Quantitative Trading Module

Signals, Strategies, and Market Microstructure

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Outline

- **Fundamentals of Moving Averages**
  - Simple, Linear, and Exponential Weights
  - Impulse Response and Signal Lag
- **Frequency Domain Analysis**
  - Transfer Functions and Gain
  - High-pass vs. Low-pass Filtering
- **Quantitative Trading Strategies**
  - Trend Following (Momentum)
  - Mean Reversion (Oscillators)
- **Advanced Filtering Techniques**
  - MACD and Multi-Horizon Signals
  - Sensitivity and Signal-to-Noise Ratios

Course Reference:
Futuretesting Quantitative Strategies
`http://ssrn.com/abstract=4647103`

Part I

Trend and Momentum Strategies using Moving Averages

Moving Averages: Smoothing Price Dynamics

- **Objective of Moving Averages (MAs):**
  - Filter out short-term noise in prices
  - Extract the underlying trend component
  - Transform raw prices into tradable signals
- **Speed and Responsiveness:**
  - **Fast MA (short lookback):** low lag, reacts quickly, sensitive to noise
  - **Slow MA (long lookback):** higher lag, smoother, captures long-term trends
- **Common Types of Moving Averages:**
  - **Simple Moving Average (SMA):** equal weight on all observations
  - **Exponential Moving Average (EMA):** higher weight on recent prices $\Rightarrow$ faster reaction
  - **Weighted Moving Average (WMA):** linearly increasing weights, compromise between SMA and EMA

Key idea: moving averages convert noisy price series into structured signals suitable for systematic trading.

