Algorithmic Trading

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Lorem Ipsum
To be completed once most of the book is done

1.2 Reading Roadmap

Lorem Ipsum. To be completed once most of the book is done

This content builds upon the foundational works of Rishi K. Narang (2013), Raja Velu (2020), and Marcos Lopez Prado (2018), among others, whose insights form the backbone of our discussion.

1.3 Time Value of Money

Definition 1.3.1. *Time Value of Money Formulas*

Concept	Formula	Notes
Expected Annual Rate	$\text{EAR} = (1 + r_p)^m - 1$ $\text{EAR} = e^r - 1$	r_p periodic rate, m periods/year Continuous
Future Value (Continuous)	$FV_N = PVe^{r_s N}$	r_s stated rate, N years
Present Value (Frequent)	$PV = FV_N(1 + \frac{r}{m})^{-mN}$	m periods/year
Ordinary Annuity	$FV_N = A \left[\frac{(1+r)^N - 1}{r}\right]$	First CF one period from now
Annuity Due	$FV_N = A \left[\frac{(1+r)^N - 1}{r}\right](1 + r)$	First CF today
Perpetuity	$PV = \frac{A}{r}$	Infinite cash flows

Definition 1.3.2. *Return Metrics*

Metric	Formula / Description	Notes
Internal Rate of Return	$\text{NPV} = 0$	PV inflows = PV outflows
Money-Weighted Return	IRR on portfolio	Timing and size of CFs
Time-Weighted Return	$r = \sqrt[1/n]{\prod_{i=1}^{n} (1 + HPR_i)} - 1$	Geometric mean
Annualised Return	$r = (1 + HPR)^{365/\text{Days}} - 1$	HPR scaled to annual
Continuously Compounded	$r_{\text{CC}} = \ln(1 + HPR)$	Log return
Gross Return	Before fees	Pre-fees
Net Return	After fees	Post-fees
Pre-Tax Nominal	Before taxes	Pre-tax
After-Tax Nominal	After taxes	Post-tax
Real Return	$(1 + r_{\text{Real}}) = \frac{(1+r_{\text{Nom}})(1+r_{\text{Risk}})}{(1+\pi)}$	Inflation-adjusted
Leveraged Return	$r_L = \frac{r(V_0+V_B)-r_B V_B}{V_0}$	V_B borrowed, r_B borrow cost

1.4 Overview of Systematic Investments

A schematic of a live 'production' trading strategy is shown below, but does not include everything else necessary to create the strategy (i.e., research tools).

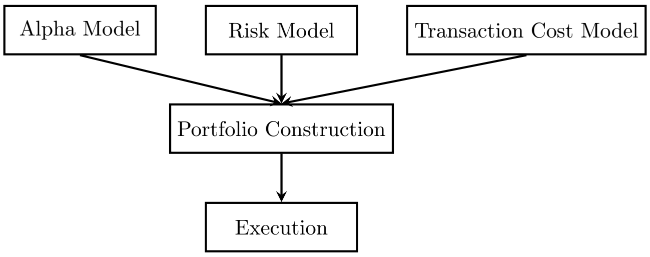

Figure 1: Live Production Trading Strategy Overview

At its core, the trading system is organised into three primary modules:
The trading system has three modules:

i. Alpha model: predicts the future of the instruments considered for trading, i.e. directional alpha

ii. Risk model: limits amount of exposure to factors that are unlikely to generate returns but could drive losses, i.e. directional exposure limit on an asset class

iii. Transaction cost model: determine if the cost of the trades needed to migrate from current portfolio to new portfolio is desirable to the portfolio construction model.

These models feed into a portfolio construction model that balances the tradeoffs of profit and risk to determine the best portfolio to hold. The model finds the differences in trades that need to be executed.
The execution model then takes the required trades, and using inputs such as urgency in which the trades need to be executed and dynamics of liquidity in the markets, executes the trades in an efficient and low cost manner.

Method 1.4.1. *Chains of Production for Alpha Signals*

i. Data Curation: for collecting, cleaning, indexing, storing, adjusting, and delivering all data to production chain. Requires experts in market microstructure and data protocols such as FIX.

ii. Feature Analysis: transform raw data into informative signals. Requires experts in information theory, signal extraction and processing, visualisation, labelling, weighting, classifiers, feature importance techniques. Feature analysts collect and catalogue libraries of findings.

iii. Strategists: informative features are transformed into actual investment algorithms. Strategists will parse libraries of features for ideas to develop an investment strategy. Require data scientists with deep knowledge of financial markets and economy. Features may be discovered by black box, but strategy is developed in a white box.

iv. Back-testers: assess profitability of investment strategy under various scenarios. Requires data scientists with deep understanding of empirical and experimental techniques. Good back-tested incorporates in analysis meta-information on how strategy was created.

v. Deployment Team: integrate strategy code into production line. Requires algorithm specialists and mathematical programmers. To ensure deployed solution is logically identical to prototype, and to optimise implementation sufficiently such that production latency is minimised.

vi. Portfolio Oversight: once strategy is deployed, follows lifecycle.

   1. Embargo: initially, strategy is run on data observed after end date of backtest. If embargoed performance is consistent with backtest, strategy is promoted to next stage.
   2. Paper Trading: strategy run on live, real-time feed. Performance accounts for data parsing latencies, calculation latencies, execution delays, and other time lapses between observation and positioning.
   3. Graduation: strategy manages real position, whether in isolation of as part of ensemble. Performance evaluated precisely, including attributed risk, returns, and costs.
   4. Re-allocation: based on production performance, allocation is re-assessed frequently and automatically. Strategy allocation follows a concave function, Initial allocation is small. As time passes and strategy performs as expected, allocation is increased. Over time, performance decays and allocations become gradually smaller.
   5. Decommission: if strategy perform below expectations for sufficiently extended period of time, strategy is discontinued.

1.4.1 Alpha Models Overview

Theory-driven models tests theories of why markets behave in a manner, and see if they can be used to predict the future. Strategies utilising price-related data are trend and mean reversion; strategies utilising fundamental data are value/yield, growth and quality. Usually more than one model is used in combination.

Definition 1.4.2. *Theory Driven Models*

i. Trend Following: markets move in given direction long enough that the trend can be identified. As more data support the bull/bear thesis in an uncertain market, more market participants will adopt the same thesis and hence move the asset price to a new equilibrium.
   Moving average crossover indicator strategy has less than one point of return for every point of downside risk taken, as market behaviour are unstable and episodic.

ii. Mean Reversion: markets move in opposite direction to the prevailing trend. Short-term imbalances between buyers and sellers due to liquidity forces prices to move abruptly in one direction, which increases probability of trend reversion as liquidity issue is resolved.
   Statistical arbitrage bets on convergence of prices of similar stocks whose prices have diverged.
   Longer-term trends can occur despite smaller oscillations around these trends occurring in the shorter term, hence both strategies may be used in conjunction.

iii. Value/Yield: value strategies uses ratios of fundamental factor against the price of the instrument, inverted to keep the ratio consistent. The higher the yield, the cheaper the instrument.
   Buying undervalued security and selling overvalued security is a *carry trade*. The difference between yield received and yield paid is the *carry*.
   Quant Long Short (QLS) ranks stocks by attractiveness based on various factors such as value, then buy the higher-ranked stocks while shorting the lower-ranked stocks.

iv. Growth: make predictions based on asset's expected or historically observed level of economic growth. Forward-looking growth expectations are typically used as a metric.
   Growth is trending, and strongest growers are becoming more dominant relative to competitors. Macro growth factors may be used on foreign exchange, while micro growth factors may be used on companies.

v. Quality: All else being equal, it is better to long high quality and short low quality. Capital safety is important. Factors include earnings quality, equity-to-debt ratios etc.

Data-driven models are more difficult to understand, with more complicated mathematics. Relies on data mining, more technically challenging and far less widely practiced. Typically more used in high-frequency space, as they can discern how market behaves without caring about the economic theory or rational.

Method 1.4.3. *Strategy Parameters*
An implementation approach requires a forecast target, time horizon, bet structure, investment universe, model specification, and run frequency.

i. Forecast Target: models may forecast direction, magnitude, duration of move, and may include probability into the forecast. Signal strength is of importance, defined by a larger expected return and/or higher likelihood of return. A higher level of signal strength results in a bigger bet taken on the position.

ii. Time Horizon: models may have forecast horizons ranging from microseconds to years. There are more variability between short-term and long-term strategies, as short-term strategies are making very large number of trades compared to long-term strategies.

iii. Bet Structure: models can be made to forecast an instrument relative in itself or to others. For relative forecasts, smaller clusters (pairs) or larger clusters (sectors) may be used. For pairs, few assets can be compared precisely and directly. Large cluster grouping may eliminate impact of general movement of the sector and hence focus on the relative movement of stocks within the sector, allowing for clearer distinction between group behaviour and idiosyncratic behaviour. Clusters may be created either via statistical methods or using heuristics (i.e., fundamentally defined industry groups).
   Statistical methods may be fooled by data, leading to bad grouping. Heuristic grouping may be imprecise for conglomerates, and may be too rigid. Relative alpha strategies tend to exhibit smoother returns during normal times than intrinsic alpha strategies, but may face incorrect groupings during stressful periods. This may be mitigated by utilising several grouping techniques in concert.

iv. Investment Universe: choices made on geography, asset class, instrument class, and exclusions. Liquidity is preferred so estimations of transaction costs are reliable. Large quantities of high quality data is required, which is found in highly liquid and developed markets. Instruments with consistent behaviour is preferred, hence biotech stocks are excluded due to sudden, violent price changes. Hence, the most common asset classes and instruments modelled are common stocks, futures (on bonds and equity indices) and forex.

v. Model Specification: focuses on definition of the strategy mathematically, and may be the source of alpha. Specification details in terms of machine learning or data mining techniques are also defined, to assist in fitting models to the data and setting parameter values. Refitting frequency is also defined to refresh the model and make it adapt to current market conditions; may lead to greater risk of overfitting.

vi. Run Frequency: defined from monthly to real time frequency. Increasing frequency of runs lead to greater number of transactions and hence higher transaction costs, and risk of moving portfolio based on noisy data. Less frequency of runs lead to smaller number of larger-sized trades, hence may move the market with block trades; may also miss opportunities to trade at more favourable prices.

Method 1.4.4. *Blending of Models*
Most common approaches are linear models, nonlinear models, and machine learning models. If models are not combined, then several portfolios are constructed based on output from each model, then combined using portfolio construction techniques. The best method depends on the model.

i. Linear Models: require independence of factors, and each factor to be additive. To determine the weight of each alpha factor, multiple regression techniques may be used.

ii. Nonlinear Models: used when factors are not independent, or the relationship changes over time. Conditional models base the weight of one factor on the reading of another factor. Rotational models assign weights of factors that fluctuate over time based on updated calculations of the various signal's weights, giving higher weights to factors with better performance recently.

iii. Machine Learning Models: developing machine learning strategies takes as much effort to produce one true investment strategy as to produce a hundred. The complexities include data curation and processing, HPC infrastructure, software development, feature analysis, execution simulations, backtesting etc. Decades ago, macroscopic alpha based on simple tools like econometrics are common, but this is quickly diminishing. Microscopic alpha however, becomes more abundant, but requires heavy ML tools.

1.4.2 Risk Models

Risk model concerns the intentional selection and sizing of exposures to improve the quality and consistency of returns. By pursing an alpha, we want to be invested in the movement of the exposure to profit in the long run.

Method 1.4.5. *Factor-Based Models*
Factor-based models decompose asset returns into contributions from systematic factors and idiosyncratic components. The most common factors include:

i. Market Factor: Captures the overall movement of the market.

ii. Size Factor: Reflects the differential risk associated with companies of varying market capitalizations.

iii. Value Factor: Accounts for risk due to discrepancies between market prices and fundamental valuations.

iv. Momentum Factor: Measures the tendency of asset prices to continue in their current trajectory.

This allows traders to understand which elements drive portfolio risk and adjust exposures accordingly.

Method 1.4.6. *Statistical Models*
Statistical risk models leverage historical data and probabilistic techniques to quantify risk parameters.

i. Historical Simulation: Directly computing risk metrics from past return distributions.

ii. Monte Carlo Simulation: Generating a large number of potential future return scenarios to estimate risk under diverse conditions.

iii. Parametric Methods: Employing analytical formulas based on assumed return distributions to calculate key risk measures.

These are useful for dynamically updating risk assessments as new market data become available.

Method 1.4.7. *Limiting Size of Risk*
The quantitative risk models that limit the size of risk varies by the manner in which size is limited, how risk is measured, and what is having its size limited.
Size limits can be limited by hard constraints and penalties. A hard limit may be arbitrary, hence penalty functions may be built to allow a position to increase beyond the limit level, only if the alpha model expects a significantly larger return. The levels of limits and penalties may be determined from either theory or data.
To measure risk, there are two methodologies. The first is longitudinal, and measures risk through the volatility of an instrument. The second is to measure the correlation or covariance between assets (dispersion).
Size limiting may be applied to single positions and groups of positions (sectors, asset classes). It may also be applied to various types of risks and the amount of portfolio leverage.

Method 1.4.8. *Limiting the Types of Risk*
To eliminate unintentional exposure as there is no expectation of being compensated sufficiently for accepting them. This can be achieved through theoretical or empirical risk models.

i. Theory-Driven Risk Models: focuses on systematic risk factors, derived from economic theory. Systematic risks cannot be diversified away. Equity may have market risk, sector risk, market capitalisation risk etc. Fixed income may have interest rate risk.

ii. Empirical Risk Models: uses historical data to determine the unnamed systematic risks that should be measured and mitigated. Uses principal component analysis (PCA) to discern unnamed systematic risks that may correspond to named risk factors. Used by statistical arbitrage traders who are betting on exactly the component of an asset's return not explained by systematic risks.

1.4.3 Transaction Cost Models

Trade is made only if it increases the odds or magnitude of return (from alpha model), or if it decreases the odds or magnitudes of loss (from risk model). However, this improvement should be higher than cost of trading. The transaction cost model is not designed to minimise cost of trading, only to inform portfolio construction engine the cost of making any given trade.

Remark 1.4.9. *Transaction Cost Components*

i. Commissions and Fees: paid to brokerages (access to other market participants), exchanges (improved transaction security) and regulators (operational infrastructure) for the services provided. The bank's infrastructure is used by quants, where the brokerage commissions are rather small on a per-trade basis. Brokers also collect clearing and settlement fees. Clearing is the activity involving regulatory reporting and monitoring, tax handling, and handling failure, taken place in advance of settlement. Settlement is the delivery of securities in exchange for payment in full.

ii. Slippage: the change in price between the time the quant system decides to transact and the time when the order is at the exchange for execution. Trend-following strategies suffer most from slippage as assets are already moving in desired direction; mean-reverting strategies suffer the least from slippage. The lower the latency to market, the smaller the slippage. The more volatile an asset, the bigger the slippage.

iii. Market Impact: measures how much an order moves the market by its demand for liquidity. The impact of the trade on the market is unknown until the trade has already been completed. There may also be interaction between slippage and market impact (i.e., selling when a stock is trending upwards).

Definition 1.4.10. *Types of Transaction Cost Models*

i. Flat Model: cost of trading is the same, regardless of size of order. Model is reasonable if size traded is nearly always about the same, and liquidity remains sufficiently constant.

ii. Linear Model: cost of trading increases at a constant rate relative to size of order. Better estimate than flat transaction cost model.

iii. Piece-Wise Linear Model: using piece-wise linear functions to model costs. Balance between simplicity and accuracy; better accuracy than flat or linear models.

iv. Quadratic Model: most computationally intensive, but also most accurate.

1.4.4 Portfolio Construction Models

Comes in two major forms: rule-based, optimisers. Rule-based models are based on heuristics, can be exceedingly simple or rather complex, and derived from human experience (trial and error). Optimisers comprises of an objective function and uses algorithms to reach the end goal.

Definition 1.4.11. *Rule-Based Models*

i. Equal Position Weighting: used if portfolio manager believes that if a position is good enough to own, no other information is needed in determining its size. Strength of signal is not used as input in weighting.
Model assumes that there is sufficient statistical strength and power to predict not only direction but also magnitude relative to other forecasts in the portfolio. Portfolio takes few large bets on 'best' forecast, many smaller bets on less dramatic forecasts; may take excess risk in an idiosyncratic event on a seemingly attractive position, resulting in adverse selection bias.

ii. Equal Risk Weighting: adjust position sizes inversely to volatilities or a measure of risk. More volatile positions given smaller allocations, less volatile positions given larger allocations.
When unit of risk is equalised, it is almost always a backward-looking measurement such as volatility. If volatility changes with time, then model will be misled.

iii. Alpha-Driven Weighting: position size based primarily on alpha model. Alpha signal determines size of position, but usually with size limits. Constraints used also includes limits on size of total bet on a group. May also have a function that relates the magnitude of forecast to size of position.
If model used in futures trend following, might suffer sharp drawdowns. Reliance on accuracy of alpha.

iv. Decision-Tree Weighting: decision path to arrive at the allocation for given instrument, depending on type of alpha model and type of instrument. Constraints may include percentage limits for allocation.
Model size grows dramatically if more alpha models or mode types of positions are included.

Remark 1.4.12. *Optimisers Models Parameters*
Harry Markowitz's mean variance optimisation (MVO) as the pioneer model. Models are based on principles of modern portfolio theory (MPT). Inputs include asset expected return (mean), asset variance, expected correlation matrix. Other inputs include size of portfolio in currency terms, desired risk level (volatility or expected drawdown), and other constraints such as liquidity, universe limits.
Model uses an objective function and an algorithm to seek the goal, usually maximising return of portfolio relative to volatility of portfolio returns.

i. Expected Return: alpha models as basis of expected return, which also includes expected direction.

ii. Expected Volatility: stochastic volatility forecasting methods is commonly used, as volatility may have high and low periods, with occasional jumps. GARCH model is most used.

iii. Expected Correlation: as instrument correlations are not stable over time, it is more appropriate to group assets together before computing correlation within the group.

Method 1.4.13. *Optimisation Techniques*

i. Unconstrained Optimisation: most basic form with no constraints. Might provide a single-instrument portfolio, where all money will be invested in instrument with highest risk-adjusted return.

ii. Constrained optimisation: constraints include position limits, limits on various groupings of instruments. Might result in constraints driving the portfolio construction more than the optimiser.

iii. Black-Litterman Optimisation: blends investor expectations with a degree of confidence about those expectations, and these with historical precedent evident in the data. Adjusts historically observed correlation levels by utilising investor's forecast of return for the various instruments.

iv. Grinold and Kahn's Approach: builds a portfolio of signals, instead of sizing positions. To build factor portfolios, each of which are usually rule-based portfolios based on a single type of alpha forecast. Each portfolio backtested, then series of returns are then treated as instruments of a portfolio by the optimiser. Number of factor portfolios is more manageable, usually not more than 20. What is optimised is then a handful of factor portfolios. The model allows for inclusion of risk model, transaction cost model, portfolio size, and risk targets as inputs.

v. Resampled Efficiency: to improve the inputs to optimisation by addressing oversensitivity to estimation error. To resample data using Monte Carlo simulation to reduce estimation error in inputs to the optimiser.

vi. Data-Mining Approaches: machine learning techniques such as supervised learning or genetic algorithms used, as MVO involves searching many possible portfolios to find the best.

1.4.5 Execution Model

Two basic ways to execute trade: through electronic, or through human intermediary. For electronic execution, achieved through direct market access (DMA), which allows traders to utilise the infrastructure and exchange connectivity of brokerage firms to trade directly on electronic markets.
Execution algorithms can be acquired through building, using broker's, or a third-party software vendors.
Brokerages offer portfolio bidding, where the 'blind' portfolio for transaction is described by characteristics such as valuation ratios of longs and shorts, sector breakdown, market capitalisation etc. Broker then quote a fee in basis points in terms of the gross market value of portfolio traded. Hence, certainty is provided by the broker to the trader. Once agreement reached, broker receives fee and assumes risk of trading out the portfolio at future market prices, which may be better or worse than prices guaranteed.

Remark 1.4.14. *Order Execution Algorithm Parameters*

i. Aggressive vs Passive: algorithm make decision of passive vs aggressive order, depending on how immediately the trader wants to do the trade. Market orders are considered aggressive. Limit order at current best order is fairly aggressive, while limit order below current bid is passive.
Many exchanges pay providers of liquidity for placing passive orders, charging traders for using liquidity provided. Orders that cross the spread are using liquidity by using a passive order placed by another

trader, reducing liquidity available. Paying for liquidity sweetens deal for passive order, only if order is actually executed; passive trader gets better transaction price and a commission rebate from the exchange. Momentum strategies uses more aggressive orders; mean reversion uses more passive orders. A stronger, more certain signal will be executed with greater aggressiveness than a weaker or less certain signal. A middle ground will be to put limit orders between best current bid and offer.

ii. Large vs Small Order: a large order may be broken into many smaller orders over a window of time, but risk price moving in adverse direction. Size of chunk depends on transaction cost model estimate, and analysis of correct level of aggressiveness.

iii. Hidden vs Visible Order: a queue as a visible order gives away a bit of information. Hidden order will provide no information to the market, staving off imbalances, but reduces priority of trade in the queue. Algorithmic trading utilising hidden order is 'iceberging', which is taking a single larger order and chopping it into many smaller chunks, most posted to order book as hidden orders.

iv. Order Routing: if there are several pools of liquidity for the same instrument, smart order routing will be used, which determines which pool of liquidity is most suitable for sending a given order. Depth of liquidity on various ECNs and connectivity speeds are also considered in smart order routing.

v. Cancelling and Replacing Orders: traders may place larger number of orders with no intention of execution, then rapidly cancelling them and replacing them with other orders. This allows gaining of information on how market responds to the changing depth of the book, providing information on how to profit from the pattern of reaction. If trader wants to buy a large number of shares, he may enter a large number of small orders to sell the shares further away from market and cancel, improving market perception.

Definition 1.4.15. *High Frequency Trading*
Alpha driving strategies on extremely near-term bets (seconds or less) are *microstructure alphas*, focusing on liquidity patterns in order book. Larger quants may also use this to guide execution models, improving costs of entering trades. Small differences over a single trade add up significantly in the long run.To trade microstructure alpha as independent high frequency strategies, large investments in infrastructure and research must be done. Machine learning techniques may also be used to discern patterns in execution of other player orders. The more inferior the execution models, the easier it is to discern the pattern, allowing the ML strategy to profit from these patterns in the future. Patterns in the shorter timescale are somewhat stable.

Definition 1.4.16. *HFT Shark Strategy*
Designed to detect large orders that are iceberged, by sending series of very small trades; if each of these small orders get filled quickly, this may be a sign of a large and iceberged order. The shark simply front-run this large, hidden order by placing visible trades in front of the iceberged order. The iceberg strategy must then push prices up to execute trades. When the iceberged order is complete, prices will be pushed up favourably for the shark, which can then exit the position with a quick and relatively riskless profit.

Remark 1.4.17. *HFT Trading Infrastructure*
Using a broker that act as trading agent allows the infrastructure requirements to be handled by the broker, instead of dealing with the regulatory and other constraints.
High frequency strategies may use colocation or sponsored access. Colocation setup is where trader attempts to place trading servers as physically close to the exchange as possible.
Financial Information eXchange (FIX) protocol is the choice of real-time electronic communication among users. The software that implements the FIX protocol is free and open source (FIX engine). High frequency traders will likely build their own FIX engines to ensure optimal speeds.

1.4.6 Research

Definition 1.4.18. *Scientific Method*

1. Researcher observe a phenomenon in the market and construct a theory.
2. Researcher seeks out information to test the theory.
3. Researcher tests the theory, and with enough confidence, risk some capital on the validity of the theory.

Remark 1.4.19. *Sources of Alpha Idea Generation*

1. Observing the market, using the scientific method to test the theory
2. Academic literature, requiring significant time to read academic journals, working papers, and conference presentations for ideas. Literature from other fields such as astronomy, physics, or psychology, may provide ideas relevant to quant finance problems.
3. Migration of a researcher or portfolio manager from one quant shop to another.

4. Lessons from activities of discretionary traders

Remark 1.4.20. *Model Quality Assessment*

i. Cumulative profit graph: if profit profile is not smooth, with long periods of inactivity, sharp losses and gains, then the model may have issues

ii. Average annual rate of return: indicates how well the strategy made on historical data

iii. Variability of returns: the less variable the level of returns, the better the strategy. May look at lumpiness of returns, which is the portion of strategy's total returns that comes from periods that are significantly above average (measures consistency of returns).

iv. Worse Peak-to-Valley Drawdowns: measures maximum decline from any cumulative peak in profit curve. The lower the drawdown the better the strategy. Also, to measure recovery period after drawdowns; the shorter the recovery period the better the strategy.

v. Predictive Power: R-squared statistic may be used, which shows how much of the variability of the predicted asset have been accounted for. A exceedingly high R^2 in would be 0.05 out of sample. Instrument returns may be bucketed by deciles; a model with reliable predictive power is one that appropriately buckets the instruments correctly.

vi. Percentage Winning Trades, Winning Time Periods: whether the strategy tends to make profits from a small portion of trades that do very well, or from a large number of trades.

vii. Ratios of Returns vs Risk: Statistics such as risk-adjusted return, Sharpe ratio, information ratio, Sterling ratio, Calmer ratio, Omega ratio.

viii. Relationship with Other Strategies: value-add of new strategy compared with results of existing strategy with and without the new idea.

ix. Time decay: understand strategy returns if trades are initiated on lagged basis after receiving a trading signal. Determine strategy sensitivity to timeliness with information received, and crowdedness of strategy.

x. Sensitivity to specific parameters: high quality strategy has small changes in outcomes from slight changes in parameters. Or else this may be a sign that model may be overfitted.

xi. Overfitting: plot a graph of parameter value vs function outcome; a good model has a flatter curve with no jumps. Models that are parsimonious (less parameters) uses less assumptions, hence less overfitting.

Remark 1.4.21. *Other Considerations in Model Testing*
Overestimation of trading costs may cause portfolio to hold positions for longer than optimal, and underestimation may result in high portfolio turnover and bleed from trading costs. Assumptions on availability of short positions must also be made; hard-to-borrow lists must be taken into consideration.

1.4.7 Risk Assessment

Definition 1.4.22. *Model Risks*
Quant models has model risk, the risk that the model does not accurately describe, match, or predict the real-world phenomenon. Each component of the quant model may all have model risk.

i. Inapplicability of Modelling: occurs when quant model is mistakenly applied to a problem. May also occur with misapplication of a technique to a given problem.

ii. Model Misspecification: occurs when the model doesn't fit the real world. Model may work fine most of the time, but fail when an extreme event occurs.

iii. Implementation Errors: erors in programming or architecting systems. Architectural error may also occur when models are loaded in a wrong sequence.

Definition 1.4.23. *Regime Change Risk*
Quant models are based on relationships prevalent in historical data. If there is a regime change, the historical relationships and behaviour may be altered, hence the model may lose effectiveness.

Definition 1.4.24. *Exogenous Shock Risk*
Risks driven by information that is not internal to the market, i.e., terrorist attacks, start of wars, bank bailouts, change in regulation such as in shorting rules. May require discretionary overrides.

Definition 1.4.25. *Contagion Risk*
Happens when other investors hold the same strategies. First part of risk factor relates to how crowded the quant strategy is. Second part relates to what else is held by other investors that could force them to exit the quant strategy in a panic (ATM effect).

Quant liquidation criss may be driven by size and popularity of quantitative strategies, subpar returns from operators leading up to the crisis, the practice of funds cross-collateralising many strategies against each other, and risk targeting (risk managers target a specific level of volatility for their funds or strategies).

