Advanced Python for Finance

Lecture 1

Class Agenda

Lecture 1: Market Microstructure and Limit Order Books
- Supply and Demand and Execution Objectives
- Order types and behaviors
- Limit Order Books: Design and Construction
- Price / Time Priority and other Matching Logic Variations
- Multiple order books and fragmented markets
- Case Study: construction of a limit order book using Python and Pandas

Lecture 2: Market Data and Transaction Cost Analysis
- Types of Market Data used in model testing and simulation
- Working with Bar Data
- Working with tick Data
- Simulating stock behavior
- Case Study 1: Monte Carlo Simulation and stock price analysis
- Case Study 2: Moving averages, MACD, etc.

Lecture 3: Execution Strategy Types
- Time Weighted Average Price
- Volume Participation
- Volume Weighted Average Price
- Event Driven Strategies
- Order Routing
- Case Study: Developing a first Execution Algorithm

Lecture 4: Simulating Execution Algorithms
- Trading Volume Distribution and Prediction
- Rules and factor based approaches
- Transaction Cost Analysis: analyzing trade performance
- Tick data and implications for Order State Management in Simulations
- Developing a simple predictive model
- Case Study: Combining multiple factors into a trading strategy

Week 5: Review and TBD

Week 6: Project Presentations

Assignments

- Weekly Assignments
  - Hands on experience with the tools
  - Write a little code
  - Answer some questions
  - Submit answers and code

- Class Participation
  - This is your class! Ask questions!
  - The more interactive, the better

- Final Project and Presentation!

Final Project and Presentations

- Get some sample financial data (we'll discuss where and how later)
- Load, clean, analyze and present this data
- Written Assignment
  - Describe what question you were asking
  - Describe your data (and note the data source!!!)
  - Describe what challenges / processing of the data you had to do
  - No more than five to ten slides
  - Include your code (program or python notebook)
- Class presentation
  - No more than ten minutes
  - Describe what your project
  - Prepare to answer questions about your project!

Lecture 1

Market Microstructure and Limit Order Books

- Supply and Demand and Execution Objectives
- Order types and behaviors
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Supply, Demand
and Execution Objectives

Market Microstructure

- Market microstructure is the study of *processes and outcomes* of *exchanging assets* under explicit *trading rules/mechanisms*.
- Market microstructure research exploits the structure provided by specific trading mechanisms to model *how prices are formed* and how *price-setting rules evolve* in the markets.
- As microstructure research is set in the markets for financial assets, this enhances our ability to understand both the *returns* to financial assets and the processes by which markets become *efficient*.
- Aside from being valuable for illuminating prices and markets, microstructure research has immediate application in the *regulation of markets*, and in design and *formulation of new trading mechanisms*.

Prices and Markets

What determines a price?

In the standard economics paradigm, it is the *intersection of supply and demand curves* for a particular good:

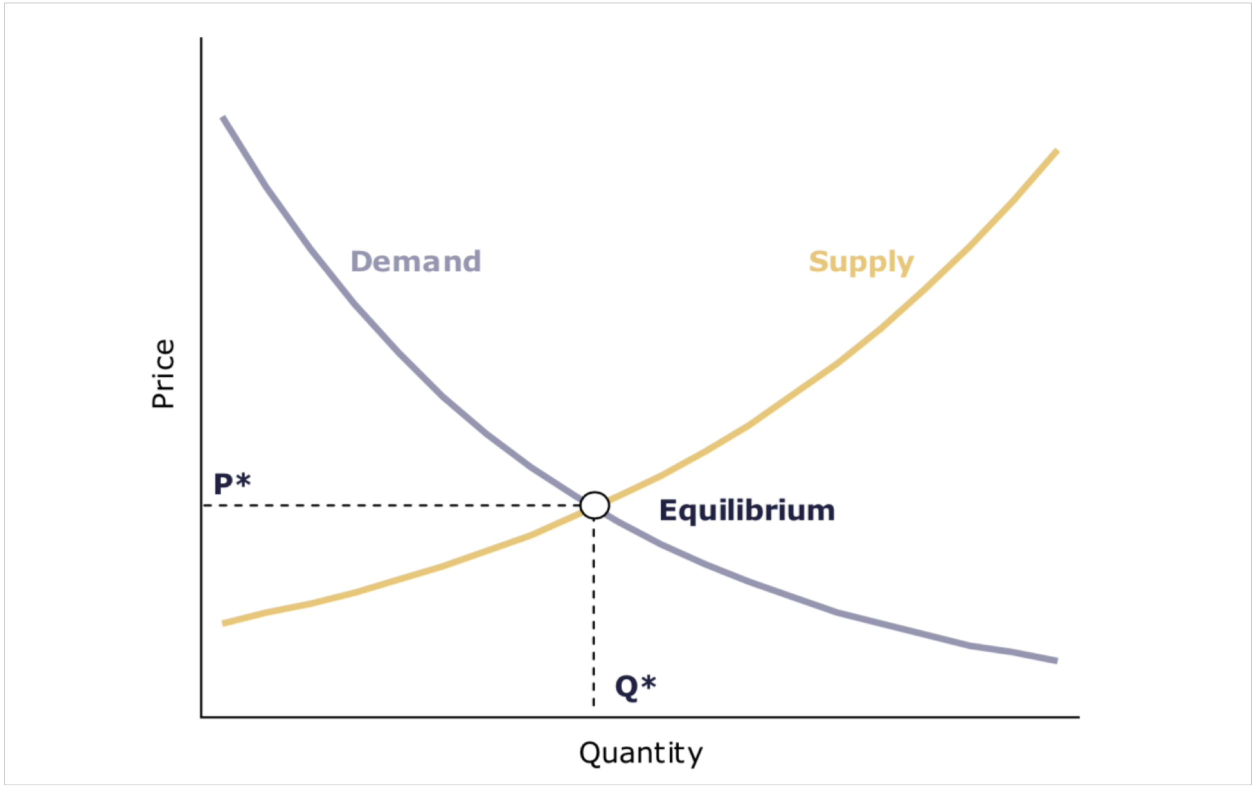
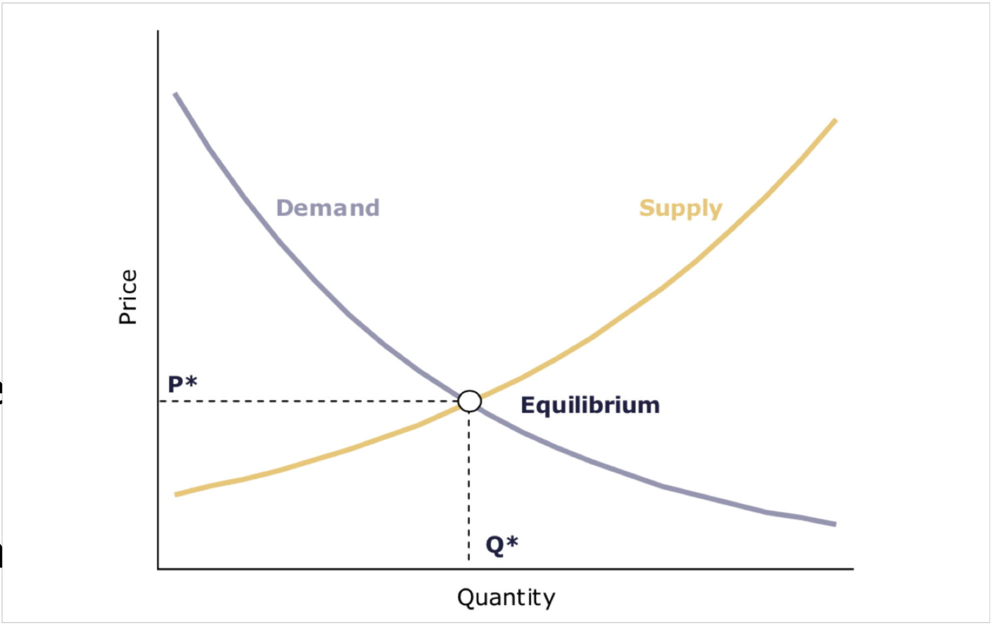