Simple Moving Averages at Different Speeds

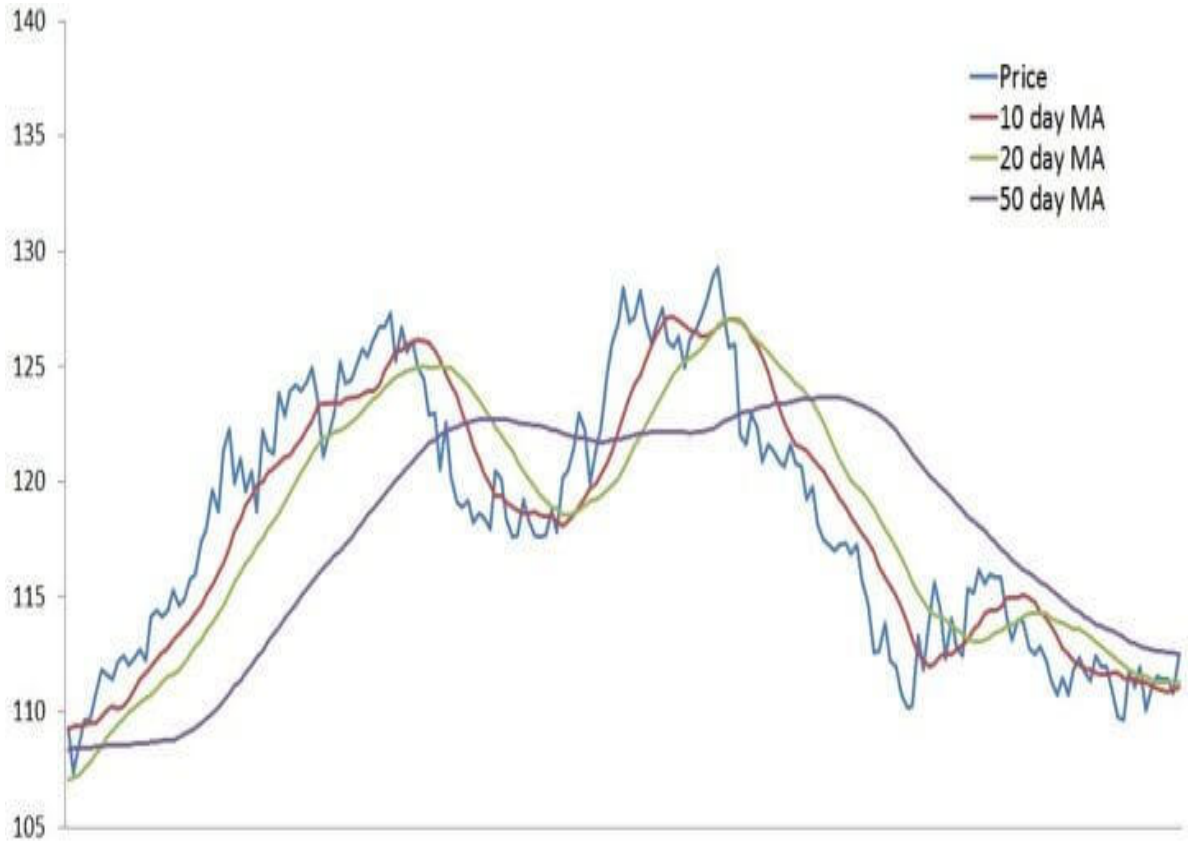

Figure 1: Simple Moving Averages (SMA) with different lookback windows.

Simple Moving Averages at Different Speeds

- Short lookback SMA:
  - Closely tracks price movements
  - Reacts quickly to trend changes
  - High sensitivity to noise and false signals
- Long lookback SMA:
  - Smooths short-term fluctuations
  - Captures persistent trends
  - Introduces lag in signal generation

Trade-off: responsiveness versus stability — a central theme in trend-following strategies.

Moving-Average-Based Trading Strategies

Moving averages form the foundation of many systematic trading rules. Common strategies can be grouped by their trading logic:

- **Trend-following strategies**
  - **Double Moving Average Crossover (DMAC):** fast MA crossing slow MA generates buy/sell signals
  - **Triple Moving Average Crossover (TMAC):** adds a medium-term MA to reduce false signals
- **Momentum indicators derived from MAs**
  - **Moving Average Convergence Divergence (MACD):** difference between fast and slow EMAs captures trend strength
  - **Relative Strength Index (RSI):** oscillator measuring persistence of gains versus losses
- **Volatility-aware MA strategies**
  - **Bollinger Bands (BB):** MA combined with volatility bands to identify extremes and breakouts

Unifying idea: prices, trends, momentum, and volatility are all filtered through moving averages.

The SMA and DMAC: Formulation & Strategy

The **SMA** at time t for a window N is defined as:

$$MA_t(N) = \frac{1}{N} \sum_{i=0}^{N-1} P_{t-i}$$

where P_t denotes the asset price at time t.

In a **DMAC** strategy, we define:

- N_S, N_L: Lookback periods for the short and long MAs ($N_S < N_L$).
- X_b: A (percent) threshold to filter out neutral signals.

The strategy (N_S, N_L, X_b), popularly $(1, 50, 0)$ or $(1, 100, 0)$, generates signals:

- **Buy Signal** at time t if:

$$MA_t(N_S) > MA_t(N_L) \times (1 + X_b)$$

- **Sell Signal** at time t if:

$$MA_t(N_S) < MA_t(N_L) \times (1 - X_b)$$

The Triple Moving Average Crossover (TMAC)

Let N_S, N_M, and N_L represent the **short**, **medium**, and **long** periods respectively ($N_S < N_M < N_L$), with X_b as the percentage band.

Long Strategy (Buy):

- A **Buy Signal** is triggered at time t if:

$$\begin{cases} MA_t(N_S) > MA_t(N_M) + X_b \\ MA_t(N_M) > MA_t(N_L) + X_b \end{cases}$$

- The long position is **unwound** (sell) when:

$$MA_t(N_S) < MA_t(N_M) - X_b \tag{1}$$

The Triple Moving Average Crossover (TMAC)

Short Strategy (Sell):

- A **Sell Signal** is triggered at time t if:

$$\begin{cases} MA_t(N_S) < MA_t(N_M) - X_b \\ MA_t(N_M) < MA_t(N_L) - X_b \end{cases}$$

- The short position is **unwound** (buy back) when:

$$MA_t(N_S) > MA_t(N_M) + X_b \tag{2}$$

The Double Moving Average Crossover (DMAC)

- Uses two moving averages with different lookback horizons:
  - **Fast MA (short-term):** reacts quickly to recent price changes
  - **Slow MA (long-term):** captures the persistent trend
- Trading signals:
  - **Buy signal (Golden Cross):** fast MA crosses above slow MA
  - **Sell signal (Death Cross):** fast MA crosses below slow MA
- Interpretation:
  - Crossing indicates a change in trend dominance
  - Acts as a low-frequency momentum filter
- Limitations:
  - Performs poorly in range-bound or sideways markets
  - Generates whipsaws due to lag and noise

Key insight: DMAC trades trend persistence, not price levels.

