Technical Indicators Efficacy in Forex Markets

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To my husband Marco, I will forever be grateful for his strength, patience, kindness, and, more importantly, for always believing in me, even in my darkest moments.

To my grandmothers for being the mother, I never had and making me the person I am today. I miss you deeply.

To every one of you – Thank you.

"If you want something you have never had, you must be willing to do something you have never done."

- Thomas Jefferson
Abstract

Technical analysis is considered one of the oldest methods used to evaluate the financial market. The technical analysis distinguishes itself from the others by predicting possible market movements through studying past prices and patterns, using a graphical representation of data as the primary tool. This analysis has aroused considerable interest in the literature, with several articles favoring or against its effectiveness in forecasting the market. In this work, it is evaluated the performance of four indicators (Exponential Moving Average, Convergence/Divergence of Moving Averages, Relative Strength Index, and Bollinger Bands) when applied to the Foreign Exchange market in two of the main currency pairs currently traded (EUR/USD and GBP/USD). To improve the consistency of the study, the time frame was extended for the last five years. All opening and closing price values were obtained from a 30-minute interval. This work aims to understand if, by combining different indicators, the strategies have more efficient and profitable results than using a single indicator. Through the signals obtained from the tested indicators, buy and sell orders were simulated using a predefined capital to assess each indicator’s overall performance and profitability and their respective combinations. After extensive backtesting simulations, we show that using specific indicators combination as a financial strategy can be more effective and profitable than just a single indicator, although significantly fewer trades are triggered. The computational results presented shows that the the efficiency of the combined strategies depends on the year’s market trend. Downtrend markets as experienced in 2016, 2018, and 2019, drastically reducing the strategies’ efficiency. While In 2020 and 2017, the market was in an uptrend, so the majority of the strategies have shown excellent efficiency.

Keywords

Foreign Exchange Market; Technical Analysis; Technical Indicators; Trading;
Resumo

A análise técnica é considerada um dos métodos mais antigos de avaliação do mercado financeiro. Esta distingue-se dos outros tipos de análise por prever possíveis movimentos de mercado através do estudo de preços e padrões passados, utilizando a representação gráfica de dados como ferramenta principal. A análise técnica tem suscitado bastante interesse na literatura, com diversos artigos a favor ou contra a sua eficácia na previsões do mercado. Neste trabalho, é avaliado o desempenho de quatro indicadores (Média Móvel Exponencial, Convergência/Divergência de Médias Móveis, Índice de Força Relativa e Bandas de Bollinger) quando aplicados ao mercado cambial em dois dos principais pares de moedas negociados (EUR/USD e GBP/USD). Para melhorar a consistência do estudo, o prazo foi estendido para os últimos cinco anos. Todos os valores de preços de abertura e fecho foram obtidos a partir de intervalos de 30 minutos. Este trabalho visa compreender se, ao combinar diferentes indicadores, as estratégias apresentam resultados mais eficientes e lucrativos do que a utilização de um único indicador. Através dos sinais obtidos a partir dos indicadores testados, as ordens de compra e venda foram simuladas utilizando um capital pré-definido para avaliar o desempenho geral e a rentabilidade de cada indicador e suas respectivas combinações. Após realização de vários testes, mostramos que combinações de indicadores específicos pode ser mais eficaz e lucrativo do que usar apenas um único indicador. Os resultados computacionais apresentados demonstram que a eficiência das estratégias combinadas depende da tendência de mercado nesse ano. Quando a tendência é de declínio como em 2016, 2018 e 2019, a eficiência das estratégias é reduzida. Enquanto em 2020 e 2017, a tendência era de subida, e a maioria das estratégias apresentou óptima eficiência.

Palavras Chave

Mercado Câmbial; Análise Técnica; Indicadores Técnicos; Negociação;
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<td>API</td>
<td>Application Programming Interface</td>
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<tr>
<td>BB</td>
<td>Bollinger Bands</td>
</tr>
<tr>
<td>CL</td>
<td>Close Line</td>
</tr>
<tr>
<td>eq</td>
<td>Equal to</td>
</tr>
<tr>
<td>EMA</td>
<td>Exponential Moving Average</td>
</tr>
<tr>
<td>EUR</td>
<td>Euro</td>
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<tr>
<td>Forex</td>
<td>Foreign Exchange</td>
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<tr>
<td>GBP</td>
<td>British Pound Sterling</td>
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<tr>
<td>gt</td>
<td>Greater than</td>
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<tr>
<td>JPY</td>
<td>Japanese Yen</td>
</tr>
<tr>
<td>lt</td>
<td>Less than</td>
</tr>
<tr>
<td>MACD</td>
<td>Moving Average Convergence Divergence</td>
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<tr>
<td>RSI</td>
<td>Relative Strength Index</td>
</tr>
<tr>
<td>SMA</td>
<td>Simple Moving Average</td>
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<td>USD</td>
<td>United States Dollar</td>
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Glossary

Backtesting
Testing a trading strategy or predictive model using existing historic data .................. 38

candlestick
A candlestick is a type of price chart used in technical analysis that displays the high, low, open, and closing prices of a security for a specific period ................................. 15

Close
This is the last price traded during the period. The close price is the most often value used for analysts ......................................................... 22

Equity
Refers to the absolute value of a Forex trader’s account .............................................. 40

Forex
The foreign exchange market .................................................................................. 3

High
The highest price traded during the period ............................................................... 22

Lagging indicators
Use past price data to confirm a recent change in price ........................................... 17

Leading indicators
Use past data to project future price levels ............................................................. 17

Low
The lowest price traded during the period ............................................................... 22

Oanda dataset
Privately-lead Forex broker .................................................................................. 35

Open
The price of the first trade for the period (eg: the first trade of a 30-minute candle) .......... 21
**Portfolio**

In the context of Forex, a portfolio include different investment types. An investor can own different trading portfolios, each geared towards a different investment strategy. 

**Trader**

Person who buys or sells goods, currency, or shares.

**Trading**

The act of buying and selling goods or an asset.
1

Introduction

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Introduction

Due to the fast computational growth, electronic trading has become more accessible through different platforms, allowing an average person to access financial markets that generally would be only for financial companies. As a result, academic research in Foreign Exchange (Forex) trading has experienced exponential growth over the past few years. The market analysis has been vital in the attempt to forecast the future price movements in order to prevent loss and generate profit. However, Forex is a highly volatile and complex market, mainly because it depends on political stability, economic events, social media posts, and many others. All these factors combined make Forex trading prediction an extremely challenging task.

Figure 1.1: Forex Market vs Other Markets
Image from DailyFx

The Forex market is one of the biggest financial markets in the world, as can be seen in Figure 1.1. According to the Bank of International Settlements, Forex is a global marketplace for exchange currencies that moves up to 5.3 trillion US dollars per day. Compared to other financial markets, Forex has the advantages of being a market with no fixed location, and open 24 hours a day, five days a week.

With the exponential growth of traders and investors in the Forex market, a high demand for forecasting methods has been experienced. There are several different analysis methods applied to Forex data, among them have stood out the Random Walk Theory, the Fundamental Analysis, and the Technical Analysis. This work evaluates the efficiency of only one method, Technical Analysis, since it is by far the most popular one [3].

John Murphy [3] defines the technical analysis as "the study of market action, primarily through the use of charts, to forecast future price trends". The controversy about the usefulness of technical analysis has led to an enormous volume of literature in recent years. About half of all empirical studies conducted after 1960 were published during 1995-2004 [4], there is no doubt that technical analysis is an arguable subject among researchers and investors. Some researchers defend that it is impossible to predict
the market based on the Random Walk theory. Others believe that history does not repeat itself, and therefore the importance of the study of price patterns is irrelevant. On the other hand, the proponents of technical analysis believe that the past price data contain important information about future price movements. The majority of the brokerage firms rely on technical analysis, and many of the advisory services are based on this technique as well [5].

Within this context, the main objective of this work is to evaluate the performance of the most popular technical indicators. This study uses two currency pairs (EUR/USD and GBP/USD), tested for a 30-minute time frame during the year of 2020. This particular time period is selected due to the pandemic situation worldwide that led to unprecedented movements in the Forex market. All types of behaviours can be found in this dataset - uptrend, downtrend, and sideways market, thus ensuring we can test the indicators for all phases. To improve the obtained results reliability, the time frame is extended for the last five years.

1.1 Objectives

The primordial objective of this work is to investigate the efficiency of the technical analysis in the Forex market forecasting. By running extensive backtesting simulations, we expect to achieve the followings:

• Study the efficiency the four most popular technical indicators: Exponential Moving Average (EMA), Moving Average Convergence Divergence (MACD), Relative Strength Index (RSI), and Bollinger Bands (BB). The backtesting is performed through a financial package, Quantstrat, in R language.

• Understand if by combining different indicators, the strategies have more efficient and profitable results than using a single indicator.

• Run the strategies with different initial capitals.

1.2 Contributions

In this section we summarize briefly the contributions we hope to succeed with this work.

• Find a combination of indicators with reasonable high efficiency (highly profitable) that proves to be consistent in the long-term.

• Prove that combining indicators strategies can be useful and even more efficient than the single strategies.
Confirm that it is possible to forecast the Forex market by relying on the technical analysis only.

1.3 Organization of the Document

The present document is organized as follows: Section 2 describes the literature review, with a brief introduction to the Foreign Exchange market, its history, the different types of market analysis, and in more detail, the technical analysis. Section 3 describes the technical indicators used in the study and its technical trading rules defined. Section 4 describes the dataset and explains the financial packages used and the tests applied. In Section 5 the results of 2020 are analyzed and in the section 6, the results from the last five years are discussed. Finally, in Section 7 is made a conclusion, as well as provide an outlook on future work.
## Literature Review

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7
Literature Review

In this chapter, the theoretical foundations about trading in the Forex market and technical analysis are laid down. These can be divided into three sections:

- Forex - Brief History and Market Concepts (section 2.1);
- Forex Analysis (section 2.2);
- Technical Analysis (section 2.3);

2.1 Forex - Brief History and Market Concepts

Financial markets include a set of markets such as Stock Market, Commodity Market, Money Market, Derivatives Market, Futures Market, Insurance Market and, Foreign Exchange Market. However, the Stock Market and the Foreign Exchange Market are the most popular among the traders [6]. The Foreign Exchange market is recognized as the largest and most liquid financial market in the world. The average daily transactions in this market are now estimated at around $5.3 trillion per day, according to the Bank for International Settlements triennial report of 2016 [7] [2]. Table 2.1 shows the difference in volume size per day between markets.

<table>
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<tr>
<th>Market</th>
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<tr>
<td>NY Stock Market Equities</td>
<td>$28 billion</td>
</tr>
<tr>
<td>Futures Market</td>
<td>$191 billion</td>
</tr>
<tr>
<td>Forex Market</td>
<td>$437 billion</td>
</tr>
<tr>
<td></td>
<td>$5.3 trillion</td>
</tr>
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The Foreign Exchange (Forex) market definition corresponds to a generic term for worldwide institutions to exchange or trade currencies. Foreign Exchange is commonly referred to as “Forex,” or “FX” [8]. In this study, we use the Forex term for the consistency of the document. The Forex market is a market with no fixed location, which means a central exchange and clearing house where orders are matched, does not exist. Forex traders and market makers worldwide are connected around the clock via the internet and telephone, creating one cohesive market.

The Forex history starts in the 1800s, with the gold standard. The gold standard guaranteed that the governments would redeem any amount of paper money for its value. During World War I, this mechanism was suspended because the European countries need to print money to pay for the war.

The turnover in the Forex market was the Bretton Woods system that occurred at the end of World War II. The Bretton Woods Accord gathered 44 countries to sign a new institutional arrangement to
govern the international economy. This system allowed the creation of two institutions to regulate international economies that maintain until now, the International Monetary Fund (IMF) and the World Bank [8]. That system eventually failed due to several factors, like the lack of gold resources and the desire of governments to control the currency exchange rates.

In 1971, President Richard Nixon ended the Bretton Woods system, which led to the free-floating of the US dollar against other currencies. A few years later, the IMF created a legalized system of floating exchange rates. This system remains until nowadays and is not connected with the gold price, and the price fluctuations reflect the forces of supply and demand for each currency [9].

In 1973 begins the modern era of the Forex market, with the introduction of computer monitors by Reuters that replaced the old methods of telephone and fax for obtaining trading quotes. A few years later, in the 80s, Reuters developed a form of electronic Forex trading that preceded the advent of the internet that served as a real-time closed network for traders. A long way of modernization takes place until we have now as electronic trading accessible to everyone with a smartphone. This modernization has broken down the barriers between the end-users of Forex services and the inter-bank market, causing changes in the world controlled by the big banks. Now the average Trader can profit and take advantage of the same opportunities as big banks [8] [10].

Figure 2.1: Forex History
Source: DailyFX [9]

Nowadays, the Forex market is built up by many different banks, which is called an inter-bank market. Forex has the advantage of being open 24 hours a day, five and a half days a week, and it is a very liquid market. This liquidity allows large trading volumes to enter and exit the market without the large fluctuations in price in less liquid markets.

