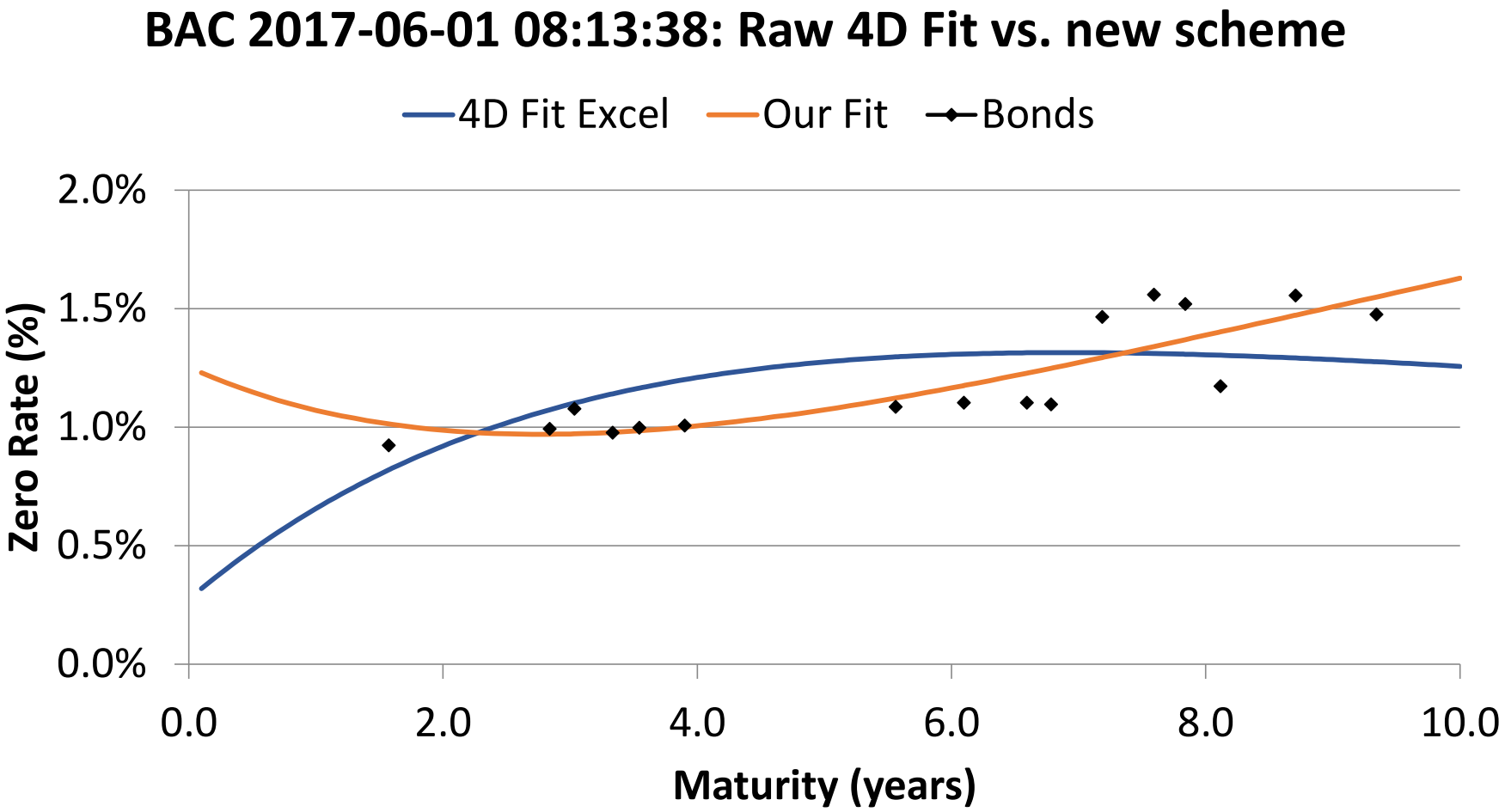


Constructing the Issuer Curve

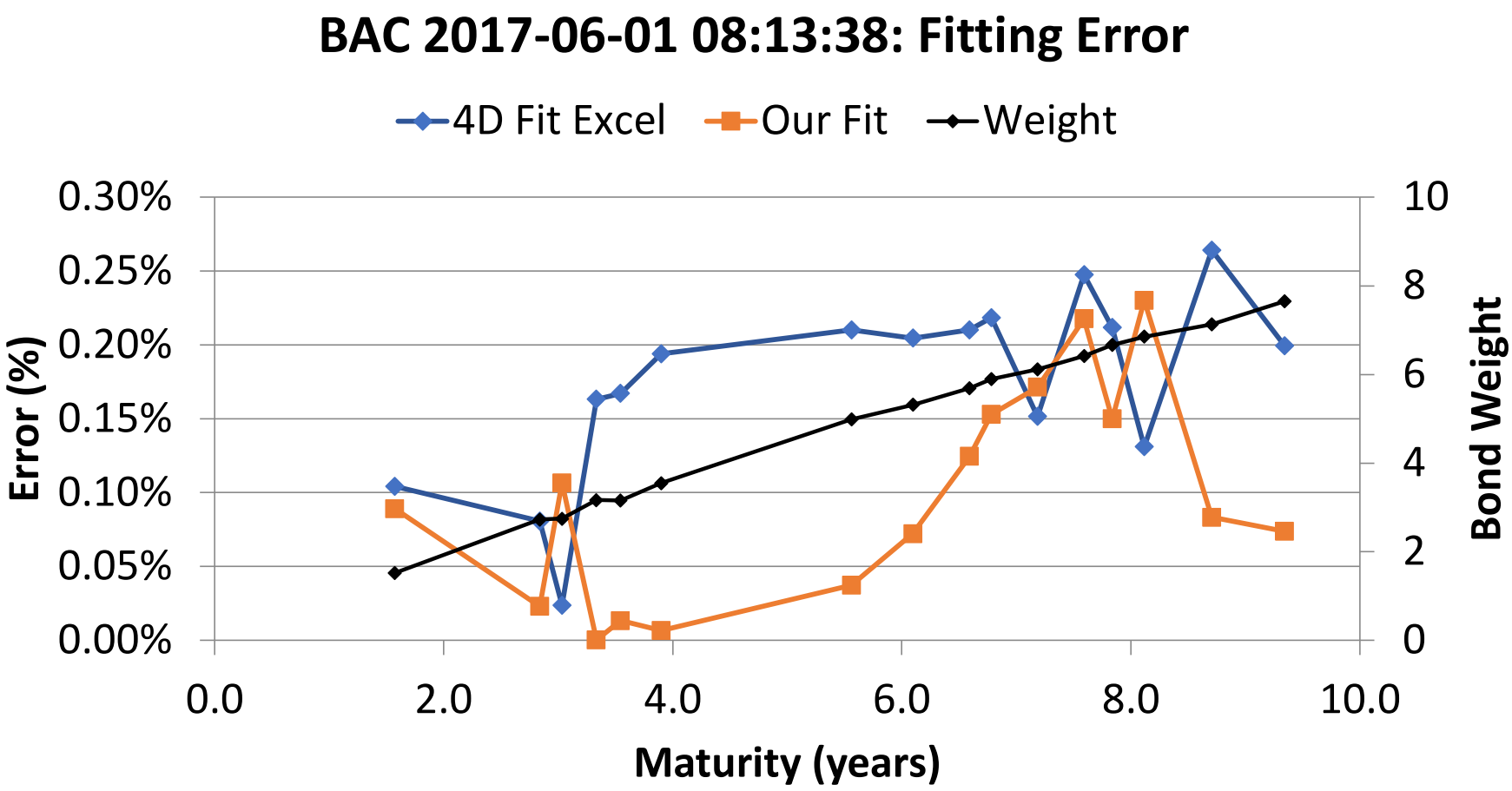
Optimize model parameter choice

- Exact non-linear optimization in 4-D is computationally intensive
- Alternative formulation allows fast progress
  - Work with *z*-Spread, not with prices directly
  - Finding just level, spread and curvature is a linear least squares problem
  - Decay determined by 1D numerical minimization of the weighted square error