Figure 1: Supply and Demand Curves and Equilibrium Prices

Prices and Markets

- In equilibrium, this certainly must be the case.
- But *how*, exactly is this equilibrium actually attained?
- What is in the economy that coordinates the desires of demanders and suppliers so that a price emerges and trade occurs?
- This is study of price formation is a key element of microstructure research.



Price Formation

There are *two traditional approaches* to the mechanism for *price formation*.

1. The Agnostic (General Equilibrium) Approach

2. The Walrasian Auctioneer

The Agnostic (General Equlibrium) Approach)

- The Trading Mechanism is irrelevant!
- Since much of economics involves the analysis of equilibrium, what mattered were the properties of the <u>*equilibrium prices*</u>.
- These properties can be determined by simply solving for the <u>*market-clearing price*</u>; how exactly this market clearing was achieved was not of interest.
- Such an *agnostic* approach to price setting can be found for example in *rational expectation* literature where the questions of interest involve how traders use information in prices to determine their equilibrium demands, and where behavior out of equilibrium is *not* considered.
- Two advantages of this approach are its simplicity and its generality. Implicit in this approach, however, is the assumption that the trading mechanism plays *no role* in affecting the resulting equilibrium; that whatever the trading mechanism employed, the *same* equilibrium will arise.
- Though simplifying, this assumption is particularly *troubling* for markets in which traders have <u>*differential (asymmetric) information*</u>.

The Walrasian Auctioneer

The price formation process could be captured by the general representation of a *Walrasian auctioneer:*

- This auctioneer *aggregates* traders' demands and supplies to find a *market-clearing price*.
- The actual mechanism by which this occurs begins with each trader submitting his demand, or even his demand schedule, to the auctioneer.
- The auctioneer announces a *potential* trading price.
- Traders then determine their optimal demands at that price.
- No actual trading occurs until each trader has a chance to *revise* his order.
- A new potential price is suggested, traders again revise any orders, and the process continues until there is no further revision.
- Equilibrium prevails where each trader submits his optimal order at the *equilibrium price*, (the price at which quantity supplied *equals* the quantity demanded)

The Walrasian Auctioneer, cont'd.

- This representation views markets prices as arising from a process of *tatonement*, or a series of preliminary auctions.
- There is *no* trading allowed outside equilibrium and incentive issues are not considered.
- Because the price is adjusted until there is no excess demand, the Walrasian auctioneer does not take any trading position, but serves *only* to redirect quantities from sellers to buyers.
- Moreover, this auction activity is *costless*, so there are no frictions in the exchange process.
- The equilibrium price thus emerges as the natural outcome of an unseen trading game in which buyers and sellers costlessly exchange assets.

Microstructure's Beginnings

- The Walrasian auctioneer provides a simple and elegant way to envision the price-setting process. But does it, in fact, capture the actual process by which prices are formed?
- In the case of financial assets, there are markets (e.g. London gold fixing) that bear at least an approximate resemblance to the Walrasian framework.
- But there are many other markets that *differ dramatically*, with specific market participants playing roles *far removed* from the *passive* one of the auctioneer.
- Perhaps more important is the issue of *trader behavior*. If trading involves more than simply matching supplies and demands in equilibrium, then the trading mechanism may have an importance of its own.
- Such concerns raised by a number of economists led to the formal study of microstructure.
- The most critical analysis of trading was that of Demsetz [1968], who examined (along with the nature of transaction costs) how the time dimension of supply and demand affected market prices, setting the stage for formal study of market microstructure.