1Person who buys or sells goods, currency, or shares
Trading Forex involves the buying of one currency and at the same time the selling of another. This is why currencies are always traded in pairs. Currencies are quoted in relation to another currency. For example, the United States Dollar (USD) and the British Pound Sterling (GBP) (USD/GBP), the Euro (EUR) and the Japanese Yen (JPY) (EUR/JPY).

To summarize a trade order action, after an investor chooses the currency pair for trading, should place an order to initiate the trade. An order is an instruction to the broker to take a specific transaction. There are three principal types of orders: market order, stop-loss order, and take-profit order. In order to start a trade in Forex, the investor should open a position. There are two ways of opening a position: buying the base currency and selling the quote currency or selling the base currency and buying the quote currency [11].

2.2 Forex Analysis

Forex analysis has been important to forecast future trading patterns, generate profit and minimize losses. However, forecasting in the Forex market is essential to consider several external factors, like economic events, political issues, tragedies (example: pandemic), social media posts, and many others. Therefore, several analysis methods are applied to Forex, but the most famous are the Random Walk Analysis, the Fundamental analysis, and the Technical Analysis. We will discuss the Technical Analysis in section 2.3, but before that, we will approach the other two analyses briefly.

2.2.1 Random Walk Theory

The Random Walk Theory is a financial model which assumes that the stock market moves in a completely unpredictable way. The hypothesis suggests that the future price of each stock is independent of its historical movements and the price of other securities. Random Walk Theory was developed by Louis Bachelier, who believed that share price movements were like the steps taken by a drunk, which means unpredictable. The theory became famous through the work of economist Burton Malkiel when he coined the term in his book "A Random Walk Down Wall Street." Malkiel, with this theory, discredit the technical analysis, saying that the analysts only buy after the price trends are established and only sell when the trends are broken, which means that analysts are buying and selling too late. According to the theory, stock prices already reflect the information when the analysts move on the stock.

Scott Page in his book The Model Thinker [12], explains the random walk model, based on the "Bernoulli urn model". The model consists of an urn containing gray and white balls. Draws from the urn represent the outcomes of random events. Each draw is independent of previous and future draws.

---

2 The act of buying and selling goods an asset
We are taking his example of setting an initial value of zero as the state of the model. If we draw a white ball, we add 1 to the total. If we choose a gray ball, we subtract 1. The state of the model at any time equals the sum of the previous outcome. Equation 2.1 above represents the explained model:

\[ V_{t+1} = V_t + R(-1, 1) \] (2.1)

Where \( V_t \) is the value of the random walk at time \( t \), \( V_0 = 0 \) and \( R(-1, 1) \) is a random variable that is equally likely to equal -1 or 1. The expected value of a random walk in any period equals zero and has a standard deviation of \( \sqrt{t} \), where \( t \) equals to the number of periods.

Figure 2.2 shows a simple random walk.

![Random Walk](image)

**Figure 2.2:** Plot of a Random Walk for 500 periods
Source: Author

Page [12] also relates the random walk with the stock market. He uses, as an example, the Facebook stock prices in the period between June of 2012 and June of 2013 and apply statistical tests to the sequence of Facebook shares prices to prove if it satisfies the hypotheses of normal random walk. Initially, the price should go up and down with equal probability. In the 249 trading days covered, Facebook’s stocks price decreased on 127 days (51 %). Next, in a random walk, the probability of an increase should be independent of a previous period increase. Facebook’s stock price moved in the same direction on consecutive days 54% of the time. Lastly, the expected longest streak of moves in the same direction should be eight days. Facebook’s stocks price increase ten consecutive ten days once during the analyzed period. In conclusion, it is possible to say that Facebook’s stock price is consistent with a normal random walk.

The fundamental analysis was found undependable by the theory due to the often inadequate information collected and its ability to be misinterpreted. Malkiel concludes that it is impossible to consistently outperform the market, especially in the short-term, due to the impossibility to predict stock prices [13] [14].

However, this theory received much criticism from analysts, saying that it is possible to outperform the market by carefully considering entry and exit points. Murphy [3], says that although exists a certain
amount of "noise" in the market, it is unrealistic to believe that all price movements are random.

2.2.2 Fundamental Analysis

Fundamental analysis is a method of evaluating the financial markets with the primary goal of price forecasting. Fundamental analysis for the Forex market evaluates the macroeconomic indicators, assets, markets, and political events of one country’s currency against another. The main focus of fundamental analysis is the economic forces of supply and demand that cause price movements. The importance of study the economic factors it is connected with the currency price that only the supply and demand can determine [3] [7].

An excellent fundamental analysis depends on examining macroeconomic indicators and asset markets when analyzing a country’s currency. Macroeconomic indicators include the following factors: Gross Domestic Product; Inflation; Unemployment; Balance of Payments; market correlations; productivity and Purchasing Market Index. Asset markets are connected with stocks, bonds, and real state [15].

<table>
<thead>
<tr>
<th>Time</th>
<th>5:02pm</th>
<th>6:10pm</th>
<th>8:30pm</th>
<th>12:00pm</th>
<th>All Day</th>
<th>3:00pm</th>
<th>3:50pm</th>
<th>4:00pm</th>
<th>10:00pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event</td>
<td>BCSI Outlook Report</td>
<td>BCSI Core CPI y/y</td>
<td>BCSI Press Conference</td>
<td>CBI Realized Sales</td>
<td>OPEC, IMF Meetings</td>
<td>PMI</td>
<td>BCSI Composites-00 PMI y/y</td>
<td>Richmond Manufacturing Index</td>
<td>CPI Consumer Confidence</td>
</tr>
<tr>
<td>Impact</td>
<td>-0.01%</td>
<td>-0.02%</td>
<td>-0.02%</td>
<td>23</td>
<td>9</td>
<td>1.0%</td>
<td>11.9%</td>
<td>17</td>
<td>121.7</td>
</tr>
</tbody>
</table>
| Source     | "https://www.forexfactory.com/calendar"

One of the most important fundamental factors to Forex traders is the economic calendar, as it shows in the Figure 2.3. The Figure 2.3 shows an example how Forex news data websites help traders understand the data by putting a flag next to the headlines. There different types of flag colors depending on the new’s impact: a yellow flag means low impact, an orange flag means medium impact, and a red flag means high impact. Next to the flags is placed the currency that will be affected by the news.

The economic calendar and the news announcements help drive both short-term and long-term movements in currency exchange rates. Many traders wait for the news released before entering a trade. However, this is a precarious way of trading for many reasons. One significant difficulty is the speed required to enter a position at the right time to take advantage of the best price moves. Adding the fact that to access the news earlier than everyone else is virtually impossible. Finally, the difficulty with the interpretation of the news. Economic data is hard for an average trader to understand, which
2.3 Technical Analysis

The technical analysis is the systematic evaluation of price, volume, breadth, and open interest for price forecasting [16]. In other words, technical analysis is the study of historical price movements to predict future price movements [10].

The modern technical analysis comes from the Dow Theory, developed by Charles Dow around 1900. Dow wrote his ideas in a series of editorials for the Wall Street Journal. His theory continues to be the cornerstone of the study of technical analysis, even with the evolution of technology and the creation of newer and better technical indicators. The Dow Theory is composed of six basic principles that fit into the modern technical analysis [3]:

1. The averages discount everything.
2. The market has three trends.
3. Major trends have three phases.
4. The averages must confirm each other.
5. Volume must confirm the trend.
6. A trend is assumed to be in effect until it gives definite signals that it has reversed.

The principles of technical analysis were a result of the observation of financial markets over hundreds of years. The oldest known evidence of technical analysis comes back from the Dutch market in the 17th century. In Asia, the oldest and most famous example of technical analysis is predicting future price movements of the rice market by analyzing past prices, developed by Homma Munehisa during the 18th century. At that time, Japan had evolved from a local and isolated market to a concept of a centralized market where rice coupons were traded. In fact, rice coupons represented the first future contracts in the history of markets.

The candlestick analysis has been prevalent in Asia for centuries but only arrived at the West in the late 80s by a Wall Street investor, Steve Nison. Nison was driven to study this type of analysis after seeing a Japanese broker looking at a candlestick chart and analyzing patterns created by those candlesticks [17].

There are currently many technical analysis types and different ways to analyze current and past price and volume data into trading decisions. However, technical analysts traditionally employed two types of analysis to distinguish trends and identify reversals: charting and mechanical (or indicator)
methods. Charting is the older method and consists of graphing the history of prices to predict future patterns from past patterns. Charting has the disadvantage of being a subjective system that requires the skills and judgment of the analyst to find and interpret patterns. On the other hand, technical indicators laid down on the analyst discipline and consistency to apply trading rules based on present and past exchange rates [18].

To understand the technical analysis is essential first to explain some basic concepts, such as chart analysis, trends, time frames, and technical indicators.

### 2.3.1 Chart Analysis

The foundation of technical analysis is the chart. There are different types of charts for analyzing the market, but the most common are the line charts, bar charts, and candlestick charts. The bar charts and candlestick charts, although there are very similar in terms of data analysis, candlestick charts have the advantage of providing a visual interpretation of the struggle between sellers and buyers [1].

The candlestick charts are composed of price candles that contained the four critical points of each trading period - open, high, low, and close. A period is the time interval that a trader has selected to analyze, such as 5 or 15 minutes for short-term traders and 1 hour, 4 hours, or daily for long-term traders.

![Japanese Candlestick](image)

**Figure 2.4**: Japanese Candlestick

Source: Author

Figure 2.4 shows an example of a candle. The rectangular section of the candle represents the range between the period’s open and close. When the candle body is red (or black), the close price was lower than the open price. If the candle body is green (or white), it shows that the close price was higher than
the open price. The thin line above and below the candle body in the shadows. The shadows represent the price extremes during a period. The shadow above the candle body is called the upper shadow (or upper body), and the shadow below the candle body is called the lower shadow (or lower body). Accordingly, the peak of the upper shadow is the maximum that a price reach during the interval period, and the lower shadow is the minimum that a price reach during the interval period [17].

The different shapes of candlesticks have different meanings, based on open, high, low, and close prices. The Japanese candlestick charting analysis is essential for making market timing decisions. For that reason, this was the chart type we used in this study.

2.3.2 Chart Timeframes

On the candlestick chart, the vertical $y$-axis corresponds to the price of one currency pair, while the horizontal $x$-axis represents the time moving forward from the left to right.

Nowadays, most charting software has available a wide variety of timeframes. The choice of the timeframe is essential for various reasons because it corresponds to how much time is contained in each candle. For example, in a five-minute candle, each candle has a duration of exactly five minutes. Popular timeframes used by Forex traders include: 5-minute, 15-minute, 30-minute, 1-hour, 4-hour, 12-hour, daily, weekly, and monthly [1].

Shorter timeframes, as 5-minute and 15-minute periods, are highly frenetic. The prices move very quickly and fluctuate rapidly. This type of timeframe is very volatile and can be very stressful to understand and interpret. A medium timeframe corresponds to a 1-hour or 4-hour period. The price movements are slower but still provides opportunities for regular trading activity. It is essential to consider that trade in shorter timeframes requires less capital and allows the traders to take advantage of leverage. Trading with longer timeframes will require more significant available capital to cover potential swings in the market [19].

2.3.3 Trends

A trend is simply the direction of the market. Markets do not usually move in a straight line in any direction. A series of zigzags characterize the moves of the market compare to less obvious peaks and troughs. The way those peaks and troughs are moving up, down, or sideways defines the market trend. An uptrend is defined by a series of successively higher peaks and troughs; a downtrend is defined by a series of declining peaks and troughs; horizontal peaks and troughs would characterize a sideways price trend. The sideways trend reflects a period of equilibrium in the price level when the forces of supply and demand are in a state of balance [3]. In Figure 2.5 it is possible to observe the three types
of trends in the market.

It is important to mention that in the Forex market, an uptrend is simultaneously an uptrend for the base currency (first currency in the pair) and a downtrend for the quote currency (second currency in the pair). On the other hand, a downtrend for a currency pair is simultaneously a downtrend for the base currency and an uptrend for the quote currency. A trend can be measure and evaluated with different instruments, including trend lines, trend channels, moving averages, and many others [1].

2.3.4 Technical Indicators

Technical indicators are mathematical tools applied to price time series data to produce another time-series data. Technical indicators are divided into three main groups: trend, momentum, and volatility [11].

- **Trend Indicators** - follow the price action and are commonly referred as Lagging indicators. The Moving Averages and MACD are examples of trend indicators.

- **Momentum Indicators** - display the rate of change in price and are commonly referred as Leading indicators. RSI and the Stochastic are examples of this type of indicators.