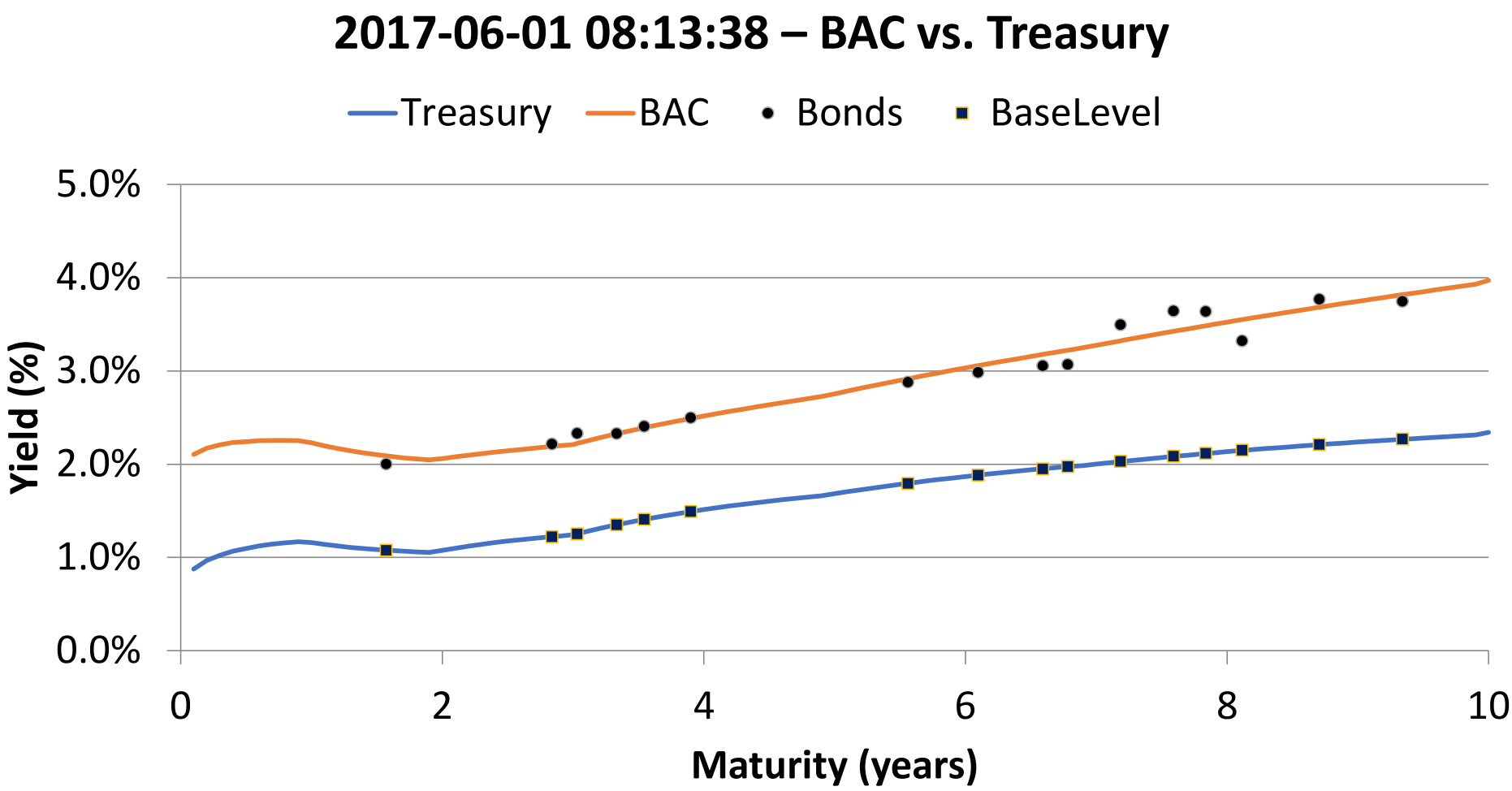
Fitting the Issuer Spread Curve



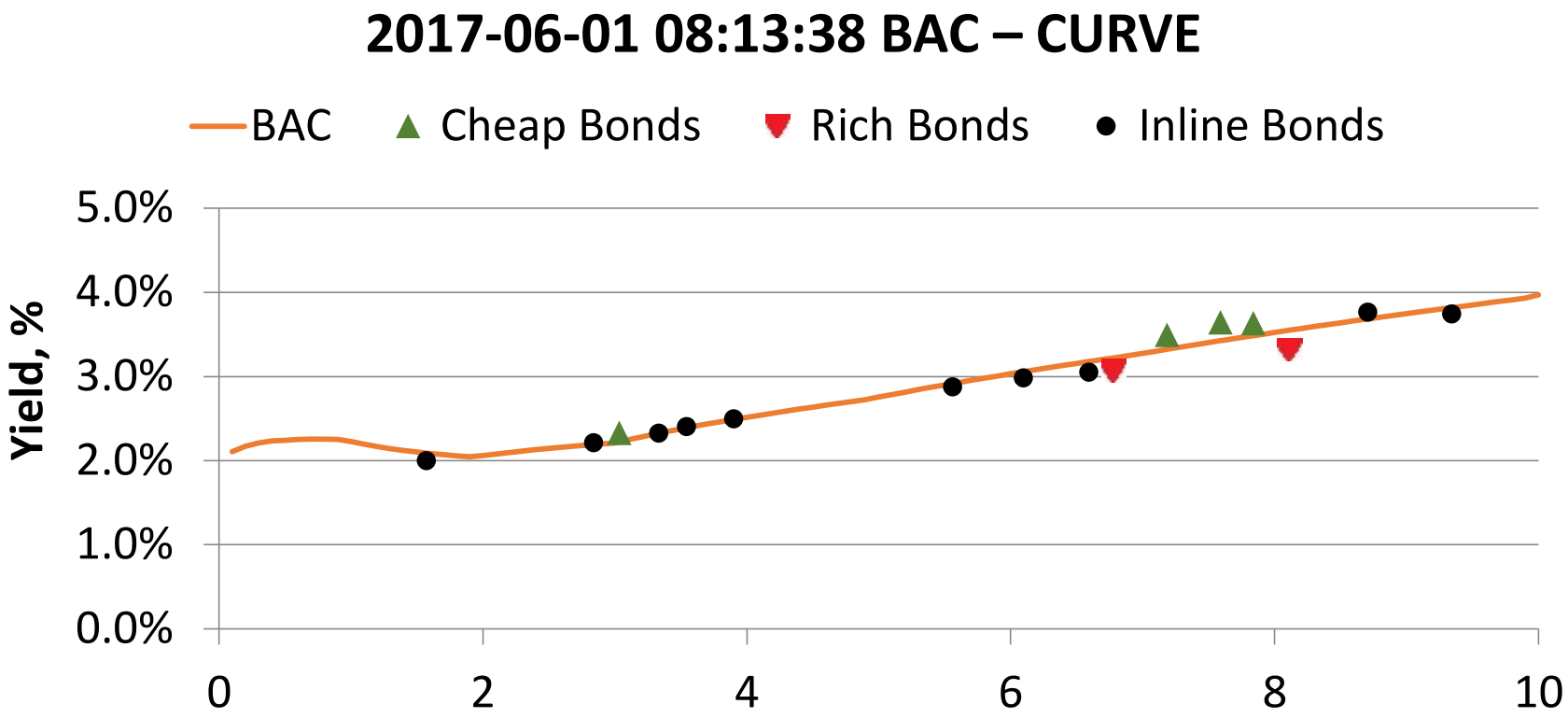
Issuer Credit Spread – Fitting Error



Constructing the Issuer Curve – Final Fit



Rich and Cheap Bonds vs. The Curve



Notes on Curve fitting

- Some bond prices are more reliable than others
  - Volume of trades [issue size, age, index inclusion]
  - Volume of market data
  - Bid-offer spread
  - Need enough bonds to build a curve (>4 for Nelson-Siegel)
  - Simplicity of bonds priced off the yield curve
    - Bullet [no options, fixed coupon]
    - Callable/Puttable => yield to worst, convention
    - Senior/Junior ➔ need to Junior curve
    - Issued by a subsidiary with a different rating ➔ mispriced
    - 144A / Reg S ➔ less liquid
    - Insured or asset-backed ➔ will always look rich
    - Step-up or step-down coupon ➔ different cash flow