Method 1.4.26. *Risk Monitoring Methods*

i. Exposure Monitoring Tools: with current positions held, the positions are grouped for the various exposures (i.e., valuation, momentum level, volatility) to monitor gross and net exposure to various sectors and industries, buckets of market capitalisation, various style factors.

ii. Profit and Loss Monitors: with current portfolio, compare that with previous day closing price. Intraday performance charts are used. May also look at source of profit, hit rate (percentage of time strategy makes money on a given position).

iii. Execution Monitors: shows progress of executions, i.e., which orders are currently being worked on, which ones are completed, with transaction size and prices. Fill rates for limit orders are used for more passive execution strategies. Slippage and market impact are also monitored.

iv. System Performance Monitors: checks for software and infrastructure errors. Checks performance of CPUs, speeds of various stages of automated processes, latency in communication of messages.

1.5 Exploratory Data Analysis

1.5.1 Data Taxonomy

A brief overview of the types of data used in systematic trading.

Four essential types of financial data

Fundamental Data	Market Data	Analytics	Alternative Data
Assets	Price/Yield/IV	Analyst Recommendation	Satellite/CCTV
Liabilities	Volume	Credit Ratings	Google Searches
Sales	Dividend/Coupons	Earnings Expectations	Twitter/Chats
Costs/Earnings	Open Interest	News Sentiment	Metadata
Macro Variables	Quotes/Cancellations	...	...
...	Aggressor Side		
	...		

Remark 1.5.1. *Fundamental Data Characteristics*

i. Data published is indexed by last date included in report, which precedes date of release.
ii. Data is often backfilled or re-instated, and data vendor may overwrite initial values with corrections.
iii. Data is extremely regularised and low frequency.

Remark 1.5.2. *Market Data Characteristics*

i. Raw feed contains unstructured information, such as FIX messages (allow full construction of trading book), or full collection of BWIC (bids wanted in competition) responses.
ii. FIX data is not trivial to process, $\sim$ 10TB generated on daily basis

Remark 1.5.3. *Analytics Data Characteristics*

i. Derivative data as processed based on original source. Signal already extracted from the original source.
ii. Costly, methodology used in production may be biased or opaque.

Remark 1.5.4. *Alternative Data Characteristics*

i. Produced by individuals, business processes, and sensors.
ii. Primary information that has not made it to other sources.
iii. Cost and privacy concerns. May be useful if it annoys data infrastructure team.

Definition 1.5.5. *Reference Data*

i. Trading Universe: evolving daily to incorporate new listings, de-listings etc. Knowing when a particular stock no longer trades is important to avoid survivor bias.
ii. Symbology Mapping: ISIN, SEDOL, RIC, Bloomberg Tickers etc. Data is not static, symbols may change, complicating historical data merges. Mapping needs to persist as point-in-time data and allow for historical 'as-of-date' usage, require implementation of bi-temporal data structure.
iii. Ticker Changes: for reasons described in symbology mapping. To maintain historical table of ticker changes to seamlessly go up and down time series data.
iv. Corporate Actions Calendars: contain stock and cash dividends (announcement, execution date), stock splits, reverse splits, rights offer, mergers and acquisitions, spin off, free float or shares outstanding adjustments, quotation suspensions etc.
For dividends, announcements may coincide with more volatility, jumps in price time series. Allow building of strategies that look to benefit from the added volatility.
For stock splits, reverse splits, rights offers, all historical data need to be adjusted backward to reflect the split (both volume and price).
For M&A, spin-offs, to account for changes in valuation, hence used in Merger Arbitrage strategies.
Suspensions result in gaps in data, may impact backtesting.
v. Static Data: country, sector, primary exchange, currency, and quote factor. May be used to group instruments based on fundamental similarities (hence for pairs trading). Maintaining a table of quotation currency per instrument necessary to aggregate positions at portfolio level.
vi. Exchange Specific Data: individual exchanges have variety of differences to be accounted for when designing trading strategies. First group of information concerns the hours and dates of operations:

1. Holiday Calendar: Strategies trading simultaneously in several markets and leveraging correlation may not perform as well if one market is closed and another is open.
2. Exchange Sessions Hours: Different sessions (Pre-Market, Continuous Core, After-Hour etc.); auction times and respective cutoff times for oder submission; lunch break restricting intraday trading and auctions before/after lunch; settlement times for futures market. Daylight Saving Time (DST) adjustments; length of trading hours during course of the year; different trading hours by venue.
3. Disrupted Days: Exchange outages or trading disruptions, market data issues. To be recorded so they can be filtered out when building or testing strategies.

Second group of information governing the mechanics of trading:

1. Tick Size: Minimum eligible price increment; may vary by instrument and as a function of price.
2. Trade and Quote Lots: Minimum size increment for quotes or trades.
3. Limit-Up and Limit-Down Constraints: Maximum daily fluctuations of securities, and whether trading is paused or can only be traded at better prices than the threshold.
4. Short Sell Restrictions: Restrict shot sells not to trade at price worse than last price, or not to create a new quote that will be lower than the lowest prevailing quote. Impact ability to source liquidity.

vii. Market Data Condition Codes: vary per exchange and asset class, and each market event may be attributed to several codes at once. To build mapping table of condition codes and what they mean (i.e., auction trade, lit or dark trade, cancelled or corrected trade, regular trade, off-exchange trade reporting, block-size trade, trade originating from multi-leg order such as option spread trade etc.). To access liquidity for trading algorithm, trades published for reporting purposes must be excluded and not be used to update some of the aggregated daily data used in construction of trading strategies.

viii. Special Day Calendars: days wth distinct liquidity characteristics to be accounted for in both execution strategies and in alpha generation process. These (non-exhaustive) irregular events may be:

1. Half trading days preceding Christmas and following thanksgiving in US
2. Ramandan even in Turkey
3. Taiwan market opening on weekend to make up for lost trading days during holiday periods
4. Korean market changing trading hours on day of nationwide university entrance exam
5. Brazilian market opening late on day following the Carnival
6. Last trading days of months and quarters (investors rebalance portfolios)
7. Index rebalancing dates, where intraday volume distribution is significantly skewed toward EODs
8. Options and futures expiry dates (quarterly/monthly expiry, Triple Witching in US, Special Quotations in Japan) where excess trading volume and different intraday patterns result from hedging activity and portfolio adjustments.

Model normal days first. Special days are modelled either independently, or using normal days as baseline.

ix. Futures-Specific Reference Data: to know which contract was live at any point of time by using expiry calendar, and the most liquid contract. Equity index futures are most liquid for first contract available (front month), energy futures such as oil are more liquid for second contract. Hence to know which contract carry the most significant price formation characteristics, and what is true liquidity available.
Note there is no real standardised expiry frequency that applies across markets. When computing rolling-window metrics, to account for potential roll dates (due to investors rolling forward positions) that may have happened during the time span. May blend volume time series prior to roll date and after roll date.
Futures market also have different market phases during the day with significantly different liquidity characteristics. Various market data metrics (volume profile, average spread, average bid-ask sizes etc) should be computed separately for each market phase by maintaining a table of start and end times of each session for each contract.

x. Options-Specific Reference Data (Options Chain): expiry date and strike price combination (option chain). Map of equity tickers to option tickers with strike and expiry dates allow for design for more complex investment and hedging strategies (i.e., distance to strike, change in open interest of puts and calls).

xi. Market-Moving News Releases: macroeconomic announcements. To maintain calendar of dates and times of their occurrences to assess their impact on strategies. Central bank announcements or meeting minutes releases about major economies (FED/FOMC, ECB, BOE, BOJ, SNB), Non-Farm Payrolls, Purchasing Managers' Index, Manufacturing Index, Crude Oil Inventories etc.
Stock-specific releases such as earnings calendars, specialised sector events (for healthcare, biotech etc).

xii. Related Tickers: tickers that are related to each other as they fundamentally represent the same underlying asset. Allows efficient opportunity exploitation. Primary tickers to composite tickers mapping (for markets with fragmented liquidity), dual listed/fungible securities in US and Canada, ADR or GDR, local and foreign boards in Thailand etc.

xiii. Composite Assets: ETFs, Indexes, Mutual Funds etc. May be used to achieve desired exposures, or as cheap hedging instruments, and provide arbitrage opportunities when they deviate from NAV. To maintain information such as time series of their constituents and value of any cash component, divisor used to translate NAV into quoted price, constituent weights.

xiv. Latency tables: for higher frequency trading strategies. Contains distribution of latency between different data centres for more efficient order routing, and reordering data that are recorded in different locations.

Definition 1.5.6. *Market Data Feed*

i. Level I Data (Trade and BBO Quotes): trades and top of book quotes. Enough to reconstruct Best Bid and Offer (BBO). Also contains information in form of trade status (cancelled, reported late etc), trade and quote qualifiers (odd lot, normal trade, auction trade, Intermarket Sweep, average price reporting, on which exchange etc). May be used to analyse sequence of events and decide if a given print should be used to update the last price and total volume traded at a point in time.

ii. Level II Data (Market Depth): addition of quote depth data, displays all lit limit order book updates (price changes, addition or removal of shares quoted) at any level in the book, for all of the lit venues in fragmented markets.

iii. Level III Data (Full Order View): message data. Each order arriving is attributed a unique ID for tracking over time, and is precisely identified when it is executed, cancelled, or amended. Possible to build a full (with national depth) book at any moment intraday. Example from US market:

   1. Timestamp: number of milliseconds after midnight
   2. Ticker: equity symbol (up to 8 char)
   3. Order: Unique order ID
   4. T: message type. 'B' is add buy order; 'S' is add sell order'; 'E' is execute outstanding order in part; 'C' is cancel outstanding order in part; 'F' is execute outstanding order in full; 'D' is delete outstanding order in full; 'X' is bulk volume for cross event; 'T' is execute non-displayed order
   5. Shares: order quantity for 'B', 'S', 'E', 'X', 'C', 'T' messages. Zero for 'F', 'D' messages
   6. Price: order price for 'B', 'S', 'X', 'T' messages. Zero for cancellation and executions. Last 4 digits are decimal, padded to right with zeroes. Divide by 1000 to convert to currency value.
   7. MPID: Market Participant ID associated with transaction (4 char)
   8. MCID: Market Centre Code for originating exchange (1 char)

   A few special types of orders worth mentioning are:

   1. Order subject to price sliding: execution price may be one cent worse than display price at NASDAQ; ranked at locking price as hidden order, displayed at the price one minimum price variation inferior to locking price. New order ID will be used if order is replaced as a display order.
   2. Pegged order: based on NBBO, not routable, new timestamp given upon repricing; display rule vary over exchanges
   3. Mid-point peg order: non-displayed, may result in half-penny execution
   4. Reserve order: displayed size is ranked as displayed limit order; reserve size is behind non-displayed orders and pegged orders in priority.
      Minimum display quantity is 100, amount replenished from reserve size when it falls below 100 shares; New timestamp created, displayed size re-ranked upon replenishment.
   5. Discretionary order: displayed at one price while passively trading a more aggressive discretionary price. Order becomes active when shares are available within discretionary price range. Order ranked last in priority. Execution price may be worse than display price.
   6. Intermarket sweep order: can be executed without need for checking prevailing NBBO.

   Using these data, we may model: the pattern of inter-arrival times of various events; arrival and cancellation rates as a function of distance from nearest touch price; arrival and cancellation rates as a function of other information, such as in the queue on either side of the book, order book imbalance etc.
   Once modelled, we may analyse: the impact of market order on limit order book; chances for limit order to move up the queue from given entry position; probability of earning the spread; expected direction of price movement over a short horizon.

Definition 1.5.7. *Binned Data*

i. Open, High, Low, Close (OHLC) and Previous Close Price: indication on trading activity and intraday volatility. Distance traveled between lowest and highest points is indication of market sentiment. Previous close has to be adjusted for corporate actions and dividends.
ii. Last Trade before Close (Price/Size/Time): how much the close price may have jumped in final moments of trading; how stable it is as a reference value for next day.
iii. Volume: trading activity indicator, especially when level jumps from long term average. Collect volume breakdown between lit and dark venues for execution strategies.
iv. Auctions Volume and Price: price discovery event when significant volume prints occur.
v. VWAP: indication of trading activity on the day. Easier to algorithmically execute large orders with VWAP than a single print.
vi. Short Interest/Days-to-Cover/Utilisation: good proxy for investor position. Short pressure an indication of upcoming short term moves: large short interest is bearish view from institutional investors. Utilisation level of available securities to borrow gives indication of how much room is left for future shorting. Days-to-Cover to assess magnitude of potential short squeeze (if sellers unwind position, fraction of available daily liquidity needed); larger value indicates larger potential of sudden upswing on heavily shorted securities.
vii. Futures Data: insight into activity or large investors through open interest data. Offer arbitrage opportunities if their basis exhibits mis-pricing compared to one's dividend estimates.
viii. Index-Level Data: source of relative measures for instrument specific features (index OHLC, volatility). Normalised features identify individual instruments deviating from their benchmarks.
ix. Options Data: information on position of traders through open interest and Greeks.
x. Asset Class Specific: yield/benchmark rates (repo, 2y, 10y, 30y), CDS spreads, US Dollar Index

Definition 1.5.8. *Granular Intraday Microstructure Activity*

i. Number and Frequency of Trades: proxy for activity level, and how continuous it is. Low number of trades mean harder execution, and may be more volatile
ii. Number and Frequency of Quote Updates: similar proxy for activity level
iii. Top of Book Size; proxy for liquidity of instruments (larger top of book size makes it possible to trade larger order quasi immediately)
iv. Depth of Book (price and size): similar proxy for liquidity
v. Spread Size (average, median, time weighted average): proxy for cost of trading. Parametrised distribution used to identify opportunities if they are cheap or expensive
vi. Trade size (average, median): to identify intraday liquidity opportunities when examining volume available in the order book.
vii. Ticking time (average, median): representation of how often one should expect changes in the order book first level. For execution algorithms for which the frequency of updates (adding/cancelling child orders, re-evaluating decisions etc.) should commensurate with characteristics of the traded instrument.

Daily distribution can be used as start of day estimates and updated intraday with online Bayesian updates. Last group of daily data is derived from previous two groups but stored pre-computed to save time during research phase, or to be used as normalising values:

i. X-day Average Daily Volume (ADV) / Average Auction Volume
ii. X-day Volatility (close-to-close, open-to-close etc)
iii. Beta with respect to index or sector (plain beta, or asymmetric up-days/down-days beta)
iv. Correlation matrix

When binning data, this may be grouped into bins ranging from a few seconds to 30 minutes. Minute bar data are used for volume and spread profiles to prevent introducing excess noise due to market friction.

Definition 1.5.9. *Fundamental Data and Other Data*

i. Key Ratios: Earnings Per Share (EPS), Price-to-Earning (P/E), Price-to-Book (P/B), etc.
ii. Analyst Recommendations: aggregated values given consensus valuation
iii. Earnings data: estimations by research analysts provide quarterly earning estimates which can be used as indication of performance of stock before actual value is published

iv. Holders: sudden changes in ownership indicate changes in sentiment by sophisticated investor

v. Insiders Purchase/Sale: indicator of future stock price moves from group of people who have access to best possible information about the company

vi. Credit Ratings: credit downgrades resulting in higher funding costs have negative impact on equity prices

1.5.2 Financial Data Structures

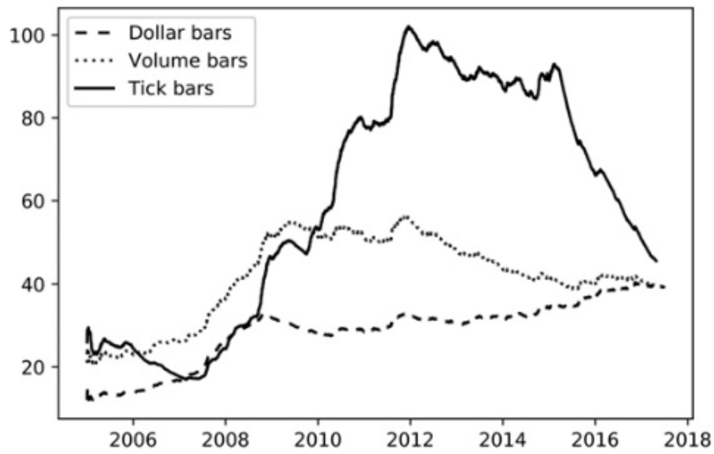

Figure 2: Average daily frequency of tick, volume, and dollar bars

Remark 1.5.10. *Standard BARS*
Method to transform a series of observations arriving at irregular frequency into a homogeneous series derived from regular sampling.

i. Time Bars: obtained by sampling information at fixed intervals. Information collected includes timestamp, volume-weighted average price (VWAP), open price, close price, high price, low price, volume etc.
To be avoided as markets do not process information at constant time interval. Time bars oversample information in low-activity periods and under-sample information in high-activity periods. Time bars exhibit poor statistical properties, i.e., serial correlation, heteroscedasticity, non-normality of returns.

ii. Tick Bars: sample variables extracted each time a pre-defined number of transactions take place. Allows synchronisation of sampling with a proxy of information arrival.
Sampling as a function of trading activity creates returns closer to IID Normal (Thierry and Helyette (2000)). When constructing tick bars, to be aware of outliers, as many exchanges carry out auction at open and at close; order book accumulates bids and offers without matching. Order fragmentation introduces some arbitrariness in number of ticks. Matching engine protocols may split one fill into multiple artificial partial fills as a matter of operational convenience.

iii. Volume Bars: samples every time a pre-defined amount of security's units that have been exchanged.
Achieves better statistical properties than sampling tick bars.
Convenient artefact for studying market microstructure theories.

iv. Dollar Bars: samples an observation every time a pre-defined market value is exchanged. Used when the analysis involves significant price fluctuations. Robust against corporate actions such as splits, reverse splits, issuance of new shares, buying back existing shares.
Bar size could be dynamically adjusted as a function of free-floating market cap of a company or outstanding amount of issued debt.

Remark 1.5.11. *Information-Driven Bars*
Method to sample more frequently when new (micro-structural) information arrives to the market.

i. Tick Imbalance Bars: sample bars whenever tick imbalance exceeds expectations. To determine tick index T such that accumulation of signed ticks exceeds a given threshold.
Let $\{(p_t, v_t)\}_{t=1,\dots,T}$ be sequence of ticks where p_t and v_t is the price and volume associated with tick t.
Let tick rule define a sequence $\{b_t\}_{t=1,\dots,T}$ where

$$b_t = \begin{cases} b_{t-1} & \text{if } \Delta p_t = 0 \\ \frac{|\Delta p_t|}{\Delta p_t} & \text{if } \Delta p_t \neq 0 \end{cases}$$

The tick imbalance at time T is defined as

$$\theta_T = \sum_{t=1}^{T} b_t$$

Compute expected value of θ_T at beginning of the bar,

$$E_0[\theta_T] = E_0[T](P[b_t = 1] - P[b_t = -1]) = E_0[T](2P[b_t = 1] - 1)$$

where $E_0[T]$ is expected size of tick bar, $P[b_t = 1]$ and $P[b_t = -1]$ is unconditional probability that a tick is classified as a buy and sell. In practice, $E_0[T]$ and $(2P[b_t = 1] - 1)$ may be estimated as an exponentially weighted moving average of T and b_t values from prior bars.
Define the tick imbalance bar (TIB) as a T^* contiguous subset of ticks such that

$$T^* = \arg\min_T \{|\theta_T| \geq E_0[T] \mid 2P[b_t = 1] - 1\}$$

where the size of expected imbalance is implied by $|2P[b_t = 1] - 1|$.
When θ_T is more imbalanced than expected, a low T will satisfy the conditions.
TIBs are produced more frequently under presence of informed trading (asymmetric information that triggers one-side trading). TIBs are buckets of trades containing equal amounts of information.

ii. Volume/Dollar Imbalance Bars: sample bars when volume or dollar imbalances diverge from expectations. First, define imbalance at time T as

$$\theta_T = \sum_{t=1}^{T} b_t v_t$$

where v_t may represent ether number of securities traded (VIB) or dollar amount traded (DIB). The expected value of θ_T at the beginning of the bar is then computed as

$$\begin{aligned} E_0[\theta_T] &= E_0\left[\sum_{t|b_t=1}^{T} v_t\right] - E_0\left[\sum_{t|b_t=-1}^{T} v_t\right] \\ &= E_0[T](P[b_t = 1]E_0[v_t|b_t = 1] - P[b_t = -1]E_0[v_t|b_t = -1]) \\ &= E_0[T](v^+ - v^-) \end{aligned}$$

where the initial expectation of v_t is decomposed into component contributed by buys and sells. Then

$$E_0[\theta_T] = E_0[T](2v^+ - E_0[v_t])$$

In practice, $E_0[T]$ and $(2v^+ - E_0[v_t])$ may be estimated as exponentially weighted moving average of T and $b_t v_t$ values from prior bars. Next, define VIB or DIB as a T^*-contiguous subset of ticks such that

$$T^* = \arg\min_T \{|\theta_T| \geq E_0[T] \mid 2v^+ - E_0[v_t]\}$$

where the size of expected imbalance is implied by $|2v^+ - E_0[v_t]|$.
When θ_T is more imbalanced then expected, a low T will satisfy the conditions.
VIB and DIB addresses concerns on tick fragmentation and outliers, and also addresses the issues of corporate actions, as the bar size is adjusted dynamically.

iii. Tick Runs Bars: sample bars when the sequence of buys in overall volume diverges from expectations. For the case when large traders sweep order book, use iceberg orders, or slice parent orders into multiple children, all leaving a trace of runs in the $\{b_t\}_{t=1,\dots,T}$ sequence. Define length of current run as

$$\theta_T = \max\left\{\sum_{t|b_t=1}^{T} b_t - \sum_{t|b_t=-1}^{T} b_t\right\}$$

The expected value of θ_T at beginning of bar is computed as

$$E_0[\theta_T] = E_0[T]\max\{P[b_t = 1], 1 - P[b_t = 1]\}$$

In practice, $E_0[T]$ and $P[b_t = 1]$ may be estimated as exponentially weighted moving average of T and proportion of buy ticks from prior bars. Next, define TRB as T^*-contiguous subset of ticks such that

$$T^* = \arg\min_T \{\theta_T \geq E_0[T] \max\{P[b_t = 1], 1 - P[b_t = 1]\}\}$$

where the expected count of ticks from runs is implied by $\max\{P[b_t = 1], 1 - P[b_t = 1]\}$.
When θ_T exhibits more runs than expected, a low T will satisfy these conditions.
Instead of measuring length of longest sequence, count number of ticks of each side without offsetting.

iv. Volume/Dollar Runs Bars: sample bars when volume or dollars traded by one side exceed expectation for a bar. First, define volume or dollars associated with a run as

$$\theta_T = \max\left\{\sum_{t|b_t=1}^{T} b_t v_t - \sum_{t|b_t=-1}^{T} b_t v_t\right\}$$

where v_t may either represent volume (VRB) or dollar amount exchanged (DRB). The expected value of θ_T at beginning of the bar is then

$$E_0[\theta_T] = E_0[T] \max\{P[b_t = 1]E_0[v_t|b_t = 1], (1 - P[b_t = 1])E_0[v_t|b_t = -1]\}$$

In practice, $E_0[T], P[b_t = 1], E_0[v_t|b_t = 1], E_0[v_t|b_t = -1]$ may be estimated as exponentially weighted moving average of T, proportion of buy ticks, buy volumes, and sell volumes from prior bars. Next, define a volume runs bar (VR) as T^*-contiguous subset of ticks such that

$$T^* = \arg\min_T \{\theta_T \geq E_0[T] \max\{P[b_t = 1]E_0[v_t|b_t = 1], (1 - P[b_t = 1])E_0[v_t|b_t = -1]\}\}$$

expected volume from runs is implied by $\max\{P[b_t = 1]E_0[v_t|b_t = 1], (1 - P[b_t = 1])E_0[v_t|b_t = -1]\}\}$.
When θ_T exhibits more runs than expected, volume from runs is greater than expected, a low T will satisfy these conditions.

Definition 1.5.12. *Multi-Product Series: ETF Trick*
To model a basket of securities as if it was a single cash product. To transform any complex multi-product dataset into a single dataset that resembles a total return ETF.

Method 1.5.13. *ETF Trick*
Produce a time series that reflects the value of \$1 invested. Changes in the series will reflect changes in PnL, series will be strictly positive, and implementation shortfall will be taken into account. The bars contain:

i. Raw open price of instrument $i = 1, \dots, I$ at bar $t = 1, \dots, T$: $o_{i,t}$
ii. Raw close price of instrument $i = 1, \dots, I$ at bar $t = 1, \dots, T$: $p_{i,t}$
iii. USD value of one point of instrument $i = 1, \dots, I$ at bar $t = 1, \dots, T$: $\varphi_{i,t}$. This includes forex rate.
iv. Volume of instrument $i = 1, \dots, I$ at bar $t = 1, \dots, T$: $v_{i,t}$
v. Carry, dividend, or coupon paid by instrument i at bar t: $d_{i,t}$. Variable can also be used to charge margin costs or costs of funding.

All instruments $i = 1, \dots, I$ were tradable at bar $t = 1, \dots, T$. Even if some instruments were not tradable over entirety of time interval $[t - 1, t]$, at least they were tradable at times $t - 1$ and t.
For basket of securities with allocation vector ω_t rebalanced (or rolled) on bars $B \subseteq \{1, \dots, T\}$, the \$1 investment value $\{K_t\}$ is derived as

$$h_{i,t} = \begin{cases} \frac{\omega_{i,t} K_t}{o_{i,i+1}\varphi_{i,t} \sum_{i=1}^{I} |\omega_{i,t}|} & \text{if } t \in B \\ h_{i,t-1} & \text{otherwise} \end{cases}$$

$$\delta_{i,t} = \begin{cases} p_{i,t} - o_{i,t} & \text{if } (t-1) \in B \\ \Delta p_{i,t} & \text{otherwise} \end{cases}$$

$$K_t = K_{t-1} + \sum_{i=1}^{I} h_{i,t-1}\varphi_{i,t}(\delta_{i,t} + d_{i,t})$$

where $K_0 = 1$ is the initial AUM. Variable $h_{i,t}$ is the holdings of instrument i at time t, $\delta_{i,t}$ is change of market value between $t - 1$ and t for instrument i. Note profits or losses are being reinvested whenever $t \in B$, hence preventing negative prices. Dividends $d_{i,t}$ are already embedded in K_t.

The purpose of $\omega_{i,t}\left(\sum_{i=1}^{I}|\omega_{i,t}|\right)^{-1}$ is to de-lever the allocations.
Let τ_i be transaction cost associated with trading \$1 of the instrument. Three additional variables that the strategy needs to know for every observed bar t are:

i. Rebalance Costs: variable cost $\{c_t\}$ associated with allocation rebalance is

$$c_t = \sum_{i=1}^{I}(|h_{i,t-1}|\, p_{i,t} + |h_{i,t}|\, o_{i,t+1})\varphi_{i,t}\tau_i \quad \forall t \in B$$

Note c_t is not embedded in K_t, as shorting will generate fictitious proceeds when allocation is rebalanced. In code, $\{c_t\}$ is treated as a (negative) dividend.

ii. Bid-Ask Spread: the cost $\{\tilde{c}_t\}$ of buying or selling one unit of this ETF,

$$ildec_t = \sum_{i=1}^{I}|h_{i,t-1}|\, p_{i,t}\varphi_{i,t}\tau_i$$

When a unit is bought or sold, strategy must charge this cost $\tilde{c}_t$.

iii. Volume: volume traded $\{v_t\}$ is determined by least active member in the basket. Let $v_{i,t}$ be volume traded by instrument i over bar t. The number of tradable basket units is

$$v_t = \min_i \left\{\frac{v_{i,t}}{|h_{i,t-1}|}\right\}$$

Transaction costs functions may not be linear, and can be simulated by the strategy.