The Triple Moving Average Crossover (TMAC)

- Uses three moving averages:
  - **Fast MA:** short-term market reaction
  - **Medium MA:** intermediate trend confirmation
  - **Slow MA:** long-term market regime
- Entry signals:
  - **Buy:** fast MA crosses above both medium and slow MAs
  - **Sell:** fast MA crosses below both medium and slow MAs
- Signal confirmation:
  - Medium MA acts as a filter against short-term noise
  - Reduces false breakouts relative to DMAC
- Trade management:
  - Exit when fast MA crosses back through medium MA
  - Or when MA ordering breaks down

Key trade-off: fewer trades, but higher signal reliability.

Moving Average Convergence Divergence (MACD)

- The MACD is a momentum indicator derived from moving averages.
- It measures the **distance** between a fast and a slow EMA:
  - Large positive values $\Rightarrow$ strong upward momentum
  - Large negative values $\Rightarrow$ strong downward momentum
- Unlike simple MA crossovers:
  - MACD provides a *continuous* measure of trend strength
  - Signals can be anticipated before actual MA crossovers
- MACD generates signals through:
  - Crossings with a signal line (smoothed MACD)
  - Zero crossings (trend confirmation)
  - Divergences between price and momentum

Interpretation: MACD combines trend-following and momentum in a single indicator.

The MACD Line: Definition

- The **MACD line** measures momentum as the difference between two exponential moving averages (EMAs).

MACD Line

$$DIFF_t = EMA(n_S)_t - EMA(n_L)_t$$

- n_S: short-term lookback window (fast EMA)
- n_L: long-term lookback window (slow EMA)
- Standard choice: $n_S = 12$, $n_L = 26$
- Interpretation:
  - $DIFF_t > 0$: short-term momentum exceeds long-term trend (bullish)
  - $DIFF_t < 0$: downward momentum dominates (bearish)

Remark: MACD is equivalent to a *double EMA crossover expressed in difference form*.

The MACD Signal Line

- The MACD line is smoothed using an exponential moving average, called the **signal line**.

Signal Line

$$SL_t = EMA_{DIFF}(n)$$

- Standard choice: $n = 9$
- The signal line filters noise from the raw MACD line
- Trading interpretation:
  - **Buy signal:** MACD line crosses above the signal line
  - **Sell signal:** MACD line crosses below the signal line

Key insight: the MACD-signal interaction is equivalent to a *triple EMA crossover* expressed in compact form.

The MACD Histogram

- The MACD histogram measures the distance between the MACD line and the signal line.

MACD Histogram

$$Hist_t = DIFF_t - SL_t$$

- Interpretation:
  - $Hist_t > 0$: MACD above signal line (bullish momentum)
  - $Hist_t < 0$: MACD below signal line (bearish momentum)
- Dynamics:
  - Increasing histogram $\Rightarrow$ momentum strengthening
  - Decreasing histogram $\Rightarrow$ momentum weakening
  - Zero crossing anticipates MA crossover

Key advantage: the histogram reduces lag by signalling changes in momentum before crossover events.

MACD Lines and Histogram

Figure 2: MACD line, signal line, and histogram.

MACD Lines and Histogram

- MACD line (blue): difference between fast and slow EMAs
- Signal line (orange): smoothed MACD (EMA of MACD)
- Histogram: distance between MACD and signal line

Reading the chart: histogram turning points often precede signal-line crossovers.

MACD: Trading Strategy

- The MACD line ($DIFF_t$) and the signal line ($MACD(n; n_S, n_L)_t$) provide entry and exit signals.
- Simplified trading rules:
  - **Go long:** MACD line crosses above the signal line, or histogram turns up below zero ($Hist_t > \epsilon$)
  - **Go short:** MACD line crosses below the signal line, or histogram turns down above zero ($Hist_t < \epsilon$)
  - **No trade:** Otherwise
- Histogram anticipates crossovers and reduces lag inherent in moving-average systems.
- Works best in trending markets; may give false signals in sideways markets.

Tip: Use this slide to visually relate MACD lines, signal lines, and histogram to trading decisions.