Homework assignment

1. Download from WRDS enhanced end of month data for 4+ of your favorite large issuers(e.g. MSFT, AAPL) for a period of year+:
   - https://wrds-www.wharton.upenn.edu/pages/get-data/wrds-bond-returns/wrds-bond-returns/
   - Make sure your issuers have enough bonds to cover maturity spectrum.
   - Dataset covers up to 09/2022, so choose earlier days
2. Filter data: `SECURITY_LEVEL` and `RATING` to have same value across all bonds
3. Plot Treasury spread `T_Spread` vs `DURATION` for each issuer
4. Use basis of your choice to fit the spread curve with a 3 parameter model of YOUR CHOICE
   - E.g. spread = a + b*log(1+TMT)+ c*TMT + d*coupon , as shown in the example below
   - Consider weighting regression on reliable points (actively traded, large issues)
   - take a look at outliers: is there anything special about these bonds?
5. Built a duration-neutral portfolio (short rich bonds, long cheap bonds)
   - Monthly rebalance as data allows
6. Evaluate its return, PNL, turnover etc on the next month data.
   - Make necessary assumptions.
   - make sure it includes accruals (or add them yourself as a 1/12 of a coupon)
   - Summarize your finding

Can you tell a good curve from bad curve?

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- What is the purpose?
- Back-test “sanity check” for mean reversion
  - Buy cheap at mid
  - Short rich at mid
  - Control risk (e.g. DV01-neutral)
  - Compute PNL, analyze “losers”
- Back test for real
  - Replay [possibly preprocessed] market data
  - Compute your pricing model
  - Replicate your actions (place orders, RFQ responces)
  - Develop a “fill model” (simulated counterparties)
  - Compute PNL, analyze exposures, “losers”
  - Update your model

Risk model (one of)

Consider a portfolio of bonds, with positions w_i and prices P_i, $i=1..N$

- Note that trading ultimately done in dollar terms.
- $P = w_i P_i$ with double indexing representing summation

Suppose we have a signal α_i and utility function U

- $U = w_i \alpha_i - \lambda R(\boldsymbol{w})$ where R is an expected variance of portfolio PNL.

Suppose we can model each bond via a combination of real-valued factors f_j, $i=1..M$

- $P_i = P_i(f_1, f_2, \dots)$
- In our case factors can be
  - Treasury curve level, slope, curvature
  - Principal components of treasury rates
  - Issuer's spread curve level, or some other parameterization
- $\Delta P_i = \frac{\partial P_i}{\partial f_j} \Delta f_j$

Variance of the portfolio is then

- $R = \langle (\Delta P)^2 \rangle = \left\langle \left(w_i \frac{\partial P_i}{\partial f_j} \Delta f_j \right) \left(w_k \frac{\partial P_k}{\partial f_m} \Delta f_m \right) \right\rangle = w_i \frac{\partial P_i}{\partial f_j} \langle \Delta f_j \Delta f_m \rangle \frac{\partial P_k}{\partial f_m} w_k$
- $U = \alpha^T w - \lambda w^T L^T C L w$
- $L[N \times M]$ loadings aka sensitivities extracted from yield curves
- $C[M \times M]$ covariance matrix estimated e.g. from time history of curve parameters

Portfolio Trading and ETFs

- Fixed income ETFs volume is comparable with trading volume of underlying
- Portfolio trading grew to 10% of credit volume
  - Can be tracked by TRACE timestamps historically
  - PT flag added to TRACE May 2024
  - Create noise in individual bond pricing
- Convenience of a single price for buy-side
- “Time is alpha” but is price really better than buying piece-meal?

Fixed income ETF AUM $1.5 Trillion

Vanguard Total Bond Market ETF BND with $94.94B in assets

https://www.etf.com/topics/fixed-income

Exchange-Traded Funds (ETF)

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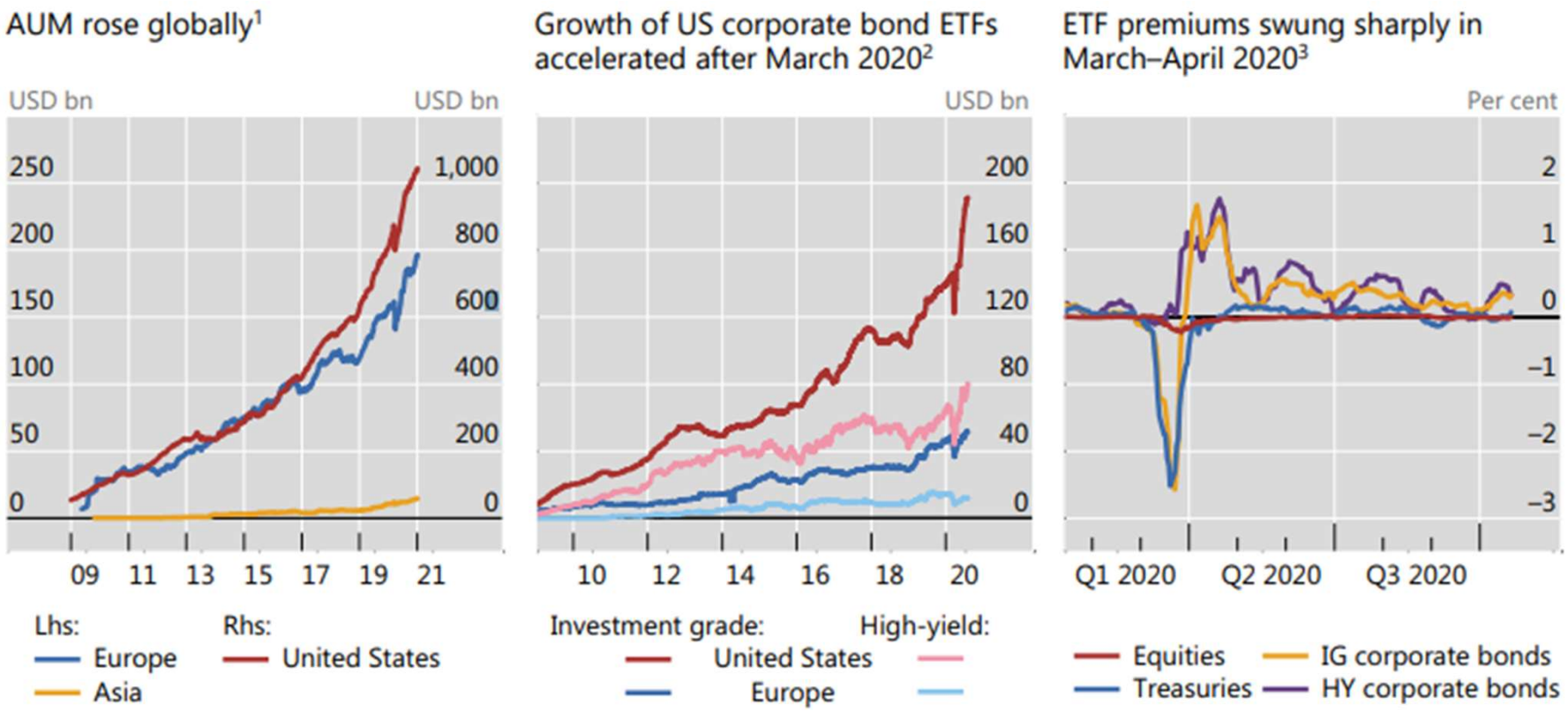
- Trade as equities
- Much more liquid than individual instruments
- Prices move with supply-demand (equity side) and with underlying securities (Fixed income side)
- Price divergence is ~~removed~~ limited by creation-redemption mechanism
  - Only executed via Authorized Participants (AP)
  - Basket are negotiable
  - Each ETF has some peculiarities
- Major managers: Blackrock (iShares), Vanguard, State Street, major banks
- Great for:
  - Getting broad exposure to a segment
  - Hedging residual risk (rates and credit)
- Not to be confused with “Exchange Funds” where investors pool their individual portfolios

