SoS'22 Algorithmic Trading

Pulkit Adil

Mentor : Nishika Tolambiya
Mentee : Pulkit Adil

Contents

1 Finance

1.1 Initial stages of a company

When a founder creates a company he invests some seed fund. He then holds some percent of the stake as his own and the rest of the stake is said to be unassigned. The valuation of the company at this point is just the fraction of its assets given by the stake of the owner. The owner may at a later point sell some of the unassigned stake to a venture capitalist or make an IPO. Unassigned stake is not the owner's wealth, it belongs to the company. Moreover, if the company borrows money as a loan or as bonds, then that is not a stake in the company.

The total assets of a company is not the same as its valuation. The valuation of a company is how much the world expects the company to be worth if completely sold off. So the company may have assets worth 5 Cr, but if an investor buys a 10% stake at 1 Cr, that means the valuation of the company is 10 Cr. This means the world believes that the company has a potential to grow to assets of 10 Cr.

1.2 IPO

Now once the company has worked for a few years on seed fund, venture capitalist and private equity, it may need more capital (Capex) and hence raises an IPO. Once an IPO is made the company makes some of its unassigned stake available for buying. Moreover any shareholder may buy or sell a stake. The company may also give some stocks at a discounted rate to its employees, called employee stock option. The company makes a price band in which it allows the public to subscribe (book before actual IPO) to its shares. Everything till here is called the primary market. Once the IPO happens and the company hits the stock exchange it is the secondary market.

1.3 Stock market

Once the company becomes public, it is liable to disclose all important data with the public. When the public expects the company to grow, its valuation increases and hence the stock price goes up. The reverse happens when there is some bad news about the company. The "price of the stock" at any point of time is the price of the last stock that was traded. In the market, there are several people who wish to sell at different prices. When a buyer expects the company to grow, he is willing to buy at a price higher than that of the last price, so the "stock price" goes up. Similarly now sellers tend to increase the price at which they wish to sell sensing the increased demand and the fact that they wish to sell at a price at which they expect the company to grow to i.e. its valuation. Hence the price of the stock is an unbiased estimator of its value and any variation around that is just a random walk.

When you wish to buy or sell a stock, you place an order and in the order you mention the price that you wish to trade at. The market automatically matches buyers and sellers who wish to buy and sell at the same price. The stocks are stored in a digital locker called a DEMAT account. What do people get out of a stock? The company pays them dividends of its profit every quarter because they are also owners. And the stock fetches some value in the market if and when it is sold. This is always compared against the bank interest rates. If a stock is bought at X and sold at Y after T years, then the price fetched as a result of the transaction is equivalent to $\frac{Y}{X}^{\frac{1}{T}} - 1$ interest rate. This calculation excludes profit dividends.

1.4 Market Index

The market index (like the CNX Nifty) is a way to summarise all the companies in the market. It just includes the price of some important companies weighted by their price*number of stocks in the market. It also serves as a benchmark of market movement and public sentiment. A good trader will make trades so as to outperform the market index. People may also perform "Index trading" i.e. place a bet on the price of the index; this is a part of derivatives.

1.5 Jargon

- Long Position: When you buy a stock,and later sell it.
- Short Position: When you sell a stock before buying it. In shorting you first sell a stock that you don't own and buy it at a later point of time. This is done when you believe the market is bearish. So when you short sell, the exchange internally borrows that stock from some owner and gives it to the person you sold it to. When you actually buy the stock, it goes to the person the exchange borrowed from internally (that person doesn't know anything like this happened).
- Stop loss: You fix a maximum acceptable loss with the broker and if the price moves so that that much loss is happening, the broker automatically trades the stock.
- T+2 day: The day you make a trade is called the T day. The stocks/money comes to your DEMAT/bank account only on the T+2 day and becomes available for trading at the T+3 day. If you trade it again in between, there are risks involved.

1.6 Stock Effects

- Dividends: The company decides every year the amount of dividend it will pay per stock. Even if the company is in loss, it may still pay a dividend in an attempt to keep its stockholders.

- Bonus issue: The company may give out free shares out of its unissued shares to its stockholders as a bonus.
- Stock split: The company can decide to split the atomic size of its equity.
- Buyback: The company buys back some of its public stake.

2 Strategies Overview

2.1 Momentum

Momentum strategies are short term strategies that are implemented following the trend. Momentum is employed when the price has not reacted as much as valuation and so it will continue to move towards the valuation

2.2 Statistical Arbitrage

This is a short term strategy, in which if a particular change is predicted to happen but has not happened yet, make use of the opportunity. It exploits the mispricing of an asset with respect to its expected value. If there are two positively correlated stocks, and one has outperformed the other, then we can long the outperforming stock and short the outperformed stock as we expect them to eventually equilibrate. Similarly for two negatively correlated stocks. These are called pair strategies. Similar strategies exploit co-integration.