MACD: Entry Rule Algorithm

Algorithm 1 Set Entry Rule for MACD

Require: Current time t_j, stock price S_{t_j}
Require: MACD line $DIFF_{t_j}$, Signal line $MACD(n; n_S, n_L)_{t_j}$
Require: Histogram $Hist_{t_j}$, threshold ϵ

1: **if** $Hist_{t_j} > \epsilon$ **then**
2: Enter **long position**: $BoolLong \leftarrow$ True, $BoolTrade \leftarrow$ True
3: **else if** $Hist_{t_j} < \epsilon$ **then**
4: Enter **short position**: $BoolLong \leftarrow$ False, $BoolTrade \leftarrow$ True
5: **else**
6: **No trade**: $BoolTrade \leftarrow$ False
7: **end if**
8: **return** $BoolTrade, BoolLong$

Note: Histogram provides early signals before actual MACD crossover, helping to reduce lag

MACD: Exit Rule Algorithm

Algorithm 2 Set Exit Rule for MACD

Require: Current time t_j, stock price S_{t_j}
Require: MACD line $DIFF_{t_j}$, Signal line $MACD(n; n_S, n_L)_{t_j}$
Require: Histogram $Hist_{t_j}$, threshold ϵ
Require: Current trade status: *BoolTrade*, *BoolLong*

1: **if** *BoolLong* **and** $Hist_{t_j} < \epsilon$ **then**
2: Exit long position: *BoolTrade* $\leftarrow$ False
3: **else if** $\neg$*BoolLong* **and** $Hist_{t_j} > \epsilon$ **then**
4: Exit short position: *BoolTrade* $\leftarrow$ False
5: **end if**
6: **return** *BoolTrade*

Note: The exit logic mirrors the entry signal, using the histogram to minimize lag and lock in gains.

Bollinger Bands: Calculation Formula

1. **Typical Price:**

$$M_t = \frac{H_t + L_t + C_t}{3}$$

Average of high, low, and close prices.

2. **Simple Moving Average (SMA):**

$$SM_t(n) = \frac{1}{n} \sum_{i=1}^{n} M_{t-i+1}$$

Computes the mean of last n Typical Prices.

3. **Standard Deviation:**

$$SD_t(n) = \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(M_{t-i+1} - SM_t(n)\right)^2}$$

Measures recent volatility.

The Bollinger band

Figure 3: Bollinger bands.

Bollinger Bands: Calculation Formula

1. **Upper Band:**

$$\text{TopBand} = SM_t(n) + \alpha \times SD_t(n), \quad \alpha = 2$$

2. **Middle Band:**

$$\text{MidBand} = SM_t(n)$$

3. **Lower Band:**

$$\text{BotBand} = SM_t(n) - \alpha \times SD_t(n)$$

Tip: Bands expand with volatility and contract during calm periods, providing dynamic support/resistance.

Bollinger Bands: Interpretation and Use

- Bollinger Bands define a **dynamic price channel** around a moving average.
- The middle band represents the short-term trend, while the upper and lower bands adapt to volatility.
- **Band expansion** signals rising volatility, often following news or regime changes.
- **Band contraction** ("volatility squeeze") often precedes large price moves.
- Prices touching or exceeding the bands are *not* automatic buy/sell signals:
  - In trending markets, prices may "walk the band"
  - In range-bound markets, bands act as support and resistance

Key insight: Bollinger Bands measure relative price extremes conditional on recent volatility, not absolute overvaluation or undervaluation.

Bollinger Bands: Trading Strategy

- Bollinger Bands can be used to design **mean-reversion** or **breakout** strategies.
- **Mean-reversion strategy (range-bound markets):**
  - Go **long** when price touches or crosses the lower band
  - Go **short** when price touches or crosses the upper band
  - Exit near the middle band
- **Breakout strategy (trending markets):**
  - Enter positions when price breaks out after a volatility squeeze
  - Trade in the direction of the breakout
- Bands should be combined with momentum or trend indicators (e.g., MACD, RSI).

Warning: Using Bollinger Bands mechanically without regime detection leads to frequent false signals.

The Bollinger Double Bands (BDB)

The BDB strategy utilizes two sets of bands: one based on a single standard deviation (σ) and another on two. Given a Simple Moving Average $SMA_t(n)$, the bands are defined as:

Primary Bands (Inner):

$$\text{TopBand}_1 = SMA_t(n) + \alpha_1 \times SD_t(n)$$
$$\text{BotBand}_1 = SMA_t(n) - \alpha_1 \times SD_t(n)$$

where α_1 is typically set to 1.