- **Volatility Indicators** - are based on the rapid changes in volatility in price. The Bollinger Bands and Chandelier Exits are examples of volatility indicators.
2.4 Summary

In this chapter was described some concepts in the Forex market, its history, different types of analysis, and more in detail the Technical Analysis. On the Chapter 3 the indicators will be explained in detail using graphics and mathematical formulas.
3

Technical Indicators

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Technical Indicators

This section explains each technical indicator and its rules used to calculate their performance in the Forex market. The chapter is divided into four sections:

• Exponential Moving Average (section 3.1);

• Moving Average Convergence Divergence (section 3.2);

• Relative Strength Index (section 3.3);

• Bollinger Bands (section 3.4);

Technical indicators can be separated into three categories: trend indicators, momentum indicators, and volatility indicators.

• **Trend Indicators**: this type of indicator help to determine the overall direction of the trend and identify trending market conditions. They are based on an average value of the price, which helps trade in the trend direction. The most popular trend indicators are simple moving average, exponential moving average, average directional index.

• **Momentum Indicators**: this type of indicator provides information about the trend strength. The indicator's value commonly oscillates around a baseline within a predefined range, but the oscillation may not be bounded within a range. As the momentum measures the rate of change, a swift increase in price will result in solid momentum, while small price changes will correspond to a weak momentum. The most popular momentum indicators are the RSI and MACD.

• **Volatility Indicators**: this type of indicator considers the price changes in a certain period. Knowing the volatility can help a trader make a profit with more volatile securities, and during higher volatility, a trend can be easily formed. Less volatility can indicate a low possibility for a trader have profitable trading because the price does not change. The most popular volatility indicators are Bollinger Bands, average directional movement, average true range.

The indicators applied in this study are among the most popular technical indicators considered in academic reports and technical analysis literature. Notice that exists other indicators can be used to achieve more gains inside to market. However, with the sample of indicators chosen, it is possible to study the different market environments through the most critical parameters.

Before start to analyze each indicator individually, it is important to reference that is used four values in the indicators calculation, as it shows in Figure 3.1:

• **Open** - open price of the currency pair for a giving period;
3.1 Exponential Moving Average

A moving average is the average closing price of a period of bars on a price chart. The moving average technique aims to identify that a new trend has started or an old one has finished. Moving averages are most helpful in smoothing the price action and cut out the "noise" [3].

The Simple Moving Average (SMA) is the most common indicator used by investors. However, there are a few disadvantages to this technique. The first one is that only taken into account the period cover (for example, the last ten days). The second disadvantage is that this moving average gives equal weight to each day's price [3].

The EMA is considered a better tool than the simple one because it gives more weight to current data and corresponds to faster price changes. EMA is a mean of smoothing random fluctuations with the following properties: declining weight is put on older data, effortless to compute, and minimum data is required [20].
3.1.1 EMA Calculation

Depending on the period of the moving average, different signals can occur. If a short-term average is employed (for example, 12 days), the average follows the price very closely and occurs a good amount of crossings. This is a sensitive average and produces many fall signals. In the long term, averages (for example, 26 days) are less sensitive and do not respond rapidly to fast changes in the market. In other words, a slower moving average works better in a continuous trend, but a faster moving average is better when the trend is reversing [3]. For that reason, we used in this study the method crossover.

In this work, the parameters for the calculation of the EMA indicator are as follows:

- **Long-term EMA**: 26, 50, and 200-day period.
- **Short-term EMA**: 12 and 50-day period.

There are three steps for calculating an EMA. First, calculate the SMA:

\[
SMA_n(P, m) = \frac{\sum_{i=n-(m-1)}^{n} P_i}{m}
\]  

(3.1)

Where \( m \) denotes the period window defined, \( n \) is the \( n^{th} \) data of the exchange price, and \( P_i \) is the applied price (closing price).

Second, calculate the weighting multiplier. Third, calculate the EMA. The formula is the following:

\[
EMA_n(P, m) = (P_n - EMA_{n-1}) \times \alpha + EMA_{n-1}
\]  

(3.2)

\[
= (1 - \alpha) \times EMA_{n-1} + \alpha \times P_n
\]  

(3.3)

Where the smoothing coefficient \( \alpha \) is:

\[
\alpha = \frac{2}{n + 1}
\]  

(3.4)

Where \( P_i \) denotes the current exchange price, \( n \) is the \( n^{th} \) data of the exchange price and \( EMA_n \) is the EMA value of the \( n^{th} \) index. The \( \alpha \) is the lag factor and \( m \) is the time period window defined.

As the number of days \( n \) increases, the \( \alpha \)'s values grow smaller, and the EMA becomes less sensitive to new data.

The table 3.1 shows the conversion from the simple \( n \) days to the exponential smoothing constant and back. To calculate a new EMA, on the first day of calculation using a \( n \) day simple moving average to approximate the previous day's EMA [21].

23
Table 3.1: Example table

<table>
<thead>
<tr>
<th>n days</th>
<th>( \alpha = \frac{1}{\sqrt{n}} )</th>
<th>n days</th>
<th>( \alpha = \frac{1}{\sqrt{n}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00000</td>
<td>10</td>
<td>0.18182</td>
</tr>
<tr>
<td>2</td>
<td>0.66667</td>
<td>20</td>
<td>0.09624</td>
</tr>
<tr>
<td>3</td>
<td>0.50000</td>
<td>30</td>
<td>0.06452</td>
</tr>
<tr>
<td>4</td>
<td>0.40000</td>
<td>40</td>
<td>0.04878</td>
</tr>
<tr>
<td>5</td>
<td>0.33333</td>
<td>50</td>
<td>0.03922</td>
</tr>
<tr>
<td>6</td>
<td>0.28571</td>
<td>60</td>
<td>0.03279</td>
</tr>
<tr>
<td>7</td>
<td>0.25000</td>
<td>70</td>
<td>0.02817</td>
</tr>
<tr>
<td>8</td>
<td>0.22222</td>
<td>80</td>
<td>0.02469</td>
</tr>
<tr>
<td>9</td>
<td>0.20000</td>
<td>90</td>
<td>0.02198</td>
</tr>
<tr>
<td>10</td>
<td>0.18182</td>
<td>100</td>
<td>0.01980</td>
</tr>
</tbody>
</table>

3.1.1.A EMA Strategy

The most common strategy is to use a stand-alone moving average. The moving average is plotted on the chart, and when the closing price moves above the moving average, a buy signal is triggered. On the other hand, a sell signal is triggered when the closing price moves below the moving average.

| Crossover: | Crossovers are one of the leading moving average strategies. A crossover is a signal of a trend reversal when one moving average crosses another. Two moving averages can be used together to generate crossover signals. |

This method, as can be seen in the Figure: 3.2, \( EMA(t,12) \) and \( EMA(t,26) \) we used as short and long term \( EMA \), the trading rules are the following:

- **Long position:** if \( EMA_{t-1}(\text{short-term}) < EMA_{t-1}(\text{long-term}) \) and \( EMA_t(\text{short-term}) > EMA_t(\text{long-term}) \)

- **Short position:** if \( EMA_{t-1}(\text{short-term}) > EMA_{t-1}(\text{long-term}) \) and \( EMA_t(\text{short-term}) < EMA_t(\text{long-term}) \)

- **Close positions:** when the opposite occurs.

3.2 Moving Average Convergence Divergence

Moving Average Convergence Divergence (MACD) was developed by Gerald Appel in 1970 and is represented by a MACD line, Signal line, and histogram. The MACD is a trend/momentum indicator that shows the relationship between prices and moving averages. This indicator combines two trend-following indicators (EMA) to sign buying and selling momentum.

The MACD line (faster line) results from the difference between two EMA, usually the 12-day and a 26-day period. The Signal line (slower line) is a 9-day period EMA of the MACD line. Geral Appel recommended a set number of trade signals; however, most traders use the default values of 12, 26,
The histogram is a visual representation of bars that show the difference between the MACD line and the Signal line. The histogram has a zero line of its own. When both lines are positive (faster line over the slower line), the histogram is above zero. The lines crossing the histogram above and below its zero lines correspond with the MACD crossover buy and sell signals.

One of the most valuable advantages of MACD is the potential to combine the aspects of both trend and momentum in a single indicator. As a trend indicator, MACD will not be erroneous for an extended period. The moving averages used in the calculation will follow the movements of the underlying security. A momentum indicator can predict the moves in the underlying security. Another advantage of this indicator is that an application in the time frame can be adjusted to the trading style, risk tolerance, and objectives of the trade [22].

### 3.2.1 MACD Calculation

In this work, the parameters for the calculation of the MACD indicator are as follows:
• **Long-term EMA**: 26-day period.

• **Short-term EMA**: 12-day period.

• **Signal line**: 9-day period.

The MACD is calculated based on moving averages. It is calculated by subtracting a slower EMA from a faster EMA: The equation of MACD is the following:

\[
MACD(n) = \sum_{i=1}^{n} EMA_k - \sum_{i=1}^{n} EMA_d
\]  

Where \(k = 12\) and \(d = 26\) and \(n\) is the number of days. In this study we focus on the 12 and 26-day EMA, which are commonly used in order to calculate MACD [3].

In addition, we used a *sign* in order to generate the trading orders of MACD, which the calculation is the following:

\[
Sign(n) = EMA_9(MACD(n))
\]  

Where \(EMA\) is a exponential moving average of 9 days of MACD.

\[
MACD \text{ histogram} = MACD(n) - Sign(n)
\]  

### 3.2.1.A MACD Strategy

The MACD strategy can be traded by getting signals from crossovers of the two lines, crosses above and below the zero lines, and other utilities [1]. This method, as can be seen in the Figure: 3.3, the trading rules are:

• **Long position**: if \(MACD(n)\) and \(Sign(n) > 0\).

• **Short position**: if \(MACD(n)\) and \(Sign(n) < 0\).

• **Close positions**: when the opposite of open orders occurs.

### 3.3 Relative Strength Index

The RSI indicator was developed in 1978 by J. Welles Wilder, Jr and presented in his book, *New Concepts in Technical Trading Systems*. Wilder referenced that one of the significant problems in constructing a momentum line is the erratic movement. They are usually caused by abrupt changes in the values being dropped off, so it is necessary to smoothing to reduce the distortions. Another
problem is the necessity for a constant range for comparison purposes. The RSI formula solves the first problem by providing the smoothing and the second problem by creating a vertical range of 0 to 100 [3].

The Relative Strength Index is an oscillator used in technical analysis to show price strength by comparing increasing and decreasing prices. The RSI is usually used to identify when the price is overbought or oversold, respectively, according to Wilder, 70 and 30. When the RSI moves higher or lower than values, the market is read as overbought or oversold [23]. The disadvantage with the RSI is that it can be misleading for strong market moves because it is maximum at 100, an it can be misleading for strong market moves [24].

3.3.1 RSI Calculation

In this work, the parameters for the calculation of the RSI indicator are as follows:

- **Oversold parameters**: 30, 20.
- **Overbought parameters**: 70, 80.
- **Number of observations**: 14-day period.

RSI calculation can be translated by doing daily calculations of a change in price, and requires several steps:

1. For each trading period, an upward change or downward change is calculated. Upwards periods mean that the close price is higher than the previous close price, and the closing price characterizes a down period is lower than the previous one [25].

\[
U_t = \begin{cases} 
1, & P_t > P_{t-1} \\
0, & P_t < P_{t-1} 
\end{cases} 
\]  

(3.8)

and,

\[
D_t = \begin{cases} 
0, & P_t > P_{t-1} \\
1, & P_t < P_{t-1} 
\end{cases} 
\]  

(3.9)
Where $U_t$ denotes the up movement over a period, and $D_t$ a down movement over the same period.

2. Relative Strength (RS) is the ratio of the (simple or exponential) average number of up days to the average of down days.

$$up_t(n) = \frac{U_t + U_{t-1} + \ldots + U_{t-n+1}}{n}$$  \hspace{1cm} (3.10)

and,

$$down_t(n) = \frac{D_t + D_{t-1} + \ldots + D_{t-n+1}}{n}$$  \hspace{1cm} (3.11)

Where $up_t(n)$ and $down_t(n)$ are average numbers of upward moves and downward moves of closing prices of past $n$ days. The relative strength is calculated by the following equation:

$$RS_t = \frac{up_t(n)}{down_t(n)}$$  \hspace{1cm} (3.12)

3. The relative strength index (RSI) calculation normalizes the $RS_t$ to the scale from 0 to 100:

$$RSI_t(n) = 100 - 100 \left( \frac{1}{1 + RS_t} \right)$$  \hspace{1cm} (3.13)

Where $RSI_t$ is the relative strength index at time $t$ and $n$ is the number of $RSI$ periods. In this study, we used a 14-day period, as Wilder recommended, *The shorter the time period, the more sensitive the oscillator becomes and wider its amplitude*.