Method 1.5.14. *ETF Trick: Computation of Allocation Vector with PCA*
Consider an IID multivariate Gaussian process with means vector μ of size $N \times 1$, and covariance matrix V of size $N \times N$. First, perform spectral decomposition $VW = W\Lambda$, where columns in W are reordered so that elements of Λ diagonal are sorted in descending order. Second, given allocations vector ω, portfolio risk is

$$\sigma^2 = \omega' V\omega = \omega' W\Lambda W'\omega = \beta'\Lambda\beta = (\Lambda^{1/2}\beta)'(\Lambda^{1/2}\beta)'$$

where β is projection of ω on orthogonal basis. Third, Λ is a diagonal matrix, thus

$$\sigma^2 = \sum_{n=1}^{N}\beta_n^2\Lambda_{n,n}$$

The risk attributed to the nth component is

$$R_n = \beta_n^2\Lambda_{n,n}\sigma^{-2} = [W'n]_n^2\Lambda_{n,n}\sigma^{-2}$$

with $R'1_N = 1$, and 1_N is a vector of N ones.
Note $\{R_n\}_{n=1,\ldots,N}$ is distribution of risks across orthogonal components.
Next, compute vector ω which delivers user-defined risk distribution R. Note from earlier,

$$\beta = \left\{\sigma\sqrt{\frac{R_n}{\Lambda_{n,n}}}\right\}_{n=1,\ldots,N}$$

which represents allocation in new (orthogonal basis).
The allocation in old basis is $\omega = W\beta$. Rescaling ω re-scales σ, hence keeping risk distribution constant.

Method 1.5.15. *ETF Trick: Single Futures Roll*
To work with non-negative rolled series, derive price series of \$1 investment as follows:

i. Compute time series of rolled futures prices

ii. Compute return r as rolled price change divided by previous roll price

iii. Form a price series using these returns

These methods allow us to produce a continuous, homogeneous, and structured dataset from collection of unstructured financial data. Note however, that several ML algorithms do not scale well with sample size. ML algorithms achieve higher accuracy when they attempt to learn from relevant examples.

Method 1.5.16. *Sampling for Reduction*
To reduce the amount of data used to fit ML algorithm, downsampling could be used.

i. Sequential sampling at constant step size (linspace sampling)
ii. Sampling randomly using uniform distribution (uniform sampling)

Note both samples do not necessarily contain subset of most relevant observations.

Method 1.5.17. *Event-Based Sampling: CUMSUM Filter*
Bets are often placed after some event takes place, hence to let ML algorithm learn whether there is an accurate prediction function under these circumstances, CUSUM filter could be used.
This is a quality-control method, to detect shift in mean value of measured quantity away from a target value.
Let $\{y_t\}_{t=1,\dots,T}$ be IID observations arising from a locally stationary process. The cumulative sums are

$$S_t = \max\{0, S_{t-1} + y_t - E_{t-1}[y_t]\}, \quad S_0 = 0$$

An action will be recommended at the first t satisfying $S_t \geq h$ for some threshold h (filter size).
Note $S_t = 0$ whenever $y_t = E_{t-1}[y_t] - S_{t-1}$, The zero floor means some downward deviations will be skipped.
The filter is set up to identify a sequence of upside divergences from any reset level zero.
The threshold is activated when

$$S_t \geq h \Leftrightarrow \exists \tau \in [1, t] \mid \sum_{i=\tau}^{t} (y_i - E_{i-1}[y_t]) \geq h$$

This concept of run-ups can be extended to include run-downs, giving symmetric CUSUM filter.

$$\begin{aligned}
S_t^+ &= \max\{0, S_{t-1}^+ + y_t - E_{t-1}[y_t]\}, \quad S_0^+ = 0 \\
S_t^- &= \min\{0, S_{t-1}^- + y_t - E_{t-1}[y_t]\}, \quad S_0^- = 0 \\
S_t &= \max\{S_t^+, -S_t^-\}
\end{aligned}$$

1.5.3 Data Labelling Techniques

Method 1.5.18. *Labelling with Fixed-Time Horizon Method*
Given features matrix X with I rows, $\{X_i\}_{i=1,\dots,I}$ drawn from some bards with index $t = 1, \dots, T$, where $I \leq T$, let an observation X_i be assigned a label $y_i \in \{-1, 0, 1\}$,

$$\begin{aligned}
y_i &= \begin{cases} -1 & \text{if } r_{t_{i,0}, t_{i,0}+h} < -\tau \\ 0 & \text{if } \left| r_{t_{i,0}, t_{i,0}+h} \right| \leq \tau \\ 1 & \text{if } r_{t_{i,0}, t_{i,0}+h} > \tau \end{cases} \\
r_{t_{i,0}, t_{i,0}+h} &= \frac{p_{t_{i,0}+h}}{p_{t_{i,0}}} - 1
\end{aligned}$$

where τ is a pre-defined constant threshold, $t_{i,0}$ is index of bar immediately after X_i takes place, $t_{i,0} + h$ is index of h-th bar after $t_{i,0}$, and $r_{t_{i,0}, t_{i,0}+h}$ is price return over bar horizon h.

Remark 1.5.19. *Limitations of Fixed-Time Horizon Method*

i. Time bars do not exhibit good statistical properties (as seen earlier)
ii. The same threshold τ is applied regardless of observed volatility.
Compute daily volatility at intraday estimation points, applying span of n days t an exponentially weighted moving standard deviation.

Method 1.5.20. *Labelling with Triple-Barrier Method*
Labels an observation according to first barrier touched out of three barriers.

i. Set two horizontal barriers and one vertical barrier. Horizontal barriers are defined by profit-taking and stop-loss limits, which are a dynamic function of estimated volatility (realised or implied). Third barrier is the number of bars elapsed since the position was taken (expiration limit).
ii. If upper barrier is touched first, label observation as 1. If lower barrier is touched first, label observation as -1. If vertical barrier is touched first, either label by sign of the return or with 0.

Note that the method is path-dependent. To label an observation, need to account for entire path spanning $[t_{i,0}, t_{i,0} + h]$ where h defines the vertical barrier (expiration limit). Let $t_{i,1}$ be the time of first barrier touch with return as $r_{t_{i,0}, t_{i,1}}$. The horizontal barriers may not be symmetric.

Remark 1.5.21. *Triple-Barrier Method Configurations*
Denote a barrier configuration by triplet $[pt, sl, t1]$ which are the upper barrier, lower barrier, physical barrier. Set value as 0 if barrier is inactive, and 1 if barrier is active.
The three useful configurations are:

i. $[1, 1, 1]$: to realise profit, but have set a maximum tolerance for losses and a holding period.
ii. $[0, 1, 1]$: to exit after a number of bars, unless stopped-out.
iii. $[1, 1, 0]$: take profit as long as not stopped-out.

The three less realistic configurations are:

i. $[0, 0, 1]$: equivalent to fixed-time horizon method.
ii. $[1, 0, 1]$: position held until a profit is made or maximum holding period is exceeded, without regard for immediate unrealised losses
iii. $[1, 0, 0]$: position is held until a profit is made. Could lock in loose position for years.

The two illogical configurations are:

i. $[0, 1, 0]$: aimless. Hold position until stopped-out.
ii. $[0, 0, 0]$: no barriers. Position locked forever, no label generated.

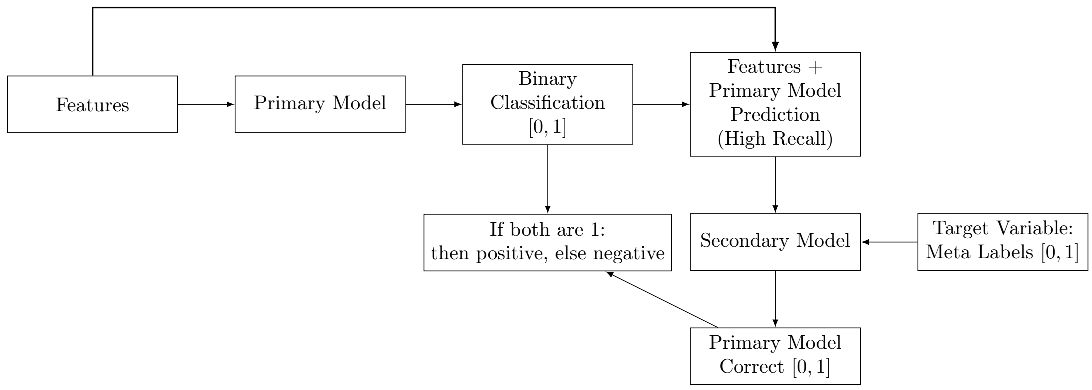

Figure 3: Meta-Labelling Process

Method 1.5.22. *Meta-Labelling*
The technique is particularly helpful to achieve higher F1-scores.
First, build a model that achieves high recall, even if precision is not particularly high. Second, correct for low precision by applying meta-labelling to positives predicted by primary model.
Meta-labelling will filter out false positives, where majority of positives have been identified by primary model.
The second model's purpose is to determine if the positive from primary model is true or false.

i. Train a primary model (binary classification)
ii. A threshold level is determined at which the primary model has a high recall, ROC curves could be used to help determine a good level.
iii. Typical features of second model are as follows:
   i. Primary model features concatenated with predictions from first model.
   ii. Market state
   iii. Features indicative of false positives
   iv. Distribution related
   v. Recent model performance

   Meta Labels are used as target variable in second model. Fit the second model
iv. Prediction from the secondary model is combined with the prediction from the primary model and only where both are true, is your final prediction true.

Remark 1.5.23. *Limitations of Meta-Labelling*

i. If model has overfit the data, meta-labelling will not add much value

ii. If every trade is not treated as an independent observation, the meta-model is forced to determine day-to-day exposures, which is the wrong way to apply the technique

iii. Technique trades recall for precision. Require a large number of trades to train on, while being happy with reduction in trade frequency

1.5.4 Data Sample Weights

Note that most of ML literature is based on IID assumption, and ML applications usually fail in finance as these assumptions are unrealistic in the case of financial time series.

Remark 1.5.24. *Overlapping Outcomes*
Let label y_i be assigned to an observed feature X_i, where $y_i = f([t_{i,0}, t_{i,1}])$ is a function over the interval. When $t_{i,1} > t_{j,0}$ and $i < j$, then y_j will depend on common return $r_{t_{j,0},\min\{t_{i,1},t_{j,1}\}}$ (over interval $[t_{j,0}, \min\{t_{i,1}, t_{j,1}\}]$). The series of labels $\{y_i\}_{i-1,\dots,J}$ are not IID whenever there is overlap between any two consecutive outcomes, i.e., $\exists i \mid t_{i,1} > t_{i+1,0}$. If this is resolved by restricting bet horizon to $t_{i,1} \leq t_{i+1,0}$, there is no overlap, but this will lead to coarse models where features sampling frequency is limited by horizon used to determine outcome. To investigate outcomes that lasted a different duration, samples have to be resampled with different frequency. In addition, if path-dependent labelling technique is to be applied, the sampling frequency will be subordinated to first barrier's touch. Hence, to use $t_{i,1} > t_{i+1,0}$, leading to overlapping outcomes.

Method 1.5.25. *Estimating Uniqueness of Label*
Let two labels y_i and y_j be concurrent at time t, both a function of at least one common return $r_{t-1,t} = \frac{p_t}{p_{t-1}} = 1$. To compute the number of labels that are a function of given return $r_{t-1,t}$:

i. For each $t = 1, \dots, T$, form a binary array $\{1_{t,i}\}_{i=1,\dots,I}$ where $1_{t,i} \in \{0, 1\}$.
Variable $1_{t,i} = 1$ if and only if $[t_{i,0}, t_{i,1}]$ overlaps with $[t-1, t]$ and $1_{t,i} = 0$ otherwise.

ii. Compute the number of labels concurrent at t, $c_t = \sum_{i=1}^{I} 1_{t,i}$

Method 1.5.26. *Average Uniqueness of Label*
To estimate label's uniqueness (non-overlap) across its lifespan.

i. Uniqueness of label i at time t is $u_{t,i} = 1_{t,i} c_t^{-1}$.

ii. Average uniqueness of label i is average $u_{t,i}$ over label's lifespan, $\overline{u}_i = (\sum_{t=1}^{T} u_{t,i})(\sum_{t=1}^{T} 1_{t,i})^{-1}$.

Note that $\{\overline{u}_i\}_{i=1,\dots,I}$ are not used for forecasting the label, hence there is no information leakage.

Remark 1.5.27. *IID and Oversampling*
Probability of not selecting item i after I draws with replacement on set of I items is $(1 - I^{-1})^I$. As $I \to \infty$, note that $(1 - I^{-1})^I \to e^{-1}$. Number of unique observations drawn to be expected is $(1 - e^{-1}) \approx \frac{2}{3}$.
If maximum number of overlapping outcomes is $K \leq I$, probability of not selecting a particular item i after I draws with replacement on set of I items is $(1-K^{-1})^I$. As sample size increase, probability can be approximated as $(1 - I^{-1})^{I\frac{K}{I}} \approx e^{-\frac{K}{I}}$. Implication is that incorrectly assuming IID draws lead to oversampling.

Method 1.5.28. *Sampling with Bootstrap, Redundancy*
Sampling with bootstrapping on observations where $I^{-1} \sum_{i=1}^{I} \overline{u}_i \ll 1$, in-bag observations will increasingly be redundant to each other, and very similar to out-of-bag observations. Two solutions may be:

i. Drop overlapping outcomes before performing bootstrap.
As overlaps are not perfect, dropping an observation due to overlap will lead to extreme loss in information.

ii. Utilise the average uniqueness $I^{-1} \sum_{i=1}^{I} \overline{u}_i$ to reduce undue influence of outcomes that contain redundant information. Ensure in-bag observations are not sampled at frequency much higher than uniqueness.

Method 1.5.29. *Sequential Bootstrap*
Draws made according to changing probability that controls for redundancy.

i. Observation X_i is drawn from uniform distribution, $i \sim U[1, I]$.
Probability of drawing any value i is $\delta_i^{(1)} = I^{-1}$.

ii. Second draw, to reduce probability of drawing observation X_j with highly overlapping outcome.
Let φ be sequence of draws (may include repetitions), where $\{\varphi^{(1)}\} = \{i\}$.
Uniqueness of j at time t is $u_{t,j}^{(2)} = 1_{t,j}(1+\sum_{k\in\varphi^{(1)}} 1_{t,k})^{-1}$, which is the uniqueness from adding alternative j's to existing sequence of draws $\varphi^{(1)}$.

Average uniqueness of j is average $u_{t,j}^{(2)}$ over j's lifespan, $\overline{u}_j^{(2)} = (\sum_{t=1}^{T} u_{t,j})(\sum_{t=1}^{T} 1_{t,j})^{-1}$.
A second draw can be made based on updated probabilities $\{\delta_j^{(2)}\}_{j=1,\dots,I}$:

$$\delta_j^{(2)} = \overline{u}_j^{(2)} \left(\sum_{k=1}^{I} \overline{u}_j^{(2)} \right)^{-1}$$

where $\sum_{j=1}^{I} \delta_j^{(2)} = 1$. Do a second draw, update $\varphi^{(2)}$, and re-evaluate $\{\delta_j^{(3)}\}_{j=1,\dots,I}$.

iii. Process is repeated until I draws have taken place.

Process draws samples much close to IID, verified by increase in $I^{-1} \sum_{i=1}^{I} \overline{u}_i$.

Method 1.5.30. *Weighting Observations by Uniqueness and Absolute Return*
Let labels be a function for return sign ($\{-1, 1\}$ for standard label, $\{0, 1\}$ for meta-label). The sample weights can be defined in terms of sum of attributed returns over event's life-span, $[t_{i,0}, t_{i,1}]$,

$$\tilde{w}_i = \left| \sum_{t=t_{i,0}}^{t_{i,1}} \frac{r_{t-1,t}}{c_t} \right|, \quad w_t = \tilde{w}_i \left(\sum_{j=1}^{I} \tilde{w}_j \right)^{-1}$$

where $\sum_{i=1}^{I} w_i = I$. The method weigh an observation as a function of absolute log returns that can be attributed uniquely to it. Lower returns should be assigned higher weights.

Method 1.5.31. *Time Decay Weighting*
To let sample weights decay as new observations arrive.
Let $d[x] \geq 0 \ \forall x \in [0, \sum_{i=0}^{I} \overline{u}_i]$ be time-decay factors multiplying sample weights from earlier.
The final weight has no decay, $d[\sum_{i=1}^{I} \overline{u}_i] = 1$, and all other weights will adjust relative to that.
Let $c \in (-1, 1]$ be user-defined parameters that determines decay function as follows:

i. If $c \in [0, 1]$, then $d[1] = c$ with linear decay

ii. If $c \in (-1, 0)$, then $d[-c \sum_{i=1}^{I} \overline{u}_i] = 0$, with linear decay between $[-c \sum_{i=1}^{I} \overline{u}_i, \sum_{i=1}^{I} \overline{u}_i]$, and $d[x] \ \forall x \leq -c \sum_{i=1}^{I} \overline{u}_i$.

If given linear piecewise function $d = \max\{0, a + bx\}$, requirements are met by following boundary conditions:

i. $d = a + b \sum_{i=1}^{I} \overline{u}_i = 1 \Rightarrow a = 1 - b \sum_{i=1}^{I} \overline{u}_i$

ii. Contingent on c:

   1. $d = a + b0 = c \Rightarrow b = (1 - c)(\sum_{i=1}^{I} \overline{u}_i)^{-1} \quad \forall c \in [0, 1]$
   2. $d = a - bc \sum_{i=1}^{I} \overline{u}_i = 0 \Rightarrow b = [(c + 1) \sum_{i=1}^{I} \overline{u}_i]^{-1} \ \forall c \in (-1, 0)$

In the implementation, decay takes place according to cumulative uniqueness. Note that

i. $c = 1$ means there is no time decay

ii. $0 < c < 1$ means weights decay linearly over time, but every observation still receives strictly positive weight, regardless of age

iii. $c = 0$ means weights converge linearly to zero over time

iv. $c < 0$ means oldest portion cT of observations receive zero weight (erased from memory)

Method 1.5.32. *Class Weighting*
Weights for underrepresented labels. Critical in classification problems where the most important classes have rare occurrences. To assign higher weights to samples associated with those rare labels.

1.5.5 Fractionally Differentiated Features

Standard stationarity transformations (i.e. integer differentiation) reduce signal by removing memory. Although stationarity is necessary for inferential purposes, it is rarely the case that we want all memory to be erased. Fractionally differentiated processes exhibit long-term persistence and anti-persistence, hence enhancing the forecasting power compared to standard ARIMA approach.

Definition 1.5.33. *BackShift Operator*
Let B be the backshift operator applied to a matrix of real-valued features $\{X_t\}$, where $B^k X_t = X_{t-k}$ for any integer $k \geq 0$. By binomial expansion, we then have

$$
\begin{aligned}
(1-B)^d = \sum_{k=0}^{\infty} \binom{d}{k} (-B)^k &= \sum_{k=0}^{\infty} \prod_{i=0}^{k-1} (d-i) \frac{(-B)^k}{k!} = \sum_{k=0}^{\infty} (-B)^k \prod_{i=0}^{k-1} \frac{d-i}{k-i} \\
&= 1 - dB + \frac{d(d-1)}{2!} B^2 - \frac{d(d-1)(d-2)}{3!} B^3 + \cdots
\end{aligned}
$$

Remark 1.5.34. *Properties of Fractionally Differentiated Features*
Let d be a real (non-integer) positive number. The arithmetic series consists of dot product

$$
\begin{aligned}
\tilde{X}_t &= \sum_{k=0}^{\infty} \omega_k X_{t-k} \\
\omega &= \left\{ 1, -d, \frac{d(d-1)}{2!}, -\frac{d(d-1)(d-2)}{3!}, \ldots, (-1)^k \prod_{i=0}^{k-1} \frac{d-1}{k!}, \ldots \right\} \\
X &= \{X_t, X_{t-1}, \ldots, X_{t-k}, \ldots\}
\end{aligned}
$$

where ω are the weights, X are the values. Properties of these features are:

i. Long memory: if d is a positive integer number, then

$$\prod_{i=0}^{k-1} \frac{d-i}{k!} = 0 \quad \forall > d$$

and memory beyond that point is cancelled.

ii. Iterative weight generation: given sequence of weights ω, for $k = 0, \ldots, \infty$, the weights are

$$\omega_k = -\omega_{k-1} \frac{d-k+1}{k}, \quad \omega_0 = 1$$

iii. Convergence: For $k > d$, if $\omega_{k-1} \neq 0$, then

$$\left| \frac{\omega_k}{\omega_{k-1}} \right| = \left| \frac{d-k+1}{k} \right| < 1$$

and $\omega_k = 0$ otherwise. Hence weights converge asymptotically to zero.
For positive d and $k < d+1$, then $\frac{d-k+1}{k} \geq 0$, which makes initial weights alternate in sign.
For non-integer d, once $k \geq d+1$, ω_k will be negative if $\text{int}[d]$ is even, and positive otherwise.
In summary, $\lim_{k \to \infty} = 0^-$ when $\text{int}[d]$ is even, and $\lim_{k \to \infty} = 0^+$ when $\text{int}[d]$ is odd.
In special case $d \in (0,1)$, that $-1 < \omega_k < 0 \; \forall k > 0$. Alternate weight signs makes $\{\tilde{X}_t\}_{t=1,\ldots,T}$ stationary, as memory wanes or is offset over the long run.

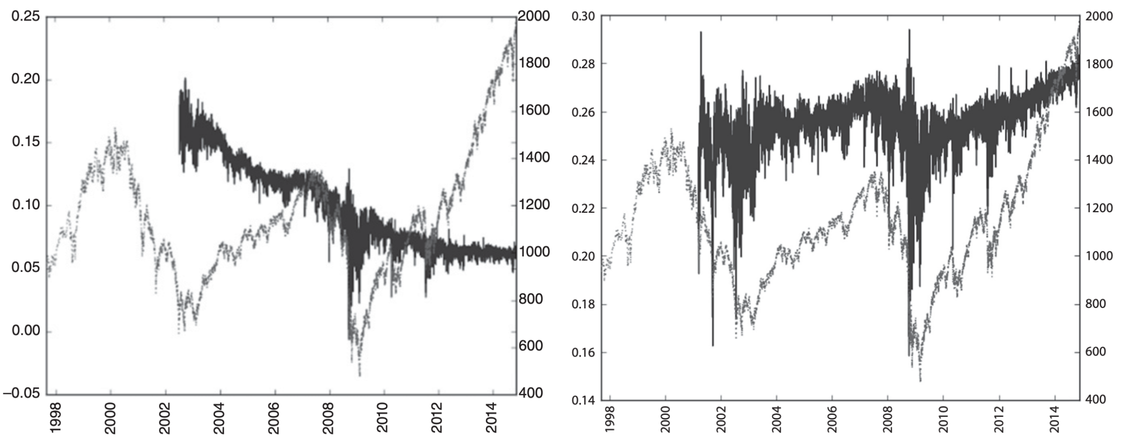

Figure 4: Fractional differentiation controlling for weight loss with expanding and fixed-width window

Method 1.5.35. *Expanding Window*
Given time series T with real observations $\{X_t\}_{t=1,\dots,T}$, for each l, the relative weight loss is defined as

$$\lambda_l = \sum_{j=T-l}^{T} |\omega_j| \Bigg/ \sum_{i=0}^{T-1} |\omega_i|$$

Given tolerance level $\tau \in [0,1]$, determine value l^* such that $\lambda_{l^*} \leq \tau$ and $\lambda_{l^*+1} > \tau$. This value l^* corresponds to the first results $\{\tilde{X}_t\}_{t=1,\dots,l^*}$, where weight-loss is beyond acceptable threshold $\lambda_t > \tau$.
From Remark 1.5.34, it is clear λ_{l^*} depends on convergence speed of $\{\omega_k\}$, which in turn depends on $d \in [0,1]$. For $d = 1, \omega_k = 0\ \forall k > 1$, and $\lambda_l = 0\ \forall l > 1$, hence it suffices to drop $\tilde{X}_1$.
As $d \to 0^+$, l^* increases, and larger portion of initial $\{\tilde{X}_t\}_{t=1,\dots,l^*}$ needs to be dropped to keep the weight loss $\lambda_{l^*} < \tau$. Note that there will be negative drift caused by negative weights added to initial observations as window is expanded. By controlling for weight loss, negative drift is still substantial as $\{\tilde{X}_t\}_{t=l^*+1,\dots,T}$ are computed on an expanding window.

Method 1.5.36. *Fixed-Width Window*
Drop weights after their modulus $|\omega_k|$ decreases below a given threshold τ. This is equivalent to finding the first l^* such that $|\omega_{l^*}| \geq \tau$ and $|\omega_{l^*+1}| \leq \tau$, setting a new variable $\tilde{\omega}_k$:

$$\tilde{\omega_k} = \begin{cases} \omega_k & \text{if } k \leq l^* \\ 0 & \text{if } k > l^* \end{cases} \quad , \qquad \tilde{X}_t = \sum_{k=0}^{l^*} \tilde{\omega}_k X_{t-k} \;\; \text{for } t = T - l^* + 1, \dots, T$$

Note that the same vector of weights is used across all estimates of $\{\tilde{X}_t\}_{t=l^*,\dots,T}$, hence avoiding negative drift caused by expanding window's added weights.
Distribution has skewness and excess kurtosis from memory, but it is stationary.

2 Macro and Global Market Analysis

Global macro is the strategy of identifying economic regime shifts early and expressing them through the most liquid instruments. The primary objective is surviving and profiting from crises, rather than maximising returns in stable periods (Gliner (2014)).

2.1 Regime and World State

2.1.1 Survey of Global Macro Landscape

Definition 2.1.1. *Global Macro*
Global macro is a top-down investment strategy that trades economic regimes, not securities.
The core idea is simple but powerful: macro forces dominate asset prices when they shift, and those forces operate across countries, asset classes, and policy domains. Global macro traders

i. Form views on growth, inflation, monetary policy, and geopolitics
ii. Express those views via equities, rates, FX, and commodities
iii. Are unconstrained by geography, asset class, or direction (long/short)

Global macro is often considered the most flexible and opportunistic hedge fund strategy, due to the scope of traded products and the number of markets it covers. Its aim is to preserve capital, using stringent risk management to limit drawdowns.

Remark 2.1.2. *Existence of Global Macro as a Strategy*
Macro exists because economic regimes are unstable, but markets price them slowly and asymmetrically.
Three structural reasons:

i. Policy is discrete, markets are continuous: Central banks and governments move in jumps (rate decisions, QE, capital controls). Markets must reprice entire distributions after the fact.
ii. Capital is sticky: Large allocators (pensions, insurers, sovereign funds) cannot reposition quickly. Macro traders exploit this inertia.
iii. Cross-asset linkages are under-arbitraged: Many investors specialise in a single asset class. Macro traders operate between silos.

Hence macro is a strategy of structural inefficiency, not informational advantage.