Microstructure's Beginnings

- Demsetz began with the simple observation that trade may involve some *cost*.
- This cost could be ***explicit***, arising, for example, from the charges levied by a particular market venue (operations, equipment, etc.),
- Or it could be ***implicit***, reflecting costs connected with the immediate execution of trades. These implicit costs, referred to as the *price of immediacy*, arose because, unlike in the Walrasian auction, trading had a *time dimension*.
- In particular, while over time the number of sellers might equal the number of buyers, at any particular point in time such an outcome was *not* guaranteed.
- If the number of traders wishing to sell immediately did not equal the number who wished to buy immediately, the imbalance of trade would make it impossible to find a market-clearing price at a give time *t*.

The Time Dimension of Trading

Let’s look at the Widget Market

Scenario 1:

1. One market participant wishes to buy at the same time another wishes to sell
2. An orderly auction (whether Walrasian or otherwise) can proceed
3. An equilibrium price is established and a trade occurs

Scenario 2:

1. One market participant wishes to buy (or sell) but no other market participants wish to sell (or buy) *at that time.*
2. How can an equilibrium price be achieved???

The Price of Immediacy

By paying a price! Demsetz argued that this lack of equilibrium could be *overcome* by paying a price for immediacy:

- Specifically, at any point in time there are *two sources* of supply and demand in the markets
- On the demand side, there is one demand arising from traders who want to buy *immediately*, and other coming from traders who want to buy but do not feel the need to do so at this particular time
- The same is true on the supply side
- If there is an imbalance of traders wanting to buy now, then either
  - Some buyers have to wait for sellers to arrive, or
  - Buyers can offer a *higher price* to induce waiting sellers to transact immediately
  - Similarly, if there is an imbalance of *sellers* wanting to trade now, a *lower price* must be offered to induce more demanders (buyers) to trade immediately
- This results in *two prices*, not one, characterizing the equilibrium

Departure from the Walrasian Framework

- This idea that the price could contain a cost of immediacy captured an aspect of price process not envisioned in Walrasian framework.

- Now there are actually *two supply curves* and *two demand curves*, reflecting the *two time frames* of the trading process.

- While a traders willing to wait might trade at the simple price envisioned in the Walrasian framework, trades occurring immediately would not share this outcome.

- This meant that even the notion of an equilibrium price was problematic – the price depended on whether one *wanted* to buy or to sell, and not simply on the *willingness* to trade

Departure from the Walrasian Framework

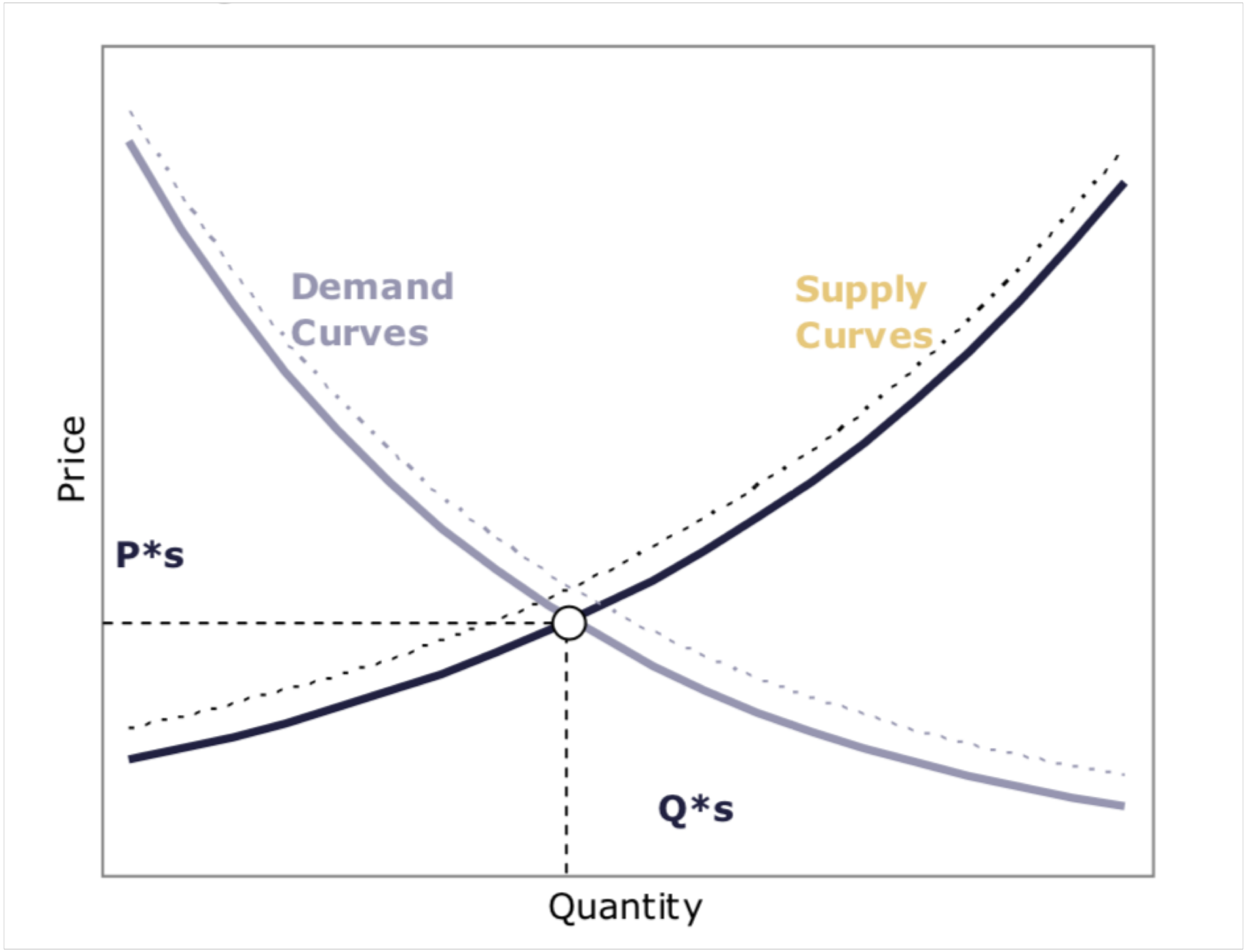


Figure 2: Multiple Supply and Demand Curves and Prices

Departure from the Walrasian Framework

- Of equal importance was the implication that the specific ***structure*** of the market mechanism could ***affect*** the trading price.
- Since the size of the price concession needed to trade immediately, i.e. the ***spread***, depended on the number of traders, factors such as volume could affect the cost of immediacy and thus the market price.
- Demsetz addressed these structural issues, and empirically investigated the relation of the size of the spread and the volume of trade on NYSE. His work suggested that the behavior of the markets, much like the behavior of the firms, cold *only* be understood by examining their structure and organization.
- If the actual mechanism used to set prices is *not merely a channel* to an inevitable outcome, but rather is an *input* into the equilibrium price itself, then how such mechanisms work cannot be ignored.