Liquidity and Bond ETFs

- Bond's minimum trade size/increment $1000
- Major brokerage minimum size $100,000
- Many bonds not accessible to retail investors
- Trading cost for 1-10 bond is 3x that for 1000 bonds
- Per trade ticket charges don't favor many small trades
- Access to illiquid market benefits from introduction of basket trading opportunity according to Market Accessibility, Corporate Bond ETFs, and Liquidity, C.W. Holden, J. Nam (2019)
  - Used TRACE data
  - out-of-index bonds to benchmark
  - improvement for 144a, high yield, large tenors

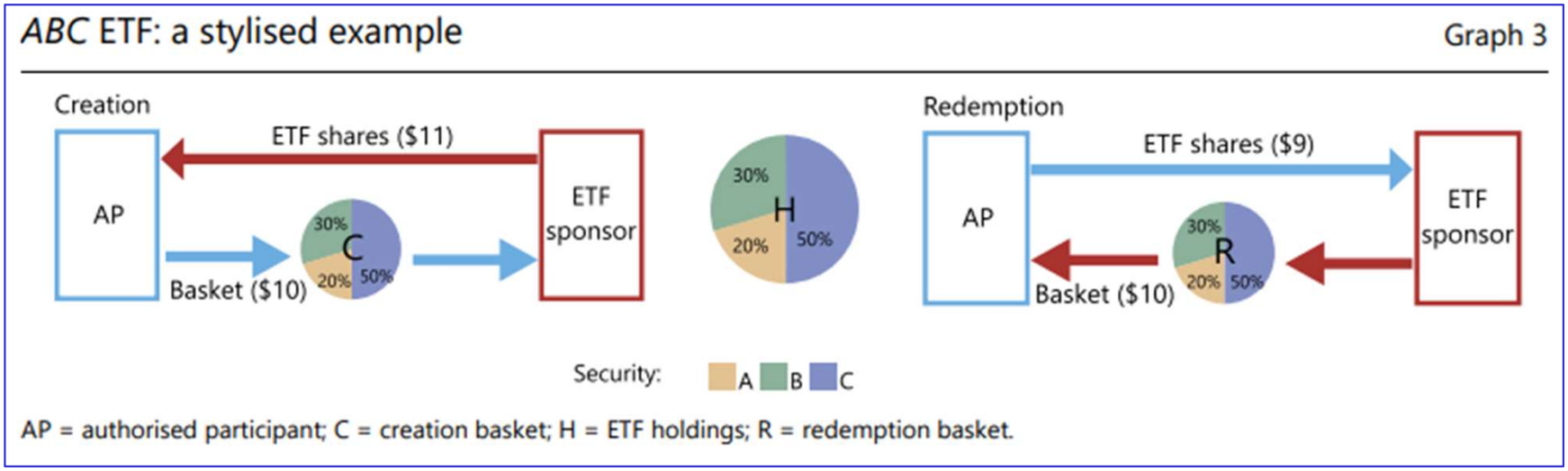
Bond ETF Arbitrage

- Creation redemption is ~10% of ETF trading volume
- Largest AP's:
  - Banks: BAML, GS, JPM, MS
  - Market makers: Citadel, Jane St, Flow Traders, Virtu



The anatomy of bond ETF arbitrage by K. Todorov (BIS Quarterly Review, March 2021)

Bond ETF Arb Illustration



Suppose ETF trades at premium:

- NAV@(T-1) = $10 (3A + 2B + 5C)
- ABC ETF price is **$11**

AP Creation Arbitrage

- Buy A, B, C in secondary market (-$10)
- Exchange {A,B,C} for shares of ETF (~$0)
- Sell ETF on exchange (+$11)

Suppose ETF trades at discount:

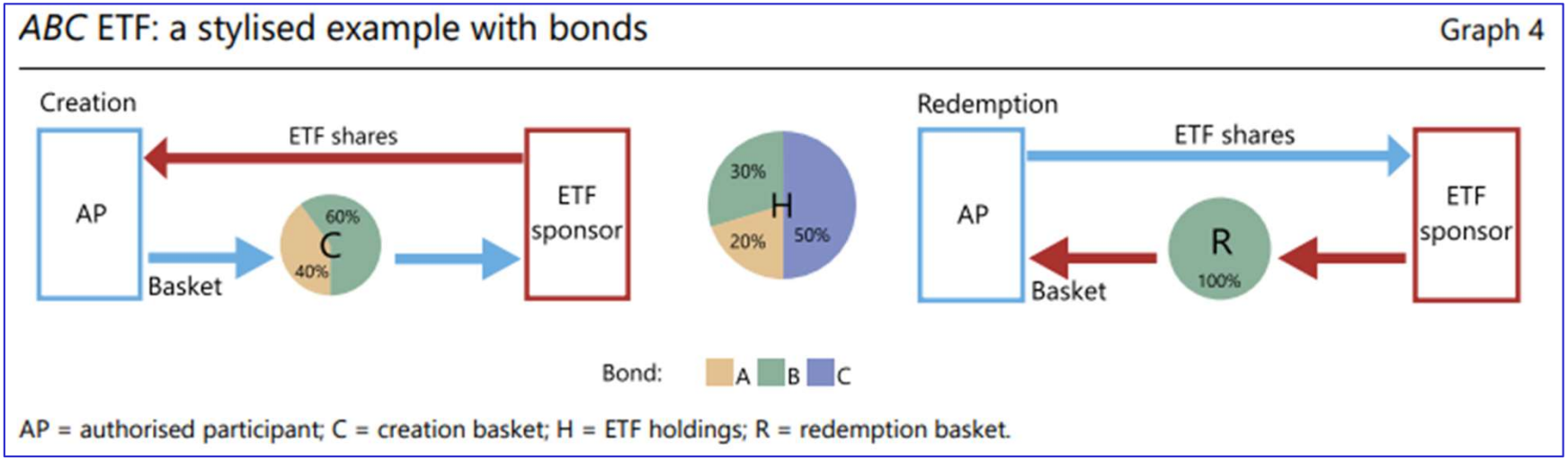
- NAV@(T-1) = $10 (3A + 2B + 5C)
- ABC ETF price is **$9**

AP Redemption Arbitrage

- Buy ETF on exchange (-$9)
- Exchange shares of ETF for {A,B,C} (~$0)
- Sell A, B, C in secondary market (+$10)

The anatomy of bond ETF arbitrage by K. Todorov (BIS Quarterly Review, March 2021)

Bond ETF Arb Illustration II



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For illiquid bonds 1000+ names in benchmarks, baskets are impossible to replicate:

- C/R baskets cover by 50-200 names, subject to negotiation
  - ETF managers want to get rid of maturing/aging bonds
  - ETF managers like illiquid bonds to reduce tracking errors
- NAV methodology may be proprietary to exchange find (reverse engineer?)
- Creating a good replicating basket with a subset of bonds **is a non-trivial problem**
- Other participants can engage AP to create/redeem for them. Unit size ~100K shares

Timing risk

- Premiums/discounts may disappear
- NAVs for creation/redemption are not known at time of trade

Portfolio Trading in Fixed Income

- Single price paid for a portfolio of bonds
- Price can be established in competition over RFQ protocol
- Portfolio trading grew from ~0 in 2017 to 7%-10% of TRACE volume
- PT trades are flagged as such in TRACE since May 2023
- Portfolio Trading in Corporate Bond Markets by M. Jeffery and Z. Torodova (2023)
  - 40% improvement in trading costs relative to piece-meal RFQ'ing
  - Mostly benefits illiquid bonds
  - Explained as a spillover of ETF creation/redemption activity
  - Most pronounced for buys when ETF trades cheap, and sells when ETF rich.
- Trading venues such as Bloomberg, MarketAxess, Tradeweb, Trumid rush to add portfolio trading functionality to their workflows and trading stations
- Individual bond prices still need to be determined correctly for reporting and allocations to sub-accounts.