Remark 2.1.3. *Types of Global Macro Strategies*
The four broad approaches are:

i. Discretionary Macro
Relies on trader experience, intelligence, and knowledge to take subjective bets on global markets. Requires serious organization and data processing skills. Uses top-down analysis of risks and opportunities across industries, sectors, countries, and the macroeconomic situation.
Discretionary traders can execute *directional trades* (betting on asset direction) or *relative value trades* (pairing assets to capture value differentials). Strong in crises and regime breaks where human judgment outperforms models.
ii. Systematic Macro
Model-driven, employing quantitative factors to produce trading positions that remove human emotion. Prides itself on stringent process, strong back-tests, and ability to operate solely on quantitative analysis. Over long periods, systematic funds produce more consistent returns than discretionary strategies; however, in periods of high volatility, they tend to underperform (e.g., 2008).
The ability to trade multiple liquid asset classes allows these funds to scale to very large AUM.
iii. High-Frequency Macro
Uses sophisticated technology to trade very short-term (millisecond to hours) dislocations around macro events. Processing speed is paramount. Limited scalability compared to discretionary and systematic.
iv. CTAs (Commodity Trading Advisors)
Primarily futures-based, momentum-driven trend-following strategies. Position sizing methodology originated with the Turtle Traders. Perform well over longer periods but subject to large drawdowns.

It is wise to allocate to both discretionary and systematic macro in a balanced manner. Discretionary is negatively correlated during stress, while systematic provides predictable allocation with back-tested drawdowns.

Remark 2.1.4. *Trade Types in Macro*
Discretionary macro traders express views through two primary trade structures:

i. Directional Trades: Betting on an asset moving in a particular direction. Example: going long copper on a bullish commodities view.
ii. Relative Value Trades: Pairing or grouping assets to capture the relative value differential between them. Example: during European crisis, short Italian 5-year BTPs vs. long German Bobls, betting Italy will see yields rise relative to Germany.
iii. Thematic Trades: Longer-term positions based on structural macro views.
Examples: "fiat money debasement", hence long gold; "Japan debt unsustainability", hence short JGBs. Thematic trades should be sized smaller than short-term trades because they can take years to play out and may incur negative carry.

Remark 2.1.5. *Return Profile Across Cycles*
Global macro's defining feature is return asymmetry across market regimes. Empirical characteristics:

i. Lower average volatility than equities
ii. Comparable or higher long-run returns
iii. Low or negative correlation to equities during crises
iv. Higher Sharpe ratio than most hedge fund strategies

Macro tends to underperform in bull markets (when staying long works), but outperform during dislocations, recessions, and policy shifts. This asymmetry exists because macro traders can go short, can hold cash, can trade volatility, rates, and FX directly (flexibility that equity-focused strategies lack).

Remark 2.1.6. *Behaviour in Economic Crisis*
In stress regimes:

i. Equity managers are trapped long (mandates prevent shorting or holding cash)
ii. Credit liquidity vanishes (bids disappear, spreads gap wider)
iii. Correlations converge toward 1 (diversification fails)

Macro funds, by contrast, can:

i. Reduce gross exposure rapidly
ii. Short risk assets directly
iii. Express views via rates, FX, or volatility instead of equities
iv. Profit from the dislocation rather than merely survive it

Remark 2.1.7. *Global Macro Correlation Properties*
Global macro's real value is conditional correlation:

i. In normal times: low correlation to equities
ii. In crises: negative correlation to equities

This makes macro an effective portfolio diversifier and tail-risk hedge. Combined with high liquidity (trading the most liquid markets globally), macro is the most popular hedge fund allocation by pension funds.

Remark 2.1.8. *Liquidity Advantage*
One of most liquid hedge fund strategies because it trades the most liquid underlying markets:

i. G10 FX and major EM currencies
ii. Government bond futures (Treasuries, Bunds, JGBs, Gilts)
iii. Equity index futures (S&P 500, Euro Stoxx, Nikkei, etc.)
iv. Major commodity futures (crude oil, gold, copper, etc.)

This liquidity allows macro funds to:

i. Scale to very large AUM without market impact
ii. Enter and exit positions quickly during stress
iii. Offer better redemption terms than illiquid strategies

2.1.2 Role of Central Banks in Global Macro

Remark 2.1.9. *Monetary Policy Regimes*
Central banks define the macro regime more than any other actor. Markets do not trade rates, they trade policy intent under constraints. Regimes fall into following types:

i. Conventional Policy Regime: Policy rate is the main tool. Yield curve responds normally. Transmission is through rates to credit, to growth, then to inflation.
ii. Unconventional Policy Regime: Policy rate loses effectiveness (zero lower bound). Balance sheet becomes the primary tool. Transmission shifts to asset prices, expectations, and FX.
iii. Crisis/Emergency Regime: Stability is more important than inflation targeting. Rules are suspended. Liquidity provision dominates all other objectives.

Remark 2.1.10. *Objectives of Central Banks*
Central banks typically have mandates that include:

i. Price Stability: Most central banks target inflation around 2%
ii. Full Employment: Explicit in Fed's dual mandate; implicit elsewhere
iii. Financial System Stability: Lender of last resort function; systemic risk monitoring
iv. Currency Stability: Explicit for some (SNB, PBOC); implicit for others

Under stress, these objectives may conflict. Central banks must choose which objective to sacrifice. Understanding these trade-offs is critical for macro trading.

Remark 2.1.11. *Conventional Central Bank Tools*

i. Policy Rate: Set by changing overnight rate at which banks lend and borrow to meet reserve requirements. The primary tool in normal times.
ii. Reserve Ratio: Raising reserve ratio decreases money multiplier and contracts money supply.
iii. Open Market Operations (OMO): Buying and selling government bonds in local currency. Repos are short-term agreements where the central bank agrees to repurchase securities within a specified time.
iv. Currency Intervention:
    1. Sterilised intervention: Trading own currency via FX reserves without changing monetary base
    2. Unsterilised intervention: Allows for changes in monetary base

Remark 2.1.12. *Taylor's Rule*
Maps macroeconomic deviations to policy stance:

$$i_t = r^* + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y_t^*)$$

where r^* is the neutral real rate (unobservable, typically estimated 2–3%), π_t is current inflation, π^* is the inflation target, $(y_t - y_t^*)$ is the output gap, and α, β are response coefficients (typically 0.5).
The rule states that the nominal policy rate must rise more than one-to-one with inflation (Taylor Principle); otherwise real rates fall, inflation becomes self-reinforcing, and expectations de-anchor.
Central banks treat Taylor's rule as a benchmark, communication tool, and political shield.

Remark 2.1.13. *The Impossible Trinity*
A country cannot simultaneously maintain:

i. Fixed exchange rate
ii. Free capital flows
iii. Independent monetary policy

This constraint explains currency crises (ERM 1992, Asian crisis 1997), forced rate hikes or cuts, FX pegs breaking, and why EM central banks behave "irrationally" under stress. Countries must choose two of three.

Remark 2.1.14. *Central Bank Balance Sheet*

i. Monetary Base: Sum of currency in circulation and reserves held at the central bank. Can only be controlled via open market operations.

ii. Money Supply: Changes in money supply are leading predictors of GDP growth and inflation. The Quantity Theory of Money:

$$M \times V = P \times Y$$

where M is money supply, V is velocity of money (turnover rate), P is price level, Y is real output.

Post-2008, central bank balance sheets expanded dramatically. The Fed releases weekly H.4.1 report showing sources and uses of reserves.

Remark 2.1.15. *Types of Money Supply*

i. $M0$: Physical currency in circulation (notes and coins)
ii. $M1$: $M0$ + demand deposits, checking accounts, traveler's checks
iii. $M2$: $M1$ + savings deposits, money market accounts, small time deposits, retail money market funds
iv. $M3$: $M2$ + large time deposits, institutional money market funds, repos, eurodollars

Central banks primarily control $M0$; broader measures depend on banking system credit creation.

Remark 2.1.16. *Zero Lower Bound and the Liquidity Trap*
When central bank rate is at or near zero:

i. Rate cuts lose marginal effectiveness
ii. Expectations dominate outcomes
iii. Forward guidance becomes critical
iv. Fiscal policy starts to matter more

Yield curves flatten naturally; carry trades distort; volatility is suppressed artificially.
Some central banks have gone to negative rates, testing the effective lower bound.

Remark 2.1.17. *Quantitative Easing (QE)*
Central banks purchase financial assets (government bonds, MBS, corporate bonds), creating electronic reserves to expand the balance sheet. QE works through multiple channels:

i. Portfolio rebalancing (investors pushed into riskier assets)
ii. Risk premia compression (term premium, credit spreads)
iii. Signalling effects (commitment to low rates)
iv. Exchange rate channel (currency weakening)

Bank lending does not mechanically follow reserve creation. Transmission depends on credit demand and bank capital. Effectiveness diminishes with successive rounds.
Fed research shows QE1 lowered 10-year yields by 100bp; QE2 by only 14bp.

Remark 2.1.18. *Hawks and Doves*
Central bankers have individual biases that shape their policy views:

i. Hawks: Wary of inflation, favour tighter policy, defend currency value
ii. Doves: Favour growth and employment, tolerate higher inflation, support looser policy

When a known hawk makes dovish statements (or vice versa), it signals a significant shift and moves markets more than statements consistent with known bias.
Tracking individual central banker positions is essential for anticipating policy shifts.

Remark 2.1.19. *Central Bank Communication*
Central bank communication is a policy tool in itself:

i. Statements: Released after each meeting; market moves on hawkish/dovish tone changes
ii. Minutes: Released with lag (2 to 3 weeks); reveal vote splits and internal debates
iii. Press Conferences: Chair/President Q&A; tone and body language matter
iv. Projections: Dot plots (Fed), staff forecasts; reveal expected rate path
v. Speeches: Individual members signalling; watch for coordinated messaging

Example: BOE June 2012 minutes revealed 5–4 vote against QE (vs 8–1 in May), correctly predicting QE expansion in July.

Remark 2.1.20. *Major Central Banks*

i. Federal Reserve (Fed): Dual mandate (price stability, full employment). FOMC meets 8 times/year with 12 voting members (7 governors, NY Fed, 4 rotating).
Most important central bank globally due to USD reserve status.

ii. European Central Bank (ECB): Price stability mandate (HICP $< 2\%$). Governing Council of 25 members. Key rates: Main Refinancing Operations (MRO), deposit facility rate. Tools include LTRO, TLTRO, OMT, APP.

iii. Bank of Japan (BOJ): Targets 2% inflation (chronically undershoots). Policy Board of 9 members. Pioneer of QE, yield curve control (YCC), negative rates.

iv. Bank of England (BOE): 2% inflation target. MPC of 9 members with individual accountability. First major central bank to publish inflation forecasts.

v. Swiss National Bank (SNB): Inflation target $< 2\%$. Notable for 2011–2015 EUR/CHF floor at 1.20 and subsequent abandonment. Massive FX reserve accumulation.

vi. People's Bank of China (PBOC): Multiple objectives including growth, stability, FX management. Manages CNY within trading band. Uses reserve requirements actively.

Remark 2.1.21. *ECB-Specific Tools*

i. LTRO/TLTRO: Long-Term Refinancing Operations provide multi-year funding to banks against collateral. 3-year LTROs in 2011 to 2012 injected over EUR1 trillion.

ii. OMT (Outright Monetary Transactions): Announced September 2012. Unlimited bond purchases for countries in EFSF/ESM programs. Never actually used but stabilised spreads.

iii. APP (Asset Purchase Programme): QE-equivalent. Purchases of government bonds, covered bonds, corporate bonds, ABS.

iv. TARGET2: Payment system showing intra-Eurozone imbalances. German TARGET2 claims rose to EUR700B+ during crisis, reflecting capital flight from periphery.

Remark 2.1.22. *Fed Crisis-Era Programmes*
During and after 2008, the Fed deployed unprecedented tools:

i. Central Bank Swap Lines: USD liquidity to foreign central banks to prevent LIBOR spikes

ii. TAF (Term Auction Facility): 28–84 day unsecured lending without discount window stigma

iii. TSLF (Term Securities Lending Facility): Treasury lending against lower-quality collateral

iv. CPFF (Commercial Paper Funding Facility): Commercial paper purchases to prevent market freeze

v. TALF (Term ABS Loan Facility): Lending against consumer ABS to support credit markets

vi. Agency MBS Purchases: $1.25 trillion in QE1 alone

Understanding these tools helps anticipate future crisis responses.

2.1.3 Economic Data Releases and Demographics

Remark 2.1.23. *Data Releases and Market Impact*
Data releases are central bank inputs, not just statistics. Markets price expectations before the release; the move comes from the surprise, not the level. Key principles:

i. Surprise Direction: Above/below consensus drives immediate price action. Magnitude of surprise matters more than absolute level.

ii. Revision Risk: Prior releases are frequently revised. Initial release moves markets; revisions move markets again if material.

iii. Hierarchy: Not all data is equal. NFP and CPI dominate in the US; PMIs dominate globally due to frequency and forward-looking nature.

iv. Regime Dependence: What data matters depends on the regime. In low-inflation regimes, growth dominates. In high-inflation regimes, inflation dominates everything.

Back-testing asset responses to past data releases (queries) can inform trade sizing and direction. However, false positives are common. If wrong, cut quickly.

Remark 2.1.24. *Growth Indicators*
Growth data sets the directional bias for risk assets, but markets trade changes, not levels.

i. GDP (Headline, QoQ, YoY): Measures total production in current or constant prices (nominal, real GDP). Released quarterly with preliminary, revised, and final prints. Backward-looking but sets narrative.
ii. Purchasing Managers' Indices (PMIs): Survey business managers on employment, new orders, inventories, production, supplier deliveries, prices, backlogs, imports, and exports on scale of better/same/worse vs prior month. Above 50 = expansion; below 50 = contraction. Most important leading indicator.
iii. Industrial Production: Measures growth in manufacturing, utilities, and mining. More cyclical than services. Released monthly. Leading indicator for GDP forecasting.
iv. Trade Volumes, Baltic Dry Index (BDI): Shipping costs for dry bulk cargo. Leading indicator on global trade activity since it cannot be speculated (no futures market).

PMIs and surveys move markets more than GDP because they are higher frequency and forward-looking.
Growth surprises affect equities (earnings expectations), commodities (demand), FX (via growth differentials).

Remark 2.1.25. *Inflation*
Inflation data is primarily a policy variable. It constrains or enables central bank action.

i. Consumer Price Index (CPI)/Core CPI: Prices paid by consumers for basket of goods and services. Core excludes food and energy (volatile). Central banks target core.
ii. Producer Price Index (PPI): Average change in selling prices received by domestic producers. Leads CPI by 1–3 months as input costs pass through.
iii. PCE (Personal Consumption Expenditures): Fed's preferred inflation measure. Differs from CPI in weights and methodology.
iv. Inflation Expectations: Market-based (breakevens from TIPS) or survey-based (Michigan, NY Fed). Central banks watch expectations closely. De-anchoring is a regime change.

Inflation surprises directly affect real yields, curve shape, FX via real rate differentials.
Inflation matters most when central banks are near constraints (ZLB, credibility questioned).

Remark 2.1.26. *Employment Data*
Labor data bridges growth, inflation, and central bank reaction function.

i. Non-Farm Payrolls (NFP): Number of workers in US excluding farms, private households, nonprofits, self-employed, and military. Released first Friday of each month. Among highest-volatility releases for rates, FX, equities.
ii. Unemployment Rate: Unemployed as percentage of labor force. Headline number; can be distorted by participation changes.
iii. Participation Rate: Labor force as percentage of civilian population. Structural decline (aging) vs cyclical decline (discouraged workers) matters.
iv. Wage Growth (Average Hourly Earnings): More important than job count for inflation outlook.
v. JOLTS (Job Openings and Labor Turnover Survey): Shows job openings, hires, quits. Quits rate indicates labor market tightness and worker confidence.

Wage growth drives services inflation, which is stickier than goods inflation.
Fed's dual mandate makes employment data directly policy-relevant.

Remark 2.1.27. *External Accounts*
External balances define structural currency pressure and financing needs.

i. Current Account: Net exports + net foreign income + transfer payments. Deficit countries need capital inflows or currency depreciation; surplus accumulate reserves and have structurally stronger currencies.
ii. Capital Account/Financial Account: Portfolio flows, FDI, banking flows. Can finance current account deficits but creates vulnerabilities (sudden stop risk).
iii. Trade Balance: Exports minus imports. Incremental changes in exports or imports can have big impact on trade balance as percentage of GDP.
iv. Terms of Trade (ToT): Export prices divided by import prices. Improves when export prices rise relative to imports. Currency depreciation typically worsens ToT.
v. FX Reserves: Central bank holdings of foreign currency and gold. Countries with large reserves can intervene; watching reserve changes indicates intervention.

Persistent current-account deficits require higher yields to attract capital or eventual currency adjustment.

Remark 2.1.28. *Government/Fiscal Indicators*
Fiscal data determines long-term sustainability, not short-term price action.

i. Budget Balance: Revenues minus expenditures. Deficit = borrowing required. Deficit/GDP ratio matters more than absolute level.
ii. Debt-to-GDP: Stock measure of accumulated borrowing. Matters more for EM and Euro periphery than for reserve currency issuers.
iii. Primary Balance: Budget balance excluding interest payments. Shows underlying fiscal stance; positive primary balance means debt/GDP can stabilise if growth exceeds interest rate.
iv. Debt Sustainability: Interest payments as % of revenue. Rising share means deteriorating sustainability.

Fiscal deterioration matters when markets doubt financing ability or central bank independence.
Sovereign risk appears first in bond spreads, CDS, FX (especially EM).

Remark 2.1.29. *Consumption Indicators*
Consumption drives developed-market growth (70%+ of US GDP).

i. Retail Sales: Consumer demand for finished goods. Durable vs non-durable breakdown matters.
ii. Consumer Confidence: Survey of expected financial situation. Conference Board and Michigan surveys in US. Leading indicator, confidence leads spending, but noisy.
iii. Personal Income and Spending: Income growth enables spending growth. Savings rate = income minus spending.
iv. Savings Rate: Higher savings = lower current consumption but more sustainable. US savings rate has declined structurally; Asian savings rates remain high.

Consumption data is most relevant for equity indices, cyclical sectors, domestic currencies.
US consumer accounts for $\sim$ 15% of global GDP directly through consumption.

Remark 2.1.30. *Housing Indicators*
Housing is cyclically important and credit-sensitive.

i. Building Permits: Lead housing starts since permits are required before construction. Most forward-looking housing indicator.
ii. Housing Starts: Counted when construction begins. Gauge of housing demand and construction activity.
iii. Existing/New Home Sales: Volume of transactions. Prices vs volumes can diverge.
iv. Home Price Indices: Case-Shiller, FHFA. Lag actual market conditions.
v. Household Formations: Structural driver of housing demand. Post-crisis decline reduced demand.

Housing matters for rate sensitivity, consumer wealth effects, and financial stability.

Remark 2.1.31. *Business and Industry Indicators*
These indicators show where growth is coming from and where it's heading.

i. Manufacturing vs Services PMI: Manufacturing is more cyclical and globally linked. Services dominate GDP but move slower.
ii. New Orders: Most forward-looking PMI subcomponent. Rising new orders = future production.
iii. Inventories: High inventories relative to sales = future production cuts. Inventory cycles matter for commodities and industrial equities.
iv. Capacity Utilisation: Actual output relative to potential. Over 100% = overheating, inflation risk. Well under 100% = slack, deflation risk.
v. Durable Goods Orders: Capital expenditure intentions. Core capital goods orders (ex-aircraft, ex-defence) is key business investment indicator.

ISM New Orders minus Inventories spread is a reliable leading indicator of manufacturing cycles.

Remark 2.1.32. *Demographics*
Slowest-moving macro variable, but the hardest constraint. Demographics cannot be QE'd.

i. Working-Age Population (15–64): Drives potential growth. Many developed countries have peaked or will peak soon.

ii. Prime Saving Age (35–69): Peak saving years. Countries past this peak see declining savings and current accounts.
iii. Dependency Ratio: Non-working population (young + old) divided by working population. Higher ratio = more fiscal pressure, lower savings.
iv. Median Age: Summary statistic for demographic structure. Europe/Japan: 40s; US: 38; EM: 20s–30s.
v. Retirement Age vs Life Expectancy: Gap determines pension system sustainability. Life expectancy rising; retirement ages barely moving.

Demographics affect long-term growth, savings rates, current accounts, equilibrium real rates.

Remark 2.1.33. *Demographic Implications by Country*
Peak working-age populations determine structural trajectories:

i. Already peaked: Germany (2006), Japan (2016), Netherlands (1989), UK (2009), US (2007)
ii. Peaking soon: China (2032), Korea (2023), Russia (2025), Spain (2022)
iii. Long runway: India (2050), Indonesia (2050), Nigeria (2050), Philippines (2050)

Countries past peak will see declining current accounts, rising dependency ratios, pressure on fiscal positions. Jean-Claude Trichet: "Current account balance is an important summary indicator that signals losses of competitiveness and emerging imbalances."

Remark 2.1.34. *Building Queries for Data Events*
Queries back-test asset behaviour around past occurrences of specific events:

i. Identify the event (e.g., BOE QE announcement, Fed rate hike, NFP beat)
ii. Find historical dates with similar conditions
iii. Calculate asset returns +1 day, +2 days, +1 week, +1 month after event
iv. Compute hit rates (percentage of times asset moved in expected direction)
v. Assess risk/reward: average return vs standard deviation

Queries are powerful for short-term event trading and understanding portfolio exposure to upcoming releases. Caveat: False positives are common. If position moves against you immediately after event, cut quickly.

Remark 2.1.35. *Key Data Release Calendar (US)*
Monthly cadence of major releases:

i. First Friday: Employment Report (NFP, unemployment rate, wages)
ii. Mid-month: CPI, Retail Sales, Industrial Production
iii. Third week: Housing Starts, Building Permits
iv. Late month: GDP (quarterly), PCE, Durable Goods
v. First business day: ISM Manufacturing PMI
vi. Third business day: ISM Services PMI

FOMC meetings (8 per year) and ECB meetings (6 per year) often dominate all other releases.
Economic calendars (Bloomberg ECO, Reuters, Trading Economics) are essential tools.

2.2 Transmission and Cross-Asset Mapping

This section services as a primer for four basic asset classes and their usage in global macro trading.

2.2.1 Building Blocks of Global Macro

Remark 2.2.1. *Macro Strategy Product Groups*
The four core product groups in global macro are:

i. Fixed Income (FI) (Policy and Growth Sensor): encodes growth expectations, inflation expectations, central bank credibility. Yield curves summarise the entire macro narrative; steepening means growth/reflation; flattening or inversion means slowdown/recession. Fixed income tells what the market thinks will happen before it happens.
ii. Foreign Exchange (FX) (Adjustment Mechanism): FX reflects relative, not absolute, macro conditions. Sensitive to rate differentials, capital flows, balance of payments, risk-on/risk-off regimes. FX absorbs and redistributes macro shocks across countries.
iii. Equities (Growth Expression): equities are long growth, long liquidity, short uncertainty. Equity indices aggregate earnings expectations, discount rates, risk appetite. Volatility (VIX) is a second-order macro signal, not just an equity signal. Equities express the confidence (or fear) embedded in the macro outlook.
iv. Commodities (Inflation and Real-Economy Link): driven by physical supply and demand, inventories, geopolitics. Highly sensitive to growth cycles, inflation shocks, currency moves (especially USD). Commodities anchor macro views in real economic constraints.

These are the most liquid markets globally, which allows macro strategies to scale to large AUM while maintaining execution quality.

Remark 2.2.2. *Relationship Between Assets*
These relationships are regime-dependent, not permanent laws:

i. Growth Shocks: rates rise, equities rally, cyclicals outperform, commodities rise. FX favours growth-linked currencies (AUD, CAD, EM FX).
ii. Recession Shocks: rates fall, curves flatten/invert, equities sell off, USD strengthens (flight to safety), commodities weaken (except gold).
iii. Inflation Shocks: nominal rates up, real rates determine equity impact. Commodities outperform. FX punishes low-credibility central banks.
iv. Liquidity Shocks: USD strengthens sharply, credit spreads widen, correlations spike toward 1, volatility explodes. Cross-currency basis blows out.

A single macro thesis should have expressions across multiple asset classes, each with different risk profiles and convexity characteristics.

Remark 2.2.3. *Asset Correlation Dynamics*
Asset correlations change under stress. Diversification fails when needed most, where assets that appear uncorrelated in calm periods may collapse together in crises.
Macro traders profit when they anticipate correlation breakdowns and position for nonlinear regime shifts. This is why macro portfolios use convex instruments (options), size conservatively, and focus on liquidity.
Traders must know what assets they are trading in aggregate. If entire portfolio has assets with high correlation to one another, they can be stopped out of all positions more easily if the market turns against them.

Remark 2.2.4. *Position Sizing Framework*
Position sizing is arguably more important than knowing what to buy or sell. The first rule of investing is to preserve capital and avoid loss.
Position sizing aims to adjust each position for volatility. This normalises all positions such that losses are more predictable and have the same probability of occurring:

i. Calculate N = 20-day exponential moving average of True Range
ii. True Range = max(High − Low, High − Previous Close, Previous Close − Low)
iii. Use $2N$ for stop-loss calculation (two standard deviations) to avoid being stopped out by normal volatility
iv. With $2N$, there is approximately 2% chance of being stopped out on any given day (vs. 16% with $1N$)

This methodology, developed by the Turtle Traders, allows traders to take positions in a broad range of markets while monitoring risk consistently.

Remark 2.2.5. *Risk/Reward Discipline*
Given human error and transaction costs, traders can only hope to be right about 50% of the time. Having good risk/reward on each trade will make or break long-term success.
As a baseline, always strive for a 1:3 risk-to-reward ratio or higher:

i. For every trade risking 25 basis points, expect to make at least 75 basis points
ii. Set targets before the trade is executed to avoid biases of irrational human decision making
iii. Log reasons for each trade in a trade journal
iv. If original thesis no longer holds true, take trade off, but do not create excuses for taking trades off early

Remark 2.2.6. *Gap Risk*
Gap risk is one of the biggest risks when sizing positions. Gap risk occurs when prices change without any trading in between (e.g., overnight, over weekends). This risk is especially acute in:

i. EM currencies and assets (less liquid, more event-driven)
ii. Positions held over weekends or holidays
iii. Periods of elevated geopolitical risk
iv. Earnings/data release windows

Remark 2.2.7. *Risk Utilisation*
Risk-taking is nonlinear. Even with 50% conviction, should not run 50% of risk utilisation.

i. Base case: set a maximum VaR limit (e.g., 5% daily VaR at 95% confidence)
ii. If up 5% on the year, allow VaR limit to increase to 6%
iii. If down 2.5% on the year, decrease VaR limit to 4%
iv. At the start of each new year, reset to 0% return regardless of prior year performance

The intention is to create steady returns while preserving capital and avoiding blow-up risk.

Remark 2.2.8. *Stress Testing*
Stress testing aims to go beyond VaR to find potential worst-case scenarios:

i. Run historical back-test on P&L for previous 500 trading days ($\approx$ 2 years)
ii. Sort from best to worst days; examine the average of the 5 worst days (worst 1%)
iii. In periods of low volatility, also test against extreme historical events: October 1987 crash, 1998 LTCM/Russian default, 2008 financial crisis, 2011 Japan earthquake, 2015 CNY devaluation, 2020 COVID crash

Knowing maximum loss outside of VaR helps traders understand exposure to tail events.

Remark 2.2.9. *Performance Metrics*
Key metrics for evaluating macro trading performance:

i. Sharpe Ratio: $\frac{E[R]-R_f}{\sigma}$, risk-adjusted return; higher is better. Assumes normal distribution.
ii. Sortino Ratio: Sharpe with only downside volatility, differentiating between good and bad volatility.
iii. Maximum Drawdown: peak-to-trough decline; critical for understanding worst-case capital loss.
iv. Value at Risk (VaR): 95% or 99% daily VaR (expected loss exceeded on 1 in 20 or 100 days).