2.3 Mean Reversion

This is a long term strategy, in which we believe that the market price has overreacted and will come back to the mean in the long term.

2.4 Market Making

In a market with low volatility, a market maker makes a bid(a sell offer) for a slightly higher price and a ask(a buy offer) for a slightly lower price. This way he makes profit from his bid-ask spread. The market maker does not operate in a highly volatile market as there is a risk that he may get stuck with a bought stock as the volatile market plummeted. Market makers increase liquidity of the asset and put a cap on its volatility.

2.5 Machine Learning

Machine learning techniques such as RL or deep learning can be used to predict market movement

3 Momentum Based Strategies

The probability of a trend persisting is inversely related to the time it has already persisted. These strategies are generally based on closing price.

3.1 Moving Averages

Moving averages are averages of the past few data points. They help to smoothen out the data. More is the moving average window, the slower it responds to trends and smoother it becomes. Types of moving averages:

- Simple moving averages: Equal weight to all data points in the window. Preferred for long trading periods.
- Exponential moving average: Exponentially decreasing weights to past data. More reliable than SMA as it gives more weight to recent data, preferred for short trading periods.
- Linear moving averages: Linear decreases to weights to past data.
- Volatility moving average: It uses a measure of variance to improve upon the EMA. If variance is high, the current price is given more weightage.

Strategies

- Dual Crossover: Keep a fast and a slow moving average. When the fast moving average goes above the slow one, buy and when it goes below the slow one, sell.
- Triple Crossover: Keep a fast, medium and slow moving average. Buy when the configuration is fast ¿ medium ¿ slow and exit the position when it becomes medium ¿ fast ¿ slow. Similarly when the configuration is slow ¿ medium ¿ fast, sell, and when it becomes slow ¿ fast ¿ medium exit the position.
- Moving average convergence-divergence (MACD). We take a fast and a slow moving average. The difference fast - slow is called the MACD. We then consider the EMA of the MACD as the signal line. When the MACD crosses above the signal line it is a buy and when it goes below the signal line, it is a sell. The sign of the MACD provides confirmation for a long buy or a short sell.

3.2 RSI

The RSI is an indicator of trend reversal in the market. It is based on the belief that a very bullish or bearish trend can't last long and soon there will be reversal. This strategy fails when the market is highly bearish or bullish due to fundamental reasons. The RSI is calculated as $100\frac{RS}{1+RS}$, where RS is the ratio of the non-negative gains to the non-negative losses in a certain window. The

RS is calculated so that it gives more weightage to recent values. So if the RSI goes above 70, it indicates that the market is overbought and it will soon fall. If it goes below 30 it indicates the market is oversold and will soon rise.

3.3 Hurst Exponent

The Hurst Exponent is a measure of the deviation of the market from a random walk. It indicates whether the market is trending or will go into mean reversal. $H < 0.5$ — a mean-reverting (anti-persistent) series. The closer the value is to 0, the stronger the mean-reversion process is. $H = 0.5$ — a geometric random walk. $H > 0.5$ — a trending (persistent) series. The closer the value is to 1, the stronger the trend. Method of finding Hurst exponent : Wikipedia

4 Arbitrage Based Strategies

4.1 Pairs Trading

Two stocks can be correlated or co-integrated.

Correlation is the ratio of their covariance to the product of their standard deviations. It lies between +1 and -1. A positive correlation would mean they move together and a negative one means they move in opposite directions. If the magnitude of correlation is high, say 0.8, traders may choose that pair for pairs trading.

Cointegration is a better technique than correlation. Cointegration indicates that a linear combination of two time series variables remains stationary. This means the mean and variance of the linear combination remains constant over time. We may consider the cointegration of the stock prices, or that of their logarithmic values. To check for cointegration between two time series variables X and Y, we run a linear regression on a parameter n such that $X - nY$ is as close to 0 as possible. To check whether $X - nY$ is stationary, then the time series for it will have a unit root. We can check this using the ADF test, thus allowing us to check for stationary behaviour.

To generate signals in pair trading, we make use of the z-score $= \frac{x-mean}{stddev}$. In stock analysis the mean and standard deviation are generally of a window. We can have a threshold for the z score like 1.5. If $z > 1.5$ or $z < -1.5$, short the higher stock and buy the lower one. These are the entry points for our position.

To exit the position we may make use of the following:

- Stop Loss: If the cointegration continues to be violated, we are in for a loss. To limit the loss, we can place a stop loss (exit from position) at something like $|z| = 3$
- Take Profit: We take our profit when $|z|$ becomes small and exit the position.

5 Market Making

The market maker participates in buying and selling simultaneously (HFT). He buys at the lowest possible price and sells at the highest possible price. Market makers are allowed to make such dual trades as they bring liquidity and trading volume in the market. In return they profit out of the ask-bid difference (the spread).