Fixed Income Vs Equities Trivia II

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Measure	Fixed Income (Municipal)	Fixed Income (Corp)	Equities
Market Size,$	**4.0T**	**11.5T**	**47T**
Issuance,$	400B	2.3T	400B
Daily Trading Volume,$	**10B**	**46B**	**481B**
Electronic Volume,$	1B	3B (*)	350B
Number of trades	**45k**	70k	59m
ElectronicTrades	4k	12.5k	50m
Instruments	1MM	100K	10K
Average trade size,$	250K	650K	8K
Electronic trade size,$	200K	240K	7K

*Sources: FINRA, SIFMA, MSRB

Munis – a new FI darling

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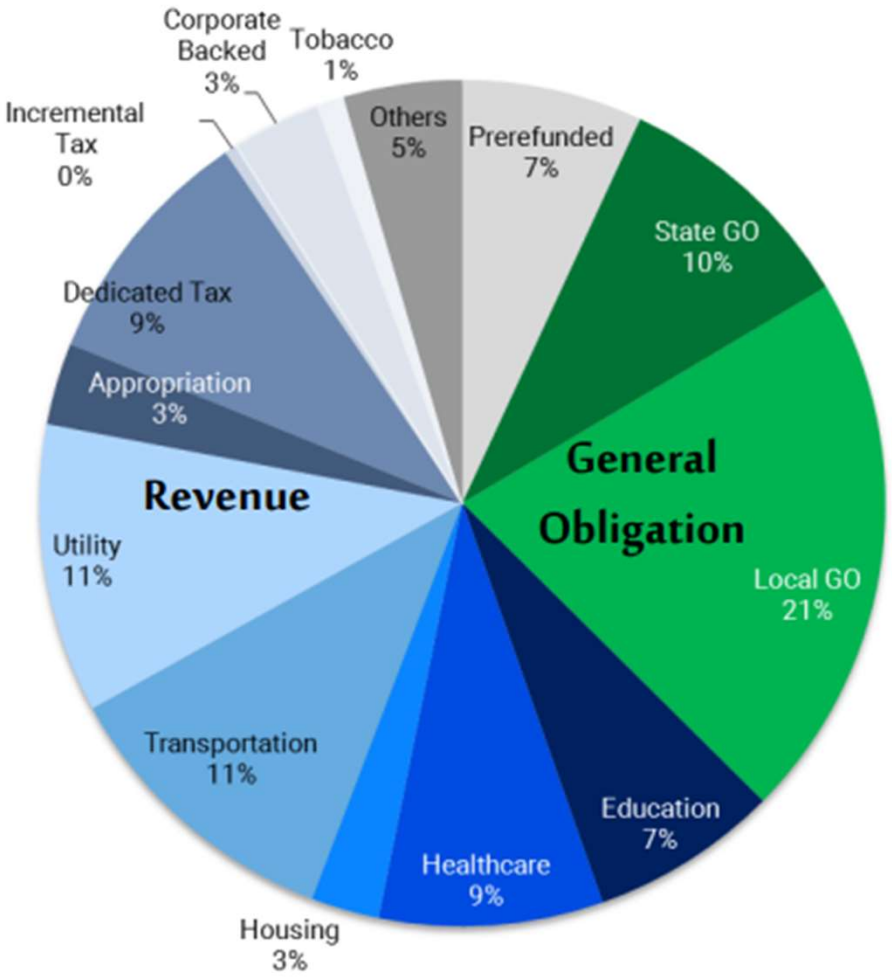
- 1MM unique municipal bonds
- Very low historical default rate
- Pre-refunded (no new issuance), insured*, or asset backed
- Mostly exempt from local and federal tax
- Mostly illiquid.
- Cannot be shorted.
- Marked against a MMD muni curve (or BBG equivalent)
- Mostly held by individual investors
- Sold when money is needed (retirement, big purchases, inheritance)
- Trades reported by dealers on https://www.msrb.org/ (much like TRACE)

* Investor attention and municipal bond returns, by K. Cornaggia, J. Hund, G. Nguyen

Munis by security and issuer type



General Obligation (30%)

- Backed by "full faith and credit" of US municipalities with taxation authority
- States, cities, counties, school districts, etc.

Revenue (63%)

- Secured by revenue pledges
- Public enterprises: utilities, toll roads, airports, etc.
- Nonprofit organizations: hospitals, universities, etc.

Pre-refunded / Escrowed to Maturity (7%)

- Funds securing bonds invested in indirect or direct federal obligations and placed in escrow

- 15% Federally Taxable
- 78% Federelly Tax-Exempt

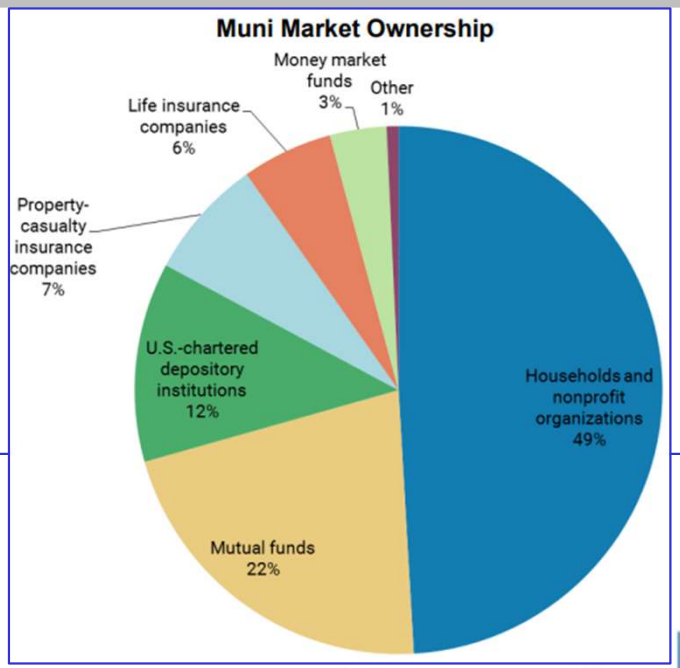
- 75% have coupon in (5,6] %
- 10% have coupon in (4,5] %