When evaluating strategies, test Sharpe ratios rather than raw returns. Break down P&L by asset class, duration, and conviction level to identify strengths and weaknesses.

Remark 2.2.10. *Macro View Thesis*
A macro view expressed in only one asset class is incomplete. A single macro thesis should have multiple expressions, each with different risk profiles:

i. Growth view: rates (duration), equities (beta), FX (pro-cyclical currencies), commodities (cyclicals)
ii. Inflation view: commodities (energy, agriculture), breakevens, FX (commodity currencies), TIPS
iii. Crisis/Deflation view: bonds (duration), USD/JPY/CHF (havens), volatility (VIX, swaptions), gold
iv. Policy divergence view: FX (rate differentials), yield curve spreads, relative equity indices

Having multiple expressions allows for confirmation across asset classes and provides natural hedging if one leg underperforms.

2.2.2 Foreign Exchange in Global Macro

FX plays three special roles simultaneously:

i. Macro shock absorber
ii. Macro transmission channel
iii. Macro expression instrument

Remark 2.2.11. *FX Market Structure*
The FX market is the world's largest and most liquid market, and operates 24 hours per day, 5.5 days per week across global financial centers (London, New York, Tokyo, Singapore, Hong Kong).
Key participants include: central banks (intervention, reserve management), commercial banks (market-making, proprietary trading), corporations (hedging trade flows), asset managers (currency overlay, alpha generation), hedge funds (macro speculation, carry trades), and retail traders.
The market is predominantly OTC, with spot, forwards, and swaps as the main instruments. FX futures trade on exchanges (CME) but represent a small fraction of total volume.

Remark 2.2.12. *Role of the US Dollar*
Global macro is de facto USD-centric. USD is the global reserve currency, most commodities are USD-priced, global funding markets clear in USD, and cross-border leverage is USD-denominated.
The USD is involved in approximately 85% of all FX transactions globally. Many "local" macro trades are actually USD liquidity trades in disguise.
Stress often appears first in US Dollar Index (DXY), cross-currency basis, EM FX before local assets.
The DXY Index measures USD against a basket of six major currencies: EUR (57.6%), JPY (13.6%), GBP (11.9%), CAD (9.1%), SEK (4.2%), CHF (3.6%). The DXY is not trade-weighted and over-represents EUR.

Remark 2.2.13. *Special Drawing Rights (SDRs)*
SDRs are international reserve assets created by the IMF to supplement member countries' official reserves. The SDR basket is reviewed every five years. SDRs serve as a unit of account for IMF transactions and provide insight into official reserve diversification trends.

Remark 2.2.14. *Currency Regimes*
Currency regimes matter more than models. FX does not behave uniformly. Regime dominates signal.

i. Free-floating: price discovery happens in FX
ii. Managed/pegged: pressure builds elsewhere such as in rates, reserves, capital controls
iii. Hard pegs/Currency boards: FX looks stable until it breaks violently

FX valuation only works within regime constraints. Ignore the regime and "cheap" can stay cheap forever.

Remark 2.2.15. *Central Bank Intervention*
Central banks intervene in FX markets for multiple objectives:

i. Defend a peg or managed float band
ii. Smooth excessive volatility
iii. Counter speculative attacks
iv. Accumulate or deploy reserves

Intervention effectiveness depends on: reserve adequacy, policy credibility, coordination with monetary policy, and market liquidity conditions. Intervention against fundamental pressures typically fails. Watch for reserve depletion as a leading indicator of forced adjustment.

Remark 2.2.16. *Valuation Techniques*

i. Market Implied and Risk-Appetite Signals
   1. Equity Index Price Performance: strong local equities (vs peers) attract inflows and support currency; sharp equity underperformance foreshadows FX weakness via risk-off deleveraging and foreign selling.
   2. Credit/Sovereign Risk: widening sovereign spreads/CDS signals default/policy credibility/funding stress, weakening FX or raising devaluation risk premia. Also a regime detector for EM FX.
   3. Sentiment/Positioning: call-put skew on three-month risk reversals. Acts as a multiplier. Can create overshoots/undershoots around fair value in crowded carry or crisis episodes.

ii. Trade and Competitiveness Fundamentals

1. Trade Balance/External Account: structurally strong trade position often supports FX; persistent deficits can make the currency reliant on financing.
2. Trade-Weighted Index (TWI): reflects currency's effective competitiveness against trading partners; the currency basket that matters for the real economy.
3. Economic Activity: strong activity can support FX via higher expected returns and inflows, but it can also worsen the trade balance.
4. Export Partner Growth: mapping who buys exports and whether those buyers are expanding/contracting. Export partner growth leads exporter's FX through expected trade receipts.

iii. Macro Sustainability Indicators

1. Debt-to-GDP: high public debt with FX liabilities or weak domestic savings can increase risk premia and currency vulnerability, as it tightens the policy constraint set (inflation vs austerity vs default).
2. Current Account Balance: persistent deficits require capital inflows; sudden stops trigger sharp FX adjustment.
3. FX Reserves: adequacy (months of import cover, short-term debt coverage) determines policy space.

iv. Long-Term Valuation Anchors

1. Purchasing Power Parity (PPP): the idea that exchange rates should adjust so that identical goods cost the same in different countries. In practice, PPP convergence can take years or decades.
2. GDP Per Capita: structural development/productivity proxy. Richer, higher productivity economies tend to sustain stronger real exchange rates over time (Balassa-Samuelson effect).

v. Carry Indicators

1. OIS Differential: compares respective policy rates of two countries. Carry is the interest rate differential between two currencies.
2. LIBOR/SOFR Differential: reflects unsecured interbank rates. Can be decomposed into risk-free rate + credit spread component. Using relative spreads gives a sense of direction; interest rate differential drives demand for a currency.
3. Risk-Adjusted Carry: adjusts carry for volatility. Outperforms standard carry trades and is useful in cross-currency analysis:

$$\text{Carry-to-Risk Ratio} = \frac{\text{3M Carry (Rate Differential)}}{\text{30D Realized Volatility}}$$

Within high-yielding currency pairs, one would ideally want the highest carry-to-risk ratio. Volatility and carry components are always in flux, so adjustments should be made frequently.

Remark 2.2.17. *Carry Trade Mechanics*
Carry strategies are typically executed by borrowing in lower-yielding currencies and buying higher-yielding currencies. The carry trade is a crowded trade; in large risk-off markets, the strategy suffers significant losses as positions unwind simultaneously.
Carry is the return earned on holding a currency, assuming the exchange rate is held constant. In practice, exchange rate moves often dominate carry returns. Historically, carry strategies exhibit positive returns on average but with significant negative skewness (small gains, occasional large losses).

Remark 2.2.18. *Carry Trade Risk Factors*
Key risks to carry trades include:

i. Crowding Risk: carry trades are popular, leading to violent unwinds during risk-off episodes.
ii. Gap Risk: EM currencies can gap significantly on weekends or during crises, bypassing stop-losses.
iii. Regime Shifts: central bank policy changes can rapidly alter rate differentials.
iv. Correlation Breakdown: in stress, all carry currencies tend to sell off together against funding currencies.
v. Liquidity Risk: EM FX can become illiquid precisely when exits are needed most.

Finding the carry-to-risk ratio is useful, as is comparing all currency pairs on a relative basis. Measuring the standard error of the sample and finding the most attractive pairs helps in mean-reverting carry strategies.

2.2.3 Equities in Global Macro

In macro, a trader should understand equity in terms of market behaviour in the country being traded, the sectors that make up those indices, and correlation risk.

Remark 2.2.19. *Top-Down Macro Approach to Equities*
Many macro traders take a top-down approach to trading equities:

i. Start with a global view
ii. Narrow to countries expected to outperform
iii. Select the best sectors within those countries
iv. Optionally, select best companies within sectors

If the investor has a knack for knowing where the next opportunity lies, the most reward typically comes from concentrated exposure rather than diversified index holdings.

Remark 2.2.20. *Major Equity Indices by Region*

i. United States: S&P 500, Nasdaq, DJIA, Russell 2000, Wilshire 5000
ii. Europe: Euro Stoxx 50, DAX, CAC 40, FTSE 100, FTSE MIB, IBEX 35, AEX
iii. Asia Ex-Japan: Shanghai Comp, Hang Seng, KOSPI, ASX 200, NZX 50
iv. Japan: Nikkei, Topix, JASDAQ
v. Emerging Markets: Bovespa, NIFTY, Micex/RTS, Mexico IPC, TOP 40/JALSH, BIST 30/100 etc.

Indices can be traded directionally or as relative value trades (long one index, short another). Different indices have different sector exposures: Bovespa is more commodity-sensitive than NIFTY; S&P 500 has more financial exposure than Nasdaq (technology-weighted).

Remark 2.2.21. *Index Construction Methods*
Index construction methodology affects interpretation:

i. Price-Weighted: considers only stock price, ignores market cap. A single large stock move can dominate.
ii. Market-Cap Weighted: weighted by market capitalisation. Large-cap stocks dominate performance.
iii. Equal-Weighted: each constituent has equal weight regardless of size.

Understanding weighting structure is essential for accurate interpretation of index moves.

Remark 2.2.22. *Sector Rotation Across Economic Cycles*
Different sectors outperform in different economic regimes:

i. Recession/Contraction: Consumer Staples, Utilities, Healthcare (defensive sectors)
ii. Recovery: Financials, Consumer Discretionary, Real Estate
iii. Expansion: Industrials, Materials, Technology
iv. Slowing Growth/Late Cycle: Energy, Materials (inflation hedges)

To best position an equity portfolio, it is critical to know whether the economy is in contraction, recovery, expansion, or slowing growth.

Remark 2.2.23. *Equity Derivatives Overview*
Key equity derivatives for macro trading:

i. ETFs: fast, cheap exposure to indices, sectors, countries, commodities, FX, FI. Trade like stocks.
ii. ADRs (American Depositary Receipts): foreign stocks listed on U.S. exchanges in USD. Subject to FX risk since underlying shares are held locally.
iii. Index Futures: liquid, leveraged exposure to equity indices.
iv. Options: provide asymmetric payoffs for hedging and directional views.

Remark 2.2.24. *The Volatility Index (VIX)*
The VIX measures implied volatility of S&P 500 options one month out. Key properties:

i. Negatively correlated with equity returns (volatility rises when equities fall)
ii. During large selloffs, VIX can move from mid-teens to 30+ in days

iii. VIX options provide asymmetric hedges for equity portfolios

iv. VIX futures typically trade in contango; during sharp selloffs, shift to backwardation

Volatility is measured relative to $\sqrt{252} \approx 16$. A VIX of 16 implies approximately 1% expected daily move; VIX of 24 implies 1.5% daily move ($24/16 = 1.5\%$).
V2X (Euro Stoxx), VXN (Nasdaq), VXD (DJIA), RVX (Russell 2000), GVZ (Gold), OVX (Crude Oil).

Remark 2.2.25. *Variance Swaps*
Variance swaps are OTC products providing pure variance exposure. Advantages over options:

i. Pure volatility exposure without delta hedging

ii. Priced with realised volatility (usually lower than implied)

iii. No interest rate or dividend risk

Payoff structure is convex and nonlinear. Long variance benefits disproportionately from large moves in either direction. Quoted by strike (reference realised volatility), vega notional, variance units, maturity.
Variance units $= \frac{\text{Vega Notional}}{2\times\text{Strike}}$, Payoff $= (\sigma^2_{\text{realised}} - K^2) \times$ Variance Units

Remark 2.2.26. *Dividend Swaps*
An OTC or exchange-traded product that allows one to take a view on dividends of an index to be higher, or lower, than a fixed amount.

Remark 2.2.27. *Equity Valuation Techniques for Macro*

i. Price-to-Book (P/B): P/B $> 2.5\times$ generally overbought; P/B $< 1.5\times$ oversold. Useful for detecting bubbles and value opportunities.

ii. Dividend Yield: dividend/price. Holder gets paid while waiting (long carry). Useful for relative value across markets.

iii. Price-to-Earnings (P/E): price per $1 of earnings. Best for comparable analysis across countries, sectors, stocks. Forward P/E uses analyst EPS estimates.

iv. Free Cash Flow Yield: FCF/Price. Cash flow from operations minus capital expenditures. Graham and Dodd value investors use this as top screen.

v. Market Cap to GDP: useful for locating potential bubbles. Above 100% warrants caution; rapid rises to 150%+ indicate bubble conditions (Japan 1989).

Remark 2.2.28. *Leading Indicators for Equities*
Useful macro indicators that lead equity performance:

i. PMI (Purchasing Managers' Index): leading indicator scored 0-100. Sharp slope changes and deviations from 50 provide strong signals. ISM below 50 typically indicates U.S. recession.

ii. Baltic Dry Index: shipping prices for raw material dry bulk. Supply is fixed (ships take years to build), demand is inelastic. Leading indicator for raw material demand.

iii. CDX High Yield Index: CDS spread on high-yield corporates. Highly correlated with VIX; inversely related to equity prices. Rising spreads signal risk-off.

iv. Consumer Confidence: in the U.S., consumption accounts for $> 70\%$ of GDP. Higher confidence leads to higher spending and GDP growth.

v. Commodity Prices (YoY): rising commodity prices are inflationary, typically met by central bank tightening, which has bearish equity implications.

Remark 2.2.29. *AUD Volatility as Risk Barometer*
The Australian dollar is a main risk-on currency due to Australia's commodity exports and reliance on Asian economies. AUD moves in tandem with equity prices.
Three-month AUD/USD implied volatility is highly correlated with VIX and inversely correlated with S&P 500. In times of stress, the rate of change in AUD volatility shifts suddenly and aggressively.
Using VIX and AUD volatility combined on an absolute basis smooths out error as a more useful measure.

2.2.4 Fixed Income in Global Macro

Fixed income is the lifeblood of the global financial system. Bank credit and debt capital markets fund governments, corporations, and consumers. Understanding fixed income is essential for macro trading because yields encode growth expectations, inflation expectations, and central bank credibility.

Remark 2.2.30. *Fixed Income Universe*
The fixed income market can be decomposed into:

i. Money Markets: Short-term instruments (maturity < 1 year). Includes T-bills, commercial paper, repos, Fed Funds, SOFR.
ii. Government Bonds: Sovereign debt across the curve (2Y, 5Y, 10Y, 30Y). Risk-free rate benchmark.
iii. Inflation-Linked Bonds: TIPS in US, Linkers in UK, OATi in France. Index to CPI.
iv. Corporate Bonds: Investment grade (IG) and high yield (HY). Credit spread over risk-free rate.
v. Municipal Bonds: State and local government debt, often tax-exempt.
vi. Mortgage-Backed Securities (MBS): Agency and non-agency. Prepayment risk.
vii. Asset-Backed Securities (ABS): Auto loans, credit cards, student loans.

Fixed income is the largest of the four product groups by notional outstanding.

Remark 2.2.31. *Money Markets and Funding*
Money markets allow short-term capital flow between lenders and borrowers:

i. Treasury Bills (T-Bills): Short-term US government obligations (4-week, 13-week, 26-week, 52-week). Risk-free benchmark.
ii. Commercial Paper: Unsecured short-term corporate debt, typically 90–270 days. Lower rates than bank borrowing.
iii. Repurchase Agreements (Repos): Sale of securities with agreement to repurchase. Critical for short-term funding and leverage.
iv. Certificates of Deposit (CDs): Bank time deposits, 30 days to 5 years.
v. Banker's Acceptances: Promissory notes issued by firms to banks, typically for trade finance.

Money market stress (rising repo rates, LIBOR-OIS widening) often precedes broader financial stress.

Remark 2.2.32. *Key Reference Rates*
Reference rates anchor pricing across the fixed income universe:

i. Fed Funds Rate: Unsecured overnight lending rate between depository institutions.
ii. SOFR (Secured Overnight Financing Rate): Overnight Treasury repo rate as USD benchmark.
iii. LIBOR (Legacy): London Interbank Offered Rate. Historically the most important rate in global finance. Phased out post-2021 due to manipulation scandals.
iv. EONIA/EURSTR: Euro overnight rates. EURSTR replaced EONIA in 2022.
v. SONIA: Sterling overnight rate for GBP.

The transition from LIBOR to risk-free rates (SOFR, SONIA, EURSTR) is one of the largest market structure changes in decades.

Remark 2.2.33. *Overnight Index Swaps (OIS)*
OIS is a fixed-for-floating interest rate swap indexed against an overnight rate (Fed Funds effective in US, EONIA/EURSTR in Europe):

i. Excellent tool to hedge or speculate on central bank action
ii. Typically maturity less than two years
iii. Customisable dates for precise central bank meeting targeting
iv. Less volatile than LIBOR, especially in periods of stress

Example: If BOE rate is 0.50% and December MPC OIS trades at 0.625%, the market prices 50% chance of a 25bp hike.

Remark 2.2.34. *LIBOR-OIS Spread*
The LIBOR-OIS spread is a key gauge of funding stress:

i. LIBOR is unsecured interbank lending; OIS is effectively risk-free overnight rate
ii. Spread widens during credit stress as banks demand higher compensation for counterparty risk
iii. 2008 financial crisis: LIBOR-OIS spiked as institutions stopped trusting each other
iv. European crisis: Spread widened as European banks faced USD funding stress

A widening spread does not automatically indicate crisis. Serves as useful barometer for funding market pressure.

Remark 2.2.35. *Eurodollar Futures*
Eurodollar deposits are USD time deposits at banks outside Fed jurisdiction. Eurodollar futures are the most heavily traded futures contracts in the world:

i. Contract on 3-month LIBOR (transitioning to SOFR futures)
ii. Contract size: $\$1,000,000$ notional
iii. Price: $100 -$ 3-Month LIBOR Yield
iv. Tick value: 1 basis point $= \$25$
v. Months: March (H), June (M), September (U), December (Z)
vi. Colour codes by year: White (Y1), Red (Y2), Green (Y3), Blue (Y4), Gold (Y5)

Eurodollar futures used to hedge LIBOR exposure, manage weighted average maturity of short-term liabilities.

Remark 2.2.36. *Interest Rate Swaps*
Interest rate swaps allow exchanging one set of interest payments for another:

i. Fixed-for-Floating: Most common. Exchange fixed rate for floating rate (SOFR, EURSTR).
ii. Receiver: Receives fixed, pays floating. Profits if floating rates fall.
iii. Payer: Pays fixed, receives floating. Profits if floating rates rise.
iv. Swap curve driven by future rate expectations; increasingly exchange-traded post-Dodd-Frank.

Interest rate swaps are the largest derivatives market by notional. Used for hedging, speculation, and transforming asset/liability profiles.

Remark 2.2.37. *Forward Rate Agreements (FRAs)*
FRAs are OTC contracts to exchange a reference rate (SOFR, formerly LIBOR) for a fixed rate:

i. More customisable than Eurodollar futures (pick specific dates)
ii. Notation: "3×6" means 3-month forward, 3-month rate
iii. Fixing date, settle date, and maturity date are key terms
iv. Used for hedging or speculating on short-term rate movements

FRAs allow precise targeting of rate exposure around central bank meetings or data releases.

Remark 2.2.38. *US Treasury Futures*
Treasury futures are standardised contracts for trading various maturities:

i. 2-Year (TU): Contract size $\$200,000$, tick \$15.625
ii. 5-Year (FV): Contract size $\$100,000$, tick \$7.8125
iii. 10-Year (TY): Contract size $\$100,000$, tick \$15.625
iv. 30-Year (US): Contract size $\$100,000$, tick \$31.25
v. Ultra-Long (WN): 25+ years, contract size $\$100,000$, tick \$31.25

Treasury futures are physically settled (cheapest-to-deliver mechanics). Most traders roll positions before delivery. Futures curve typically in backwardation due to term premium.

Remark 2.2.39. *German Bund Futures*
German government bonds (Bunds) are the European benchmark:

i. Schatz (DU): 1.75–2.25 year maturity
ii. Bobl (OE): 4.5–5.5 year maturity
iii. Bund (RX): 8.5–10.5 year maturity
iv. Buxl (UB): 24–35 year maturity

Bunds trade as "risk-free" for the Eurozone. Spreads to Bunds (e.g., BTP-Bund spread for Italy) are key measures of peripheral sovereign risk.

Remark 2.2.40. *Yield Curve Trades*
Curve trades express views on the shape of the yield curve (done DV01 neutral):

i. Steepener: Long short-end, short long-end. Profits from curve steepening.
ii. Flattener: Short short-end, long long-end. Profits from curve flattening.
iii. Bull Flattener: Rates fall, long end falls more than short end.
iv. Bear Flattener: Rates rise, short end rises more than long end (often Fed hiking).
v. Bull Steepener: Rates fall, short end falls more than long end (often Fed cutting).
vi. Bear Steepener: Rates rise, long end rises more than short end (inflation fears).

The 2s10s spread (10Y yield minus 2Y yield) is a classic recession indicator. Inversion has preceded every US recession since 1970.

Remark 2.2.41. *Carry and Rolldown*
Fixed income positions have carry and rolldown components:

i. Carry: Coupon income − financing cost. + for steepeners, − for flatteners in normal yield curve.
ii. Rolldown: Return from bond "rolling down" a positively sloped yield curve as it approaches maturity.
iii. In DV01-neutral trades, carry differential between legs must be accounted for.
iv. Rolldown is deterministic if curve shape unchanged; carry is known at trade inception.

Total return = Price change + Carry + Rolldown. Carry and rolldown dominate in low-volatility environments.

Remark 2.2.42. *Treasury Inflation-Protected Securities (TIPS)*
TIPS are US government bonds indexed to inflation (CPI-U NSA):

i. Principal adjusts with CPI; coupon is fixed rate applied to adjusted principal
ii. 5Y, 10Y, and 30Y maturities issued quarterly
iii. Floor at par: At maturity, receive greater of par value or inflation-adjusted principal
iv. 3-month lag between CPI and index calculation

TIPS allow investors to take views on real rates or inflation. Short-end TIPS trade like food and energy.

Remark 2.2.43. *Breakeven Inflation*
Breakeven inflation rate is the implied inflation rate from TIPS:

$$\text{Breakevens} = \text{Nominal Treasury Yield} - \text{TIPS Real Yield}$$

For example, if 10Y Treasury yields 4.0% and 10Y TIPS yields 1.5%, 10Y breakeven is 2.5%.

i. Breakevens reflect market-implied inflation expectations
ii. Can be traded directly via breakeven swaps
iii. Rising breakevens = market expects higher inflation
iv. Fed monitors breakevens for inflation expectations anchoring

Negative real rates (TIPS yield < 0) indicate investors accepting guaranteed loss of purchasing power for safety.

Remark 2.2.44. *Sovereign Credit Risk*
Sovereign debt is issued by national governments. Key concepts:

i. Reference Entity: Legal name for CDS purposes (e.g., Hellenic Republic for Greece)
ii. Curve Inversion: When short-term yields exceed long-term yields, market prices default risk
iii. Credit Events: Failure to pay, restructuring, moratorium
iv. Recovery Rate: Typically assumed 40% for sovereigns; historical average 55% with high variance

Peripheral European spreads (Italy, Spain, Portugal, Greece) to German Bunds are key risk indicators.

Remark 2.2.45. *Credit Default Swaps (CDS)*
CDS provides insurance-like protection against credit events:

i. Protection Buyer: Pays spread (premium), receives par if credit event occurs
ii. Protection Seller: Receives spread, pays par minus recovery if credit event occurs
iii. Premium quoted as annual spread, paid quarterly (March, June, September, December)
iv. Can buy protection without owning underlying bond ("naked CDS")

CDS provides asymmetric payoff: pay small premium for potentially large payout. Attractive risk/reward for tail hedging. Counterparty risk is critical.

Remark 2.2.46. *CDS Credit Events*
Credit events trigger CDS settlement:

i. Failure to Pay: Sovereign/corporate misses interest or principal payment
ii. Restructuring: Postponement, reduction, or deferral of obligations
iii. Bankruptcy: Corporate only (sovereigns cannot file bankruptcy)

For sovereigns, restructuring is not automatic trigger. Both buyer and seller have right (not obligation) to trigger CDS. Greece 2012 required ISDA determination committee ruling.

Remark 2.2.47. *Historical Sovereign Defaults*
Recent sovereign defaults and restructurings:

i. Russia 1998: Devaluation and default on local currency obligations, \$73B
ii. Argentina 2001: Largest sovereign default at time, \$82B, 70% haircut
iii. Uruguay 2003: Contagion from Argentina, 5-year maturity extension
iv. Greece 2012: PSI restructuring, largest sovereign default in history, \$200B+
v. Argentina 2020: Ninth default, \$65B restructured

Recovery rates vary widely (20%–80%). "Orderly" restructurings tend to have higher recovery.

Remark 2.2.48. *Fixed Income ETFs*
Fixed income ETFs provide liquid, diversified exposure:

i. Treasury: SHY (1–3Y), IEF (7–10Y), TLT (20+Y), TBT (2x inverse 20+Y)
ii. TIPS: TIP (broad TIPS)
iii. Investment Grade: LQD (corporate IG), AGG (aggregate bond)
iv. High Yield: HYG, JNK (high yield corporate)
v. Emerging Markets: EMB, PCY (EM sovereign debt)
vi. Municipals: MUB (muni bonds)
vii. MBS: MBB (mortgage-backed)

ETFs provide quick and cheap exposure to markets otherwise requiring large minimums or dealer relationships.

Remark 2.2.49. *Duration and DV01*
Duration measures sensitivity to interest rate changes:

i. Modified Duration: Approximate percentage price change for 1% yield change
ii. DV01 (Dollar Value of 01): Dollar change for 1bp yield change $= \frac{\text{Duration} \times \text{Price}}{10000}$
iii. Longer maturity = higher duration = more rate sensitivity
iv. Curve trades are structured DV01-neutral to isolate curve shape from level

A 10Y bond with duration 8 loses approximately 8% if yields rise 100bp.

Remark 2.2.50. *Convexity*
Convexity measures how duration changes as yields change:

i. Positive convexity: Bond gains more when yields fall than it loses when yields rise (most bonds)
ii. Negative convexity: MBS, callable bonds. Gains are capped due to prepayment/call risk
iii. Convexity matters more for large yield moves
iv. Long convexity = long volatility; benefits from rate moves in either direction

Convexity adjustment:

$$\Delta P \approx -\text{Duration} \times \Delta y + \frac{1}{2} \times \text{Convexity} \times (\Delta y)^2$$

Remark 2.2.51. *Curve Inversion as Recession Indicator*
Yield curve inversion (short rates exceeding long rates) has predicted every US recession since 1970:

i. 2s10s inversion: 10Y yield below 2Y yield
ii. 3m10s inversion: 10Y yield below 3-month T-bill
iii. Typical lead time: 6–18 months before recession
iv. Mechanism: Markets expect Fed to cut rates in response to coming weakness

Curve inversion is necessary but not sufficient for recession. Duration and depth of inversion also matter.

Remark 2.2.52. *Fixed Income in Different Macro Regimes*

i. Growth Shock (positive): Rates rise, curve steepens, credit spreads tighten
ii. Recession: Rates fall sharply, curve bull steepens then flattens, credit spreads widen
iii. Inflation Shock: Nominal rates rise, real rates may fall initially, curve bear steepens, TIPS outperform nominals
iv. Deflation/Disinflation: Nominal rates fall, breakevens collapse, duration rallies
v. Financial Crisis: Flight to quality (Treasuries rally), credit spreads explode, funding markets seize

Fixed income tells what the market thinks will happen before it happens. The curve summarises the entire macro narrative.