3.3.1.A RSI Strategy

![Figure 3.4: RSI for EUR/USD strategy](Source: Author)

This RSI indicator is an exceptional oscillator at giving overbought and oversold signals on ranging markets. Murphy [3] says in his book that the RSI most excellent values occur over 70 and under level
30. However, he alerts for the premature readings when a strong trend occurs. Take an example of a strong uptrend, and the market can stay overbought for a long time. Because of that, he suggests paying attention to the indicator's second move. This method, as can be seen in the Figure: 3.4, the trading rules are:

- **Long position**: if \( RSI_{t-1} < 30 \) and \( RSI_t > 30 \).
- **Short position**: if \( RSI_{t-1} < 70 \) and \( RSI_t > 70 \).
- **Close positions**: when the opposite occurs.

### 3.4 Bollinger Bands

The BB were developed by the technical analyst John Bollinger in the 1980s. The bands allow the traders compare volatility and relative price levels over a period [3].

The Bollinger Bands consists of a centerline and two price bands above and below it. The centerline is a simple moving average, and the price bands are the standard deviation of the stock being studied. The bands will expand and contract as the security price becomes volatile (expansion) or becomes bound into a tight trading pattern (contraction). The standard deviation guarantees that 95.4 percent of the price action will fall between the two trading bands. When the price touch the upper band is considered overbought, and when the price touch the lower band is considered oversold.

The principal objective of this indicator is to measure a currency pair’s volatility around the simple moving average. The bands are commonly used to give the direction of impending volatility increase (when the bands tighten) [1]. The Bollinger Bands have the characteristic to be versatile and also can be adapted to different time frames. They are designed to respond quickly to significant market moves and show whether prices are high or low compared to average trading ranges [21].

#### 3.4.1 Bollinger Bands Calculation

The central line of the Bollinger Bands indicator is calculated using the moving average formula using the closing prices of the latest 20 days:

\[
CL = \frac{\sum_{i=1}^{N} Close_i}{N}
\]  

(3.14)

Where: **Close Line** \((CL)\) is the central line(moving average), \(Close_i\) the close price of the candle number \(i\), \(N\) the period of the Bollinger Band.

Before proceeding to the formula of the upper and lower bands, we have to calculate the standard deviation:
\[ \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\text{Close}_i - CL)^2} \]  

(3.15)

Where: \( \text{Close}_i \) is the close price of the candle number \( i \), \( CL \) the average value for the \( N \) periods (calculated as the central line earlier), \( N \) the periods of the bands.

The lower band is corrected using two standard deviations according to the following formula:

\[ down_n = CL - 2 \cdot \sigma \]  

(3.16)

Where: \( down_n \) is the lower band, and the \( CL \) the central line.

The upper band is calculated in the similar manner:

\[ up_n = CL + 2 \cdot \sigma \]  

(3.17)

Where: \( up_n \) is the upper band, and the \( CL \) the central line.

### 3.4.1.A Bollinger Bands Strategy

There are different ways to trade with the Bollinger Bands. The most commonly used is when the price above the upper band is considered overbought and when it is below the lower band is considered oversold. However, like in the RSI indicator, it is difficult to predict how long a price stays in the oversold/overbought region. Because of that, it is better to enter a position when the price moves away from those regions [26]. This method, as can be seen in the Figure: 3.5, the trading rules are:

![Figure 3.5: Bollinger Bands for EUR/USD strategy](image)

Source: Author
• **Long position**: if \( \text{Close}_i(t - 1) < \text{down}_n(t - 1) \) and \( \text{Close}_i(t) > \text{down}_n(t) \).

• **Short position**: if \( \text{Close}_i(t - 1) > \text{up}_n(t - 1) \) and \( \text{Close}_i(t) < \text{up}_n(t) \).

• **Close positions**: when the \( \text{Close}_i \) cross the opposite band line.

Therefore, a buy signal will be triggered when the price crosses the lower band from below, as well as, a sell signal will be triggered when the price crosses the upper band from above [26].

### 3.5 Summary

This chapter described the four indicators used in this work, through graphical representations and mathematical formulas. The rules for all the technical indicators are defined and their calculations explained. In the next chapter, will be discussed the technical indicators implementation in the R language.
Indicators, Signals, Rules, Strategies, and Implementation in R

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Indicators Implementation in R

In this chapter, is described the dataset used and its implementation in R language. Then, it is explain all the necessary steps to evaluate the indicators and its strategies in the parameters defined. Lastly, it is defined all the signals and rules for each indicator and combination. This chapter is divided as follows:

- Dataset (section 4.1);
- Trading with Technical Indicators in R (section 4.2);
- Single Strategies (sections from 4.3 to 4.6);
- Combined Strategies (sections from 4.7 to 4.12);

4.1 Dataset

The data was collected from Oanda dataset broker for the most popular currency pairs in the Forex market: EUR/USD and GBP/USD.

To fetch the historical data from Oanda is necessary to generate an Application Programming Interface (API) key. The API key is required to be passed as Bearer Token into Oanda’s system, so it can authenticate and process or pass information that is associated with the associated account. There are a variety of instruments that can be retrieved using the API object created in Oanda, like all that is traded on the platform. In this study, the instruments are currencies.

Listing 4.1: Python script set up

```python
import pandas as pd
import requests

API_KEY = 'Bearer (personal key)'
HEADERS = {
    'Content-Type': 'application/json',
    'Authorization': API_KEY
}

INSTRUMENT = 'GBP_USD'
GRANULARITY = 'M30'
ACCOUNT_TYPE = 'practice'
```

Retrieving the data can be done through the date, granularity, and instruments. In Listing 4.1. the granularity is set at "M30", meaning thirty-minute candlestick and the instrument "GBP/USD". It is crucial to notice that the data is retrieved chunk-wise and appended to the data frame object. The data was stored into six columns: time, open price, high price, low price, close price, and volume, as it

---

1. Oanda corporation is a privately-lead Forex and CFD (Contrat for Difference) broker that provides bonds, Forex trading, commodities trading, and stocks indices all over the world.
2. Is a software intermediary that allows two applications to talk to each other.
3. The bearer token is a cryptic string, usually generated by the server in response to a login request.
shows in Listing 4.2. Finally, the data was converted into a CSV file.

Listing 4.2: Python function to fetch candles

```python
def export_ba_data():
    try:
        r = requests.get("https://api-fx.oanda.com/v3/instruments/{}/
                         .format(ACCOUNT_TYPE, INSTRUMENT), headers=HEADERS, params=PARAMS).json()
        df = pd.DataFrame((candle['time'], candle['ask']['o'], candle['ask']['h'],
                           candle['ask']['l'], candle['ask']['c'], candle['volume'])
                         for candle in r['candles']),
                         columns=['Time', 'Open', 'High', 'Low', 'Close', 'Volume'])
        print(from_DATE)
        print(to_DATE)
        # df.to_csv('ask_data.csv', index=False)
        return df
    except:
        print('request failed, likely that candlestick count is out of range (max=50000)')

from_year = 2020
from_month = 1
to_year = 2021
to_month = 1
first_time = 1
for y in range(from_year, to_year+1):
    if ((y == to_year) and (y == from_year)):
        m_range_min = from_month
        m_range_max = to_month-1
    elif(y == from_year):
        m_range_min = from_month
        m_range_max = 12
    elif(y == to_year):
        m_range_min = 1
        m_range_max = to_month-1
    else:
        m_range_min = 1
        m_range_max = 12
    for m in range(m_range_min, m_range_max+1):
        m1 = m
        m2 = m+1
        if(m1 >= 10):
            FROM_DATE = str(y)+'-'+str(m1)+'-01T15:00:00.000000000Z'
        else:
            FROM_DATE = str(y)+'-0'+str(m1)+'-01T15:00:00.000000000Z'
        if(m2 >= 10):
            TO_DATE = str(y)+'-'+str(m2)+'-01T15:00:00.000000000Z'
        else:
            TO_DATE = str(y)+'-0'+str(m2)+'-01T15:00:00.000000000Z'
        PARAMS = {
            'from': FROM_DATE,
            'to': TO_DATE,
            'count': COUNT,
            'granularity': GRANULARITY
        }
        if(first_time):
            df = export_ba_data()
            first_time = 0
        else:
            df_aux = export_ba_data()
            df = df.append(df_aux)
        df.to_csv('ask_data_GBP.csv', index=False)
        print('bid/ask data exported to "ask_data_GBP.csv"')
```

Source: Author

For each currency pair, was collected 30 minutes time frame candles from January, 1st of 2020 to January, 1st of 2021.
The choice of these two currency pairs was connected with their high popularity. According to the Bank of Internal Settlements, the U.S. Dollar is the most traded currency, with more than 85% of average daily turnover in Forex trading. The second place is the Euro with 37% share, followed by the Japanese Yen and the British Pound with 16% and 15% respectively [1].

The EUR/USD is the most currency pair trade in the Forex market. The standard market convention is to quote EUR/USD in terms of numbers of USD per EUR. For example, a EUR/USD rate of 1,2000 means that it takes $1,20 to buy 1,00. The EUR/USD is traded contrary to the USD value, which means that when EUR/USD is rising, the Euro is getting stronger and the U.S. dollar weaker.

The GBP/USD is the third most traded pair. Its trading volume and liquidity are significantly less than the EUR/USD and USD/JPY. However, this pair is prone to sharp price movements and has very active price action⁴ [10].

---

⁴Price action is the movement of a security's price plotted over time. Price action forms the basis for all technical analysis of a
The year 2020 was an out of the average year due to pandemics. The COVID-19 has affected the global economy in a short time. The countries were obligated to impose travel restrictions, shutdown borders, lockdowns, and social distancing to control the pandemic. These measures had affected economic activities and international trade at all scales. In April of 2020, the International Monetary Fund predicted that the global economy might contract by 3% in 2020. Since the beginning of the pandemic, the Forex market is by far the primary financial market. However, it has also witnessed unpredictable movements [27]. Because the Forex market is so difficult to predict and even more in this pandemic, it is vital to understand if the technical indicators can be efficient in such an unpredictable market.

<table>
<thead>
<tr>
<th>Currencies</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital</td>
<td>$10,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>Positions</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Price applied</td>
<td>Close price</td>
<td></td>
</tr>
<tr>
<td>Time-frame</td>
<td>30min</td>
<td></td>
</tr>
<tr>
<td>Historical data</td>
<td>from 01/01/2020 to 01/01/2021</td>
<td></td>
</tr>
<tr>
<td>Indicators</td>
<td>EMA</td>
<td>MACD</td>
</tr>
</tbody>
</table>

Table 4.1: Inputs for Technical Trading

In Table 4.1 shows the variables used for the technical trading. In this study, we did not apply any leverage or margin into considerations.

4.2 Trading with Technical Indicators in R

R is an open-source scripting language that has become very popular in recent years. R is a functional programming language by nature and supports the object-oriented and imperative programming package [28]. As a result, analysts and traders widely use R to develop quantitative strategies that can be executed manually or through programming trading.

4.2.1 Backtesting

Backtesting is the process of historical feeding data into the trading strategy and sees how it would have performed. The goal is that its historical performance tells what to expect for its future performance [29].

This study aimed to combine different technical indicators and analyze what combination could be more profitable for the currency pairs EUR/USD and GBP/USD. The indicators and their combination

stock, commodity, or other asset charts.
were tested for all year of 2020 in a 30 minutes timeframe. Typically, the last step of the backtesting is to perform in a live trade, but it would not be done since it is not intended to profit from this study.

For backtesting the indicators strategies in R, we use the Quantstrat package. The Quantstrat package is a library for creating signal-based trading systems in a more simple code. Quantstrat provides the base functions to build our strategies, add indicators and signals, and create the rules of when to buy and sell. Figure 4.3 shows how Quantstrat works, and the first step is to define the instrument, which in this case is the two pairs of currencies. The second step identifies the indicators for testing the strategies. The third step specifies the buy and sells signals, followed by the fourth step where rules correspond to orders when entering or exit the market. The final step is to apply the strategy and analyze the results of the defined strategy.

![Quantstrat Framework](Figure 4.3: Quantstrat Framework Source: Author)

In Figure 4.4 shows an example of backtesting strategy. It is possible to divided the backtesting strategy in five sections: initialization, define the strategy, processing, updated and reporting. In the initialization section it is the first step, and defines the account and portfolios, which in this work for simplify purpose we only have one account and one portfolio. Also, the time tested, the currencies and the other dataset parameters are defined in this stage. In the define strategy are the steps the were explained above, that corresponds to define the indicators, signals, and rules. In order to run the strategy and obtain results, we must conduct the processing the strategy by the applyStrategy() function, and then update our portfolio and account in that order. After apply the strategy, we need to call these functions to update R’s analytic environment (by first updating the portfolio with transactions the strategy took and then the account and ending equity). With the reporting section we can see the strategy performance in a plot. The plots from our strategies are displayed in the section A.

![Quantstrat Backtesting Strategy](Figure 4.4: Quantstrat Backtesting Strategy Source: Author)
4.2.2 Initialization

Initialization means creating the object in the context of the quantstrat package. For this purpose, it is necessary to provide the correct parameters for each of these objects. Trading strategies developed using quantstrat contain several characteristics, including:

- indicators developed from market data,

- signals triggered by certain combination of indicators,

- and rules acted on certain signals.

