MP6212: Computational Finance

Introduction

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Slides are prompts (for me). You are expected to make your own notes when material is explained using the white-board, and by referring to textbooks and papers.

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Logistics

- Teaching slots
  - Mondays 14:00-16:00 Laboratory
  - Thursdays 9:00-10:00 Lecture
- Philosophy: Learning by doing, **not** learning by observing.
- This is not a module on Finance as taught in business schools
  - *i.e.* not a lot of descriptive material on details of financial instruments and how they are traded.
- This is not a module on Mathematical Finance as taught in the School of Mathematics
  - We will not be too *formal* with fundamental theory
- Our focus will be on some tools that are *computational*; we will use real data, implement computational algorithms and understand the basics of some interesting problems.
- We will need some continuous mathematics for this.

If your expectations are different, please do not take this module.

Rapid Review of Some Basics
Organization of Businesses

- Sole ownership

A sole proprietorship, also known as the sole trader or simply a proprietorship, is a type of enterprise that is owned and run by one natural person and in which there is no legal distinction between the owner and the business entity. The owner is in direct control of all elements and is legally accountable for the finances of such business and this may include debts, loans, loss, etc.

- Limited liability company

A limited liability company (LLC) is the United States-specific form of a private limited company. It is a business structure that combines the pass-through taxation of a partnership or sole proprietorship with the limited liability of a corporation.[1][2] An LLC is not a corporation in itself; it is a legal form of a company that provides limited liability to its owners in many jurisdictions.

- Corporation

A corporation is a company or group of people authorized to act as a single entity (legally a person) and recognized as such in law.

- Purpose: Maximize profit
  - Profit Margins

Net income, reflects the total amount of revenue left over after all expenses and additional income streams are accounted for. This includes COGS and operational expenses as referenced above, but it also includes payments on debts, taxes, one-time expenses or payments, and any income from investments or secondary operations.

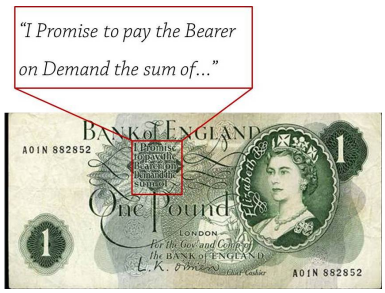
The net profit margin reflects a company's overall ability to turn income into profit.

COGS includes only those expenses directly associated with the production or manufacture of items for sale, including raw materials and wages for labor required to make or assemble goods. Excluded from this figure are, among other things, any expenses for debt, taxes, operating or overhead costs, and one-time expenditures such as equipment purchases.

operating profit also takes into account all overhead, operating, administrative and sales expenses necessary to run the business on a day-to-day basis. While this figure still excludes debts, taxes and other non-operational expenses, it does include the amortization and depreciation of assets.

  - Gross Profit Margin = (Sales - Cost of Goods Sold) / Sales
  - Operating Profit Margin = EBIT / Sales
    (earnings before interest and taxes)
  - Net Profit Margins = Net Profits after Taxes / Sales
- Minimize Cost
- Maximize Market Share

Rapid Review of Some Basics
Money

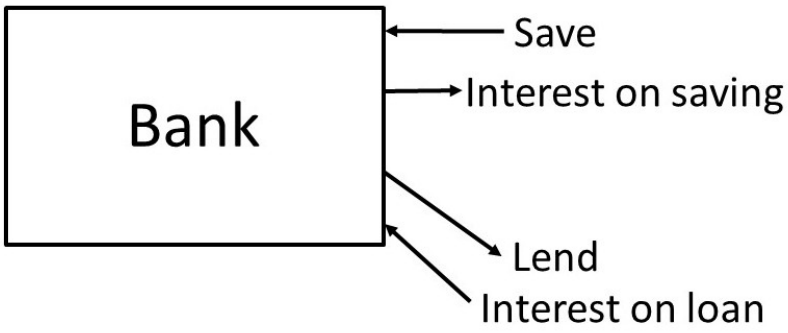


- *"For the love of money is the root of all evil"*
  – New Testament `Timothy 6:10`
- *"every object has two uses, the first being the original purpose for which the object was designed, and the second possibility is to conceive of the object as an item to sell or barter"*

–

Aristotle (384-322 BC)

Basic Institutions



Rapid Review of Some Basics

Financial Institutions

- Commercial Banks
- Investment Banks
- Insurance Companies
- Brokerages
- Investment Companies
- Investment Trust
- Building Society

Rapid Review of Some Basics
Financial Markets

There are two types of options: a call and a put. A call gives the holder a right, but not the obligation, to purchase a share at a fixed price, known as the exercise price (Warrants and TSRs are essentially calls). A put gives the holder the right, but not the obligation, to tender a share and receive, in return, a fixed price.