Departure from the Walrasian Framework

- Demsetz's model analyzes the behavior of one simple trading mechanism, and has limited scope in addressing the much more complex aspects observed in actual trading mechanisms.
- Equally important, however, are the *interactions* between the *market mechanism* and *trader behavior*.
- If the trading mechanism matters in setting prices, then so too will it matter in affecting trader's *order decisions*.
- Consequently, the *exogeneity* of the order process to the price-setting mechanism is *unlikely* to hold.
- The question of how prices are set, then, is a lot more complicated than the simple concept of the Walrasian auctioneer!

Departure from the Walrasian Framework

- Microstructure theories depart from the standard theory of exchange (in the sense of Walrasian tatonement) by
  - Assuming market agents' trading activities are *asynchronous*, *discrete*, and *temporary*
  - And by treating moment-to-moment *aggregate exchange behavior* on the part of market agents as essential to the price-formation process and an important descriptive aspects of the markets.
- Although the study of microstructure dates back to early history, with the rapid developments in financial markets, the advent of modern exchanges and alternative exchange mechanisms and venues, the field has acquired a distinct and important identity.

Sources of Value and Reasons for Trade

Why do trades happen, and how are they valued? It is generally assumed that security value consists of *private* and *common* value components:

- Private values
  - *Idiosyncratic* to the agent and are usually known by the agent when the trading strategy is decided.
  - These components arise from the price difference in investment horizon, risk exposure, endowments, tax situations etc.
- Common values
  - The same for everyone in the market, are often realized only after trade has occurred.
  - Common value component reflects the cash flows from the security, as summarized in the present value of the flows or the security's resale value.
  - Common value effects generally dominate the private value effects in security markets.

Trade Mechanisms in Economic Settings

Microstructure analyses are usually very specific about the mechanisms or *protocols* used to accomplish trade.

- One common and important mechanism is the *continuous limit order market* (LOM).
- Other specific mechanisms include
  - *bargaining*
  - *auctions*
  - *dealer markets*
  - a variety of *derivative markets*
- These mechanisms may operate in *parallel*, and hence many markets are *hybrids*.

Multiple Characterizations of Prices

- The *market-clearing price*, at least as it arises from Walrasian tatonement, *rarely* appears in microstructure analyses.

- At a single instant there may be *many prices* (See Figure 2 above), depending on
  - *direction* (buying or selling)
  - the *speed* with which the trade must be accomplished (immediacy)
  - the agent's *identity* or other attributes (transparency)
  - *trade size* (quantity)
  - and the agent's *relationship* to the counterparty

- Some prices (like bids and offers) may be hypothetical or conditional

Liquidity

"Liquidity" refers to the availability of participants and their willingness to trade in a market:

- The *more* participants there are in a market and/or the more participants are willing to trade, the more ***liquid*** a market is considered to be.

- The *less* participants there are in a market and/or the more participants are willing to trade, the more ***illiquid*** a market is considered to be.

Liquidity

Liquidity is sometimes characterized as “depth, breath and resiliency” of a market:

- In a *deep market*
  - If we look a little above the current market price, there is a *large incremental quantity* available for sale.
  - Similarly, below the current price, there is a large incremental quantity that is sought by one or more buyers.
- A *broad market* has *many participants,* none of whom is presumed to exert significant market power.
- In a *resilient market*, the *price effects* that are associated with the trading process (as opposed to fundamental valuations) are *small* and *die out quickly*.

Suppliers and Demanders

It is sometimes useful to characterize agents as *suppliers* or *demanders* of liquidity:

- Liquidity suppliers have traditionally been associated with the *financial services industry*, that is brokers, dealers and other intermediaries that are (sometimes called the *sell side*) of the market.

- Liquidity *demanders* in this view are the *customers*, the *individuals and institutional investors* characterized by trading needs (and sometimes called the *buy side*).

Suppliers and Demanders

From a narrower perspective, liquidity supply and demand differentiates agents who are available for trade or *offer the option to trade*, and those who spontaneously *decide to trade:*

- Thus, the liquidity *suppliers are passive*, and *demanders are active*. In any particular trade, the *active* side is the party who "seals the deal" by *accepting the terms offered* by the passive side. In other words, the passive side "makes" the markets and the active side "takes" the market.

- With the rise of markets that are widely, directly, and electronically accessible, the role of liquidity demander and supplier is a strategic choice that can be quickly *reversed*.

The alignment of liquidity demand and supply with a particular type of institution is therefore of diminished relevance in many (but not all!) modern markets.

Consolidation vs. Segmentation of Venues

- As we mentioned earlier, liquidity is generally *enhanced*, and individual agents can trade at lower cost, when the number of participants *increases*.

- This force favors market *consolidation* (concentration) of trading activity in a single mechanism or venue.

- Differences in market participants (e.g. retail versus institutional investors), and innovations by market participants, however, may drive market *segmentation* (fragmentation).

Consolidation vs. Segmentation of Venues

The *number of participants* in a security markets logically depends on attributes of the security, in addition to the trading mechanism.