The first step in developing any trading system is to obtain market data and define the symbols and currencies used. In this study, we used the USD currency with a multiplier of 1 by default. A multiplier is applied to price and will vary depending on the financial instrument. The function `getSymbols()` is usually used to fetch the data. However, in our case, we couldn’t use this function because the Forex data wasn’t updated in this library, so instead, we developed a Python script to load the data from Oanda.

Before start, the initialization steps, the CSV data needs to be converted into data similar to the data fetched from the function `getSymbols()` and defined the setup parameters. As it shows in Listing 4.3 the currency pair is defined as “GBP/USD”, the `initEq` corresponds to initial Equity(capital) of $10,000, `timespan` represents a time interval, in this case, corresponds a 24 hours a day. The trade parameters, threshold\(^5\) and transaction fees\(^6\) is the default by the broker. The order quantity is the same as the initial equity/capital. The `initdate` corresponds to the initial date of the backtest and starts one day after the defined time frame because this variable needs a date that must occur before the start of data in a backtest. If this is not the case, the portfolio will demonstrate a massive drawdown on the initialization date, and many of the backtest statistics will be misleading or nonsensical.

\(^5\)A trade threshold constraint means that if an asset is traded at all, then at least some number of units of the asset must be traded.

\(^6\)A transaction fee is an expense that businesses pay a service provider each time a customer payment is processed electronically.
Listing 4.3: R script set up

```r
# setup
currencypair <- "GBPUSD"
initEq <- 10000

# trading window
.timespan = 'T00:00/T23.59'

# trade parameters
.threshold = 0.0005
.txnfees = -6
.orderqty = 10000

initDate = '2020-01-02'
.from <- initDate #start of backtest
to <- '2021-01-01' #end of backtest

# get historical data
data <- read.csv("ask_data_GBP.csv",header= TRUE)
data$Time <- substr(data$Time,1,nchar(data$Time)-11)
data$Time <- str_replace(data$Time, "T", " ")
data$Time <- ymd_hms(data$Time)
GBPUSD <- xts(data[,2:6],order.by=data[,1])
names(GBPUSD)[names(GBPUSD) == "Open"] <- paste(currencypair,"Open",sep=".")
names(GBPUSD)[names(GBPUSD) == "High"] <- paste(currencypair,"High",sep=".")
names(GBPUSD)[names(GBPUSD) == "Low"] <- paste(currencypair,"Low",sep=".")
names(GBPUSD)[names(GBPUSD) == "Close"] <- paste(currencypair,"Close",sep=".")
names(GBPUSD)[names(GBPUSD) == "Volume"] <- paste(currencypair,"Volume",sep=".")
```

Quantstrat requires three different objects to work:

1. Account - an account is comprised of objects.
2. Portfolio\(^7\) - a portfolio is comprised of strategies.

An account may contain one or multiple portfolios. Furthermore, each portfolio may contain one or multiples strategies, however in this study there is only type of portfolio tested. In Quantstrat, each strategy runs on a specific portfolio and account. These elements need to be defined and initialized in order to build and backtest a strategy.

To create the portfolio object its necessary to provide the portfolio name, stock symbols, or instruments that the portfolio will contain and the initialization date of the backtesting. After creating the portfolio object, it is necessary to define the account object. The account can be related to one or more portfolios. Finally, create the strategy object. The strategy name should be passed as the first parameter when generating the indicators, signals, and rules of the strategy to link all these elements to the strategy defined.

---

\(^7\)Include different investment types. An investor can own different trading portfolios, each geared towards a different investment strategy.
4.2.3 Indicators, Signals and Rules

After the initialization parameters are defined, the following step is to select the indicator we want to test, as is signals and entry/exit rules. First we defined the indicator, following the signals, and lastly the rules.

4.2.3.A Indicators

Indicators are typically standard technical or statistical analysis outputs, such as moving averages, bands, or pricing models. Indicators are applied before signals and rules, and the output of indicators may be used as inputs to construct signals or fire rules.

Indicators do not know current positions or trades. A common mistake is to confuse indicators with strategy. An indicator is a model, on its own, not a strategy. The strategy depends on interactions with the rest of its components to be fully specified [30]. Quantstrat has the function `add.indicator()` to add indicators. The parameters of this function are:

```
add.indicator(strategy, name, arguments, label):
    #strategy = string name of the strategy defined in the Initialization step;
    #name = is the indicator function;
    #arguments = list with the required inputs to calculate the indicator passed in the name argument;
    #label = label of the variable. This must be unique for each indicator added.
```

In the arguments exists a special parameter, the `mktdata`. The `mktdata` is an internal object that has an OHLVC\(^8\) information loaded into an environment and will store all indicators and signals used. The `add.indicator()` function is not evaluated until the strategy is run. All it does is add the specifications to the strategy object.

\(^8\)OHLVC is a short-hand for: Open, High, Low, Close, and Volume
4.2.3.B Signals

Signals are interactions of indicators with market data or other indicators. Essentially, they are used to determine when to buy or sell one of the pre-defined assets in the portfolio.

After adding the indicators, the next step is to add signals generated from the interaction of indicators and market data. In Quantstrat, a signal is added using the `add.signal()` function, which takes the following form:

```python
add.signal(strategy, name, arguments, label):
#strategy = string name of the strategy defined in the Initialization step;
#name = built-in functions that specify the signal type (crossovers, threshold, etc.);
#arguments = has a list containing the mktdata columns (for the indicators), and the relationship(“Greater than (gt)”, “Less than (lt)”, “Equal to (eq)”, “gte”, “lte”) that these columns should hold for creating the new signal in a specific moment of time.;
#label = label of the variable.
```

There are five types of signals found in the table 4.2:

<table>
<thead>
<tr>
<th>Signals</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>sigComparison</td>
<td>Signal continuously comparing two different quantities, returns 1 if the relationship is true</td>
</tr>
<tr>
<td>sigCrossover</td>
<td>The same as sigComparison but only returns of 1 on the first occurrence of the relationship changing from false to true</td>
</tr>
<tr>
<td>sigThreshold</td>
<td>Compares a range-bound indicator to a static quantity defined</td>
</tr>
<tr>
<td>sigFormula</td>
<td>Essentially combines 2 or more indicators signal to form ensemble signals</td>
</tr>
<tr>
<td>sigPeak</td>
<td>Identify local minimum or maxima if an indicator</td>
</tr>
</tbody>
</table>

Table 4.2: Type of signals in quantstrat package

In the sigCrossover, sigComparison, and SigThreshold signals is necessary to specify the relationship between the variables:

- `gt` - greater than;
- `lt` - less than;
- `eq` - equal to;
- `gte` - greater than or equal to;
- `lte` - less than or equal to;

In this work, we used only three types of signals: sigCrossover for the EMA and the BB indicators; the sigThreshold for the RSI and MACD indicators; the sigFormula in the strategies two indicators combined.
Figure 4.5 demonstrates an example of EMA strategy. The function sigCrossover triggers a signal only when the parameters defined for the crossover are TRUE.

![Figure 4.5: sigCrossover Example](image)

Source: Author

Figure 4.6 demonstrates an example of RSI strategy. The function sigThrshold triggers a signal when the RSI crosses a pre-defined value.

![Figure 4.6: sigThrshold Example](image)

Source: Author

4.2.3.C Rules

After indicators and signals are created, the next step is the creation of the strategy rules. Rules use market data, indicators, signals, and current account/portfolio properties to generate orders. The strategy rule is path-dependent because they are related to the portfolio, with the strategy’s orders and risk management.

In Quantstrat the `add.rules()` function is used to generate rules and determines the position taken based on the signals, the type of orders placed, the trade size, and transaction costs of the broker. Overall, the rules allow functionality to enter positions (long/buy and short/sell) and to exit positions(long/buy and short/sell).
add.rule(strategy, name, arguments, label):

#strategy = string name of the strategy defined in the Initialization step;
#name = have just one function in the name parameter, which is called ruleSignal;
#arguments = has a list containing several types of parameters:
  sigcol = column name to check for signal;
  signal = boolean;
  orderqty = specifies the order quantity;
  ordertype = specifies the type of the order (market, limit, stop loss, stop limit, trailing stop);
  orderside = can be "long" or "short";
  TxnFees = transaction fees associated with an order replace = command tells that this order would
            replace any open order if it is equal to TRUE.;
  type = argument generally has the value “enter” and “exit”;
#label = label of the variable.

In Quantstrat, market orders are executed at the next candle after receiving the signal. This can cause some gaps with daily data, as the signal is generated in the current candle, and the order candle is the next candle of the signal. However, with intraday data, the open of the next candle should be very similar to the close of the current candle.

Table 4.3: Market Positions and Orders

<table>
<thead>
<tr>
<th>Positions</th>
<th>Long  - Buy the underlying currency in the hope that its price will go up in the future.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short - Sell the underlying currency in the hope that its price will go down in the future.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Orders</th>
<th>Enter - enter a position for &quot;buy&quot; or &quot;sell&quot;, when the strategy conditions are TRUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exit - exit a position for &quot;buy&quot; or &quot;sell&quot;, when the strategy conditions are FALSE</td>
</tr>
</tbody>
</table>

4.2.3.D Apply Strategy

To run the strategy is necessary to applied the applyStrategy() function. This function applies the strategy to arbitrary market data. The main arguments of the function are:

- **strategy**: an object of type ‘strategy’;
- **portfolios**: a list of portfolios to apply the strategy to;
- **parameters**: named list of parameters to be applied during evaluation of the strategy.

Calling applyStrategy generates transactions in the specified portfolio.

```
results <- applyStrategy(strategy, portfolios, symbols):
# The applyStrategy() outputs all transactions (from the oldest to recent transactions) that the strategy sends.
```

Executing the applyStrategy also creates the variable mktdata. It is a time series object that contains the historical price data and the calculated indicators, signals, and rules.
4.2.3.E Update Portfolio, Account and Equity

After executing the strategy, the next step is to update the account’s portfolio, account, and final equity. This step has the finality to analyze the effectiveness of the implementation. The update step issue the proper calls to update the P&L and to generate the transactions history. Trade statistics include the percentage of correct trades, the profit factor (ratio between gross profit and gross loss), the average win-to-loss ratio, and so forth.

```
updatePortf() = calculate the Profit and Loss for each symbol in symbols
updateAcct() = calculate the equity from the portfolio data
updateEndEq() = updates the ending equity for the account
```

4.3 EMA Strategy

The initialization step explained above it was the same for all the strategies. The EMA strategy has only one indicator, EMA but with different parameters. The specifications for this strategy are:

<table>
<thead>
<tr>
<th>Indicator - EMA</th>
</tr>
</thead>
<tbody>
<tr>
<td># Slower EMA = 26, 50 and 200 day-period;</td>
</tr>
<tr>
<td># Faster EMA = 12 and 50 day-period;</td>
</tr>
<tr>
<td>Order Long position = if $EMA_{t-1}$(short-term) &lt; $EMA_{t-1}$(long-term) and $EMA_{t}$(short-term) &gt; $EMA_{t}$(long-term);</td>
</tr>
<tr>
<td>Order Short position = if $EMA_{t-1}$(short-term) &gt; $EMA_{t-1}$(long-term) and $EMA_{t}$(short-term) &lt; $EMA_{t}$(long-term);</td>
</tr>
</tbody>
</table>

4.3.1 Add Indicator

After the initialization, the next step is to implement the indicator EMA:

```
Listing 4.5: Add indicator EMA to strategy

1 strategy("ema", store = TRUE)
2 #add a 12-day EMA to strategy = "ema"
3 add.indicator("ema", name = "EMA",
4     arguments = list(x=quote(Cl(mktdata)), n=12), label = "ema12")
5 #add a 26-day EMA to strategy = "ema"
6 add.indicator("ema", name = "EMA",
7     arguments = list(x=quote(Cl(mktdata)), n=26), label = "ema26")
```

Source: Author

4.3.2 Add Signals

In the EMA strategy was used the function `sigCrossover()`, to triggered the signals. This function compares two columns and only return TRUE on the timestamp (candle) that the relationship moves from FALSE to TRUE. In the EMA crossover setup, the `sigCrossover` is only TRUE in the crossover.
Listing 4.6: Add signals to strategy

```r
# add signal sigCrossover which specifies that the EMA 12 is greater
# than the EMA 26 and label it ema12.gt.ema26
add.signal("ema", name = "sigCrossover",
arguments = list(columns=c("ema12", "ema26"), relationship="gt"),
label="ema12.gt.ema26")

# add signal sigCrossover which specifies that the EMA 12 is less
# than the EMA 26 and label it ema12.lt.ema26
add.signal("ema", name = "sigCrossover",
arguments = list(columns=c("ema12", "ema26"), relationship="lt"),
label="ema12.lt.ema26")
```

4.3.3 Add Rules

The strategy rules define the enter and exit orders in the market.