If you think that the share price of a company is going to rise, one way to profit from this is to buy its shares. However, if you are wrong, and the share price falls instead, you would have suffered a loss. The size of the loss would depend on how much the price falls, something difficult to know ahead of time. Such an uncertainty may prevent you from acting on your hunch.

However, if from the start you know exactly how much you stand to lose if your hunch is wrong, you may be emboldened to act. This is possible if you buy a call with the exercise price equal to the current share price. The maximum amount you can lose is the price of the call.

- Capital Markets
  – governments / companies sell securities to raise capital
- Stock Markets
  – investors buy and sell shares in publicly traded companies
- Bond Markets
  – debt instrument in which an investor loans money; borrower (company, government)promises to pay a regular fixed rate for a fixed period
- Money Market
  – short term borrowing and lending (days to one year)
- Spot or Cash Market
  – goods are sold for cash and are delivered immediately
- Derivatives Markets
  trading contracts on the future price of an asset

A derivative is a financial instrument whose value is derived (hence the name) from an underlying asset. For example, the value of a warrant depends on the value of the underlying share (or "mother share"). Or the value of a gold futures contract is derived from the current price of gold. Derivatives come in two forms: options and futures.

Why? Remember that a call gives you the right, but not the obligation, to purchase a share. If the share price rises above the exercise price, you would exercise the option. You pay the exercise price and receive a share which is worth more.

However, if the share price falls below the exercise price, you do nothing. The maximum amount you can lose is the call price, regardless of how much the share price has fallen.

Rapid Review of Some Basics
Macroeconomic Policy

Which is more effective monetary or fiscal policy?

In recent decades, monetary policy has become more popular because:

Monetary policy is set by the Central Bank, and therefore reduces political influence (e.g. politicians may cut interest rates in desire to have a booming economy before a general election)
Fiscal policy can have more supply side effects on the wider economy. E.g. to reduce inflation – higher tax and lower spending would not be popular, and the government may be reluctant to pursue this. Also, lower spending could lead to reduced public services, and the higher income tax could create disincentives to work.
Monetarists argue expansionary fiscal policy (larger budget deficit) is likely to cause crowding out – higher government spending reduces private sector expenditure, and higher government borrowing pushes up interest rates. (However, this analysis is disputed)
Expansionary fiscal policy (e.g. more government spending) may lead to special interest groups pushing for spending which isn't really helpful and then proves difficult to reduce when the recession is over.
Monetary policy is quicker to implement. Interest rates can be set every month. A decision to increase government spending may take time to decide where to spend the money.

Government interventions:

- Monetary Policy
  - Control of money supply
    - Interest rates
    - Print / devalue / "quantitative easing"

Quantitative easing is an unconventional monetary policy in which a central bank purchases government securities or other securities from the market in order to lower interest rates and increase the money supply. Quantitative easing increases the money supply by flooding financial institutions with capital in an effort to promote increased lending and liquidity. Quantitative easing is considered when short-term interest rates are at or approaching zero, and does not involve the printing of new banknotes.

- Fiscal Policy
  - Taxation and government spending

However, the recent recession shows that monetary policy too can have many limitations.

