# Time Series Modeling

A Preview Before the Lectures

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*Prediction is very difficult, especially if it's about the future.*
— Niels Bohr, *Nobel laureate (Physics, 1922)*

## Preamble

I have prepared these notes for past and current students who are new to time series modeling of financial market data.

When you encounter it for the first time, you are usually greeted with a barrage of strange terms like *"stationarity", "Augmented Dickey-Fuller test", "Gaussian white noise", "ARMA", "GARCH"* and others. There is considerable background theory pertaining to the subject. So it's totally normal to feel overwhelmed and sometimes lose track of the link between models/tests and how they are connected to our forecasting objective.

I promise not to go deep into the details of these issues unless absolutely essential. For those interested in learning more about them, I point you to resources here and in other material that I share with you.

My focus here and in the lectures is to give you a high-level overview of key ideas and illustrate them through practical examples from the financial markets. Hopefully, that should give you a first-level understanding of the concepts at play (minus the derivations).

The material presented during the lectures should be approachable to anyone who has a basic understanding of statistics, can read Python code and is interested in the analysis/forecasting of asset prices in the financial markets.

# 1 Introduction

Below is a simple definition of time series.

**Time Series:** *Sequential observations of the same variable.*

The sequence we refer to is observed over time.

For example, the daily closing prices of the INFY stock price over the last 500 trading days, annual CPI over the past 25 years, etc.

We use the following notations to represent it.

$$\{x_1, x_2, \ldots, x_T\}$$

or

$$\{x_t\},\ t = 1, 2, \ldots, T$$

You see time series everywhere. Like medicine (recording the weight, sugar levels, blood pressure of a patient over time), climate studies (sea levels, temperatures observed daily for years), engineering, social sciences, etc.

As quant finance professionals, we deal with time-series data day in and day out. The most important question we ask and seek to answer is **"What will be the price (or volatility) in the next time period?"**. The time period under consideration could be intra-day or much longer.

We use different prediction methods to answer it depending on the assets and the markets where they are traded, the length of the forecast period, the dataset used, the required quality of prediction, the capital invested, etc.

# 2 A very brief note on Technical Analysis (TA) and Time Series Analysis (TSA)

*Technical analysis* has been around since the end of the nineteenth century. It is an investment analysis style that mainly relies on charts and moving

averages to identify patterns in asset price movements. Technical analysts use them to formulate buy and sell signals.
*Time series analysis* is a more broad-based approach and applicable to fields far beyond finance. It uses statistical theory to describe, analyze and forecast the process being studied.

Marshall et al. (2014) and Fang and Xu (2003) observe that most academic studies on financial asset returns predictability have proceeded along both paths separately. This is because each line of inquiry recognizes different predictable components in the returns.

The profit generating ability of technical trading rules in their plain vanilla form is usually limited and has declined over the years (Fang and Xu 2003).

That gives us quite a good reason to learn about techniques like time series modeling and incorporate it in our quest for alpha generating strategies.

I now introduce some commonly seen terms in the literature. These will start to make more sense when we go through examples in class.

# 3 Commonly Used Terminology

## 3.1 Stationarity & Non-Stationarity

**A stationary process is one whose statistical properties (like mean, variance, covariance, etc.) remain constant in time.**

However, most business and financial time series are **non-stationary** in their original forms ex. stock prices, market index levels.

Stationary processes are easier to deal with due to the constancy of their statistical properties. We can therefore simply forecast that their characteristics remain the same in the future as they were in the past.

So a critical step in our analysis is to transform a non-stationary process into a stationary one (we will do this in class). We then make predictions and just reverse the transformation to obtain predicted values of the actual series we started with.

All of the painful details that I've mentioned above are usually taken care of by modern statistical software like Python, R, etc.

The below images help us visualize the differences between stationary and non-stationary processes.