Listing 4.7: Add rules to strategy

```r
# Create an entry rule to enter in a Long position when all the conditions are TRUE
add.rule("ema",
name = 'ruleSignal',
arguments = list(sigcol="ema12.gt.ema26", sigval=TRUE, orderside='long',
ordertype='stoplimit', prefer='High',
treshold=.threshold, orderqty=+.orderqty,
replace=FALSE), type = 'enter', label='EnterLONG')

# Create an entry rule to enter in a Short position when all the conditions are TRUE
add.rule("ema",
name = 'ruleSignal',
arguments = list(sigcol="ema12.lt.ema26", sigval=TRUE, orderside='short',
ordertype='stoplimit', prefer='Low',
treshold=.threshold, orderqty=-.orderqty,
replace=FALSE), type = 'enter', label='EnterSHORT')

# Close long positions when the shortSignal column is True
add.rule("ema", name = 'ruleSignal',
arguments = list(sigcol="ema12.lt.ema26", sigval=TRUE, orderside='long',
ordertype='market',orderqty='all',
TxnFees=.txnfees,replace=TRUE), type = 'exit',
label = 'ExitLONG')

# Close Short positions when the longSignal column is True
add.rule("ema", name = 'ruleSignal',
arguments = list(sigcol="ema12.gt.ema26", sigval=TRUE, orderside='short',
ordertype='market',orderqty='all',
TxnFees=.txnfees,replace=TRUE), type = 'exit',
label = 'ExitSHORT')
```

4.3.4 Apply Strategy

The following step is to run the strategy. The EMA strategy uses two separates indicators and two separate signals. The strategy requires:

- "EMA 12" greater than "EMA 26" to enter in a long/buy position;
- "EMA 12" less than "EMA 26" to enter in a short/sell position;
### Listing 4.8: Apply EMA strategy

```r
# apply strategy
fastMA = 12
slowMA = 26
maType="EMA"

results <- applyStrategy("ema", portfolios = "strat.ema",
                          parameters = list(nFast=fastMA, nSlowMA=slowMA, maType=maType),
                          verbose=TRUE)
```

Source: Author

After running the strategy, the final step is to update the portfolio, account, and equity to analyze the profit and loss of the strategy, as it showing in the Listing 4.9.

### Listing 4.9: Update EMA strategy

```r
# update
updatePortf("strat.ema")
updateAcct("strat.ema")
updateEndEq("strat.ema")
```

Source: Author

The results will be discussed in the section 5. The EMA strategy was also tested for the combined indicators, EMA 12-day and 50-day period crossover, and EMA 50-day and 200-day period crossover, for the two currencies and the initial equities. The strategy plots A.1, A.2, A.3 are displayed in the Appendix A.

### 4.4 MACD Strategy

The MACD strategy has only one indicator, the MACD. The specifications for this strategy are:

<table>
<thead>
<tr>
<th>Indicator - MACD</th>
</tr>
</thead>
<tbody>
<tr>
<td># Slower EMA = 26-day period;</td>
</tr>
<tr>
<td># Faster EMA = 12-day period;</td>
</tr>
<tr>
<td># Signal line = 9-day period;</td>
</tr>
</tbody>
</table>

**Order Long position** = if $MACD(n)$ and $Sign(n) > 0$;

**Order Short position** = if $MACD(n)$ and $Sign(n) < 0$

#### 4.4.1 Add Indicator

After the initialization, the next step is to implement the indicator MACD:

### Listing 4.10: Add indicator MACD to strategy

```r
# define MACD indicator
strategy("macd", store = TRUE)
add.indicator("macd", name = "MACD",
             arguments = list(x=quote(Cl(mktdata))),
             label = "macd")
```

Source: Author

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4.4.2 Add Signals

In the MACD strategy was used the function `sigThreshold()`, to triggered the signals. This function exists specifically to cover those situations outside the bounds. The `sigThreshold()` takes the `cross` argument, which specifies whether it will function similarly to `sigCrossover(cross=TRUE)`.

Listing 4.11: Add signals to strategy

```r
#add signal sigThershold which specifies that macd must be greater than zero
add.signal("macd", name = "sigThreshold",
arguments = list(column="signal.macd", relationship="gt", threshold=0, 
cross=TRUE),label = "signal.gt.zero")

#add signal sigThershold which specifies that macd must be less than zero
add.signal("macd", name = "sigThreshold",
arguments = list(column="signal.macd", relationship='lt', threshold=0, 
cross=TRUE),label = "signal.lt.zero")
```

Source: Author

4.4.3 Add Rules

The strategy rules define the entry and exit orders in the market and follow the same code as in the EMA strategy. The MACD strategy rules are displayed in the Appendix A.

4.4.4 Apply Strategy

The following step is to run the strategy. The MACD strategy uses one indicator and two separate signals. The strategy requires:

- MACD and MACD signal greater than zero to enter in a long/buy position;

- MACD and MACD signal less than zero to enter in a short/sell position;

Listing 4.12: Apply MACD strategy

```r
#apply strategy
fastMA = 12
slowMA = 26
signalMA = 9
maType="EMA"

results <- applyStrategy("macd", portfolios = "strat.macd",
parameters = list(nFast=fastMA, nSlowMA=slowMA, nSIg=signalMA, 
maType=maType),verbose=TRUE)
```

Source: Author

After running the strategy, the final step is to update the portfolio, account, and equity to analyze the profit and losses of the strategy. The results will be discussed in the results section. The MACD strategy plots A.4 are displayed in the Appendix A.
4.5 RSI Strategy

The RSI strategy has only one indicator, the RSI. The specifications for this strategy are:

- **Indicator**: RSI
- **#Oversold parameters**: 30, 20.
- **#Overbought parameters**: 70, 80.
- **Number of observations**: 14-day period.
- **Long position**: RSI\(_{t-1}\) < 30 and if RSI\(_{t}\) > 30.
- **Short position**: RSI\(_{t-1}\) < 70 and if RSI\(_{t}\) > 70.

4.5.1 Add Indicator

After the initialization, the next step is to implement the indicator RSI:

**Listing 4.13: Add indicator RSI to strategy**

```r
# define RSI indicator
strategy("rsi", store = TRUE)
add.indicator("rsi", name = "RSI",
  arguments = list(price = quote(Cl(mktdata)), n=14, maType="SMA"),
  label = "RSI")
```

Source: Author

4.5.2 Add Signals

In the RSI strategy was used the function `sigThreshold()`, to triggered the signals.

**Listing 4.14: Add signals to strategy**

```r
# add signal sigThershold which specifies that RSI must be greater than 70
add.signal("rsi", name="sigThreshold", list(threshold=70, column="RSI",
  relationship="gt", cross=TRUE),
  label="RSI.gt.70")

# add signal sigThershold which specifies that macd must be less than 30
add.signal("rsi", name="sigThreshold", list(threshold=30, column="RSI",
  relationship="lt", cross=TRUE),
  label="RSI.lt.30")
```

Source: Author

4.5.3 Add Rules

The strategy rules define the entry and exit orders in the market and follow the same code as in the EMA strategy. The RSI strategy rules are displayed in the Appendix A.

4.5.4 Apply Strategy

The following step is to run the strategy. The RSI strategy uses one indicator and two separate signals. The strategy requires:
• RSI greater less than 30 to enter in a long/buy position;

• RSI greater than 70 to enter in a short/sell position;

Listing 4.15: Apply RSI strategy

```r
#apply strategy
maType="SMA"
N = 14
results <- applyStrategy("rsi", portfolios = "strat.rsi",
parameters = list(n=N, maType=maType))
```

Source: Author

After running the strategy, the final step is to update the portfolio, account, and equity to analyze the profit and losses of the strategy. The results will be discussed in the section 5. The RSI strategy was also tested in the other parameters defined for the two currencies and the initial equities. The strategy plots A.5, A.6 are displayed in the Appendix A.

4.6 Bollinger Bands Strategy

The Bollinger Bands strategy has only one indicator, the BB. The specifications for this strategy are:

<table>
<thead>
<tr>
<th>Indicator</th>
<th>BB</th>
</tr>
</thead>
<tbody>
<tr>
<td>#Simple Moving Average: 20-day period.</td>
<td></td>
</tr>
<tr>
<td>Long position: if $\text{Close}_i(t-1) &lt; \text{down}_n(t-1)$ and $\text{Close}_i(t) &gt; \text{down}_n(t)$.</td>
<td></td>
</tr>
<tr>
<td>Short position: if $\text{Close}_i(t-1) &gt; \text{up}_n(t-1)$ and $\text{Close}_i(t) &lt; \text{up}_n(t)$.</td>
<td></td>
</tr>
<tr>
<td>Close positions: when the $\text{Close}_i$ cross the opposite band line.</td>
<td></td>
</tr>
</tbody>
</table>

4.6.1 Add Indicator

After the initialization, the next step is to implement the indicator BB:

Listing 4.16: Add indicator BB to strategy

```r
#define BB indicator
strategy("bbands", store = TRUE)
add.indicator("bbands", name = "BBands",
arguments = list(HLC = quote(HLC(mktdata)), maType='SMA'),
label='BBands')
```

Source: Author

4.6.2 Add Signals

In the BB strategy was used the function `sigCrossover()`, to triggered the signals.
4.6.3 Add Rules

The strategy rules define the entry and exit orders in the market and follow the same code as in the EMA strategy. The BB strategy rules are displayed in the Appendix A.

4.6.4 Apply Strategy

The following step is to run the strategy. The BB strategy uses one indicator and three separate signals. The strategy requires:

- When the close price is lower than upper band enter in a long/buy position;
- When the close price is greater than the upper band enter in a short/sell position;

Listing 4.18: Apply BB strategy

```r
# apply strategy
SD = 2
N = 20
results <- applyStrategy("bbands", portfolios = "strat.bb", parameters = list(sd=SD, n=N))
```

After running the strategy, the final step is to update the portfolio, account, and equity to analyze the profit and losses of the strategy. The results will be discussed in the section 5. The strategy plot A.7 is displayed in the Appendix A.

4.7 Combined Indicators: EMA & MACD Strategy

In this strategy, the goal is to combine the EMA indicator and MACD indicator and only enter the market for a short or long position when the conditions of both are True. To combined both of indicators signals we used the function `sigFormula()`. The `sigFormula()` function uses string evaluation to offer
immense flexibility in combining various indicators and signals that are already added to the strategy to create composite signals. We want to enter into a position when both EMA and MACD signals become true at the same time.

The indicator’s specifications have already been defined in the previous sections.

### 4.7.1 Add Signals

We used the function `sigCrossover()` to defined the EMA signals, the function `sigThreshold()` to defined the MACD signals, and the function `sigFormula()` to combined both indicators.

**Listing 4.19: Add signals to strategy**

```
#add combined signals EMA + MACD for enter in a long position
add.signal("ema.macd", name = "sigFormula",
arguments = list(columns=c("ema12.gt.ema26", "signal.gt.zero"),
formula= "ema12.gt.ema26 & signal.gt.zero",
label="trigger",
cross=TRUE), label = "Buy")

#add combined signals EMA + MACD for enter in a short position
add.signal("ema.macd", name = "sigFormula",
arguments = list(columns=c("ema12.lt.ema26", "signal.lt.zero"),
formula= "ema12.lt.ema26 & signal.lt.zero",
label="trigger",
cross=TRUE), label = "Sell")
```

Source: Author

### 4.7.2 Apply Strategy

This strategy uses three separate indicators and six separate signals. The strategy requires:

- When the short-term EMA is greater than the long-term EMA AND the MACD signal is greater than zero enter in a long position;
- When the short-term EMA is less than the long-term EMA AND the MACD signal is less than zero enter in a short position;

The strategy was tested with the different EMA parameters and for both currencies and equities. The plots A.8, A.9 from each strategy tested are displayed in the Appendix A.

### 4.8 Combined Indicators: EMA & RSI Strategy

In this strategy, the goal is to combine the EMA indicator and RSI indicator. We want to enter into a position when both EMA and RSI signals become true at the same time.

The indicator’s specifications have already been defined in the previous sections.
4.8.1 Add Signals

We used the function `sigCrossover()` to defined the EMA signals, the function `sigThreshold()` to defined the RSI signals, and the function `sigFormula()` to combined both indicators.

```r
#add combined signals EMA + RSI for enter in a long position
add.signal("ema.rsi", name = "sigFormula",
arguments = list(columns = c("RSI.lt.30", "ema12.gt.ema26"),
formula= "RSI.lt.30 & ema12.gt.ema26",
label="trigger", cross=TRUE),
label="buy")

#add combined signals EMA + RSI for enter in a short position
add.signal("ema.rsi", name = "sigFormula",
arguments = list(columns = c("RSI.gt.70", "ema12.lt.ema26"),
formula= "RSI.gt.70 & ema12.lt.ema26",
label="trigger", cross=TRUE),
label = "sell")
```

Source: Author

4.8.2 Apply Strategy

This strategy uses three separate indicators and six separate signals. The strategy requires:

- When the short-term EMA is greater than the long-term EMA AND the RSI signal is less than 30 enter in a long/buy position;
- When the short-term EMA is less than the long-term EMA AND the RSI signal is greater than 70 enter in a short/sell position;

The strategy was tested with the different EMA and RSI parameters for both currencies, and equities.