Secondary Bands (Outer):

$$\text{TopBand}_2 = SMA_t(n) + \alpha_2 \times SD_t(n)$$
$$\text{BotBand}_2 = SMA_t(n) - \alpha_2 \times SD_t(n)$$

where α_2 is typically set to 2.

Note: While *SMA* is standard, the logic can be extended to Exponential (*EMA*) or Weighted Moving Averages (*WMA*) for increased sensitivity.

The Bollinger Double Bands (BDB): Strategy

The BDB strategy combines trend-following and mean-reversion by identifying specific 'action zones'. These zones are defined as:

$$\text{Buy Zone} = [\text{TopBand}_1, \text{TopBand}_2] \tag{3}$$

$$\text{Sell Zone} = [\text{BotBand}_2, \text{BotBand}_1] \tag{4}$$

Trading Rules:

- **Long Position:** Enter when the price enters the Buy Zone. **Unwind** when the price exits the zone (either from above or below).
- **Short Position:** Enter when the price enters the Sell Zone. **Unwind** when the price exits the zone (either from below or above).
- **Neutral:** If the price is outside these specific zones, no trades are executed.

Set entry rule for BDB

Algorithm 3 Set entry rule for BDB.

Require: The current time t_j, the stock price S_{t_j}, the window size.
Require: The Buy Zone given in Equation (3) and the Sell Zone given in Equation (4)

1: **if** S_{t_j} enters the Buy Zone **then**
2: Identify the trade as long: set $BoolLong = \text{True}$ and $BoolTrade = \text{True}$.
3: **else if** S_{t_j} enters the Sell Zone **then**
4: Identify the trade as short: set $BoolLong = \text{False}$ and $BoolTrade = \text{True}$.
5: **else**
6: Do not trade : set $BoolTrade = \text{False}$.
7: **end if**
8: **return** BoolTrade, BoolLong

Set exit rule for BDB

Algorithm 4 Set exit rule for BDB.

Require: The current time t_j, the stock price S_{t_j}, the window size.
Require: The Buy Zone given in Equation (3) and the Sell Zone given in Equation (4)
Require: BoolTrade, BoolLong

1: **if** *BoolLong* And S_{t_j} exit the Buy Zone **then**
2: Identify the exit time of a long position: set *BoolTrade* = False .
3: **else if** !*BoolLong* And S_{t_j} exit the Sell Zone **then**
4: Identify the exit time of a short position: set *BoolTrade* = False .
5: **end if**
6: **return** BoolTrade

The Relative Strength Index (RSI): Formula

The RSI is a momentum oscillator that measures the speed and change of price movements, calculated as:

$$RSI = \frac{AU(n)}{AU(n) + AD(n)} \times 100 \tag{5}$$

where the components are defined as:

- **Average Up (AU):** The average of upward price changes over n periods.

$$UP_t = \max(C_t - C_{t-1}, 0) \implies AU(n) = \frac{1}{n} \sum_{i=0}^{n-1} UP_{t-i}$$

- **Average Down (AD):** The average of downward price changes over n periods.

$$DW_t = \max(C_{t-1} - C_t, 0) \implies AD(n) = \frac{1}{n} \sum_{i=0}^{n-1} DW_{t-i}$$

The Relative Strength Index (RSI): Formula

Range Interpretation: The index is bounded in $[0, 100]$.

- $RSI = 100$: Only upward moves ($AD = 0$).
- $RSI = 0$: Only downward moves ($AU = 0$).

The Relative Strength Index (RSI): Alternative Form

The RSI is often expressed in its normalized form to facilitate the identification of overbought and oversold extremes:

$$RSI = 100 - \frac{100}{1 + RS(n)} \tag{6}$$

where the **Relative Strength (RS)** is the ratio of average gains to average losses:

$$RS(n) = \frac{AU(n)}{AD(n)} = \frac{SMA(U, n)}{SMA(D, n)}$$

The Relative Strength Index (RSI): Alternative Form

Key Variations and Implementation:

- **Smoothing:** While the standard uses SMA, using an Exponential Moving Average (EMA) increases sensitivity to recent price action:

$$RS(n) = \frac{EMA(U, n)}{EMA(D, n)} \tag{7}$$

- **Data Requirements:** Robust calculation typically requires at least 250 data points to allow the averages to stabilize.
- **Normalization:** While RS and RSI plots share the same profile, the RSI scale $[0, 100]$ is preferred for standardized signal generation.