Market making should be avoided in highly volatile markets. Market makers should have the latest information, otherwise they risk being stuck in a loss position.

6 Machine Learning

6.1 Autoregressive models:

These model the dependency of the current value as a linear combination of the past few values. Hence, the parameters can be tuned as a simple linear NN RNNs RNNs, LSTMs, GRUs and transformers can be used to predict the time series data of stock markets.

6.2 Linear Regression

The stock price can be expressed as a linear combination of several market variables and then linear regression can be used to carry out prediction.

6.3 KNN

Similar to regression, we can have a parameter space which we believe defines the stock price. And then we can use the k nearest neighbours of a particular query and average out their stock prices to get the prediction.

6.4 Clustering

We can classify whether the market will go up or down based on a Gaussian clustering in the parameter space.

6.5 Random Forest

Decision tree based algorithms can also be used to classify if the kind of market trend.

7 Options Trading

7.1 Call Option

When you buy a call option, you buy the right to buy the underlying share at a particular price (strike price) in the future. You may choose to not buy it, i.e. it is right, not an obligation. So if you expect the stock price to rise beyond current price (underlying price) + option price (premium), it makes sense to buy a call option.

The seller of the call option is obligated to sell the underlying asset at the agreed upon price if and when the buyer demands it (exercises the option contract). The option contract can only be exercised on the day of the expiry, not before that if it is a European option. If it is an American option, it can be exercised at or before the expiry date. The IV(intrinsic value) at expiry of a call option is the non-negative difference of the stock price at that time and the strike price.

The profit of the call buyer is IV-premium, and the loss of the seller is premium-IV. Note that we consider the stock that is being held by the buyer/seller also in the profit/loss, not just the cash. Since the loss of a seller has not bound, hence to prevent people from defaulting, a call option seller must always deposit a margin (a minimum amount) with the stock exchange.

The premium is influenced by the probability of the contract getting exercised. So a good fundamental news or a large expiry or a strike price close to the stock price would lead to higher premium. An American call option has a higher price than a European call option due to the greater flexibility it offers.

7.2 Put Option

When you buy a put option, you buy the right to sell the underlying asset at the strike price in the future. Again this is a right, not an obligation. So if the price falls below the current price - strike price, the option buyer can exercise his option and short the stock, and then immediately buy the stock. This way he achieves a profit. The IV at expiry of a put option is the non-negative difference between its current price and the strike price. The profit to the buyer is IV - premium and the loss to the seller is premium - IV.

7.3 Moneyness of the option contract

Intrinsic value

The intrinsic value of an option is the difference that an option buyer can make if he exercises the option on a particular day. So for a call option it is max(spot price-strike price, 0) and for a put it is max(strike price-spot price, 0)

Moneyness

If the IV ¿ 0, then the stock is ITM(in the money), if IV = 0, the stock is ATM(at the money) if strike price = spot price, otherwise it is OTM(out of the money)

7.4 Option Greeks

Option premiums, greeks and the demand-supply, all influence each other.

Delta

The delta is the change in option price over the change in stock price. So for a call it generally lies between 0 and 1 and for a put between 0 and -1. A high magnitude of delta (¿ 0.5) indicates an ITM option while a low value (¡ 0.5) indicates an OTM option. This is because when the stock is OTM, the seller's payoff is not so sensitive to small changes in price as he is when the stock is ITM.

Delta itself is sensitive to changes in the spot price. The rate of change of delta is small when the market is deeply ITM or OTM and is maximum around the ATM range.

The delta of a position of options on a particular underlying asset is just the sum of deltas of individual options. It expresses the sensitivity of the option position to the underlying price. A delta neutral position has 0 delta.

The value of delta indicates the probability that the stock will be in ITM at expiry.

Gamma

The gamma is the rate of change of delta with respect to the stock price. Since gamma expresses the rate of change of risk of holding a position, it is important to keep track of it. In particular, if a trader is shorting options, he should avoid doing so ATM as the gamma is high there and carries a lot of risk for him.

Theta

Theta expresses the time risk of an option. More is the time span, lesser the risk involved and hence higher the premium. The time value of a stock is its premium - its current IV. Theta is the rate of change of the value of the option per day, all other things remaining the same. A long option (a bought option) has a negative theta and a short option (a sold option) has a positive theta. This is because the shorted option can be bought back at a later time to make a profit. The effect of theta is high as we approach the expiry.

Vega

Vega is the rate of change of option premium with respect to volatility.