There will tend to be greater interest (and liquidity) in a security if:

- The *aggregate value* of the underlying asset is high
- The value-relevant *information* is comprehensive, uniform, and credible
- The security is a component of an important *index*, there will be high interest in trading the security.

Transparency

Transparency is a *market attribute* that refers to how much *information* market participants (and potential participants) posses:

- *Electronic markets* that communicate the bids and offers of buyers and sellers and the process of executed trades in real time are considered *highly transparent*.

- *Dealer markets*, on the other hand, often have no publicly visible bids or offers, nor any trade reporting, and are therefore usually considered *opaque*.

- The line between these two is increasingly blurred, however, as innovation creates various types of hybrid markets.

Data Characteristics

Let’s talk about four characteristics of microstructure:

- Microstructure data are *discrete.*
- Microstructure data are often *well-ordered.*
- Microstructure data samples are typically *large.*
- Microstructure data can be considered to be *new* (and *old* as well)

Microstructure Data are Discrete

- Most microstructure series consist of *discrete* events *randomly* arrange in *continuous time*.

- Within the time series taxonomy, they are formally classified as point processes.

- Point process characterizations are becoming increasingly important, but for many purposes it suffices to treat observations as continuous variables realized at regular discrete times.

Microstructure Data are Well-Ordered

- The sequence of observations in the data set closely correspond to the sequence in which the economic events actually happened.

- In contrast, most *macroeconomic* data are *time-aggregated*. This gives rise to simultaneity and uncertainty about the direction of causality.

- The fine temporal resolution (sometimes described as “ultra-high frequency”) often supports stronger conclusions about causality.

Microstructure Data Samples are Large

- By most economic standards, observation counts are (very!) large.
- Tens of thousands of data points for a single asset on one day is not unusual.
- One would not ordinarily question the validity of asymptotic statistical approximations in the samples of this size.
- Furthermore, despite the number of observations, the data samples are often *small* in terms of *calendar span* (on the order of days or at best months).

Microstructure Data are New (and Old)

- Microstructure data samples are *new* - we don't have a long historical date for many markets, at least compared to the availability of non-microstructure economic data.

- Data samples may also be characterized as old, though, because market institutions are changing so rapidly that even samples a few years previous may be seriously out of date. It is essential to consider market structure regime changes and their potential effects on studies.

Important Microstructure Questions

Below are some significant outstanding questions (along with countless other ones) that market structure studies need to address:

- How exactly is information impounded in prices?
- How is (a given) market structure related to the valuation of securities?
- How do we enhance the information aggregation process?
- How do we avoid market failures?
- What type of trading arrangement maximizes efficiency?
- What is the most optimal reward process for liquidity provision?
- What is the trade-off between “fairness” and “efficiency”?
- What is the optimal balance between centralization and fragmentation?
- What is the significance of human interactions in trading process?

Transaction Costs

Money managers consistently *underperform* their paper portfolio benchmarks (some by as much as 2 to 3% annually).

- One contributing factor to the underperformance is the *transaction costs* associated with implementing of investment decisions.
- The implementation of a financial decision is *not free*. It has an associated cost and usually results in reduced portfolio return.
- If managers do not properly manage these costs during all phases of investment cycle, many of the fund's superior investments will become unprofitable.

Investment Cycle

The financial investment cycle consists primarily of four stages.

Transaction costs affect the decisions in *each* and every phase of the investment cycle:

- Asset Allocation
- Portfolio Construction
- Execution Services
- Performance Attribution

Asset Allocation

- The process of distributing investment dollars across various investment classes as a means of *diversifying* risk and targeting a specific level of portfolio *return*.

- The more traditional asset classes consist of cash, bond and stocks.

- More recently other investment classes such as commodities, real estate, private equity, hedge funds, oil and gas and timber have become more conventional.

Regardless of investment class, transaction costs have a *significant* effect on overall portfolio returns.

Portfolio Construction

- The portfolio construction phase of the investment cycle consists primarily of specifying the *exact instruments* to purchase or sell in each asset class, for example bonds and stocks.
- In the construction of an equity portfolio, managers often need to decide upon different categories of stock such as large cap, mid cap, or small cap; different sectors; or even the decision of growth or value stock.
- The stocks are selected based on their expected return and associated risk.
- If transaction costs are not incorporated into the investment decision, the result could be an *inefficient* portfolio mix caused by an *inaccurate* assessment of risk.

Execution Services

- The execution services phase of the investment cycle consists of the actual implementation of the investment decision.
- This phase, which is also referred to as the *implementation phase* or trading phase, involves making decision regarding how, when and where to buy or sell stocks.
- Decision makers have the responsibility of evaluating all potential trading options to determine the best method of implementing the specific trading list. They need to decide on:
  - The appropriate *trading strategy* (aggressive or passive)
  - the appropriate *trading option* (principal or agency)
  - the appropriate *trading venue* (traditional broker, ECN, or crossing system)
  - the *broker(s)* who will execute the trade.
- Since this phase is the most involved with the actual trading of an order, decision makers need to exert careful cost control.

Performance Attribution

- Involves measuring a fund’s performance and determining the reasons for missing the target level of return (either higher or lower).
- It also helps differentiate between superior stock selection and pure luck.
- For implementations, attribution (or alternatively “post-trade analysis”) refers to the measurement of *transaction costs* and assessment of *broker / trader performance*.
- The goal is to measure costs to *improve* future decisions and distinguish between exceptional broker / trader performance and luck.

Transaction Cost Components

- Transaction cost is comprised of a number of components:
  - broker commissions
  - exchange fees
  - taxes
  - bid-ask spread
  - investment delay
  - price appreciation
  - market impact
  - timing risk
  - opportunity cost.

- Each adversely affects portfolio returns in different ways and in various degrees. Transaction cost are either *visible* or *hidden*. It is the *hidden costs* that make up the largest percentage of total transaction costs and visible costs that make up the smallest percentage of total transaction costs.