4.9 Combined Indicators: EMA & BB Strategy

In this strategy, the goal is to combine the EMA indicator and the BB indicator. We want to enter into a position when both EMA and BB signals become TRUE at the same time.

The indicator’s specifications have already been defined in the previous sections.

4.9.1 Add Signals

We used the function `sigCrossover()` to defined the EMA and BB signals, and the function `sigFormula()` to combined both indicators.
Add signals to strategy

```r
#add combined signals EMA + BB for enter in a long position
add.signal("ema.bb", name = "sigFormula",
arguments = list(columns=c("ema12.gt.ema26", "Cl.lt.LowerBand"),
formula= "ema12.gt.ema26 & Cl.lt.LowerBand",
label="trigger", cross=TRUE), label = "Buy")

#add combined signals EMA + BB for enter in a short position
add.signal("ema.bb", name = "sigFormula",
arguments = list(columns=c("ema12.lt.ema26", "Cl.gt.UpperBand"),
formula= "ema12.lt.ema26 & Cl.gt.UpperBand",
label="trigger", cross=TRUE), label = "Sell")
```

Source: Author

### 4.9.2 Apply Strategy

This strategy uses three separate indicators and six separate signals. The strategy requires:

- When the short-term EMA is greater than the long-term EMA AND the close price is less than lower band in the BB enter in a long/buy position;
- When the short-term EMA is less than the long-term EMA AND the close price is greater than upper band in the BB enter in a short/sell position;

The strategy was tested with the different EMA parameters for both currencies, and equities.

### 4.10 Combined Indicators: MACD & RSI Strategy

In this strategy the goal is to combined the MACD indicator and the RSI indicator. We want to enter into a position when both MACD and RSI signals become TRUE at the same time.

The indicators specifications have already defined in the previous sections.

#### 4.10.1 Add Signals

We used the function `sigThreshold()` to defined the MACD and the RSI signals, and the function `sigFormula()` to combined both indicators.

```r
#add combined signals MACD + RSI for enter in a long position
add.signal("macd.rsi", name = "sigFormula",
arguments = list(columns=c("signal.gt.zero", "RSI.lt.30"),
formula= "signal.gt.zero & RSI.lt.30",
label="trigger", cross=TRUE), label = "Buy")

#add combined signals MACD + RSI for enter in a short position
add.signal("macd.rsi", name = "sigFormula",
arguments = list(columns=c("signal.lt.zero", "RSI.gt.70"),
formula= "signal.lt.zero & RSI.gt.70",
label="trigger", cross=TRUE), label = "Sell")
```

Source: Author
4.10.2 Apply Strategy

This strategy uses two separate indicators and six separate signals. The strategy requires:

- When the MACD signal is greater than zero AND the RSI is less than 30 enter in a long/buy position;
- When the MACD signal is less than zero AND the RSI is greater than 70 enter in a short/sell position;

The strategy was tested with the different RSI parameters for both currencies, and equities.

4.11 Combined Indicators: MACD & BB Strategy

In this strategy the goal is to combined the MACD indicator and the BB indicator. We want to enter into a position when both MACD and BB signals become true at the same time.

The indicators specifications have already defined in the previous sections.

4.11.1 Add Signals

We used the function \texttt{sigThreshold()} to defined the MACD and the function \texttt{sigCrossover()} to defined the BB signals, and the function \texttt{sigFormula()} to combined both indicators.

```
Listing 4.23: Add signals to strategy
```

```
1  #add combined signals MACD + BB for enter in a long position
2  add.signal("macd.bb", name = "sigFormula",
3      arguments = list(columns=c("signal.gt.zero", "Cl.lt.LowerBand"),
4        formula= "signal.gt.zero & Cl.lt.LowerBand",
5        label="trigger", cross=TRUE), label = "Buy")
6  
7  #add combined signals MACD + BB for enter in a short position
8  add.signal("macd.bb", name = "sigFormula",
9      arguments = list(columns=c("signal.lt.zero", "Cl.gt.UpperBand"),
10        formula= "signal.lt.zero & Cl.gt.UpperBand",
11        label="trigger", cross=TRUE), label = "Sell")
```

Source: Author

4.11.2 Apply Strategy

This strategy uses two separate indicators and six separate signals. The strategy requires:

- When the MACD signal is greater than zero AND the close price is less than lower band in the BB enter in a long/buy position;
- When the MACD signal is less than zero AND the close price is greater than upper band in the BB enter in a short/sell position;

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4.12 Combined Indicators: RSI & BB Strategy

In this strategy, the goal is to combine the RSI indicator and the BB indicator. We want to enter into a position when both RSI and BB signals become TRUE at the same time.

The indicator’s specifications have already been defined in the previous sections.

4.12.1 Add Signals

We used the function \texttt{sigThreshold()} to define the RSI signals and the function \texttt{sigCrossover()} to define the BB signals, and the function \texttt{sigFormula()} to combine both indicators.

\begin{verbatim}
# add combined signals RSI + BB for enter in a long position
add.signal("rsi.bb", name = "sigFormula",
            arguments = list(columns=c("RSI.lt.30", "Cl.lt.LowerBand"),
                             formula= "RSI.lt.30 & Cl.lt.LowerBand",
                             label="trigger", cross=TRUE), label = "Buy")

# add combined signals RSI + BB for enter in a short position
add.signal("rsi.bb", name = "sigFormula",
            arguments = list(columns=c("RSI.gt.70", "Cl.gt.UpperBand"),
                             formula= "RSI.gt.70 & Cl.gt.UpperBand",
                             label="trigger", cross=TRUE), label = "Sell")
\end{verbatim}

Source: Author

4.12.2 Apply Strategy

This strategy uses two separate indicators and six separate signals. The strategy requires:

- When the RSI signal is less than 30 AND the close price is less than lower band in the BB enter in a long/buy position;
- When the RSI signal is greater than 70 AND the close price is greater than upper band in the BB enter in a short/sell position;

The strategy was tested with the different RSI parameters for both currencies, and equities. The plots A.10, A.11 from each strategy tested are displayed in the Appendix A.

4.13 Summary

In this chapter was described the dataset, the financial package (Quantstrat), and each of the steps were defined in detail. All the indicators and their combinations were explained, as well as their implementation in the R language, through code listings. In the next chapter, will be presented the computational results.
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Computational Results

The computational results of our empirical study are presented, initially, by summarizing the performance of each indicator alone, followed by the combination of two different indicators, in order to understand in detail the performance of each of those strategies by currency pair and initial capital. This chapter is divided by the following sections:

- Indicators Results (section 5.1);
- Combined Indicators Results (sections 5.2);
- Discussion 2020 Results (section 5.3);

5.1 Indicators Results

Before start analyzing the strategy’s results, it is important to explain some concepts. One of the most important statistics of any trading system is the profit factor. The profit factor is the ratio between gross profits and gross losses. The profit factor is how many dollars make for each dollar loss. This means that a strategy that lost $200 but won $400 has a profit factor of two.

\[
\text{Profit Factor} = \frac{\text{Gross Profit}}{\text{Gross Loss}}
\]  

(5.1)

If the profit factor function is higher than 1, the trading strategy has a positive return. If the profit factor is equal to zero, the final return is zero. If the profit factor is lower than 1, then the strategy produces negative returns.

While the profit factor is one important statistic, the Percent Profitable statistic shows how many of the trades were winners. This metric is calculated by dividing the number of winning trades by the total number of trades for a specific period.

\[
\% \text{ Percent Profitable} = \frac{\text{Winning Trades}}{\text{Total Trades}}
\]  

(5.2)

The last parameter for analyzing the strategy performance is the Equity Curve. An equity curve is a graphical representation of the change in the value of a trading account over a time period. The input data for equity curve analyses are the data, which represent progress of gains and losses of specific trading strategy in time [31].

Since it presents performance data in graphical form, an equity curve is ideal for providing a quick analysis of how a strategy has performed. An equity curve that has an over all uptrend and is near all
time highs usually shows that the investing or trading strategy used is profitable over the long term. A negative downtrend in an equity curve will show that an account is either in a drawdown \(^2\), the market is not currently conducive to the system used, or the investor of trader doesn't have an edge in the markets if the account stays in a downward slope [32].

The Equity Curve is the curve of the profits cumulated at the moment \(m\):

\[
EC = \sum_{m=1}^{\text{NoTrades}} P_{\text{trade}(m)}
\]

(5.3)

Where \(EC\) is the Equity Curve.

Here is a very simple example of an equity curve:

Let's say trade #1 is a $200 profit, trade #2 a $100 loss, trade #3 a $400 profit and trade #4 a $200 profit, and so on.

- So after trade #1, the cumulative profit is $200.
- After trade #2, the cumulative profit is $200-100 = $100.
- After trade #3, the cumulative profit is $200-100+400 = $500.
- After trade #4, the cumulative profit is $200-100+400+200 = $700.

Figure 5.1 shows an example of an equity curve. The \(y\) axis is the cumulative equity value, and the \(x\) axis is the date or number of trades.

### 5.1.1 EMA Results

In this section is displayed the results for the EMA crossover strategy with three different parameters:

<table>
<thead>
<tr>
<th>#1</th>
<th>EMA with a 12-day and 26-day period crossover;</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2</td>
<td>EMA with a 12-day and 50-day period crossover;</td>
</tr>
<tr>
<td>#3</td>
<td>EMA with a 50-day and 200-day period crossover;</td>
</tr>
</tbody>
</table>

The strategy was tested for the EUR/USD and GBP/USD currency pairs with different initial capitals.

#### 5.1.1.A EMA 12-26 Crossover Results

In the table 5.1 are displayed the results for the EMA crossover strategy during all the year of 2020. In the table 5.1 its possible to see that this strategy was not profitable for both currency pairs, except for

\(^2\)A drawdown is a peak-to-trough decline during a specific period for an investment, trading account, or fund.
the pair GBP/USD with major capital. The number of trades was similar for both currency pairs, as well as the percent profitable. The profit factor below one shows that it is not a strong strategy.

Figures 5.2 and 5.3 shows four equity curves corresponding to the currency pairs and different initial capitals. The equity curves in Figures 5.2 and 5.3 shows a downtrend for almost all strategies, except for the pair GBP/USD with the higher capital, which means that the EMA crossover strategy is not profitable.

Table 5.1: EMA 12-26 overall results

<table>
<thead>
<tr>
<th>Description</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Capital</strong></td>
<td>$10,000.00</td>
<td>$100,000.00</td>
</tr>
<tr>
<td>Gross Profits</td>
<td>$4,508.01</td>
<td>$7,990.80</td>
</tr>
<tr>
<td>Gross Losses</td>
<td>$6,682.69</td>
<td>$9,166.70</td>
</tr>
<tr>
<td><strong>Final Capital</strong></td>
<td>$7,878.20</td>
<td>$8,996.70</td>
</tr>
<tr>
<td>Total Gains/Losses</td>
<td>$(2,121.80)</td>
<td>$(1,003.30)</td>
</tr>
<tr>
<td>Nº Trades</td>
<td>343</td>
<td>337</td>
</tr>
<tr>
<td>Percent Profitable (%)</td>
<td>35.86</td>
<td>34.72</td>
</tr>
<tr>
<td>Profit Factor</td>
<td>0.67</td>
<td>0.87</td>
</tr>
</tbody>
</table>
5.1.1.B EMA 12-50 Crossover Results

In the table 5.2 are displayed the results for the EMA 12-day period and 50-day period crossover strategy. Overall this is a profitable strategy, except for EUR/USD with lower capital. The number of trades is very similar in both currency pairs. The percent profitable is higher for the GBP/USD pair, almost 5% than EUR/USD. The EUR/USD is the only one with a profit factor below one.

The EMA(12-50) equity curves are display in the Appendix A.

5.1.1.C EMA 50-200 Crossover Results

In the table 5.3 are displayed the results for the EMA 50-day period and 200-day period crossover strategy. This strategy was profitable for the EUR/USD pair, with the profit factor above one and the percent profitable higher than the GBP/USD pair. For the GBP/USD currency pair, the strategy was only profitable with a major capital, although the profit was not high. This strategy generated more trades in the pair GBP/USD than the EUR/USD.