The daily volatility is measured as the standard deviation of the (closing price/opening price)-1. The volatility over T days is sqrt(T)*daily volatility. So the volatility is not of the stock price, it is of the daily returns. We can model this variation using the normal distribution and hence get confidence intervals on the future price. We can say that after T days there is a 68% probability that the underlying asset is between present price + avg returns * T - daily volatility * sqrt(T) and present price + avg returns * T + daily volatility * sqrt(T). So we can sell call options for the lower bound and put options for the upper bound, as they are likely to be OTM at the expiry. Such a range can also provide us a way to set a stop loss. The volatility calculated above is called the historical volatility. We may also forecast the volatility (forecasted volatility) using 'Generalised AutoRegressive Conditional Heteroskedasticity (GARCH) Process'. Another way to judge volatility is Implied Volatility. It expresses the market's consensus about the volatility. It reflects in the premium price. India VIX is the official implied volatility index (which is given as annual volatility). ATM options tend to have low volatilities and OTM or ITM options tend to have high volatility.

The premium of options goes up with an increase in volatility. This is Vega.

7.5 Inter-greek interactions

Gamma vs time

Gamma tends to be small far away from the expiry as people are less sensitive to change in prices.

Delta vs volatility

When the volatility is low, delta vs spot price curve is sharp. When the volatility becomes high the curve becomes flatter.

We can use the Black Scholes model to find the appropriate premium based on all these parameters.

8 Quantitative Finance

We look at some mathematical models that are used to describe the market

8.1 Option prices

If the stock price is S and the strike price was K, then the payoff of a call option is $max(S-K,0)$ and that of a put option is $max(K-S,0)$

8.2 Zero Arbitrage and the put-call parity

A set of transactions is an arbitrage opportunity if the initial investment is ≤ 0, the payoff is ≥ 0 and atleast one of these inequalities is strict. The financial system adjusts itself to have 0 arbitrage in expectation due to the forces of

demand and supply. Mathematically, we have that if the profit of two portfolios is the same at a maturity time T, then at all times $t < T$, the two must have the same price, otherwise it provides an arbitrage opportunity.

The put-call parity is a relation between c and p the prices of a call and put option with the same underlying asset, strike price K and time to expiry τ. It states that if the bank interest rate is r, then

$$c + Ke^{-r\tau} = p + S - D$$

where D is the current price of future dividends that the stock may pay. This can be proved by showing that both sides of the equation are equally profitable portfolios.

8.3 Black-Scholes-Merton Formula

The evolution of the stock price is given by a geometric Brownian motion described by the equation

$$\frac{\partial S}{S\partial t} = \mu + \sigma\frac{\partial W}{\partial t}$$

where S is the stock price and W is a Wiener process. Here the parameter μ represents the *drift* or the direction of the market and σ represents its *volatility.* Hence, we get the stock price at a time t to be given by the random variable S_t which is

$$S_t = S_o e^{(\mu - \frac{\sigma^2}{2})t + \sigma W_t}$$

where W_t has a PDF given by

$$f_{W_t}(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{-x^2}{2t}}$$

Suppose the price of a derivative on this stock is given by the random variable $V(S,t)$. Then, by Ito's lemma, we have

$$dV = (\frac{\partial V}{\partial t} + \mu S\frac{\partial S}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 V}{\partial^2 S})dt + \sigma S\frac{\partial V}{\partial S}dW$$

We can now construct a portfolio consisting of two components: long one unit of derivative and short one unit of stock. Then, the portfolio has value $\Pi = V - \frac{\partial V}{\partial S}S$. It changes according to:

$$\begin{aligned} d\Pi &= dV - \frac{\partial V}{\partial S}dS \\ &= (\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 V}{\partial^2 S})dt \end{aligned}$$

Since this is risk free due to no stochastic term, by zero arbitrage principle, it should be equivalent to the risk free return of the bank $d\Pi = r(V - \frac{\partial V}{\partial S}S)dt$. This gives us

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial^2 S} + rS\frac{\partial V}{\partial S} = rV$$

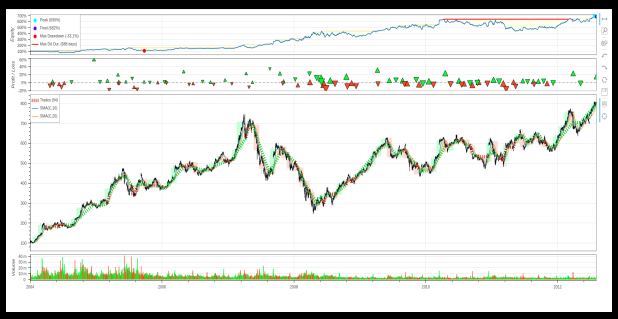
which is the Black-Scholes-Merton formula.

8.4 Greeks

$$\Delta = \frac{\partial V}{\partial S}$$
$$\Gamma = \frac{\partial^2 V}{\partial^2 S}$$
$$\Theta = \frac{\partial V}{\partial t}$$
$$\nu = \frac{\partial V}{\partial \sigma}$$

9 Implementation

The algorithmic trading strategies were implemented using `backtesting` module. Here are some results obtained during the backtesting of strategies



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