The RSI

Figure 4: RSI oscillator.

RSI: Overbought / Oversold Strategy

The RSI oscillator is primarily used to identify market extremes where price momentum may be overextended.

Threshold Definitions:

- **Overbought (> 70):** Suggests the asset may be overvalued; a reversal or pullback is possible.
- **Oversold (< 30):** Suggests the asset may be undervalued; a bounce or reversal is possible.

Trading Rules:

- **Long (Buy) Signal:**
  - **Entry:** RSI crosses *above* 30 after being in the oversold region.
  - **Exit:** RSI drops below 70 (mean-reversion/profit-taking).
- **Short (Sell) Signal:**
  - **Entry:** RSI crosses *below* 70 after being in the overbought region.
  - **Exit:** RSI rises above 30 (mean-reversion/profit-taking).

Strategy Note: This method is effective for capturing reversals but can be prone to 'false signals' in strongly trending markets.

Set entry rule for RSI

Algorithm 5 Set entry rule for RSI.

Require: The current time t_j, the stock price S_{t_j}, the window size.
Require: The RSI indicator given in Equation (6)

1: **if** RSI line crosses the level 30 from above **then**
2: Identify the trade as long: set $BoolLong =$ True and $BoolTrade =$ True .
3: **else if** RSI line crosses the level 70 from below **then**
4: Identify the trade as short: set $BoolLong =$ False and $BoolTrade =$ True .
5: **else**
6: Do not trade : set $BoolTrade =$ False .
7: **end if**
8: **return** BoolTrade, BoolLong

Set exit rule for RSI

Algorithm 6 Set exit rule for RSI.

Require: The current time t_j, the stock price S_{t_j}, the window size.
Require: The RSI indicator given in Equation (6)
Require: BoolTrade, BoolLong

1: **if** *BoolLong* And RSI line crosses the level 70 from below **then**
2: Identify the exit time of a long position: set *BoolTrade* = False .
3: **else if** !*BoolLong* And RSI line crosses the level 30 from above **then**
4: Identify the exit time of a short position: set *BoolTrade* = False .
5: **end if**
6: **return** BoolTrade

Limitations of Technical Indicators

- Most technical indicators are **backward-looking**, relying on past prices and volumes.
- Signals are often **lagged**, especially during rapid market regime changes.
- Indicators assume **stationarity** over the estimation window, which is frequently violated.
- Performance degrades in the presence of:
  - Structural breaks
  - Volatility regime shifts
  - Changes in market microstructure
- Parameter choices (window length, thresholds) introduce **model risk** and overfitting.

Key takeaway: Technical indicators are best viewed as *feature extractors*, not standalone trading systems.

From Stylised Facts to Models

- Financial time series exhibit stylised facts:
  - Heavy tails and non-Gaussian returns
  - Volatility clustering and persistence
  - Jumps, asymmetry, and regime changes
- Classical models (e.g. Brownian motion with constant volatility) fail to capture these features.
- This motivates progressively richer modelling frameworks:
  - Stochastic volatility models
  - Jump-diffusion processes
  - Regime-switching models
  - Nonlinear and data-driven models
- Model choice should be driven by the **stylised facts** relevant to the problem at hand.

Core principle: Models are approximations—use the simplest model that captures the dominant empirical features.

Summary and Outlook

- Financial time series exhibit rich dynamics that deviate strongly from classical assumptions.
- Key empirical characteristics include:
  - Heavy tails and extreme events
  - Volatility clustering and persistence
  - Jumps, asymmetries, and nonlinearity
  - Regime changes and cross-asset dependence
- These stylised facts challenge traditional econometric tools.
- Modern financial modelling integrates:
  - Stochastic processes beyond Brownian motion
  - Risk-aware statistical methods
  - Machine learning with memory and regime sensitivity

Outlook: The next part of the course will focus on stochastic volatility, jump processes, and data-driven models that explicitly address these empirical realities.

The end

Thank You !