2.2.5 Commodities in Global Macro

Commodities are driven by physical supply and demand, inventories, and geopolitics. They are highly sensitive to growth cycles, inflation shocks, and currency moves (especially USD). Commodities anchor macro views in real economic constraints.

Remark 2.2.53. *Contango and Backwardation*
The shape of the futures curve reveals market structure:

i. Contango: Near-term futures trade cheaper than further-dated contracts. Exists due to storage costs, financing costs, and opportunity cost of capital. Normal state for storable commodities like gold.
ii. Backwardation: Near-term futures trade at premium to further-dated contracts. Occurs during supply shortages or immediate demand spikes.
iii. Agricultural seasonality: Curves can exhibit both. Contango after harvest (abundant supply, storage costs), backwardation before harvest (depleted stocks, tight supply).

Contango creates negative roll yield; backwardation creates positive roll yield.

Remark 2.2.54. *Commodity Indices*
Major commodity indices for benchmarking and trading:

i. CRB (Commodity Research Bureau) Index: 22 commodities, broad representation of prices.
ii. S&P GSCI: Goldman Sachs Commodity Index. Production-weighted, heavily energy-exposed ($> 50\%$).
iii. Bloomberg Commodity Index (BCOM): Diversified, liquidity-weighted.
iv. ETFs: DBC (Deutsche Bank commodities, $> 50\%$ energy), DBA (agriculture only, includes corn, soybeans, sugar, cattle, coffee, cocoa).

Caution for ETFs: contango and roll costs can cause significant performance drag versus spot prices.

Remark 2.2.55. *Commodity Risk and Return Profile*
Commodities have distinct risk characteristics:

i. Higher volatility than FX, equities, and fixed income
ii. Historically attractive Sharpe ratio as a relative comparison
iii. Prior to 2008, exhibited negative correlation with equities (diversification benefit)
iv. Post-2008, correlations with risk assets increased significantly

v. Supply shocks can cause extreme price moves (geopolitics, weather, production disruptions)

Commodities are particularly useful as inflation hedges and for expressing views on global growth.

Remark 2.2.56. *Crude Oil Fundamentals*
Oil is the most important energy commodity, accounting for 33%of global energy demand:

i. Quality measures: API gravity (higher = lighter) and sulphur content (lower = sweeter)
ii. Light sweet crude: Most desirable (WTI, Brent). Heavy sour crude least desirable (Venezuela, Mexico)
iii. Products: Gasoline (cars), kerosene (diesel, jet fuel), heating oil, LPGs
iv. Global consumption approximately 90 million barrels per day

Remark 2.2.57. *Major Oil Benchmarks*
Key oil benchmarks and their characteristics:

i. WTI (West Texas Intermediate): Light sweet crude. Trades on NYMEX (CL). Delivery at Cushing, Oklahoma. Contract: 1,000 barrels. ETF: USO.
ii. Brent Crude: North Sea light sweet crude. Trades on ICE (CO). Prices more than half of world's internationally traded crude. Delivery at Sullom Voe, Scotland.
iii. WTI-Brent Spread: Historically WTI traded at premium (higher grade), but infrastructure constraints at Cushing and Middle East supply sensitivity pushed Brent to premium.

Remark 2.2.58. *OPEC and Oil Supply*
OPEC controls significant portion of global oil supply:

i. 12 member countries controlling $>35\%$ of global production, 73% of reserves
ii. Saudi Arabia has largest spare capacity. "The Call on OPEC" typically means Saudi increases production
iii. Key NOCs: Saudi Aramco (largest company by value, 1/6 of global reserves), NIOC (Iran), PDVSA (Venezuela), INOC (Iraq), KOC (Kuwait)
iv. OPEC quota system attempts to coordinate production to stabilise prices

Political risk in OPEC members is critical for oil price forecasting.

Remark 2.2.59. *Oil Chokepoints and Infrastructure*
Critical infrastructure for global oil flows:

i. Strait of Hormuz: Most important chokepoint. 17 million bbl/d (20% of global traded oil). Between Iran and Oman. Geopolitical flashpoint.
ii. Strait of Malacca: 14 million bbl/d. Connects Indian and Pacific Oceans. Critical for Asian supply.
iii. Mandab Strait/Suez Canal: 3 million and 2 million bbl/d respectively. Piracy risk.
iv. Pipelines: Druzhba (Russia to Europe, 2,300 miles, 1.4 million bbl/d). Keystone (Canada to US).

Supply disruption at chokepoints causes immediate price spikes, especially in Brent.

Remark 2.2.60. *Crack Spread*
The crack spread measures refining margins:

i. Spread between crude oil input and refined product output (gasoline, heating oil)
ii. $3:2:1$ Crack Spread: 3 barrels crude vs. 2 barrels gasoline + 1 barrel heating oil (most common)
iii. High crack spread: refiners profitable, incentive to increase production
iv. Low/negative crack spread: margins squeezed, refiners slow production
v. Factors: Cushing supply, driving demand, refinery shutdowns, hurricanes

Conversion: gasoline/heating oil in cents/gallon, crude in dollars/barrel. 1 barrel = 42 gallons.

Remark 2.2.61. *Natural Gas*
Natural gas is the cleanest fossil fuel (30–50% less CO_2 than gasoline/coal):

i. US and Russia account for 38% of global production
ii. Shale revolution: Horizontal drilling and hydraulic fracturing transformed US from importer to exporter
iii. Flaring: Burning unwanted natural gas, common in US due to regulatory requirements

iv. LNG: Liquefied at $-260°F$ for transport, 600x less volume than gas state
v. Uses: Power generation, heating, fertiliser (ammonia), transportation

Natural gas futures (NG) trade on NYMEX. Contract: $10,000$ MMBtu, delivery at Henry Hub, Louisiana. Quoted in \$/MMBtu. ETF: UNG (subject to contango drag).

Remark 2.2.62. *Gold*
Gold is both precious metal and monetary asset. Currency symbol: XAU.

i. Jewelry: 40%+ of demand. Investment: second largest demand driver
ii. Central banks hold $31,920$ tonnes. US largest holder ($8,134$ tonnes, 73%of reserves)
iii. China overtook South Africa as largest producer
iv. India largest consumer (50% used for weddings)
v. Real rates: Gold inversely correlated with real interest rates. Negative real rates support gold.

Trading: GLD ETF (1/10 oz per share), gold futures (GC) on COMEX (100 troy oz contract).

Remark 2.2.63. *Silver*
Silver has both monetary and industrial properties. Currency symbol: XAG.

i. Highest electrical conductivity of all metals
ii. Industrial applications: 44% of demand (batteries, electronics, solar panels)
iii. Jewelry/silverware: 22% of demand
iv. Mexico and China account for 47% of global production
v. More volatile than gold; often trades as leveraged gold play

Trading: SLV ETF (1 oz per share), silver futures (SI) on COMEX ($5,000$ troy oz). "Triple 9s" (99.9% purity) is deliverable grade.

Remark 2.2.64. *Platinum*
Platinum is extremely rare with concentrated supply:

i. South Africa holds 80% of global reserves
ii. Autocatalyst (catalytic converters): 38% of demand
iii. Jewelry: 31% of demand
iv. Almost twice as heavy as gold (density 21 vs. 19)
v. Play on emerging market growth and automotive demand

Platinum futures (PL) trade on COMEX (50 troy oz). Platinum/gold ratio is a key relative value indicator.

Remark 2.2.65. *Copper*
Copper is considered a leading economic indicator:

i. Chile dominates production (27%); China dominates consumption (43%), stockpiles are closely watched
ii. Uses: Building construction (33%), infrastructure (15%), equipment manufacturing (52%)
iii. Major input for urbanising economies, plays into EM growth story
iv. Recycled copper ("secondary copper") represents significant market share

Trading: LME (LMCADS03, \$/ton, 25 tons/contract) or NYMEX (HG, cents/lb, $25,000$ lbs/contract).

Remark 2.2.66. *Aluminium*
Aluminium is the most abundant metal in Earth's crust:

i. China accounts for 40%+ of both production and consumption
ii. Lightweight, durable, does not corrode
iii. Uses: Construction, transportation (less energy needed to move lighter vehicles), packaging
iv. One of few commodities where China is self-sufficient
v. Energy-intensive to produce (aluminium smelters locate near cheap power)

Trading: LME (LMAHDS03, \$/ton, 25 tons/contract).

Remark 2.2.67. *Agricultural Commodities Overview*
Key characteristics of agricultural trading:

i. Supply determined by weather, planting decisions, yields
ii. Demand relatively inelastic (food consumption stable)
iii. US is largest player in most agricultural products
iv. Best agriculture traders employ full-time meteorologists
v. Crop calendars define sensitive periods for each commodity
vi. Planting, flowering/silking, and harvest are critical stages

Remark 2.2.68. *Corn*
Corn is the largest cereal crop globally:

i. US accounts for 35%+ of production, 30%+ of consumption, largest exporter
ii. Western Corn Belt (Iowa, Illinois, Nebraska) produces 47% of US corn
iii. Uses: Livestock feed, ethanol (27% of US demand, growing), food
iv. Ethanol mandate: US Energy Policy Act 2005 requires ethanol blending, creating structural demand
v. China demand growth: feedstock demand from 0% (2007) to 5%+ of imports

Trading: CBOT (C), cents/bushel, 5,000 bushels/contract. 1 bushel = 56 lbs.
Delivery months: H, K, N, U, Z. Critical period: June–August (silking).

Remark 2.2.69. *Wheat*
Wheat has been cultivated for $10,000+$ years:

i. EU, China, India are largest producers; US is fourth largest but largest exporter
ii. Classifications: season (winter/spring), gluten content (hard/soft), colour (red/white/amber)
iii. Uses: Bread, flour, noodles, beer, feedstock
iv. Close substitute for corn. Prices move together
v. Russia export bans have caused supply shocks

Trading: CBOT (W), cents/bushel, $5,000$ bushels/contract. 1 bushel = 60 lbs.
Critical period: heading stage.

Remark 2.2.70. *Soybeans*
Soybeans are a critical oilseed with high protein content:

i. US largest producer (31%), Brazil second largest but largest exporter
ii. China largest consumer (crush) and importer (63% of global imports)
iii. Products: Soybean meal, vegetable oil, soy milk, tofu, edamame
iv. 90%+ of soybeans are genetically engineered (lower pesticide costs)
v. Brazil/Argentina weather critical, neighbouring countries, correlated weather risk

Trading: CBOT (S), cents/bushel, 5,000 bushels/contract. 1 bushel = 60 lbs. Most vulnerable during flowering.
Delivery months: F, H, K, N, Q, U, X.

Remark 2.2.71. *Cotton*
Cotton is the most important textile fiber:

i. China, India, US are largest producers (65% of production)
ii. China largest producer and consumer (textile industry)
iii. US third largest producer but largest exporter (30% of exports)
iv. Classifications: character (strength), grade (colour/purity), staple (fibre length)
v. More drought-resistant than other crops

Trading: ICE (CT), cents/lb, $50,000$ lbs/contract (≈ 104 bales). 1 bale = 480 lbs.
Delivery months: H, K, N, V, Z.

Remark 2.2.72. *Coffee*
Coffee has distinct supply characteristics:

i. Two types: Arabica (60% of production, higher grade, higher altitude) and Robusta (stronger taste, more caffeine, lower altitude)
ii. Brazil largest producer/exporter (37%). Vietnam second (mostly robusta)
iii. EU and US are largest importers (46% and 23% respectively)
iv. Biennial cycle: Coffee trees alternate high and low yield years
v. Tree life cycle approximately 20 years

Trading: ICE (KC), cents/lb of arabica, $37,500$ lbs/contract. Industry measures in bags (60 kg = 132 lbs). Critical period: blooming (water is critical).

Remark 2.2.73. *Ending Stocks and Supply/Demand Balance*
Ending stocks (inventory) are the most important driver of commodity prices:

i. Ending Stocks = Beginning Stocks + Production − Consumption
ii. Low stocks relative to consumption (stocks-to-use ratio) = price support
iii. High stocks = price pressure
iv. USDA WASDE reports provide monthly supply/demand estimates
v. Small changes in production or consumption can cause large price moves when stocks are tight

Remark 2.2.74. *Weather Risk in Agriculture*
Weather is the primary supply shock driver in agriculture:

i. Drought during critical growth stages (flowering, silking) is most damaging
ii. Livestock cascade: high grain prices → expensive feed → early livestock slaughter → short-term meat supply up, future supply down
iii. El Niño/La Niña cycles affect global weather patterns
iv. Monitor: NOAA drought monitors, crop condition reports, weather forecasts for key growing regions

Remark 2.2.75. *Commodities in Different Macro Regimes*

i. Growth Shock: Commodity demand rises, prices increase, especially energy and industrial metals
ii. Recession: Demand destruction, prices fall (except gold as safe haven)
iii. Inflation Shock: Commodities outperform as inflation hedge; energy and agriculture lead
iv. USD Weakness: Commodity prices rise (inverse correlation with dollar)
v. Geopolitical Crisis: Energy spikes on supply fears; gold rises on safe-haven demand

Commodities are the inflation and real-economy link in the macro framework.

2.3 Practitioner Frameworks

This section distills operational frameworks from leading global macro practitioners, drawn primarily from Steven Drobny's interviews (Drobny (2006)). Focus is on actionable principles rather than historical narratives.

2.3.1 Portfolio Construction and Risk Frameworks

Remark 2.3.1. *Systematic Risk Premia Allocation (Leitner Framework)*

i. Equal 20% risk allocation across: Equities (value screens), Fixed Income (5x leveraged short-duration), FX (carry + vol premia), Commodities (roll yield), Real Estate
ii. Additional 10% for 1–2 high-conviction opportunities annually
iii. Anchor to data first, then narratives; actively seek disconfirming evidence
iv. Not being invested = foregoing risk premia; short positions pay away premia

Remark 2.3.2. *Convexity and Optionality (Siva-Jothy/Anonymous Currency Manager)*

i. Maintain long gamma; never short gamma in macro portfolios
ii. 50–60% options (3–6 months); 75% of price moves occur 10–15% of time around data releases
iii. Systematically long options to capture regime shifts; leverage is function of correct macro analysis
iv. Never forced seller; liquidity-only mandate (G10 only)
v. Timing: buy options when consensus says inevitable and market at extreme

Remark 2.3.3. *Trade Construction Discipline (Drobny/Wadhwani)*

i. Views without actionable trades are useless; compare fundamentals to market perception
ii. Look for positioning extremes (2–5 year timeframes); CA deficit currency rising = longs building
iii. Minimum risk/reward $4:1$; after two stop-outs on same thesis, move on
iv. 3–4 major opportunities annually; overtrading as damaging as running losers
v. Positioning and sentiment dominate fundamentals short-term
vi. Stop-loss most critical; exit immediately when thesis invalidated

Remark 2.3.4. *Fixed Income Specific (Porter)*

i. Time horizon arbitrage: institutional short-termism creates medium-term opportunity
ii. Focus on one-year, one-year forwards (most volatile, greatest overshooting)
iii. Interest rate cycles 16–24 months; maximise income per VaR via front-end
iv. Curve steepener ≈ 90% bullish bonds; flattener ≈ bearish

2.3.2 Asset-Class Specific Frameworks

Remark 2.3.5. *Commodity Framework (Anderson)*

i. Pure microeconomics: supply/demand, cost curves, competitive positioning
ii. Fundamentals over price: ignore day-to-day moves, focus on economics
iii. Mean reversion: margins revert to mean, not prices
iv. Contrarian timing: front-page hysteria = reversal indicator (sell euphoria, buy panic)
v. Micro-economic inevitability: stress-test thesis against adverse macro scenarios. Long = assume low growth; short = assume high growth
vi. On-the-ground research: observe anecdotal evidence, see fundamental change before markets price it
vii. Only invest low-cost producers; high-cost assets can't be bought cheap enough
viii. Reject VaR for concentrated portfolios (assumes diversification); use volatility-adjusted sizing

Remark 2.3.6. *Equity Macro Framework (Bessent)*

i. Express macro views through equities: 50% of stock move = market, 30% = sector, 20% = stock-specific
ii. Bottom-up research for macro confirmation: micro insights reveal macro picture
iii. Entry points critical: good entry means rarely stopped out

iv. Concentrated portfolio: 8–14 large positions, not equally weighted
v. Paradigm shifts = major profits: identify when game changes, not how to play game better

Remark 2.3.7. *FX Framework (Anonymous Currency Manager)*

i. FX is tail of credit curve: Fed funds → short rates → govts → credit → equities → FX
ii. Currencies reflect relative sentiment/credit spreads between economies
iii. Three currency blocs: USD, EUR, Asia
iv. Directional concentration: 3–4 macro calls maximum (bonds, equities, USD vs blocs)
v. Five-month time horizon for thesis validation
vi. Basic law: bullish = long or flat, bearish = short or flat. Never relative value

Remark 2.3.8. *Emerging Markets Crisis Framework (Dimitrijević)*

i. Country implosion acts like company collapse: all instruments correlate
ii. Strict limits: 10% global macro fund, 15% EM fund per country
iii. Best EM trades after panics/disasters
iv. Clean sheet valuation: ignore yesterday's price. Ask: "would we invest at current price with clean sheet?"
v. Stop-loss mechanics: work in continuous markets, dangerous in distressed/value plays
vi. Internal stops only (counterparties invariably hit external stops)
vii. One-month cool-off after stop-out
viii. Hedge mismatch: short rich asset class as hedge to long attractive asset class within same country

2.3.3 Execution and Flow Analysis

Remark 2.3.9. *Flow and Cross-Market Linkages (Harris)*

i. Flow matrix: mental model tracking global money flows seeking highest risk-adjusted return
ii. Money craves stability; fear greater than greed drives capital flight
iii. Cross-market linkages: geopolitical events ripple through asset classes (e.g., Brazilian real devaluation → sell soybeans as farmers hedge USD revenues)
iv. Slower Fool Theory: exit before discontinuous leap into illiquidity
v. Risk management: 80% trades wrong, 20% profitable must exceed losses
vi. Small probes (reconnaissance) test thesis before scaling
vii. Never pray trades back to breakeven; clear books, start fresh
viii. Best at 3–4 concentrated positions; avoid overtrading

Remark 2.3.10. *Contrarian Indicators*

i. Concept exhaustion: magazine covers = fully discounted
ii. Gestalt shifts: volatility spikes when protection buying signals crowded positioning
iii. "Frozen ice theory": strong trades at edges, crowded in middle on proxies
iv. Central banks often counter-indicators in market timing

3 Market Microstructure

The material in this section is compiled from the following sources: *Trading and Exchanges* (Harris), *Market Microstructure in Practice* (Lehalle & Laruelle), *Algorithmic Trading and DMA* (Johnson), *Algorithmic and High-Frequency Trading* (Cartea, Jaimungal & Penalva), *The Financial Mathematics of Market Liquidity* (Guéant), and Almgren & Chriss (2001).

3.1 The Trading Ecosystem

Market microstructure studies the process by which investors' latent demands are ultimately translated into transactions. It examines how trading mechanisms affect the price formation process, the cost of transacting, and the informativeness of prices. This section provides a foundational overview of the trading ecosystem: the participants, their motivations, and the structure of the industry.

3.1.1 Market Participants

The trading industry divides into two broad sides: the buy side and the sell side. This division reflects the fundamental structure of financial markets and determines the relationships among market participants.

Definition 3.1.1. *Buy-Side Participants*
Buy-side trade to achieve their investment, hedging, or asset-exchange objectives.

i. Investors: Includes individual investors saving for retirement, pension funds, mutual funds, insurance, and sovereign wealth funds.
ii. Borrowers: Corps issue equity and debt to fund projects; governments issue bonds to finance spending.
iii. Hedgers: Trade to reduce risks they do not want to bear.
iv. Asset Exchangers: Trade for specific assets, i.e., central banks (forex); manufacturers (commodities).
v. Gamblers: Trade for entertainment or psychological satisfaction, often without rational profit expectations.

Definition 3.1.2. *Sell-Side Participants*
Sell-side facilitate trading rather than trading for their own investment objectives.

i. Dealers: Supply liquidity by buying at bid and selling at ask prices. Two main types:
   a. Market Makers: Provide liquidity on demand in small quantities, trade in/out many times per day.
   b. Block Facilitators: Provide liquidity for large orders, willing to hold positions longer.
ii. Brokers: Arrange trades for clients without taking positions. Earn commissions and fees for agency services. Add value by finding counterparties and providing trade execution expertise.
iii. Investment Banks: Underwrite new issues, provide advisory services, combine dealer and broker functions.
iv. Prime Brokers: Provide consolidated services including clearing, custody, financing, and securities lending.

Definition 3.1.3. *Proprietary Traders and Speculators*
Traders who exist purely to profit from trading itself. Divided into informed traders and parasitic traders.

i. Informed Traders: Profit from information about fundamental values.
   a. Value Traders: Estimate fundamental values through analysis of all available information.
   b. News Traders: Trade immediately upon new information release.
   c. Information-Oriented Technical Traders: Identify patterns indicating prices differ from fundamental.
   d. Arbitrageurs: Exploit price discrepancies across markets or related instruments.
ii. Parasitic Traders: Profit without making prices more informative.
   a. Order Anticipators: Profit from predicting other traders' actions (front runners, squeezers).
   b. Bluffers: Create misinformation to mislead other traders (rumormongers, price manipulators).
iii. High-Frequency Traders: Use sophisticated technology to trade at high speeds, often combining market-making and proprietary strategies.

3.1.2 Motivations for Trading

Remark 3.1.4. *Zero-Sum Game Property*
Trading is a zero-sum game where the total gains of winners exactly equal the total losses of losers. Successful traders must understand who loses and why they trade.

Definition 3.1.5. *Utilitarian Traders*
Utilitarian traders trade to obtain benefits other than trading profits.

i. Investors and Borrowers: Solve inter-temporal cash flow timing problems. When income exceeds expenses, they invest. When expenses exceed income, they borrow or liquidate past investments.
ii. Asset Exchangers: Use markets to exchange owned assets for others of greater immediate use.
iii. Hedgers: Trade to exchange risks they have for risks they would rather bear (or no risk at all). Effective hedgers match asset risks with liability risks. Hedging transforms risk characteristics.
iv. Gamblers: Trade for entertainment, accepting negative expected returns in exchange for excitement and the possibility of large gains. Unlike speculators, gamblers do not have rational expectations of profit.
v. Fledglings: Trade to learn whether they can trade profitably, willing to lose money to learn.
vi. Cross-Subsidisers: Trade to produce commission revenues for brokers in return for services (soft dollar arrangements). Commissions higher than if services were purchased separately.
vii. Tax Avoiders: Trade to exploit tax loopholes and minimise taxes (tax straddles, loss harvesting, dividend capture strategies).

Definition 3.1.6. *Profit-Motivated Traders*
Profit-motivated traders trade only as they rationally expect to profit. Distinguished as informed or uninformed.

i. Informed Traders: Can form reliable opinions about whether instruments are fundamentally undervalued or overvalued. Include value traders, news traders, information-oriented technical traders, and arbitrageurs. These traders make prices more informative.
ii. Parasitic Traders: Profit from predicting other traders' actions (order anticipators) or creating misinformation (bluffers). Do not make prices more informative. Include front runners, sentiment-oriented technical traders, squeezers, rumourmongers, and price manipulators.
iii. Dealers: Uninformed profit-motivated traders who profit from bid-ask spread by providing liquidity on demand. Manage inventory risk and adverse selection costs from trading with informed traders.

Remark 3.1.7. *Informed vs Uninformed Traders*
Traders are either informed or uninformed. Informed traders can form reliable opinions about fundamental values (value given all available information). Uninformed traders cannot form such reliable opinions. Informed traders are always profit-motivated. Uninformed traders include utilitarian traders, futile traders, and some profit-motivated traders (dealers, parasitic traders).

Remark 3.1.8. *Futile Traders*
Futile traders believe they are profit-motivated but their expectations are not rational. They have no informational or analytical advantages that would allow profitable trading. Utilitarian traders and futile traders systematically lose to profit-motivated traders.

Remark 3.1.9. *Importance of Understanding Motivations*

i. Strategy Selection: Optimal trading strategy depends on trading objectives. Investors should minimise transaction costs; speculators should maximise information exploitation.
ii. Volume Interpretation: Trading volume reflects all motivations. Misattributing volume to one factor when another applies leads to poor decisions.
iii. Market Design: Different market structures favour different trader types. Regulators must understand trading motivations to design markets that serve legitimate purposes.
iv. Counterparty Assessment: Successful traders identify whom they are trading against and why. Profitable trading requires trading with those who will lose.

3.1.3 The Trading Industry Value Chain

The trading industry provides a value chain connecting investment decisions to executed transactions. Understanding this chain illuminates where costs arise and value is created.

Method 3.1.10. *Order Origination*
Trading begins with an investment decision by a buy-side institution or individual.

i. Portfolio managers decide asset allocation and security selection.
ii. Research analysts provide fundamental and quantitative analysis.
iii. Risk managers impose position limits and constraints.
iv. The decision generates a parent order, which is the total quantity desired, later sliced into child orders.

Definition 3.1.11. *Execution Venues*
Orders can be executed across multiple venue types:

i. Exchanges: Regulated, transparent markets with central limit order books.
ii. Alternative Trading Systems (ATS)/Dark Pools: Non-exchange venues, reduced pre-trade transparency.
iii. Dealer Markets: Orders executed against dealer inventory.
iv. Broker Crossing Networks: Match buy and sell orders from broker's customer base.

Market structures, fragmentation, and venue types are examined in detail in subsequent sections.

Process 3.1.12. *Clearing and Settlement*
Post-trade processing ensures transaction completion.

i. Clearing: Clearinghouse becomes counterparty to both sides, guaranteeing performance.
ii. Settlement: Actual exchange of securities and cash. Settlement cycles vary by market (T+1, T+2). Custody and depository services ensure proper asset holding.
iii. Trade Reporting: Regulatory reporting, position tracking, and reconciliation.

3.2 Order Mechanics

3.2.1 Order Types, Properties and Instructions

Remark 3.2.1. *Market Order*
Trade a given quantity at the best price possible. Risk uncertainty of execution price.
For orders larger than current best bid/offer, allow market orders to progress deeper into the book.
Performance is dependent on current market conditions. Large orders have significant market impact.

Remark 3.2.2. *Limit Order*
Buy or sell given quantity at specified price or better. Will try to fill as much without breaking price limit.
If no orders that match price, order is left in order book until expiry or cancellation.
Aggressive limit price act like market order demanding liquidity; passive limit price try to capture gains from future price trends or reversions.
Risk is lack of execution certainty, hence need balance between immediacy and price.

Remark 3.2.3. *Optional Order Instructions*

i. Duration: Good for Day (GFD), Till Date (GTD), Till Cancel (GTC), After Time/Date (GAT)
ii. Auction/Crossing Session: mark for participation in auction, or trading either at open, close, or intraday
iii. Fill: Immediate-or-cancel (IOC), fill-or-kill (FOK) (IOC with 100% completion requirement), all-or-none (AON) (FOK without immediacy), minimum volume (match if quantity sufficient), must-be-filled (MBF)
iv. Preferencing: preferenced (prioritise specific market maker), directed (routed to specific market maker or dealer, may accept or reject them).
v. Routing: do-not-route (execution venue handle order locally), directed routing (host venue acts as gateway to chosen destination), inter-market sweeps (broker must ensure order protection and best execution requirements met), flashing (displayed at source venue for instant before routed away)
vi. Linking: one-cancels-other (mutually exclusive orders), one-triggers-other (supplementary order created on successful execution of main order), grouped orders.
vii. Identity Details: offer anonymity or anonymous identifiers
viii. Short-Sales: enforce tick-sensitive trading (i.e. sell only on uptick or even tick)
ix. Odd-lots: allow rounded lot orders to be matched with odd-lots
x. Sentiment Instructions: forex settlement, cash settlement etc.