- We can describe these transaction costs as a pyramid, with the most visible costs on the top (e.g, they can only be seen from a distance) and the lease transparent costs shown on the bottom (they can be only seen up close)

The Transaction Cost Pyramid

Transaction Cost Components

- In this figure, the component costs *most visible* from a distance are those costs that contribute the *least* to the total transaction cost.
- Costs *least visible* (non-transparent) from a distance contribute *most* to the total transaction cost.
- Fortunately, these non-transparent cost components provide the greatest *opportunity* for *cost reduction* by skilled mangers / traders.
- Unfortunately, the cost reduction of one non-transparent cost is typically at the *expense* of another non-transparent cost.
- Therefore, traders need to understand *all* costs and how they interact with one another.
- For example, as we reduce market impact by trading more passively we expose the fund to greater risk.
- As we trade more aggressively we reduce risk but increase market impact.
- It is not possible to reduce all costs simultaneously. Proper transaction cost management requires careful balancing of al. costs.

The Trader's Dilemma

- During the implantation of a trade list, traders experience potentially *conflicting objectives:*
  - If the trader executes too *aggressively* they incur high *market impact* costs.
  - If execution is too *passive*, traders are exposed to significant *timing risk* that could result in even higher trading costs due to adverse price movement.
- Traders should *balance* the trade-off between cost and risk, and determine an optimal balancing point consistent with fund objectives.
- Balancing these conflicting costs can be very challenging but is a critical part of the investment and execution processes.

Best Execution

Best execution means different things to different people. But it can generally be categorized as <u>*price*</u>, <u>*timing*</u> and <u>*size*</u> factors.

For example:

- Value and passive investors are concerned with *price improvement* and *preservation* of asset value.
- Growth and momentum investors require *immediacy*.
- Still others, such as *block traders* and large *mutual funds*, require liquidity and *size improvements*.

More often than not, the prescribed best execution strategy ensures <u>complete execution</u> at <u>fair market prices</u>, and more importantly within cost and price guidelines specified by managers.

Only if a strategy provides the best opportunity to achieve one’s implementation goals can it be considered a best execution strategy.

Goals of Implementation

- It is well accepted that the goal of *investment research* is the quest to uncover stocks (or other securities) most likely to achieve superior returns.
- When it comes to *implementation* of investment decisions, however, there are conflicting views regarding execution goals:
  - Some market participants believe the goal is to achieve the VWAP price because it represents a measure of fairness.
  - Some believe the goal is to achieve the closing price if that is the price that funds are valued or *marked* at.
  - Still others believe the goal is to achieve the opening price or some other price benchmark.
- These differing opinions can result in very conflicting implementation strategies.
- The one commonality, however, across all views is that <u>preservation of asset value</u> is vitally important. That is, we want to ensure that the new portfolio value is as close to the original (“decision time”, or “arrival price”) portfolio value as possible.

Goals of Implementation

- Thus, we can state the goal of implementation: to *minimize* the *difference* between the average execution price P_{avg} and the decision price at the time of investment decision P_d.
- This is formulated mathematically as:

$$Min\ \varphi = \left|P_{avg} - P_d\right|$$

Or in alternative quadratic form as:

$$Min\ \varphi = \left(P_{avg} - P_d\right)^2$$

- The value of φ is a function of random prices P_t at different times during the execution, and it is therefore itself a random variable.
- It can be best described as a distribution of expected costs and risk terms.
- The challenge is that the cost and risk terms compete with each other. Ideally both should be considered when developing an implementation strategy.
- For this reason, we will define three potential decision-making criteria incorporating cost and risk parameters that can be used by investors to develop an appropriate implementation strategy.

Goal 1: Minimize Cost

- The first criterion is to *minimize costs* within some *acceptable level of risk*.
- This quantity of risk may be specified by the firm, i.e. *maximum allowable risk exposure*, or may correspond to the level of risk from the investment model.
- This goal is formulated mathematically as:

$$Min\ \varphi = Cost$$

$$\textit{Subject to}: Risk \leq R^*$$

where R* is the maximum allowable risk exposure specified by the firm.

Goal 2: Balance the Trade-off: Cost vs Risk

- The second goal is to balance the *tradeoff* between cost and risk.
- It is often preferred by investors who are unsure of a proper maximum level of risk exposure, but have a preference to the amount of risk they will accept for a corresponding reduction in cost.
- This goal is formulated mathematically as:

$$Min\ \varphi = Cost + \lambda * Risk$$

where λ is the *risk aversion* factor that represent the investor's desired level of tradeoff between cost and risk.

Goal 3: Improving Return

- The third goal is to improve upon the price to *maximize* chances a trade is *better* than some specified cost.
- This goal is often selected by participants seeking to maximize *short-term returns* or investors seeking to maximize their chances of executing better than a principal bid. It is formulated mathematically as:

$$Min\ \varphi = Probability(Cost\ \leq C^{*})$$

where *C** is the *maximum acceptable transaction cost*, representing an upper bound on the average cost of the order.

Market Participants

The participants in and components of U.S. equity markets may be summarized as follows:

- **Customers** - are *individuals* (retail) and *institutions* (pension funds, mutual funds and other managed investment vehicles, collectively known as the *buy side*). The distinction between *retail* and *institutional* customers in mainly one of size, and should not be construed as naïve versus sophisticated. Customers often actively compete with each other in the market-making process.
- **Brokers -** act as *agents* for the customer orders and/or provide market access and often provide non-trading *services* as well (such as advice and research).
- **Dealers –** commit capital to facilitate customer orders, and act as counterparty to (i.e. trade directly with) customers.
- Brokers and dealers are collectively known as the *sell side*.

Trading Mechanisms

Trading Mechanisms

- Most markets (both displayed and non-displayed) feature an *electronic limit order book* (LOB).
- The limit order market is probably the most important mechanism of trading, and the starting point for most microstructure studies.
- But there are usually several alternative paths to accomplishing a trade for any given security.
- Most security markets are actually *hybrids*, involving *dealers*, clearing, one- and two-sided *auctions*, and bilateral *bargaining*, all of which are also discussed.