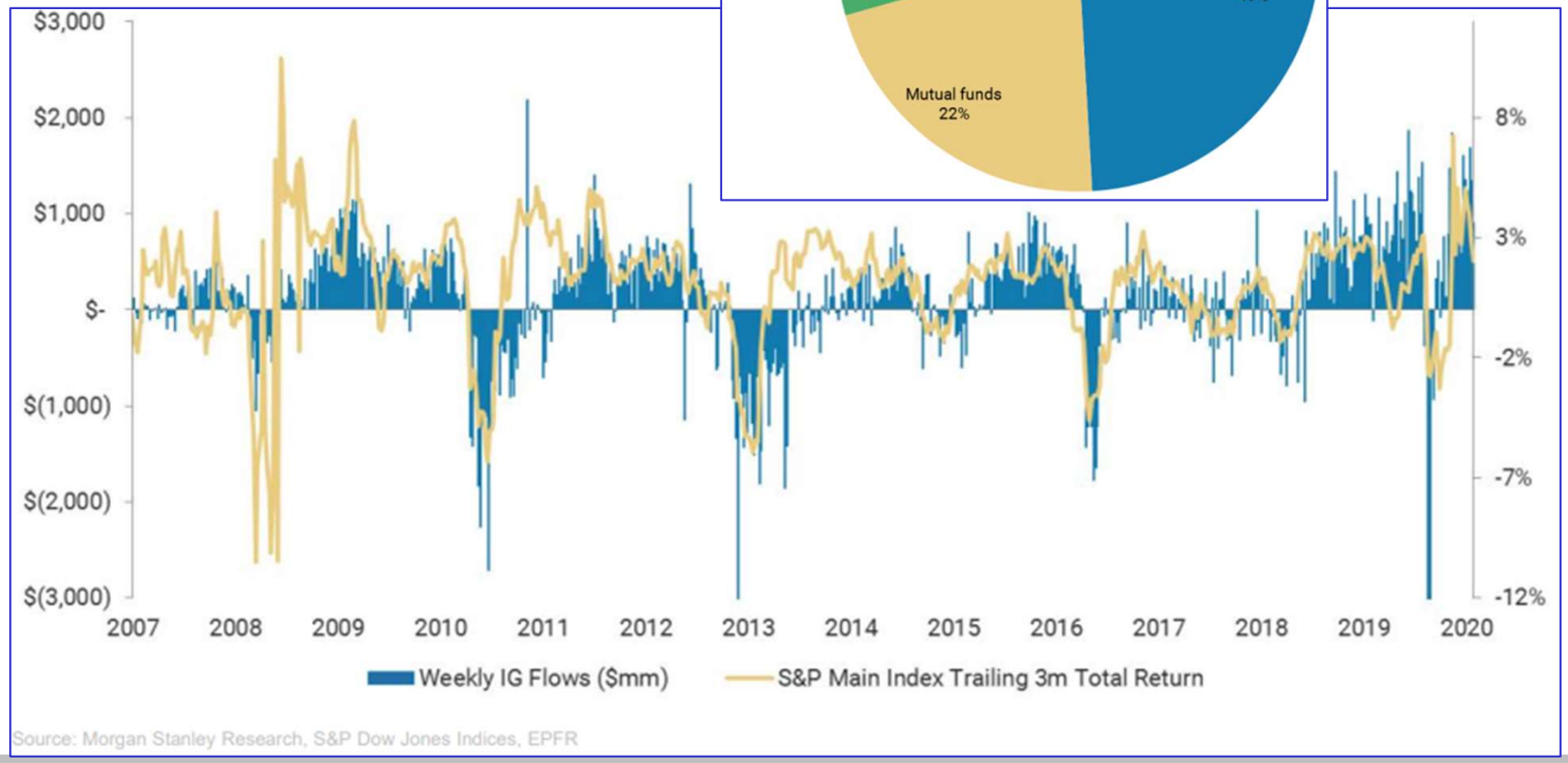
- California
- New York
- Massachusetts
- Illinois
- **Others**

Sources: *https://www.sec.gov/news/studies/2012/munireport073112.pdf and* Morgan Stanley Research, S&P Dow Jones Indices, Bloomberg *as of Aug 2020*

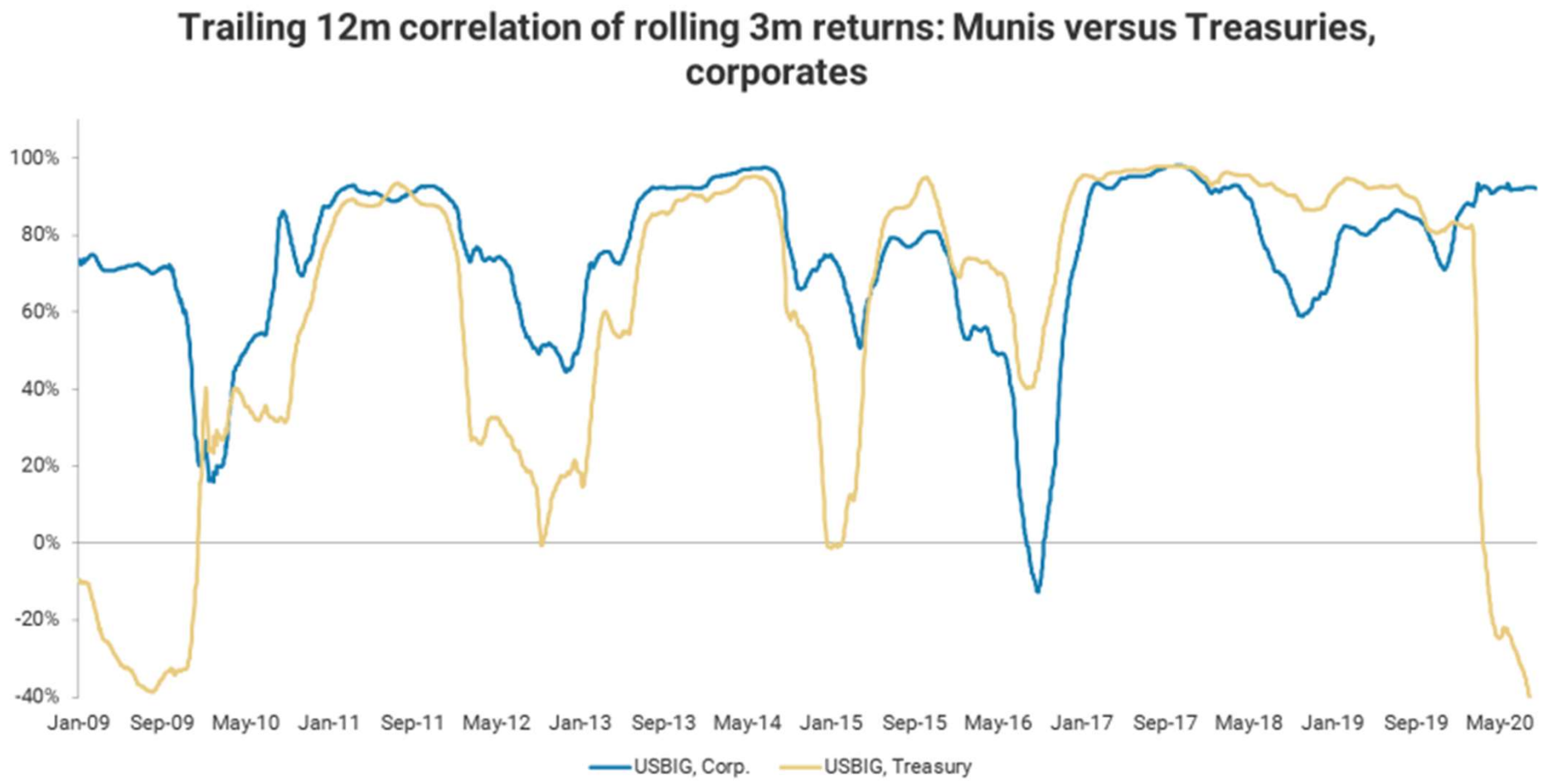
Market dominated by households.
Fund Flows Tend to Track Total Returns

- Muni buyer dynamics create conditions for recurring demand & momentum cycle.
- Individual investors exercise an outsized influence on the market.