Targeting inflation is too narrow. During the period 2000-2007, inflation was low but central banks ignored an unsustainable boom in the housing market and bank lending.
Liquidity trap. In a recession, cutting interest rates may prove insufficient to boost demand because banks don't want to lend and consumers are too nervous to spend. Interest rates were cut from 5% to 0.5% in March 2009, but this didn't solve recession in the UK.
Even quantitative easing – creating money may be ineffective if banks just want to keep the extra money on their balance sheets.
Government spending directly creates demand in the economy and can provide a kick-start to get the economy out of recession. Thus in a deep recession, relying on monetary policy alone, may be insufficient to restore equilibrium in the economy.
In a liquidity trap, expansionary fiscal policy will not cause crowding out because the government is making use of surplus saving to inject demand into the economy.
In a deep recession, expansionary fiscal policy may be important for confidence – if monetary policy has proved to be a failure.

Equilibrium: A state of stable prices brought about by the rough equality of supply and demand. This applies for consumer goods, securities, and most other goods and services.

Financial Equilibrium

Caution: A peculiar and rather personal view

jamesnichollsillustration.blogspot.co.uk

Financial Markets

www.investors411.com

- Generate products and services
- In need of
  - stability against fluctuations (e.g. demand, exchange rate)
  - capital investment (e.g. to modernise, grow)
- Pocess wealth & capital
- Driven by gambling instinct and greed

Capital investment refers to funds invested in a firm or enterprise for the purpose of furthering its business objectives. Capital investment may also refer to a firm's acquisition of capital assets or fixed assets such as manufacturing plants and machinery that is expected to be productive over many years. Sources of capital investment are manifold and can include equity investors, banks, financial institutions, venture capital and angel investors.

The Setting

- Finance gets bad publicity; bankers and fund managers are sometimes disliked
- The system can fail badly
- When the system fails, large amounts of tax-payer money is used to bail them out. I don't like this!
- Yet the system is useful
  - Investors interested in future returns
    - Greed?
    - Pay for retirement
  - Firms / Governments looking to raise capital for investment
  - Companies looking for stability; *e.g.* insure against exchange rate fluctuation
- What are the sources of computational problems?
  - Time - present value of money.
  - Uncertainty - of the future.

Overview of the Module

Topics:

- Portfolio Optimization
- Derivatives Pricing
- Time Series Analysis

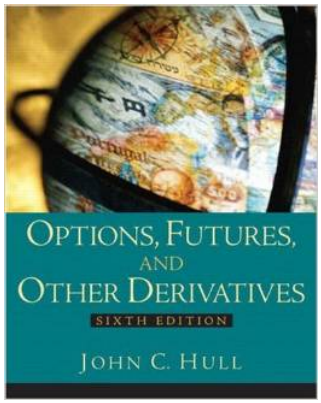
Keywords:

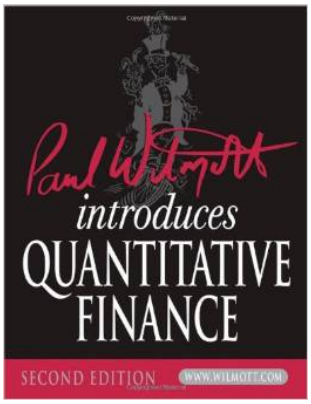
Mean-Variance optimization, Linear and quadratic programming, Multivariate Gaussian distribution, Constrained optimization, Value at risk and Conditional value at risk, Sharpe ratio, Present value, Stochastic differential equations, Ito's Lemma, Black-Scholes model, Options pricing, Stochastic Simulations, Monte Carlo methods, Autoregressive Moving Average, Autoregressioon with Conditional Heteroskedasticity, Kalman filtering, Particle filtering, Importance sampling, Stochastic volatility.

Assessment:

- Four large pieces of coursework
  `MATLAB` exercises using real data
- Each might includd a short in-class/take-home test
- You will be expected to work **independently**

Resources





- plus several academic papers.

Financial Instruments (broad classes)

A bond is a fixed income investment in which an investor loans money to an entity (typically corporate or governmental) which borrows the funds for a defined period of time at a variable or fixed interest rate. Bonds are used by companies, municipalities, states and sovereign governments to raise money and finance a variety of projects and activities. Owners of bonds are debtholders, or creditors, of the issuer.