Remark 3.2.4. *Optional Order Instructions*

i. Market-to-Limit: market order, then to standing limit order for residual amount at last execution price
ii. Market-with-Protection: market-to-limit order with limit price away from last execution price

Remark 3.2.5. *Conditional Order Types*

i. Stop: become active market order when reaching trigger price. Used for stop-loss. Stop-limit triggers a limit order. Protection stops add limit-like cap/floor around stop to reduce extreme fills.
ii. Trailing Stop: trigger price is pegged to favourable moves in price. If market turns, stop does not move, and triggers as a normal stop or stop-limit order when price reaches trigger price.
iii. Contingent/If-Touched: hidden until trigger price is reached, then activate into market or limit order. Used as entry orders in forex to establish positions, and may trigger based on another asset price.
iv. Tick-Sensitive: adds validity condition based on last trade price. Buy-on-downtick execute only on downtick; sell-on-uptick only execute on uptick. Reduce immediate market impact but sacrifice immediacy to get one-tick better price; most useful when tick size is large.

Remark 3.2.6. *Hidden Order Types*

i. Hidden: provide liquidity or trade size without revealing full interest in order book. Infer by liquidity pinging with IOC limit orders to see whether additional hidden size is available at that level. Hidden orders given lower priority than displayed orders. Venues may add variants to reduce small pinging.
ii. Iceberg/Reserve: shows only a small visible "peak" of a larger limit order; the rest is hidden. When the visible slice fills, the venue automatically reposts a new slice from the hidden reserve until the full size is done. Each reposted slice gets a new time priority, so the chosen peak size affects how quickly it fills.

Remark 3.2.7. *Discretionary Order Types*

i. Not-Held: complete discretion to trader on how the order is worked. Used for floor traders in less transparent markets as they have best knowledge of market conditions.
ii. Discretionary: limit order that displays one limit price but is allowed to execute within an extra discretion range when a matching order comes close.
iii. Pegged: limit order with trigger price pegged to a reference price, reduce risk of a resting limit becoming stale/mispriced. May have hard cap/floor. Some venues require a minimum contra size to move the peg, and some support a display size (iceberg-style) for pegged orders.
iv. Scale: splits one parent order into multiple child limit orders placed at several price levels. Orders are already in the book, may get fills with time priority as price moves.

Remark 3.2.8. *Routed Order Types*

i. Pass-Through: execute on hosting venue (typically IOC), then routes unfilled remainder to destination venue (primary exchange) as a normal order. Offered by crossing networks/dark pools to capture liquidity locally before sending residual onward, reducing information leakage.
ii. Routing-Strategy: allow more complex instructions
    1. MOPP: Route to all protected quotes for display size only. Post any residual on NASDAQ
    2. DOTI: NASDAQ for NBBO or better. Route any residual to NYSE or AMEX
    3. SKIP: NASDAQ for NBBO or better. Route to Reg NMS protected venues. Residual on NASDAQ
    4. SCAN: NASDAQ for NBBO or better. Route to alternate execution venues. Residual on NASDAQ
    5. STGY: As SCAN. Residual will route if NASDAQ subsequently locked or crossed

Remark 3.2.9. *Crossing Order Types*

i. Committed: standard market or limit orders, available for immediate execution
ii. Uncommitted: indications of interest (IOIs) that requires confirmation before execution. Match against other uncommitted orders or firm orders, but do not generate unexpected fills. To deter liquidity pinging, venues often impose safeguards like minimum size requirements and scorecard/eligibility rules.
iii. Negotiated: crossing-network orders that trigger a structured, bilateral negotiation: both sides adjust price/size till agreement, with no trade obligation. Anonymous; venues provide participant historical crossing success rates (scorecards) to help counterparties assess each other.

iv. Alerted: venue sends automated alert to approved liquidity providers/members; they respond with quotes/interest, and if match is found they submit firm order. Some implementations run a short solicitation window to gather responses, then execute eligible orders, with venue-defined priority rules.

Remark 3.2.10. *Order-Contingent Order Types*

i. Linked-Alternative: set of alternative orders tied together so that fills in one automatically reduce the remaining size of the others by the same proportion/amount. Risk is concurrent fills across venues causing an over-fill unless the linkage is enforced tightly.

ii. Contingent: link multiple legs across assets so execution happens only if all dependent legs can be matched, enabling spread/multi-leg trading (common on futures exchanges).
Specify a target spread; each leg's limit price is derived from the other asset's best price plus the spread. As market prices/sizes change, the legs are continuously repriced and resized to maintain the spread, and if one leg starts filling the other is immediately adjusted to complete the package.

iii. Implied: synthetic quotes generated by the exchange from combinations of related outright and spread orders (common in futures). By linking outright and spread order books, the venue can imply additional bid/offer prices and sizes that maintain the required spreads, creating extra executable liquidity.

    1. Implied IN: outright leg orders imply a spread quote (e.g., buy Jun and sell Sep implies a bid in the Jun–Sep spread at the price difference; size is min of the legs).
    2. Implied OUT: a spread order plus one outright leg implies a quote in the missing outright (deconstructing the spread).

    Matching gives priority to actual (explicit) orders; implied orders fill residual. Implied orders can chain (second-generation) and extend to more complex spreads, further increasing effective liquidity.

3.2.2 The Order Lifecycle

3.2.3 Limit Order Book Mechanics

3.3 Market Structures and Venues

Remark 3.3.1. *Market Design and Architecture*
For markets to work well, their design must accommodate the needs of institutional and individual investors, dealers, and speculators. A successful market allows investors to trade when they want and minimizes trading costs whilst making it worthwhile for dealers and speculators. Key characteristics of market architecture:

i. Market type (quote-driven vs order-driven; continuous vs call auctions)

ii. Order types (limit, market, stop, iceberg, etc.)

iii. Trading protocols (precedence rules, tick sizes, lot sizes, halts)

iv. Transparency (pre-trade and post-trade information disclosure)

v. Off-market trading (dark pools, OTC, internalization)

These characteristics significantly influence liquidity and the speed of price discovery, which in turn affect the overall cost of trading. However, no two markets are the same, even if based on the same design, since local regulations and traded asset universes differ.

3.3.1 Market Organization Taxonomy

Markets are classified by two key properties: trading mechanism and trading frequency.

Definition 3.3.2. *Trading Mechanism*
Determines how traders interact and how prices are established.

i. Quote-Driven: Traders transact with dealers (market makers) who quote two-way prices. Dealer provides guaranteed execution at quoted price for a set size. Examples: traditional Nasdaq dealer market.

ii. Order-Driven: All traders participate equally, placing orders in a central limit order book (CLOB) matched by consistent rules. Best bid/offer prices are indicative rather than guaranteed. Prices established by actual orders. Examples: NYSE, LSE, Euronext.

iii. Hybrid: Mix of both mechanisms. Dealers provide continuous firm quotes while also allowing limit orders. Examples: modern NYSE, Nasdaq. Many electronic quote-driven markets now function as hybrid markets since continuous firm quotes effectively force dealers to offer limit orders.

Order-driven markets provide visible liquidity and persistence of orders, enhancing price discovery. Traders have more control over order choice (price, size, timing) without negotiation. Quote-driven markets offer guaranteed execution for market orders but may require negotiation or separate firm quote requests.

Definition 3.3.3. *Trading Frequency*
Determines when requirement matches (quotes or orders) turn into executions.

i. Continuous Trading: Immediate execution when orders match. Convenient and efficient but can lead to price volatility during supply-demand imbalances.
ii. Periodic Trading (Call Auctions): Scheduled auctions at specific times. Allows liquidity accumulation and more considered price formation. Reduces volatility but sacrifices immediacy.
iii. Request-Driven: Execution upon quote request (dealer RFQ, upstairs trading). Convenient for negotiation but not necessarily efficient in terms of price achieved.

Remark 3.3.4. *RFQ vs CLOB Trading Mechanisms*
Two main mechanisms organise electronic trading:

i. CLOB (Central Limit Order Book): Multilateral, each participant sends orders to a central place which synchronises, consolidates, generates transactions, and spreads the aggregated view to everyone.
ii. RFQ (Request For Quotes): Bilateral, traders send messages to dealers declaring interest. Dealers respond with quotes (prices and quantities). Trader chooses which dealer to trade with.

In RFQ, traders are more exposed to opportunity cost; dealers are more exposed to adverse selection cost. In CLOB, all are exposed to both depending on limit vs market order usage.
Stale quotes are more frequent in RFQ than vanishing liquidity in CLOB, where what traders see is less reliable. Dealers use last look (conditional orders) in RFQ to protect against adverse selection; rarely available in CLOB.

Remark 3.3.5. *Order Types and Market Structure*
Orders differentiate by their liquidity-effect and associated risks.

i. Market Orders: Trade liquidity for execution price uncertainty.
ii. Limit Orders: Trade price certainty for risk of failing to execute.
iii. Conditional Orders: Wide range of conditions control order activation, duration, and partial fills. Enable stop orders, iceberg orders (hidden quantity), and venue-specific routing.

Markets differ in order type behavior. In dealer markets, limit orders may be hidden. In transparent order-driven markets with sufficiently visible order books, limit orders immediately appear and provide liquidity. Hybrid orders combine features: market-if-touched, stop-limit. Hidden and iceberg orders allow traders to achieve best price without disclosing full liquidity, increasingly important for institutional traders.

3.3.2 Trading Protocols and Market Rules

Markets provide a fair and orderly trading environment by defining and enforcing trading protocols. These rules affect market efficiency and transaction costs.

Definition 3.3.6. *Order Precedence*
Rules specifying how incoming orders execute with existing orders or dealer quotes. Markets give price priority to orders with best price, with secondary priority either time-based or size-based.

Definition 3.3.7. *Minimum Trade Quantities (Lot Sizes)*
Limits on minimum traceable quantities, varying from single units to thousands. Smaller lot sizes attract retail investors; larger lots favour institutional traders. Markets often accommodate both.

Definition 3.3.8. *Minimum Price Increments (Tick Sizes)*
Minimum price changes allowed between orders, affects the spread. Large ticks widen spreads, make liquidity provision more profitable. If ticks too small, time priority becomes meaningless, traders place orders one tick ahead to jump the queue. Balance between meaningful priority and competitive pricing needed.

Definition 3.3.9. *Opening/Closing Procedures*
Rules governing market open/close times and official reference prices. Most markets now use call auctions for opening and closing to improve price discovery through order batching.

Definition 3.3.10. *Trading Halts and Circuit-Breakers*
Mechanisms to pause trading during abnormal conditions.

i. Trading Halts: Stock-specific pauses triggered by pending material announcements or large price moves. Allow information dissemination and reduce volatility impact.

ii. Circuit-Breakers: Market-wide mechanisms protecting against mass selling.

Alternatively, switch to call auctions rather than complete halt.

3.3.3 Trading Venues

Remark 3.3.11. *Inter-Dealer Markets*

i. Exchanges: members are specialised dealing houses, broker/dealer firms, large investors who can justify DMA. For more standardised assets.

ii. OTC/Inter-Dealer Broker Networks: for assets generally traded OTC.

Remark 3.3.12. *Dealer-to-Client Markets*
Mix of phone-based trading, single and multi-broker/dealer electronic trading platforms.

Remark 3.3.13. *Alternative Markets*

i. Electronic Communication Networks (ECNs): uses central limit order books, with continuous auctions.

ii. Alternative Trading Systems (ATSs): opaque order-driven dark-pools. Either use standard auction, or negotiated, advertised, or internal crossing mechanisms. Price discovery mechanics is either mid-point price from main market, or full order book based.

   1. Scheduled Crosses: equivalent to scheduled anonymous call auctions
   2. Continuous Blind Crosses: trading on completely opaque electronic order book.
   3. Negotiated Crosses: continuous search into anonymous bilateral negotiation for both size and price.
   4. Advertised Crosses: highlight when liquidity is present (block price range), but size not provided.

Remark 3.3.14. *Market Transparency*
Transparency is the amount of market information available before and after a trade.

i. Pre-Trade Transparency: Information on prices and sizes of quotes/orders before execution.

ii. Post-Trade Transparency: Information on actual trade execution details (time, size, price).

Remark 3.3.15. *Transparency Across Market Types*
Market structure determines transparency level.

i. Quote-Driven Markets: Less transparent, showing only broker's best bid/offer. Bilateral nature means both parties usually know counterparty identity.

ii. Order-Driven Markets: Higher visibility, displayed order books showing all orders and volumes.

Remark 3.3.16. *Transparency Trade-offs*
Complete transparency is not appealing to all users. Key considerations:

i. Institutional Need: Large trades need to reduce potential impact, difficult if each order is identifiable.

ii. Anonymous Order Books: Common solution allowing trade execution without revealing trader identity.

iii. Hidden Orders: Markets increasingly allow hidden orders, giving traders control over visibility.

iv. Dark Pools: ATSs specialize in handling large block orders, operating opaquely to avoid signaling intentions. Most successful when accompanied by large, visible markets providing fair price reference.

v. Market Evolution: General trend is increasing transparency with anonymity. Several markets moved from fully disclosed broker identities to voluntary identification or complete anonymity.

3.3.4 Price Discovery and Trade Execution Mechanisms

Remark 3.3.17. *Price Discovery Overview*
Price discovery occurs when supply and demand requirements cross, determining the actual execution price. The mechanism by which this happens varies by market structure. Three main types:

i. Bilateral Trading: One-to-one negotiation mechanisms (quote-driven, RFQ-based)

ii. Continuous Auction: Multilateral matching with continuous order processing

iii. Call Auction: Periodic batch matching at scheduled times

Some markets lack independent price discovery. Execution prices are derived externally from primary markets (e.g., mid-point matching venues).

Definition 3.3.18. *Bilateral Trading Mechanisms*
One-to-one trading where each party generally knows the counterparty identity. Mainly used in quote-driven and negotiation-based markets, though some hybrid markets also support bilateral execution.

i. Two-Way Quotes: Market maker quotes bid/offer prices and sizes. Price discovery occurs only when client accepts quoted prices ("hit the bid" or "take the offer"). Alternatively, parties may renegotiate.
ii. Identity Transparency: Bilateral nature allows market makers to tailor quotes based on client risk. Two-way quotes provide some protection to clients by not immediately revealing their trade side.
iii. Multi-Dealer Systems: Aggregate multiple dealer quotes in a single view, allowing clients to see available prices without contacting each dealer. Prices remain indicative; continuous updates needed.

Definition 3.3.19. *Request-For-Quote (RFQ) Systems*
Client initiates by requesting quotes from dealers.

i. RFQ: Client requests quote; dealer provides; client decides to hit/lift, renegotiate, or walk away.
ii. Request-For-Stream (RFS): Client requests continuous stream of firm quotes rather than single quote. Each new update represents a firm quote allowing client to decide whether to trade on each update. More dynamic than RFQ as dealer provides continuously updating stream.

Both mechanisms widely used in fixed income (mainly RFQ) and foreign exchange (both RFQ and RFS). Anonymous bilateral mechanisms also exist (e.g., Liquidnet's crossing service), where counterparties negotiate anonymously, seeing scorecard of previous negotiations to gauge validity.

Definition 3.3.20. *Continuous Auction Mechanisms*
Multilateral process applying matching rules each time an order is added, updated, or cancelled. Requires queuing system to process orders in turn.

i. Order Processing: Each order instruction added to internal order book, matching rules applied to check for matches, order book updated, execution notifications sent for matches.
ii. Priority Rules: Markets give highest priority to price. Secondary priority typically time-based (earlier orders first) or pro-rata (allocation based on order size proportion).
iii. Equity Priority: Price-time matching common in equities. Highest priced buy orders and lowest priced sells rewarded with highest probability of execution. For orders at same price, earlier orders take priority.
iv. Futures Priority: Price-pro-rata matching common in futures. Best priced buy/sell orders take priority, but allocation between orders at same price done proportionally based on size, rewarding larger orders.

Definition 3.3.21. *Call Auction Mechanisms*
Batch auctions occurring as infrequently as once per day or as frequently as every 10-15 minutes. Orders queued and applied to auction order book; trade matching occurs at set auction time, not instantaneous.

i. Auction Crossing: Goal is to maximise volume crossed at the auction price. Orders accumulate before auction; prices form considering accumulated supply/demand.
ii. Price Determination: Venue may publish imbalance information between buy/sell orders pre-auction to help traders price auction orders. Auction crossing checks for order book crossing (market orders or limit orders with prices that cross). Best crossing price determined, typically maximising matched volume.
iii. Priority Application: Once auction price determined, order book processed to match orders within price limit. Many venues use time as secondary priority to reward early auction order entry.
iv. Opening/Closing Use: Many markets use call auctions for opening and closing to reduce price volatility and accumulate liquidity. Continuous auctions often switch to call auctions during volatility interruptions.

Remark 3.3.22. *Mid-Point Matching Without Price Discovery*
Some continuous markets do not have independent price discovery mechanisms. Instead, execution price is derived externally from primary market.

i. External Price Reference: If market orders supported, they execute at mid-point whenever sufficient volume available on other side. Limit orders execute when mid-point price reaches limit threshold.
ii. Mid-Point Definition: Typically defined as midpoint of external best bid/offer prices (often from primary market like NBBO in U.S.).

iii. Crossing Networks: Generally used to support continuous crossing for block-size orders.

Definition 3.3.23. *Reporting, Clearing and Settlement*
Final stages of the trading process after execution.

i. Reporting: Trade execution details communicated to counterparties; market authorities may be informed.
ii. Clearing: Validation of trade and settlement details, ensuring buyer and seller have required assets/funds. Often handled by specific clearing agents at regulated exchanges.
iii. Settlement: Actual exchange of assets and funds. Ownership reassignment for buyer. Most financial assets now dematerialised (book entries only). Physical delivery still applies to some assets (commodities). Custodians/depositories handle safekeeping and associated corporate actions. Security depositories and custodians have become international to support cross-border trading.

Settlement dates traditionally T+5, gradually shifting to T+1 and ultimately T+0. Straight-through-processing (STP) enables fully electronic pathway.

Definition 3.3.24. *Central Counterparty (CCP) Clearing*
Execution venues increasingly adopt CCP approach for clearing and settlement.

i. Structure: Each deal split into two parts; each half transacted versus CCP. Buyer pays CCP for asset; seller delivers asset to CCP in return for payment.
ii. Counterparty Risk Reduction: CCP bears default risk, helping reduce bilateral counterparty risk. Buyer and seller only deal with CCP, allowing fully anonymous trading.
iii. Collateral Requirements: Parties provide sufficient collateral to cover trades, also means clearing can be nearly instantaneous.
iv. Netting: Single net trade versus CCP for all participant's trades in an asset. Reduces transfers and settlements substantially, leading to cost savings and reduced required margin.
v. Cross-Margining: Central counterparties support margining across different assets, allowing futures positions to be hedged by underlying asset holdings, reducing funding/position management costs.

3.3.5 Dark Pools and Hidden Liquidity

3.3.6 Market Fragmentation

Remark 3.3.25. *Liquidity Fragmentation*
When seeking liquidity and the desired quantity is not instantaneously available in public quotes or electronic order books, the investor must split his large order in slices, through time and through trading venues or counterparts. Anticipating the optimal slicing is addressed by optimal trading theory.

Remark 3.3.26. *Fragmentation at Different Levels*

i. Market Operators: New operators appear in early phases of competition, then some merge.
ii. Trading Venues: Same operator can run multiple venues.
iii. Order Books: Same venue can offer multiple order books.
iv. Orders: As fragmentation increases, orders must be split through time and space across order books.
v. Technology: Number of protocols needed to interact with venues increases with competition.

Definition 3.3.27. *Market Share as Fragmentation Metric*
Market share is the most common metric to monitor fragmentation dynamics. Let M transactions occur from date t_1 to t_2 over N trading venues. Each trade ℓ has price P_ℓ, volume V_ℓ, timestamp τ_ℓ, and venue indicator $\delta_\ell = n$ if on venue n. The market share in traded value of venue n on stock k is:

$$M_k(n) = \frac{\sum_{t_1 \le \tau_\ell^k \le t_2} P_\ell^k V_\ell^k \cdot \mathbf{1}_n(\delta_\ell^k)}{\sum_{t_1 \le \tau_\ell^k \le t_2} P_\ell^k V_\ell^k}$$

Market share per trade, where T is total number of trades during the period:

$$M_k^T(n) = \frac{\sum_{\ell=1}^{T} \mathbf{1}_n(\delta_\ell^k)}{T}$$

Market share varies intraday and is distorted by fixing auctions where one venue has monopoly. Best practice is to compute separate market shares for fixing auctions and continuous trading (ex-fixing).

Definition 3.3.28. *Market Share on Multiple Stocks*
To aggregate market share across stocks $1 \le k \le K$:

i. Turnover-weighted: Weight by total traded value T_k of each stock:

$$M_{1,\ldots,K}(n) = \frac{\sum_{1\le k\le K} T_k \cdot M_k(n)}{\sum_{1\le k\le K} T_k}$$

ii. Index-weighted: Weight by stock's weight w_k in index I (proportional to free-float or market cap):

$$M_I(n) = \sum_{k\in I} w_k \cdot M_k(n)$$

iii. Equally-weighted: Give same weight to each stock:

$$M^u_{1,\ldots,K}(n) = \frac{1}{K} \sum_{1\le k\le K} M_k(n)$$

Fragmentation typically increases with liquidity: the more liquid a stock, the more fragmented its trading.

Remark 3.3.29. *Fixing Auctions vs Continuous Trading*
The choice of market share metric depends on the question being answered:

i. Revenue analysis: Include all trades (fixing, continuous), though fee structures may differ.
ii. Probability of execution on venue: Use $M_k^T(n)$ and separate fixing from continuous auctions, since fixing auctions often have 100% probability on a single venue.
iii. Probability per unit of currency: Use $M_k(n)$ separately for fixing and continuous.

Definition 3.3.30. *Fixing Auction Market Share Distortion*
Fixing auctions significantly distort market share calculations as primary markets typically maintain a monopoly on fixing auction trading. Let venue $T(n)$ have average market share $m(n)$ during fixing auctions, and let fixing auctions represent weight p of overall daily trading volume (where $T = \sum_{1\le \ell\le T} P^k_\ell V^k_\ell$ is average daily turnover). The relationship between market share excluding versus including fixing auctions is:

$$M(n; \text{ex-fixing}) \approx \frac{1 - m(n)p}{1-p} \cdot M(n; \text{all included})$$

The distortion is proportional to fixing auction weight p and venue's monopoly share $m(n)$ during those auctions.

Remark 3.3.31. *Intraday Market Share Variation*
Market share exhibits strong intraday variation, with different patterns on opening hours, mid-day trading, and closing sessions. This temporal dependence means market share must always be reported with specification of:

i. Time interval considered (first hour, last hour, full day)
ii. Whether fixing auctions are included or excluded
iii. Which fixing auctions are included (opening, closing, intraday, volatility interruptions)

Failure to separate fixing from continuous trading can lead to misleading conclusions about venue competitiveness and liquidity fragmentation.

Remark 3.3.32. *Drivers of Market Fragmentation*
Fragmentation benefits from several factors:

i. Market Transparency: Enables venues (such as ATSs) to reliably guarantee to match main market best prices without price discovery effort.
ii. Technological Changes: Distribution of prices and order flow between venues easier.
iii. Regulatory Policy: Mandates transparency and encourages competition by allowing venue linking.

To capture order flow from established markets, competing venues offer additional functionality such as anonymity, better block order handling, or lower costs. Some offer inducements like rebates for orders supplying liquidity, or direct payments to brokers (payment for order flow, criticized as it does not go to customer). As markets are linked, consequences of fragmentation can be minor. One main issue: fragmented markets only truly support price priority. Secondary priorities (time, size) not fully supportable across multiple linked markets when large orders trade through a range of prices at one venue. Most markets are in constant flux; new trading venues appear whilst fierce competition results in many merging or failing.

3.3.7 Auction Mechanisms

3.3.8 Brokers and Intermediaries

3.4 Price Formation and Bid-Ask Spreads

Definition 3.4.1. *Price Formation Process (PFP)*
Mechanism by which markets balance supply and demand via the occurrence of deals between traders, forming prices that constitute a fair view of the value of exchanged assets.

i. Market Impact: trading pressure not consistent with market consensus generates temporary impact. When this is coherent with market, the impact is permanent.
ii. Temporary Imbalances: Oscillating prices come from temporary imbalances between buyers and sellers that could be suppressed if investors were more synchronised.
iii. Market-Makers' Role: Profit from temporary impact by buying from early sellers and selling to later buyers. Exposed to risk from unexpected news between arrival of sellers and buyers.

Remark 3.4.2. *Information and Liquidity Paradox*
The more information available, the better the PFP. But trader fears information leakage and the threat of being front-run or having excessive market impact. Market design must balance to allow enough information sharing to ensure a fair PFP, while protecting each investor's interest from information leakage.

Remark 3.4.3. *Best Execution*
Best execution is not simply about immediate price improvement on aggressive orders. In fragmented markets, best execution requires:

i. Consolidated access to liquidity for both passive and aggressive orders.
ii. Access to internal crossing engines to value "natural liquidity" from final investors.
iii. Protection from information leakage and front-running by faster players.
iv. Consideration of adverse selection, passive split, and reversal measurements over longer time scales.

The concept of "efficient execution" can only be defined on a long time scale and must relate to the investment style of the order originator.

3.4.1 Price Discovery

3.4.2 The Bid-Ask Spread

3.4.3 Spread Decomposition

3.4.4 Tick Size and Discreteness

3.4.5 Price Impact Signatures

3.5 Information and Adverse Selection

3.5.1 Informed vs. Uninformed Trading

3.5.2 The Kyle (1985) Model

3.5.3 The Glosten-Milgrom (1985) Model

3.5.4 Probability of Informed Trading (PIN)

3.5.5 Order Flow Toxicity

3.6 Inventory Models of Market Making

3.6.1 Inventory Risk

3.6.2 The Stoll Model

3.6.3 The Ho-Stoll Model

3.6.4 The Amihud-Mendelson Model

3.6.5 Modern Inventory Control

3.7 Liquidity

Definition 3.7.1. *Liquidity Risk*

i. Time period to find needed liquidity, where prices can change adversely.

ii. Market impact due to potential sellers observing order book dynamics and offer worse prices.

Definition 3.7.2. *Liquidity Proxies*

i. Bid-Ask Spread: Distance between best bid-ask prices. Short-term proxy without emphasise on quantities.

ii. Round Trip Cost: Net loss on an immediate buy then sell of a given quantity. Accounts for depth. Computing over several quantities yields a curve associating a price to each possible demanded quantity.

iii. Market Depth: The quantities available at each price level in the order book.