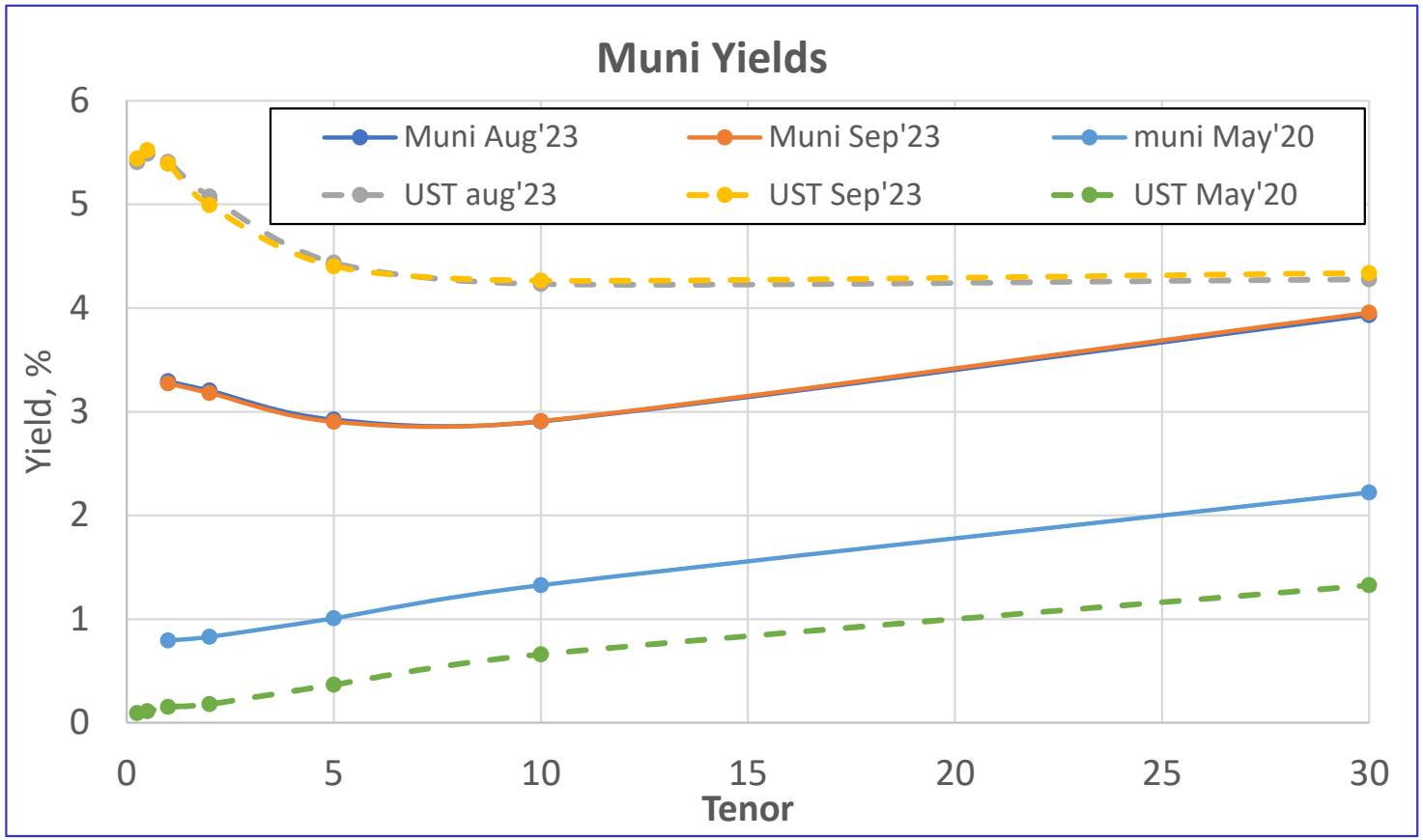




Correlation to treasuries and corporates: on-on-off



Municipal Bonds: negative spread



What Makes the Municipal Yield Curve Rise? by A. Kalotay and M. Dorigan, 2008

We have shown that as long as the yields are based on callable bonds, the curve will always be upward sloping, regardless of the shape of the underlying optionless curve. The optionless yields implied by the callable yields can be obtained iteratively, by stripping out the call options. Our analysis suggests that there may be days when the optionless municipal curve is actually inverted. This phenomenon deserves scholarly attention beyond the scope of this article.

Municipal Bonds: tax-aware strategy

Baruch COLLEGE

OPTIMAL MUNICIPAL BOND PORTFOLIOS FOR DYNAMIC TAX MANAGEMENT

by Andrew Kalotay (2016)

- Tax-loss selling of municipal bonds is typically an ad hoc year-end exercise.
- Right to execute a tax-beneficial trade is considered to be a valuable option.
- Long-duration bonds trading at a premium are best poised to achieve superior performance; bonds purchased below par are unsuitable for tax management. The incremental return from dynamic management is significant, particularly when short-term gains are available to offset short-term losses.

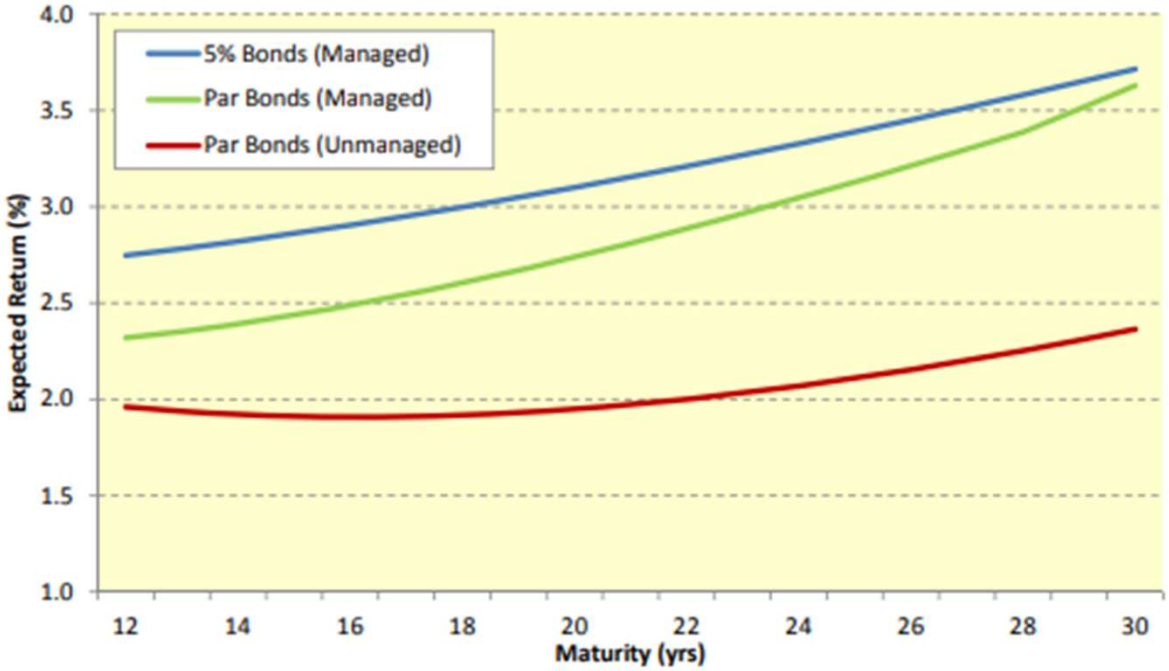


Figure 5 Performance of optionless premium and par bonds under aggressive tax management.