Characteristics of Bonds:
Face value is the money amount the bond will be worth at its maturity, and is also the reference amount the bond issuer uses when calculating interest payments. For example, say an investor purchases a bond at a premium $1,090 and another purchases the same bond at a discount $980. When the bond matures, both investors will receive the $1,000 face value of the bond.
Coupon rate is the rate of interest the bond issuer will pay on the face value of the bond, expressed as a percentage. For example, a 5% coupon rate means that bondholders will receive 5% x $1000 face value = $50 every year.
Coupon dates are the dates on which the bond issuer will make interest payments. Typical intervals are annual or semi-annual coupon payments.
Maturity date is the date on which the bond will mature and the bond issuer will pay the bond holder the face value of the bond.
Issue price is the price at which the bond issuer originally sells the bonds.

- Bonds
  - Debt instrument to raise capital; delivers periodic payment (*coupon*); has a *face value* on *maturity*. No ownership associated.
- Stocks A stock is a share in the ownership of a company. Stock represents a claim on the company's assets and earnings. As you acquire more stock, your ownership stake in the company becomes greater.
  - Own a small *share* of a company; the ownership may be traded in the market; owning the share might earn *dividends*.
- Derivatives A derivative is a financial instrument whose value is derived (hence the name) from an underlying asset. For example, the value of a warrant depends on the value of the underlying share (or "mother share"). Or the value of a gold futures contract is derived from the current price of gold. Derivatives come in two forms: options and futures.
  - Contracts written on the basis of a future value of a a stock, currency etc. Usually there is a time of *maturity* and a promised *payoff* in the contract. Variations in style of *exercising* the contract.

Time: Present Value

- Wealth W_0 deposit in bank and get W_1 after one year
- $W_1 = (1 + r) W_0$, r interest rate
- Compound interest over n years: $W_n = (1 + r)^n W_0$
- Define interest rate as r per year; allow compounding at m intervals within the year

$$W_1 = \left(1 + \frac{r}{m}\right)^m W_0$$

- Continuous compounding $m \to \infty$

$$W_1 = \exp(r) W_0$$

- Present value of your promise to give me cash C in time t is

$$\exp(-rt) C$$

Various Topics We Will Learn
Part I: Portfolio Optimization

Portfolios:

- Notion of expected return and risk in investing - balancing it out
- Investing in a portfolio of assets, than in a single asset - "not all eggs in one basket"
- Optimization techniques we will learn and use
  - Linear programming
  - Quadratic programming
  - (Second order cone programming)
  - Inducing sparsity – l_1 or *lasso* regularization
  - Convex optimization using `CVX` toolbox

Various Topics We Will Learn (cont'd)
Part II: Derivatives Pricing

Derivatives Pricing (contract in the future, in an uncertain world):

- Brownian motion, Geometric Brownian motion
- Stochastic differential equations

$$\frac{dS}{S} = \mu\, dt + \sigma\, dZ$$

$$dZ = \phi\sqrt{dt}, \quad \phi \sim (0,1)$$

- Ito's Lemma: Function of a Geometric Brownian Motion

$$dG = \left(\mu S\frac{\partial G}{\partial S} + \frac{\sigma^2 S^2}{2}\frac{\partial^2 G}{\partial S^2} + \frac{\partial G}{\partial t}\right) dt + \sigma S\frac{\partial G}{\partial S}\, dZ$$

- Black-Scholes: options pricing under specific assumptions
- Monte Carlo / Stochastic simulations: general cases

Time Series Analysis:

- Models:
  - Linear time series models: MA, AR, ARMA

$$y(t) = \sum_{j=1}^{p} a_j\, y(t-j) + \sum_{i=1}^{q} b_i\, \epsilon(t-i) + \eta$$

  - Autoregression with conditional heteroskedasticity (ARCH)
  - Stochastic volatility models
- Algorithms:
  - Maximum likelihood and Bayesian methods
  - Recursive estimation – Kalman filter, Particle filter

$$\left\{ \begin{array}{l} \boldsymbol{\theta}(n-1|n-1) \\ \boldsymbol{P}(n-1|n-1) \end{array} \right\} \rightarrow \left\{ \begin{array}{l} \boldsymbol{\theta}(n|n-1) \\ \boldsymbol{P}(n|n-1) \end{array} \right\} \rightarrow \left\{ \begin{array}{l} \boldsymbol{\theta}(n|n) \\ \boldsymbol{P}(n|n) \end{array} \right\}$$