3.7.1 Dimensions of Liquidity

3.7.2 Liquidity Measures

3.7.3 Liquidity Provision and Consumption

3.7.4 Liquidity Risk

3.7.5 Intraday Liquidity Patterns

3.8 Transaction Costs

3.8.1 Transaction Cost Taxonomy

Remark 3.8.1. *Spread Types for Cost Measurement*
Cost differences for effective and realised spreads to be doubled, as both are calculated using the mid price.

i. Quoted spread: Market quality measure (best bid − offer price)

ii. Effective spread: Execution cost (trade price − quote midpoint when order was received)

iii. Realised spread: Trading intermediary profits (trade price − quote midpoint 5 minutes after the trade)

Remark 3.8.2. *Benchmark Types for Cost Measurement*

i. Post-Trade: closing prices. Used as milestone for mark to market, and P&L computations

ii. Intraday: Open-High-Low-Close (OHLC), Time Weighted Average Price (TWAP), Volume Weighted Average Price (VWAP). Accurately reflect intraday market conditions.

iii. Pre-Trade: previous close, open price, decision price, arrival price. Measure of performance on average price achieved in execution, and market price when investor decision was first made.

Remark 3.8.3. *Components of Transaction Costs*

i. Explicit: commissions, fees, and taxes, quoted in basis points.

ii. Implicit: timing cost, delay cost, impact, opportunity cost.

3.8.2 Implementation Shortfall

3.8.3 Trading Benchmarks

3.8.4 Transaction Cost Analysis (TCA)

3.8.5 Cost Models

3.9 Market Impact

3.9.1 Temporary vs. Permanent Impact

3.9.2 The Almgren-Chriss Impact Model

3.9.3 Square-Root Impact Models

3.9.4 Impact Decay and Resilience

3.9.5 Cross-Impact and Multi-Asset Effects

3.9.6 Empirical Impact Estimation

3.10 Optimal Execution Theory

3.10.1 The Optimal Execution Problem

3.10.2 The Almgren-Chriss Framework

$$\min_{\{x_k\}} \mathbb{E}[C] + \lambda \cdot \mathrm{Var}[C] \tag{1}$$

3.10.3 Optimal Trading Trajectories

3.10.4 Risk Aversion and Urgency

3.10.5 Extensions of the Basic Framework

3.11 Execution Algorithms

3.11.1 Algorithmic Trading Overview

Although there are many variations of trading algorithms, stripping away customisations reveals a small set of core strategies commonly provided by most brokers and vendors. Understanding how these algorithms are categorised helps in selecting the appropriate execution strategy for different trading objectives.

Remark 3.11.1. *Classification by Benchmark Usage*
One classification approach is based on the benchmarks algorithms target:

i. Pre-determined benchmark: target fixed in advance (e.g., decision price for Implementation Shortfall)
ii. Dynamic benchmark: target adjusts with market conditions (e.g., intraday volume profile for VWAP)
iii. Forward-looking benchmark: aims to match a future price (e.g., Market-on-Close seeks the closing price)

Remark 3.11.2. *Classification by Fundamental Mechanisms*
Domowitz and Yegerman (2005) describe algorithm types as a continuum ranging from unstructured strategies (e.g., liquidity seeking) to highly structured approaches (e.g., VWAP). Yang and Jiu (2006) extend this by splitting the continuum into three main categories based on trader objectives:

i. Schedule-driven: follow a strictly defined trading trajectory, generally created statically from historical data. For instance, VWAP algorithms use historical intraday volume profiles as templates for order slicing over time. These algorithms are purely schedule-driven at the macro level.
ii. Evaluative: represent the middle ground, combining aspects of each approach. At the macro level they may behave in a schedule-driven fashion, whilst at the micro-level they focus on balancing the trade-off between cost and risk. Implementation Shortfall algorithms are good fits for this category.
iii. Opportunistic: completely dynamic, reacting to favourable market conditions and trading more aggressively to take advantage of them. When conditions become less favourable, they trade more passively, if at all. Liquidity-seeking algorithms fit this category.

Remark 3.11.3. *Classification by Implementation Goals*
A slightly modified scheme focuses on how traders make decisions based on objectives.

i. Impact-driven: aim to minimise overall market impact by reducing effect trading has on asset price. Large orders are split into smaller ones and traded over longer periods. VWAP is the archetypal example.

ii. Cost-driven: reduce overall trading costs, accounting for market impact, timing risk, and price trends. Implementation Shortfall most commonly used, serving as an important performance benchmark.

iii. Opportunistic: Take advantage whenever market conditions are favourable, typically being price or liquidity-driven, or involving pair/spread trading. i.e., Price Inline and Liquidity-driven algorithms.

Remark 3.11.4. *Algorithm Sensitivity Factors*
Different algorithm types exhibit varying sensitivities to market factors:

i. Pre-determined benchmark: TWAP, VWAP, POV algorithms

ii. Price sensitivity: Implementation Shortfall, Adaptive Shortfall, Price Inline algorithms

iii. Volume sensitivity: POV, Adaptive Shortfall, and opportunistic strategies

Table 1: Algorithm Classification by Implementation Goals

Type	**Key Focus**	**Algorithms**	**Benchmark**		**Sensitivity**	
			Dynamic	Pre-det.	Price	Volume
Impact-driven	Time	TWAP	$\checkmark$			
	Volume	VWAP	$\checkmark$			
		POV		$\checkmark$		$\bullet$
	Impact	Minimal Impact	$\checkmark$		$\circ$	$\circ$
Cost-driven	Price/Risk	Implementation Shortfall		$\checkmark$	$\circ$	$\circ$
		Adaptive Shortfall		$\checkmark$	$\bullet$	$\circ$
		Market On Close	$\checkmark$		$\circ$	$\circ$
Opportunistic	Price	Price Inline		$\checkmark$	$\bullet$	$\circ$
	Liquidity	Liquidity-driven		$\checkmark$	$\circ$	$\circ$
	Ratio/Spread	Pair/Spread trading		$\checkmark$	$\bullet$	

$\bullet$ = often sensitive, $\circ$ = sometimes sensitive

Remark 3.11.5. *Common Algorithm Parameters*

i. Specific parameters: Used to specify algorithm-specific behaviour. For example, how much a VWAP algorithm may deviate from the historical volume profile, or the participation required for a POV algorithm.

ii. Generic parameters: Common details, i.e., when to start and stop, whether to enforce a limit price cap.

Remark 3.11.6. *Timing Parameters*

i. Start/End Times: specific time act as hard limits even when cost-based algorithms derive their own optimal horizons. Orders with insufficient time horizons may be rejected.
Defaults: start time = now (or market open), end time = market close. Timezone handling is critical for correct transmission and interpretation. Multi-day trading requires explicit end dates.

ii. Duration: may be used instead of end times

Remark 3.11.7. *Execution Control Parameters*

i. Must-be-filled: ensure algorithm trades any residual amounts with specialised finish up logic (aggressive), which will affect overall cost/performance.

ii. Execution Style: passive, aggressive or neutral trading. Aggressiveness is a function of both size and price, so an aggressive algorithm will often execute more quickly, but at a higher impact cost than a passive one.

iii. Limit Price: offers price protection just as it would for a limit order.

Remark 3.11.8. *Volume Constraint Parameters*

i. Volume Limit (Maximum): prevents algorithm from trading more than a certain percent of the actual market volume. For preventing signalling risk, use minimal impact or liquidity-driven algorithm.

ii. Volume Limit (Minimum): may have substantial effect on market impact costs.

iii. Volume Limit (Child): limits on size of child orders, or number of orders that can be extant at any one time. For preventing signalling risk, use minimal impact or liquidity-driven algorithm.

Remark 3.11.9. *Auction Participation*

i. Auctions: flag to specify whether the order may participate in opening, closing and any intraday auctions. There may be parameters to state this as a percentage of the order size.

3.11.2 Scheduled Algorithms

Scheduled algorithms split large orders into smaller child orders to reduce market impact. TWAP and VWAP represent the first generation, tracking statically created trajectories based on their respective benchmarks with little sensitivity to market conditions. Their primary aim is complete execution within the given timeframe.

Remark 3.11.10. *Time Weighted Average Price (TWAP)*

i. Benchmark: average market price

ii. Execution: based on a uniform time-based schedule, child orders are issued at regular intervals for equal sizes throughout the trading period. The idealised completion rate charts are straight lines.

iii. Signalling Risk: other market participants only do not know total size of order. Potential poor execution quality when prices become unfavourable or available liquidity suddenly drops.

iv. Randomised TWAP: approach tracks linear target completion profile. Algorithm vary both frequency and size of trades while maintaining overall schedule, reducing predictability and signalling risk, though execution may lag or lead the target at intermediate points.

v. Common Variations:

   1. Aggressive/Passive Tilting: aggressiveness issue more orders early, reducing timing risk. Passiveness result in lower market impact costs.
   2. Price Adaptive: adjust schedule dynamically based on market price

vi. Special Parameters

   1. Tracking: controls how closely the algorithm tracks the target completion profile via on/off switches or limits (percentage/cash value) for schedule deviations. Inferred from execution style parameters.
   2. Interval Frequency: controls trading frequency and whether randomisation is used to vary intervals.

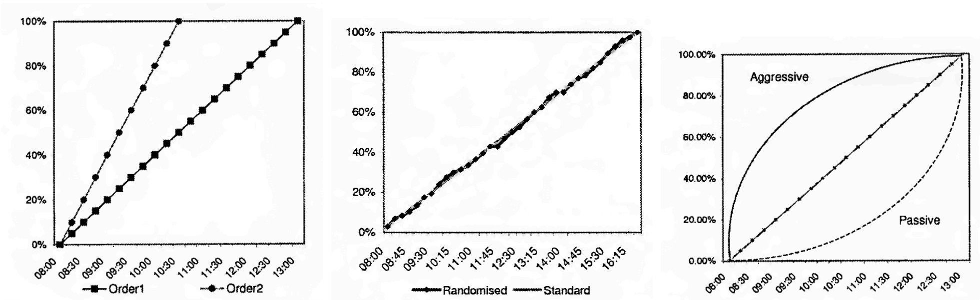

Figure 5: TWAP Completion Rates: simple uniform slicing, randomised, tilted aggressive/passive

Remark 3.11.11. *Volume Weighted Average Price (VWAP)*
Volume-weighted average corresponding to overall turnover divided by total volume

$$VWAP = \left(\sum_n v_n p_n\right) / \left(\sum_n v_n\right)$$

where v_n is the size and p_n is the price of trade n.

i. Benchmark: total traded value divided by total traded quantity. Reflects market conditions.

ii. Execution: requires trading in proportions matching expected volume distribution. As intraday volume is unknown, historical volume profiles used. Optimal trading schedule is $x_j = u_j X$ where u_j is percentage of daily volume traded at period j, X is total order size.

iii. Adaptive Variants: monitor current market conditions, creating a hybrid with dynamic volume participation. May also adjust to short-term price and volume trends.

iv. Special Parameters:

   1. Tracking: control over how closely algorithm tracks target completion profile via custom parameters or inferred from execution style.
   2. Start/End Time: can be specified for specific interval; otherwise defaults to whole trading day.

3. Trending/Tilting: VWAP is acceptable benchmark when no specific price view exists. If price expected to trend, tilting target execution profile towards start or end may be expensive.

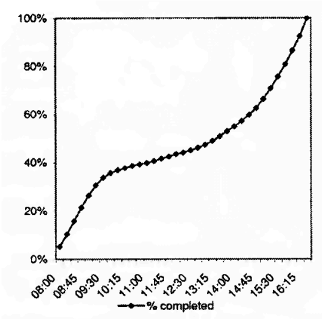

Figure 6: VWAP Completion Rate

Remark 3.11.12. *Percent of Volume (POV)*

i. Execution: participate in market at a given rate in proportion with market volume. Completes as soon as the market volume allows, or at specified end time.

ii. Market Impact Risk: multiple competing POV algorithms on illiquid assets can drive each other. Signalling risk is lower than uniform slicing since trading pattern varies with market conditions.

iii. Variants:

   1. Volume Forecasting: using historical profiles and current observed volume
   2. Price Adaptive: adjust participation rate based on how current market price compares to a benchmark price, or relative price changes for other assets.
   3. Corporate Buyback: strict timing, price, volume conditions per SEC Rule 10h-18 safe harbour provision, which protects issuers against liability for market manipulation.

iv. Special Parameters:

   1. Participation Rate: specify percentage of observed market volume to match.
   2. Tracking: Control over how closely algorithm tracks target participation rate
   3. Volume Filters: prevent unnecessary chasing of volume by excluding or setting maximum trade size limits. May track from primary exchange, composite volume, or all venues.
   4. Start/End Time: only track volume while active. End time as firm limit, completion not guaranteed.
   5. Must-be-Filled: flag for 100% completion, allowing trading style changes as time runs out.
   6. Limit Price: ignore trades outside the limit.
   7. Execution Style: passiveness for price improvement, aggressiveness to track participation more closely, especially for illiquid assets.

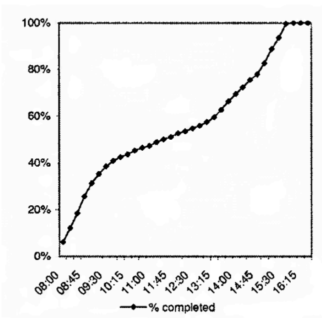

Figure 7: POV Completion Rate

Remark 3.11.13. *Minimal Impact Algorithms*

Focus on minimising market impact. Leverage dark pool ATSs, broker crossing networks, and hidden order types to reduce signal leakage risk.

i. Execution: simplest is to route entire order to dark pool ATS. As ATS fill rates can be low, split order by leaving most on ATS, trade remainder using passive VWAP or POV, or even liquidity-driven algorithm.

ii. Variants:

1. ATS Fill Models: estimate probability of ATS fills to determine optimal order allocation.
2. Impact Cost Models: forecast potential costs to use as benchmarks or compare against alternatives.
3. Stealth-Based Approaches: reduce impact via similar logic to liquidity-driven algorithms.

iii. Special Parameters:

1. Visibility: controls how much of order is displayed at execution venues. No visibility means dark pool only; low visibility uses hidden order types or IOCs at other venues.
2. Must-be-Filled: focused solely on reducing impact cost at risk of incomplete execution. A requirement for full fill may make a cost-based algorithm more appropriate.

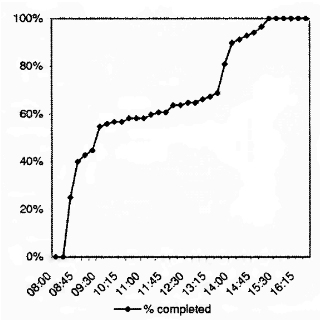

Figure 8: Minimal Impact Algorithm Completion Rate

3.11.3 Implementation Shortfall Algorithms

3.11.4 Opportunistic Algorithms

3.11.5 Smart Order Routing (SOR)

3.11.6 Algorithm Selection

3.12 Advanced Execution Methods

3.12.1 Stochastic Control for Execution

3.12.2 Limit Order Placement

3.12.3 Execution with Signals

3.12.4 Multi-Asset Execution

3.12.5 Execution with Constraints

3.12.6 Reinforcement Learning for Execution

3.13 Market Making Foundations

3.13.1 The Role of Market Makers

3.13.2 Market Making Economics

3.13.3 Market Making Risks

3.13.4 Designated vs. Competitive Market Making

3.13.5 Modern Market Making

3.14 Market Making Models

3.14.1 The Avellaneda-Stoikov Model

$$\delta^{a,b} = \frac{\gamma\sigma^2(T-t)}{2} + \frac{1}{\gamma}\ln\left(1+\frac{\gamma}{k}\right) \tag{2}$$

3.14.2 Extensions with Adverse Selection

3.14.3 Guéant-Lehalle-Fernandez-Tapia Model

3.14.4 Market Making with Constraints

3.14.5 Multi-Asset Market Making

3.14.6 Numerical Methods for Market Making

3.15 Market Making in Practice

3.15.1 Inventory Management Systems

3.15.2 Quote Management

3.15.3 Adverse Selection Detection

3.15.4 Technology Infrastructure

3.15.5 Market Making Across Asset Classes

3.15.6 Performance Measurement

3.16 High-Frequency Trading Ecosystem

3.16.1 Defining High-Frequency Trading

3.16.2 HFT Strategies

3.16.3 Technology and Infrastructure

3.16.4 Latency and the Speed Race

Definition 3.16.1. *Nyquist-Shannon Sampling Theorem*
A signal can be perfectly reconstructed from its samples if the sampling frequency f_s is at least twice the highest frequency component $f_{\max}$ in the signal:

$$f_s \geq 2f_{\max}$$

Remark 3.16.2. *Nyquist-Shannon in Market Microstructure*
The theorem has important implications for market data and trading:

i. Aliasing: If market data is sampled too slowly relative to the true dynamics, high-frequency patterns appear as spurious low-frequency patterns. Daily data cannot capture intraday mean reversion.

ii. HFT Advantage: High-frequency traders sample orderbook states at microsecond intervals, capturing dynamics invisible to slower participants sampling at seconds or minutes.

iii. Signature Plot: Realised volatility estimates depend on sampling frequency. Too high frequency introduces microstructure noise; too low misses true volatility. Nyquist frequency identify optimal sampling rate.

iv. Epps Effect: Correlation between assets appears to decrease at higher sampling frequencies due to asynchronous trading, a manifestation of sampling issues in multivariate settings.

v. Practical Implication: To study phenomena at timescale τ, one needs data sampled at least at frequency $1/(2\tau)$. Tick-by-tick data is necessary for microstructure research.

3.16.5 HFT and Market Quality

3.16.6 The HFT Business Model

3.17 Order Flow Analysis

3.17.1 Order Book Dynamics

3.17.2 Trade Classification

3.17.3 Order Flow Imbalance

3.17.4 Queue Position and Priority

3.17.5 Order Flow Toxicity Measures

3.17.6 Machine Learning for Order Flow

3.18 Regulation and Market Structure

3.18.1 Best Execution Obligations

3.18.2 US Regulatory Framework

3.18.3 European Regulatory Framework

3.18.4 Market Surveillance

3.18.5 HFT-Specific Regulations

3.18.6 Market Structure Evolution

4 Research

4.1 Alpha Research

4.2 Research in AI

4.2.1 Reading AI Papers

Remark 4.2.1. *Reading Wide*
Navigate through literature reading small amounts of individual research papers, build and improve mental model of research topic.
On *Papers with Code*, check out top benchmark models, read abstract and take note of key information only. Next step for each model, look into the datasets used by the papers and make notes.
On *Google Scholar*, check if there is any survey papers (reviews and describe state of problem space with challenges and opportunities) to get up to speed, read each paper, and make notes.
Next find related works (recently published) to understand how researchers in the field traditionally approached the problems, and what the emerging trends are. Related works will populate reading list.

Remark 4.2.2. *Reading Deep*
First pass will not understand more than 10% of research paper, and may require reading of another more fundamental paper. Then read subsequent passes until 70% $\sim$ 80% understanding.
In introduction, highlight problems and challenges, solutions to challenges, main contributions of the work. Should be able to extract a problem-solution chain from the introduction and proposed solution.
In methods, maintain list of concepts not yet understood. If there is link to paper references, keep track.
In experiments, highlight data setup, main table of results. Keep track of unfamiliar evaluation metrics.

Remark 4.2.3. *Practical AI Research Tools*
Experiment tracking tools include 'Weights & Biases', 'Tensorboard', 'Neptune'.
If using 'Weights & Biases', model artefacts can be stored directly on a system of choice.
To train deep learning pipelines by using a config which an modify depending on which dataset, model, or configuration is used, Python's Hydra package may be used.

Remark 4.2.4. *Identifying Gaps in Research Paper*

i. Identify gaps in research question by comparing with the research hypotheses of compiled papers
ii. Identify gaps in experimental gaps, such as shortcomings in evaluation of methods, the way the comparisons were chosen or implemented, and whether the experimental setup tests the research hypothesis decisively.
iii. Identify gaps through expressed limitations, implicit and explicit.

4.2.2 Writing AI Papers

Remark 4.2.5. *Generating Ideas for Building on Research Paper*

i. Change task of interest. Can the main ideas be applied to a different modality, a different data type? Can the method or learned model be applied to a different task? Can the outcome of interest be changed?
ii. Change the evaluation strategy. Can it be evaluated on a different dataset or different metric? Explore why something works well/breaks. Make different comparisons.
iii. Change the proposed method. Can training dataset or data elements be changed? Can the pre-training/training strategy be changed? Can the deep learning architecture or problem fomulation be changed?

Remark 4.2.6. *Iterating on Research Ideas*

i. Search for whether idea has been tried. Construct titles for new paper ideas, see if there is Google result.
ii. Read important related works and follow up works.
iii. Geed feedback from domain experts on drafted ideas in written form. Email to authors of the work being built on, share idea and plan, ask their opinion.

Remark 4.2.7. *Global Structure of ML Papers*
ML Papers follow the following pattern (in 6 to 7 sections):

i. Abstract (answers 5 to 6 canonical questions in $100 \sim 250$ words):
    1. What is the background and gap?
    2. What is the key desideratum?
    3. What is the proposed solution?
    4. What are its main components?
    5. What are its strengths?
    6. What are the notable results (with tasks, numbers)?
ii. Introduction (start and end position are nearly identical across papers):
    1. Context, success of prior approaches
    2. Weaknesses or gaps of prior methods
    3. Desiderata for an improved solution
    4. Proposed method: key components, contributions
    5. High-level experimental overview, positive results
iii. Related Work/Background (typically 2 to 3 subsections), each paragraph conveys:
    1. High-level mapping of approach categories
    2. Evolution of methods over time
    3. How the proposed method compares to each category
    4. What gaps persist
iv. Methods (content always includes):
    1. Overall approach description
    2. Architecture, input/output flow
    3. Loss functions, training objectives
    4. Implementation details
    5. (Sometimes) dataset descriptions or task-specific usage
v. Experiments (how results are conveyed. Always structured as such):
    1. Overall evaluation setup
    2. Dataset description (if not earlier)
    3. Implementation details
    4. Results per task type (tables/figures)
    5. Ablations at the end
    6. References to earlier figures and comparisons to prior models

vi. Conclusion, Broader Impacts (mirrors abstract but expands):

1. Solution, components
2. Strengths, notable results
3. Future directions
4. Limitations and societal considerations
5. Motivations for follow-up work

Remark 4.2.8. *Figure Progression of ML Papers*
ML Papers follow the following pattern for figures:

i. Method overview diagram (always first)
ii. Lower-level architecture or objective illustration
iii. Comparisons vs. prior models across multiple tasks
iv. Ablation studies
v. (Optional) qualitative examples, predictions, dataset samples

5 Appendix

Miscenllaneous supplementary material that does not fit elsewhere.

5.1 Financial Calculator Guide (TI BA Pro)

Method 5.1.1. Settings calibration

i. *Reset calculator*: $\boxed{2ND}$ $\boxed{+|-}$

ii. *Increase to 9 decimal*: $\boxed{2ND}$ $\boxed{.}$ (FORMAT) $\boxed{9}$ $\boxed{\text{ENTER}}$

iii. *Set period to 1 year*: $\boxed{2ND}$ $\boxed{\text{I/Y}}$ (P/Y) $\boxed{1}$ $\boxed{\text{ENTER}}$

iv. *Set as AOS mode*: $\boxed{2ND}$ $\boxed{.}$ (FORMAT) $\boxed{\uparrow}$ $\boxed{2ND}$ $\boxed{\text{ENTER}}$

Method 5.1.2. Calculator Reset

i. *Backspace button*: $\boxed{\rightarrow}$, i.e., pressing $\boxed{2}$ $\boxed{\times}$ $\boxed{3}$ $\boxed{\rightarrow}$ $\boxed{2}$ $\boxed{=}$ will give 4.

ii. *Clear previous entry*: $\boxed{CE|C}$

iii. *Clear everything*: $\boxed{CE|C}$ $\boxed{CE|C}$

iv. *Clear TVM worksheet*: $\boxed{2ND}$ $\boxed{FV}$ (CLR TVR)

Method 5.1.3. Memory management

i. *Store in memory*: $\boxed{STO}$ ($\boxed{0}$ to $\boxed{9}$)

ii. *Recall from memory*: $\boxed{RCL}$ ($\boxed{0}$ to $\boxed{9}$)

iii. *Recall last answer*: $\boxed{2ND}$ $\boxed{=}$

iv. *Clear all memory and store values*: $\boxed{2ND}$ $\boxed{0}$ $\boxed{2ND}$ $\boxed{CE|C}$

Method 5.1.4. Computation Shortcuts

i. *Set up calculator for single variable statistics*: $\boxed{2ND}$ $\boxed{8}$, then $\boxed{2ND}$ $\boxed{\text{ENTER}}$ until 1-V, then $\boxed{CE|C}$.

Enter data setting and clear the data: $\boxed{2ND}$ $\boxed{7}$ $\boxed{2ND}$ $\boxed{CE|C}$.

Enter single-var data: [VALUE] $\boxed{\text{ENTER}}$ $\boxed{\downarrow}$ $\boxed{\downarrow}$, enter value in X (data), and leave Y as 1 (frequency).

Enter stats function and toggle $\boxed{\downarrow}$ to see mean, sample s.d., population s.d.
For weighted returns, use X as the return, and Y as the weights.

ii. *Covariance and correlation*: $\boxed{2ND}$ $\boxed{8}$, then $\boxed{2ND}$ $\boxed{\text{ENTER}}$ until [LIN], then $\boxed{CE|C}$.

Enter data setting and clear the data: $\boxed{2ND}$ $\boxed{7}$ $\boxed{2ND}$ $\boxed{CE|C}$.

Enter data: [VALUE] $\boxed{\text{ENTER}}$ $\boxed{\downarrow}$ $\boxed{\downarrow}$, enter value in X and Y.

Enter stats function and toggle $\boxed{\downarrow}$ to see r, Sx and Sy, then compute covariance as $Sx \times S_y$.
Correlation is simply the value r computed earlier.

iii. *Time value of money*: Input values into all except one of these: $\boxed{\text{N}}$ $\boxed{I/Y}$ (%), $\boxed{\text{PV}}$, $\boxed{\text{PMT}}$, $\boxed{\text{FV}}$. Then use $\boxed{\text{CPT}}$ on the target variable to solve for the results.

iv. *Interest rate conversion*, i.e., convert nominal 10%, $m = 12$ payments per year into effective rate.
$\boxed{2ND}$ $\boxed{2}$ (ICONV) $\boxed{\uparrow}$ $\boxed{12}$ $\boxed{\text{ENTER}}$, $\boxed{\downarrow}$ $\boxed{10}$ $\boxed{\text{ENTER}}$, $\boxed{\downarrow}$ $\boxed{\text{CPT}}$ to get effective rate.

v. *Cash flow computation*: clear memory with $\boxed{\text{CF}}$ $\boxed{2ND}$ $\boxed{CE|C}$, then input [VALUE] $\boxed{\text{ENTER}}$ $\boxed{\downarrow}$.

Enter interest rate with $\boxed{\text{NPV}}$ [VALUE] $\boxed{\text{ENTER}}$ $\boxed{\downarrow}$, then $\boxed{\text{CPT}}$ to get present value, PV.

vi. *Amortisation schedule*: i.e., \$1000 on 3-year loan, interest rate of 10%.
Check payment per year, make sure it is 1 (with $\boxed{2ND}$ $\boxed{I/Y}$).
Input information with $\boxed{3}$ $\boxed{\text{N}}$ $\boxed{10}$ $\boxed{I/Y}$ $\boxed{1000}$ $\boxed{\text{PV}}$ $\boxed{\text{CPT}}$ $\boxed{\text{PMT}}$.
Before using amortisation worksheet, clear memory with $\boxed{2ND}$ $\boxed{\text{PV}}$ (AMORT) $\boxed{2ND}$ $\boxed{CE|C}$.
To see interest and principal repayment at each time period, set $P1$ as $\boxed{t}$ for year t, then use $\boxed{\text{CPT}}$ $\boxed{\downarrow}$ to see the values at each time period.

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