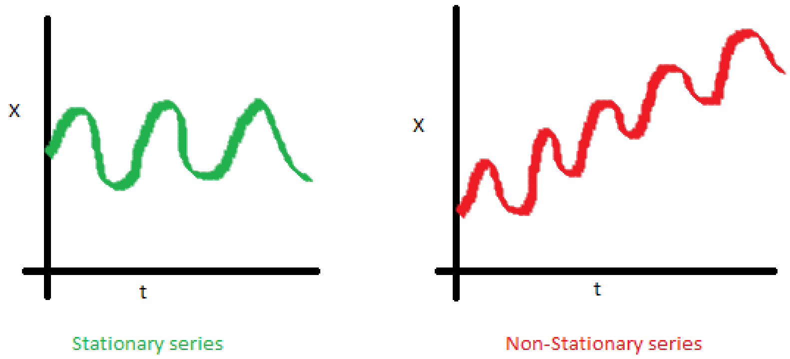


Figure 1: A sketch of processes with constant and non-constant means from Sean Abu (2016a).

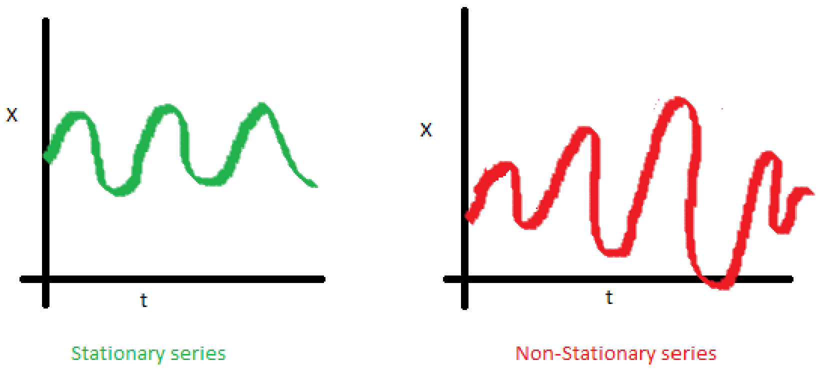


Figure 2: A sketch of processes with constant and non-constant variances, from Sean Abu (2016b).

## 3.2 ACF & PACF

In statistics, correlation measures the strength of the linear relationship between any two variables. Time series data have one peculiar feature: ***persistence in successive observations***.

The ACF and PACF are metrics that help us quantify this.

**Autocorrelation function (ACF)**: We measure the correlation of a variable with a lagged version of itself. This is also called *serial correlation*.

**Partial Autocorrelation function (PACF)**: The autocorrelation of a variable with a k-time period lagged version of itself is comprised of two effects:

- the direct effect (i.e. the pure linear relationship between the variable and its k-period lagged version) and
- the indirect effect (the linear relationship between the variable and its k-period lagged version that oozes through the shorter lags)).

PACF gives us the correlation for **only the direct effect**.

# 4 Stylized Facts of Asset Returns

There are certain statistical properties that financial asset returns share across markets, instruments and time periods (Cont 2001).

We should be cognizant of them when we build models to explain and forecast prices. We will discuss and test many of the properties in class.

# References

Cont, Rama. 2001. 'Empirical properties of asset returns: stylized facts and statistical issues'.

Fang, Yue, and Daming Xu. 2003. 'The predictability of asset returns: an approach combining technical analysis and time series forecasts'. *International Journal of Forecasting* 19 (3): 369–385.

Marshall, Ben R., Nick Nguyen and Nuttawat Visaltanachoti. 2014. 'Time-Series Momentum versus Moving Average Trading Rules'. *Available at SSRN.*

Sean Abu. 2016a. *Stationary & Non-Stationary Means.* [Online; accessed July 03, 2020]. `http://www.seanabu.com/img/Mean_nonstationary.png`.

———. 2016b. *Stationary & Non-Stationary Variance.* [Online; accessed July 03, 2020]. `http://www.seanabu.com/img/Var_nonstationary.png`.