Centralized (“Floor” and Electronic) Markets

- Consolidation of trading interest (actual and potential buyers and sellers) is important because it *enhances* the likelihood that counterparties will find each other.
- Before electronic markets allowed centralization of trading to be accomplished *virtually*, consolidation could *only* take place *physically*, on the *floor* of an *exchange*.
- In a floor market, the numerous dispersed *buyers* and *sellers* are represented by a much smaller number of *brokers* who negotiate and strike bilateral deals *face to face*.
- These brokers are often called *members*, as the exchanges were historically organized as cooperatives.

Agency vs. Principal

- These members act either as *agents*, representing customers order to others, or as *principals*, taking the other side of customer orders.
- The combination of these two functions, though, may suffer from a *conflict of interest*.
- A brokers who intends to act as counterparty to his or her customer's order does not have an interest in vigorously representing the order to others on the floor who might offer a better price.
- In practice, in most modern markets the the role of the broker acting as principal or agent is very clearly defined in transactions with clients, and is in fact restricted or regulated in many markets.

Limit Order Markets

- Most continuous security markets have at least one electronic *limit order book.*
- A limit order is an *order* that specifies a *direction*, *quantity*, and *acceptable price* (e.g. “Buy 200 shares at $28 [per share]”, or “Sell 300 shares at $30.00”).
- In a limit order market, orders arrive *randomly* in time. The price limit of a newly arrived order is *compared* to those of orders already held in the system to ascertain if there is a *match*.
- For example, if the buy and sell orders just described were to enter the system (in any order), there would be no match: the price of 28 is not acceptable to the seller; a price of $30.00 is not acceptable to the buyer.
- A subsequent order to buy 100 shares at $32.00 could be matched, however, as there is an overlap in the acceptable prices. If there is a match, the trade occurs at the price set by the *first order*: an execution will take price for 100 shares at $30.00.
- We will examine Limit Order Books in detail later.

Limit Order Markets

Brokers in LOMs

- In a limit order market, buyers and sellers interact directly, using brokers mainly as the *conduit* for their orders.
- The broker may also, however, provide *credit*, *clearing and settlement services*, *information*, and possibly *analytics* designed to implement *strategies (execution algorithms)* more sophisticated than those associated with the standard order types.
- The broker does *not* usually act as counterparty to the customer trade.

Limit Order Markets

Real-time Data in Limit Order Markets

- The *data* emanating from limit order market are usually very accurate and *detailed*.
- This real-time feed allows traders to *continuously* ascertain the *status of the book* and condition strategies on this information.
- This allows record of agents’ interactions at a level of detail that is rarely enjoyed in other settings.
- There are, nevertheless, some significant generic *limitations*.
  - First, the sheer volume and *diverse attributes* of the data pose *computational challenges* and make modeling very difficult.
  - More importantly, though, the *unit* of observation is typically the *order*, and is *rarely* possible to map a particular order to others submitted or cancelled by the *same trader*, which can constrain what can be discerned about individual trading strategies.

Limit Order Books

A Closer Look

The Order Book

- The set of *unexecuted* limit orders held by the system constitutes the “book”.
- Because limit orders can be *canceled* or *modified* at any time, the book is *dynamic*, and in active markets with *automated order management* it can change extremely *rapidly.*
- These markets are usually *transparent*, with the state of the book being widely visible to most actual and potential market participants.
- The extraordinary level of transparency trades currently enjoy is a recent phenomenon. New York Stock Exchange (NYSE) rules historically prohibited visibility of the book, but in the 1990’s this was relaxed to permit visibility of the book on the trading floor. Off-floor visibility was not available until January 2002.
- A market might have *multiple* limit order books, each managed by a different broker or other entity.
- Limit order books might also be used in conjunction with other mechanisms. When all trading for a security occurs through a single book, the market is said to be organized as a *consolidated or central limit order book* (CLOB). A CLOB is used for actively traded stocks in most Asian and European markets.

Priority Rules

A mechanism's priority rules govern the *sequence* in which orders are executed:

- *Price priority* is basic. A limit order to buy price at 100 for example, will be executed before a buy order priced at 99.
- *Time* is usually the *secondary* priority. At a given price level, orders are executed *first-in, first-out*.
- Although these priority rules may seem obvious and sensible, it should be noted that they usually *only* determine the relative trading of orders within a given book. There is *rarely* a system-wide time priority across all books or other components of a hybrid market.
- This standard combination of Price and Time priority is collectively known as Price-Time priority.
- Some alternative trading venues use other priority mechanisms, such as Price-Size.

Market Orders vs Limit Orders

- A trader may desire that an order be executed “at the market”, that is, at the *best available price*. If the order quantity is *larger* than the quantity available at single best price on book, the order will “walk the book”, achieving *partial* executions at progressively *worse prices* until the order is filled.
- This may lead to execution at prices far worse than the trader thought possible at the time of submission. For example, at 10:47:26 on January 29, 2001, the bid side of the book for IBM on Island ECN contained (in its entirety) bids at $112.50, $110.00, $108.00, and $2.63. The last bid was presumably entered in error, but should it have been executed, the seller would obtain $2.63 for a share of IBM at the time when its markets price was in the vicinity of $113.
- Euronext Market - A provision in the Euronext system illustrates how surprises of this sort can be *avoided*. On Euronext, a market order is *not* allowed to walk the book. It will only execute for (at most) the quantity posted at the best available price. Anything remaining from the original quantity is *converted* into a limit order at the execution price.
- For example, of a market order to buy 1000 shares arrives when the best offer is 200 shares at €100, 200 shares will be executed at €100, and the remaining 800 shares will be added to the book as the buy limit order priced at €100.
- If a trader in fact wants the order to walk the book, the order must be *priced* (as a market order). Attaching a price to the order forces the trader to consider the worst acceptable price. INET (Island/Instinet) requires that all order be priced.