Side note:
Tax aware SMA's (direct indexing) is a growth segment in equities too

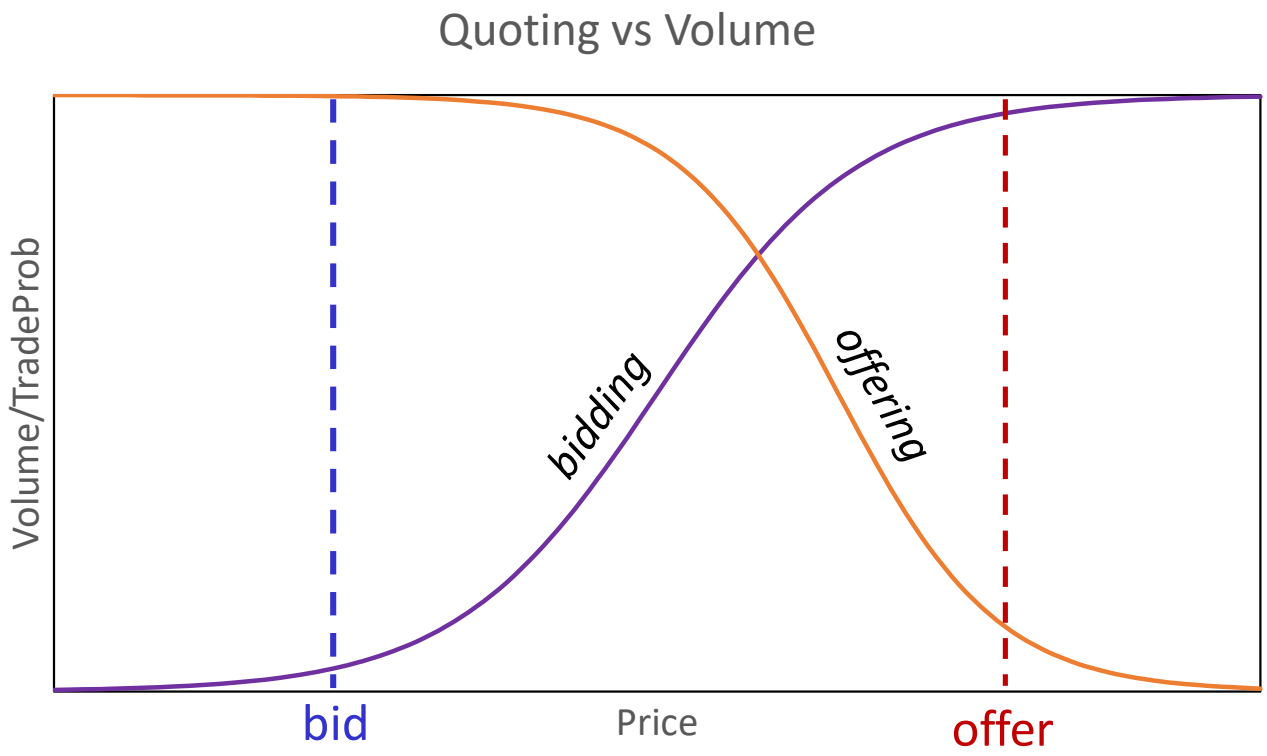
Municipal Bonds: systematic trading

Baruch COLLEGE

Systematic Dealer perspective:

- buy auctioned odd-lots in competition via RFQs aka bid-wanteds
- Sell these odd lots in competition via trading venue
- Profit = volume x spread

- Trades (MSRB)
  - Real time
- Bond Desriptions
  - Static
- Bid-wanted
  - Real Time
- Treasury data
  - Real time



Municipal Bonds: systematic trading

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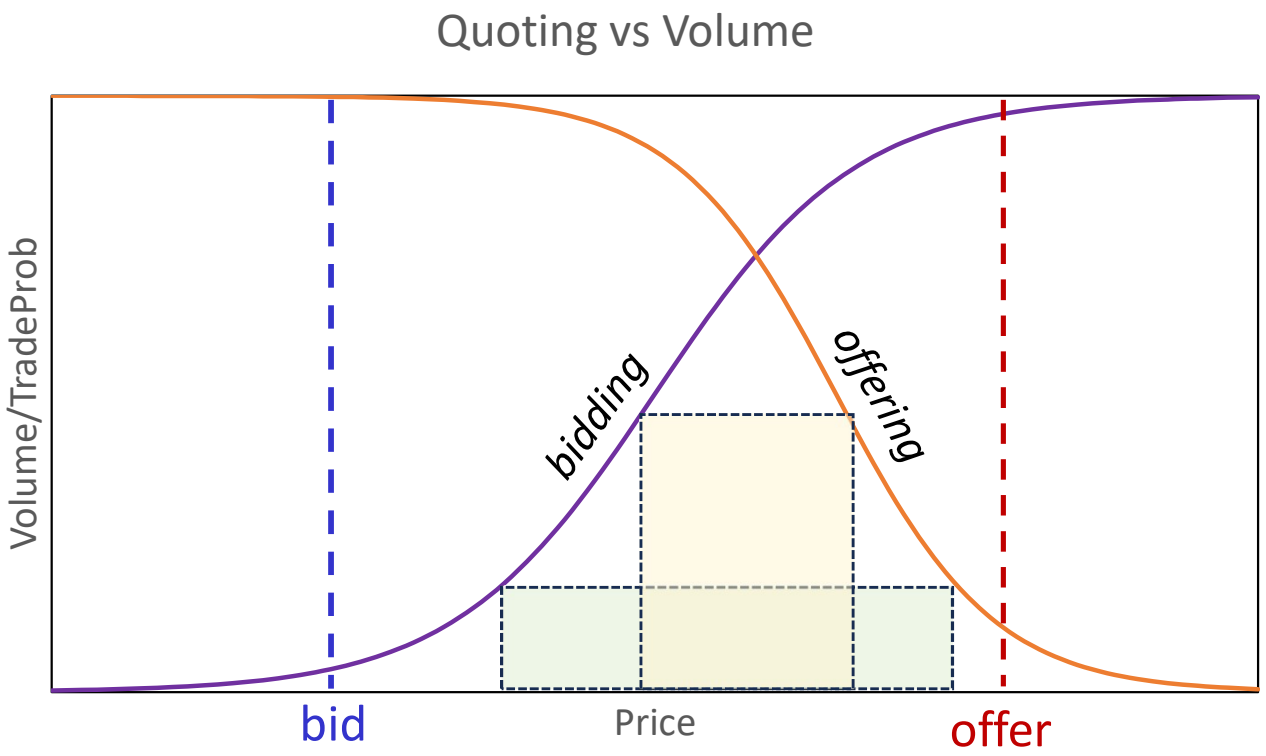

Geometry:
Maximized area, maximized profit

Caveats:
Bid/offer unknown
Curves unknown
Buy/sell rates unknown
Long only
Inventory cost

What would FI strat do*

Function	Broker-Dealer	Asset Manager
Models/Signals	Statistical Microstructure Low-latency Per symbol	Econometric Fundamental Alternative Data Cross-sectional
Attribution	FIFO/Trade+Hold	Brinson/Factor
Backtests	Intraday Fill Model	Daily Trading Costs
Trading	Quoting, market-making	Execution
Risk management	Intraday, few accounts	Daily, 000's accounts
Feature	**Broker-Dealer**	**Asset Manager**
Timescale	Nanoseconds to days	months
Developers skill emphasis	More	Less
Client facing opportunity	Less	More
Atmosphere	"Sense of urgency"	"client-oriented"
Gratification	Immediate	Delayed

**very subjective personal view*

SYSTEMATIC TRADING MTH9897
Lecture 6: Fixed Income
Quantitative Investment Framework

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“Classic” Equity Factors

$R=\alpha+\beta_m MKT+\beta_s SMB+\beta_h HML+\beta_r RMW+\beta_c CMAR$,
where

- MKT is the excess return of the market -- on the value-weighted market portfolio.
- SMB is the return on a diversified portfolio of **S**mall-cap stocks minus the return on a diversified portfolio of **B**ig-cap stocks.
- HML is the difference between the returns on diversified portfolios of stocks with **H**igh and **L**ow Book-to-Market ratios.
- RMW is the difference between the returns on diversified portfolios of stocks with **R**obust (high and steady) and **W**eak (low) profitability.
- CMA is the difference between the returns on diversified portfolios of the stocks of low and high investment firms, which we call **C**onservative and **A**ggressive. Here, low/high investment means reinvestment ratio is low/high.

Factor Investing in Credit

Baruch COLLEGE

Equity-style factors:

- Size (SMB)
- Value
- Carry High/Low
- Quality (low volatility)
- Momentum (Jaggadish & Titman)

Credit:

Houweling and Van Zundert (2017) bond-level factors similar to Equity (dates 1994-2015) all significant:

- Size: market value of all company's bonds;
- Low-risk: Market value of short-maturity bonds with a high credit rating
- Value, measured as bonds whose credit spread was high relative to a model-implied fair spread;
- momentum, bonds with high past returns.

"Factor Investing in Credit", Henke, Kaufmann, Messow, Fang-Klingler, 2021