Order Qualifications and Variations

Markets often permit qualifications and/or variations on the basic limit order:

- The Time-in-Force (TIF) attributes of an order specified *how long* the order is to be considered *active*. It is essentially a *default cancellation time*, although it does *not* preclude the sender from canceling before TIF is reached. Although the pre-commitment associated with TIF deprives the sender of some flexibility, it avoids the communication delays and uncertainties that sometime arise with the transmitted requests for cancellation. If it cannot be executed it leaves *no visible trace*, and the sender is free to quickly try another order (or another venue).

- An All-or-Nothing (AON) order is executed in its *entirely* or *not at all*. It *avoids* the possibility that a *partial fill* (execution) will, when reported to other traders, move the market price against the sender, leaving the remaining portion of the order to be executed at a less favorable price.

- Hidden Orders: A trader seeking to buy or sell an amount that is large (relative to the quantities typically posted to the book) is unlikely to feel comfortable displaying the full extent of his interest. To make the situation more attractive, many markets allow hidden and/or reserve orders. *Hidden orders* are the simpler of the two.

Order Qualifications and Variations

- If an order designated as hidden can not be executed, it is added to the book *but not made visible* to other market participants. The hidden order is available for execution against incoming orders, the sender of which may be (happily) surprised by fills at prices that are better than or quantities that are larger than what they might have surmised based on what was visible. Hidden orders often *lose priority* to the visible orders, a rule that encourages display.
- Reserve (“iceberg”) Orders: are like hidden orders, but they are only *partially invisible.* Some display is required, and if the displayed quantities executed, it is *refreshed* from the *reserve quantity*. The procedure *mimics* a human trader who might feed a large order to the market by *splitting* it up into smaller quantities.

Order Book Examples

Simple Limit Order Book: Stock XYZ

Bid Qty	Bid Px		Offer Px	Offer Qty
2000	100		100.01	2000
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Characteristics

- Unexecuted Limit Orders
- Buys(Bids) and Sells(Asks/Offers)
- Price/Time Priority is common

Market Data

- Last Price = ?
- Last Qty = ?
- Best Bid Price = 100
- Best Bid Qty = 2000
- Best Offer Price = 100.01
- Best Offer Qty = 2000

New Limit Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2000	100		100.01	2000
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 100 shares @ $100

Is this “Marketable” ?

New Limit Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	2000
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 100 shares @ $100

Market Data

- Last Price = ?
- Last Qty = ?
- Best Bid Price = 100
- Best Bid Qty = 2100
- Best Offer Price = 100.01
- Best Offer Qty = 2000

New “Marketable” Limit Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	2000
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 100 shares @ 100.01

New “Marketable” Limit Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	1900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 100 shares @ 100.01

Market Data

- Last Price = 100.01
- Last Qty = 100
- Best Bid Price = 100
- Best Bid Qty = 2100
- Best Offer Price = 100.01
- Best Offer Qty = 1900

New Market Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	1900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 1000 shares @ Mkt

New Market Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Buy 1000 shares @ Mkt

Market Data

- Last Price = 100.01
- Last Qty = 1000
- Best Bid Price = 100
- Best Bid Qty = 2100
- Best Offer Price = 100.01
- Best Offer Qty = 900

A Big Market Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
2100	100		100.01	900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Sell 3000 shares @ Mkt

A Big Market Order Arrives

Bid Qty	Bid Px		Offer Px	Offer Qty
100	99.99		100.01	900
999	99.98		100.02	1500
500	99.97		100.03	900
			100.04	450

Sell 3000 shares @ Mkt

First trade: 2100 @ 100
Second trade: 900 @ 99.99

Market Data

- Last Price = 99.99
- Last Qty = 900
- Best Bid Price = 99.99
- Best Bid Qty = 100
- Best Offer Price = 100.01
- Best Offer Qty = 900

Reserve / “Iceberg” Orders

Bid Qty	Bid Px		Offer Px	Offer Qty
2000(5000)	100		100.01	900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Sell 3000 shares @ Mkt

Reserve / "Iceberg" Orders

Bid Qty	Bid Px		Offer Px	Offer Qty
2000(2000)	100		100.01	900
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

Sell 3000 shares @ Mkt

One trade: 3000 @ 100

**Rules and Features Vary*

Market Data

- Last Price = 100
- Last Qty = 3000
- Best Bid Price = 100
- Best Bid Qty = 2000*
- Best Offer Price = 100.01
- Best Offer Qty = 900

Dark Pools (Non-displayed)

Bid Qty	Bid Px		Offer Px	Offer Qty
2000	100		100.01	2000
1000	99.99		100.02	1500
999	99.98		100.03	900
500	99.97		100.04	450

- Book is not visible
- Trades happen when orders cross (like displayed book)
- Price set relative to reference price (usually NBBO or equivalent)
- Why do we trade there??

Reg NMS

Mkt	Bid Qty	Bid Px		Offer Px	Offer Qty	Mkt
NASD	2000	100		100.01	2000	BATS
BATS	1000	99.99		100.02	1500	NASD
IEX	999	99.98		100.03	900	ARCA
ARCA	500	99.97		100.04	450	IEX

Reg NMS

- National Best Bid/Offer (NBBO)
- Order Protection / Trade Through
- Access Rule
- Sub-Penny (if P > $1, tick = 0.01)
- Market data rule

NBBO and Order Protection

- Must trade at best displayed price regardless of venue
- Example: an order to buy 500 XYZ @ 100.03 must be executed first at the National Best Offer (BATS)
- Fragmentation / Increased competition
- Complex routing rules
- Latency arbitrage

Other Order Type Variations

- Hidden Orders
- Peg orders
- Market on Open / Close (MOC / LOC)
- Limit on Open / Close (LOO / MOO)

- What to do with these (routers, algos)
- Implications for Algos
  - Flexibility, open quantity
  - signalling
  - ability to cancel

Case Study:
Construct a Limit Order Book with Python/Pandas