The EMA(50-200) equity curves are display in the Appendix A.
Table 5.2: EMA 12-50 crossover strategy results

<table>
<thead>
<tr>
<th>Description</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital</td>
<td>$10 000.00</td>
<td>$10 000.00</td>
</tr>
<tr>
<td></td>
<td>$10 000.00</td>
<td>$10 000.00</td>
</tr>
<tr>
<td>Gross Profits</td>
<td>$4 278.20</td>
<td>$7 008.20</td>
</tr>
<tr>
<td></td>
<td>$46 670.00</td>
<td>$74 672.00</td>
</tr>
<tr>
<td>Gross Losses</td>
<td>$4 924.40</td>
<td>$6 381.50</td>
</tr>
<tr>
<td></td>
<td>$(40 712.00)</td>
<td>$(55 769.00)</td>
</tr>
<tr>
<td>Final Capital</td>
<td>$9 396.20</td>
<td>$10 782.00</td>
</tr>
<tr>
<td></td>
<td>$106 436.00</td>
<td>$120 456.00</td>
</tr>
<tr>
<td>Total Gains/Losses</td>
<td>$(603.80)</td>
<td>$(74 672.00)</td>
</tr>
<tr>
<td></td>
<td>$6 436.00</td>
<td>$(55 769.00)</td>
</tr>
<tr>
<td>Nº Trades</td>
<td>231</td>
<td>234</td>
</tr>
<tr>
<td>Percent Profitable (%)</td>
<td>31.17</td>
<td>36.32</td>
</tr>
<tr>
<td>Profit Factor</td>
<td>0.87</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Table 5.3: EMA 50-200 crossover strategy results

<table>
<thead>
<tr>
<th>Description</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Capital</td>
<td>$10 000.00</td>
<td>$10 000.00</td>
</tr>
<tr>
<td></td>
<td>$10 000.00</td>
<td>$10 000.00</td>
</tr>
<tr>
<td>Gross Profits</td>
<td>$2 375.50</td>
<td>$3 247.30</td>
</tr>
<tr>
<td></td>
<td>$25 051.00</td>
<td>$33 553.00</td>
</tr>
<tr>
<td>Gross Losses</td>
<td>$(1 683.70)</td>
<td>$(3 622.20)</td>
</tr>
<tr>
<td></td>
<td>$(14 677.00)</td>
<td>$(33 468.00)</td>
</tr>
<tr>
<td>Final Capital</td>
<td>$10 686.20</td>
<td>$9 759.60</td>
</tr>
<tr>
<td></td>
<td>$110 318.00</td>
<td>$101 430.00</td>
</tr>
<tr>
<td>Total Gains/Losses</td>
<td>$686.20</td>
<td>$(240.40)</td>
</tr>
<tr>
<td></td>
<td>$10 318.00</td>
<td>$(1 430.00)</td>
</tr>
<tr>
<td>Nº Trades</td>
<td>64</td>
<td>71</td>
</tr>
<tr>
<td>Percent Profitable (%)</td>
<td>37.5</td>
<td>28.17</td>
</tr>
<tr>
<td>Profit Factor</td>
<td>1.41</td>
<td>0.9</td>
</tr>
</tbody>
</table>

We concluded that the less profitable strategy was the EMA crossover with a 12-day and 26-day period. The best EMA crossover strategy for the EUR/USD pair is with a 50-day and 200-day period. While for the pair, GBP/USD is the EMA crossover with a 12-day and 50-day period.

5.1.2 MACD Results

Table 5.4 shows the MACD strategy results for both pairs and initial capitals. The EUR/USD pair strategy triggered two hundred and forty trades during the year, with less than forty percent positive trades. The strategy was only profitable with a major capital, with a profit above one. The GBP/USD pair shared similar results with initial capitals, the number of trades, percent profitable, and the profit factor. The equity curves represented in Figures 5.4 and 5.5, for the MACD strategy shows that the EUR/USD and GBP/USD pairs with a lower capital had a downtrend almost all year with a significant drawdown.
Table 5.4: MACD strategy overall results

<table>
<thead>
<tr>
<th>MACD</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Initial Capital</strong></td>
<td>$10 000.00</td>
<td>$100 000.00</td>
</tr>
<tr>
<td><strong>Gross Profits</strong></td>
<td>$4 050.30</td>
<td>$45 255.00</td>
</tr>
<tr>
<td><strong>Gross Losses</strong></td>
<td>$(5 077.90)</td>
<td>$(42 571.00)</td>
</tr>
<tr>
<td><strong>Final Capital</strong></td>
<td>$9 028.90</td>
<td>$103 249.00</td>
</tr>
<tr>
<td><strong>Total Gains/Losses</strong></td>
<td>$(971.10)</td>
<td>$3 249.00</td>
</tr>
<tr>
<td><strong>Nº Trades</strong></td>
<td>240</td>
<td>246</td>
</tr>
<tr>
<td><strong>Percent Profitable (%)</strong></td>
<td>36.67</td>
<td>36.18</td>
</tr>
<tr>
<td><strong>Profit Factor</strong></td>
<td>0.8</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Figure 5.4: Equity Curve for MACD EUR/USD

The EUR/USD chart 5.4(a) observes an uptrend at the beginning of the year, but its behavior was volatile through the rest of the time, with many highs and lows. Finally, in the GBP/USD chart 5.5(a) also had an uptrend in the first part of the year but remained stable through the year until it started a downtrend at the end of the year. It is possible to conclude that although the strategy was profitable for both currency pairs with a major capital, it was not a strong strategy all over the analyzed period.

5.1.3 RSI Results

The RSI strategy was tested with two different parameters:

#1 RSI - oversold <30 and overbought> 70
#2 RSI - oversold <20 and overbought> 80

The strategy was tested for the EUR/USD and GBP/USD currency pairs with different initial capitals.
5.1.3.A RSI (30-70) results

In the table 5.5 are displayed the results for the RSI strategy for the parameters of oversold(30) and overbought(70).

The EUR/USD pair had fewer trades than the GBP/USD, but the percent profitable was similar in both pairs. The strategy was profitable with a major capital in both pairs and had losses with lower capital. The profit factor was similar in the two currency pairs.

Figures 5.6 and 5.7 shows the equity curves for this RSI strategy. It is possible to observe that both currency pairs occurred a downtrend at the beginning of the year with a massive drawdown between March and April. Although the pairs with a higher capital could reverse the situation and end the year with a profit, the same did not happen with lower capital.
5.1.3.B RSI (20-80) results

In the table 5.6 are displayed the results for the RSI strategy for the parameters of oversold(20) and overbought(80).

The RSI strategy was only profitable for the EUR/USD pair in the two initial capitals. The strategy triggered fewer trades in the EUR/USD pair than in the GBP/USD, although were higher positive trades. The profit factor was also above one in the EUR/USD, while the GBP/USD pair was below one in the two initial capitals. The RSI(80-20) equity curves are display in the Appendix A.

After analyzing the two types of RSI strategies tested, we can conclude that the RSI with wide parameters is more profitable for the EUR/USD currency pair. The strategy with less wide parameters is more suited for the GBP/USD pair.
5.1.4 BB Results

Table 5.7 shows the Bollinger Bands strategy results for both pairs and initial capitals. For the EUR/USD pair, the BB strategy was not profitable in either capital. Although the percent profitable was more than sixty percent, the profit factor was equal and less than one. For the GBP/USD pair, the strategy was only profitable with higher capital. The number of trades triggered was similar in both currency pairs.

Figures 5.8 and 5.9 shows the equity curves for the BB strategy. In the chart 5.8(a) it is possible to observe a downtrend through all the time tested, while for the chart 5.8(b) the strategy was unstable for the EUR/USD pair, with significant highs and lows during the year. For the GBP/USD pair, the chart 5.9(a) shows a significant downtrend at the start of the year and remained sideways until the end of the year. In the chart 5.9(b) the GBP/USD has a strong strategy, with an uptrend trough almost the year.
5.2 Combined Indicators Results

This section displays the results for the combined indicators strategies. Although we ran the 27 combined strategies, only four combinations triggered trades for time tested: the EMA with the MACD and the RSI with the BB. The remained combinations did not make any results.

5.2.1 EMA & MACD Results

We tested the EMA with different crossover parameters combined with the MACD strategy. However, we only achieved results for the EMA 12-day and 26-day crossover with MACD, and the EMA 12-day and 50-day crossover with the MACD.
5.2.1.A EMA 12-26 Crossover & MACD Results

In the Table 5.8 are displayed the combined strategy results. This strategy did not trigger any trade for the EUR/USD pair for all the time tested. In comparison, the GBP/USD pair was a profitable strategy, with only thirteen trades triggered during the year. Although the strategy has not been too strong, it was better than the single indicator strategy with a profit factor of one.

The EMA (12-26) crossover and MACD equity curves are displayed in the Appendix A.

5.2.1.B EMA 12-50 Crossover & MACD Results

In the Table 5.9 are displayed the combined strategy results. The strategy was profitable for both currency pairs, with the number of triggered trades similar. The EUR/USD had a percent profitable higher than the British pair. However, the profit factor was lower, meaning that the strategy was weaker for the EUR/USD than the GBP/USD.

The EMA (12-50) crossover and MACD equity curves are displayed in the Appendix A.
### Table 5.10: RSI(70-30) & BB strategy overall results

<table>
<thead>
<tr>
<th>Description</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Capital</strong></td>
<td>$ 10 000.00</td>
<td>$ 100 000.00</td>
</tr>
<tr>
<td>Gross Profits</td>
<td>$ 4 852.00</td>
<td>$ 51 976.00</td>
</tr>
<tr>
<td>Gross Losses</td>
<td>$(3 498.00)</td>
<td>$(33 468.00)</td>
</tr>
<tr>
<td><strong>Final Capital</strong></td>
<td>$ 11 315.40</td>
<td>$ 118 122.00</td>
</tr>
<tr>
<td>Total Gains/Losses</td>
<td>$ 1 315.40</td>
<td>$ 18 122.00</td>
</tr>
<tr>
<td>Nº Trades</td>
<td>92</td>
<td>102</td>
</tr>
<tr>
<td>Percent Profitable (%)</td>
<td>69.57</td>
<td>67.65</td>
</tr>
<tr>
<td>Profit Factor</td>
<td>1.39</td>
<td>1.17</td>
</tr>
</tbody>
</table>

### Table 5.11: RSI(80-20) & BB strategy overall results

<table>
<thead>
<tr>
<th>Description</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Capital</strong></td>
<td>$ 10 000.00</td>
<td>$ 100 000.00</td>
</tr>
<tr>
<td>Gross Profits</td>
<td>$ 2 664.30</td>
<td>$ 27 669.00</td>
</tr>
<tr>
<td>Gross Losses</td>
<td>$(1 635.10)</td>
<td>$(15 865.00)</td>
</tr>
<tr>
<td><strong>Final Capital</strong></td>
<td>$ 11 011.80</td>
<td>$ 111 630.00</td>
</tr>
<tr>
<td>Total Gains/Losses</td>
<td>$ 1 011.80</td>
<td>$ 11 630.00</td>
</tr>
<tr>
<td>Nº Trades</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>Percent Profitable (%)</td>
<td>67.86</td>
<td>72.41</td>
</tr>
<tr>
<td>Profit Factor</td>
<td>1.63</td>
<td>1.22</td>
</tr>
</tbody>
</table>

### 5.2.2 RSI & BB Results

We tested the RSI with different crossover parameters combined with the BB strategy.

#### 5.2.2.A RSI (70-30) & BB Results

In Table 5.10 are displayed the combined strategy results. The strategy was profitable for both currency pairs, with an average of hundred trades triggered. The EUR/USD pair had a profit factor higher than the GBP/USD, which tells that the strategy was more suitable for the EUR/USD. Both pairs had a percent profitable near seventy percent. The RSI (70-30) and BB equity curves are display in the Appendix A.
5.2.2.B RSI (80-20) & BB Results

In the Table 5.11 are displayed the combined strategy results. Both currency pairs had profit with the strategy. The number of trades triggered was similar in both pairs, as well as the percent profitable. The EUR/USD had a profit factor higher than the GBP/USD pair, showing a stronger strategy for this pair. The RSI (80-20) and BB equity curves are display in the Appendix A. Table 5.12 are displayed the profit factor overall results for all the strategies tested in this work. It is possible to observe that the combined strategy with better results in both currencies and initial capital was the EMA 12-day and 50-day period crossover with MACD. The worst strategy was the Bollinger Bands alone strategy.

Table 5.12: Overall Profit Factor Results of 2020

<table>
<thead>
<tr>
<th>Initial Capital</th>
<th>$10 000</th>
<th>$100 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators</td>
<td>EUR/USD</td>
<td>GBP/USD</td>
</tr>
<tr>
<td>EMA (12-26)</td>
<td>0.67</td>
<td>0.87</td>
</tr>
<tr>
<td>EMA (12-50)</td>
<td>0.87</td>
<td>1.10</td>
</tr>
<tr>
<td>EMA(50-200)</td>
<td>1.41</td>
<td>0.90</td>
</tr>
<tr>
<td>MACD</td>
<td>0.80</td>
<td>0.88</td>
</tr>
<tr>
<td>RSI(70-30)</td>
<td>0.80</td>
<td>0.85</td>
</tr>
<tr>
<td>RSI(80-20)</td>
<td>1.28</td>
<td>0.84</td>
</tr>
<tr>
<td>BB</td>
<td>0.62</td>
<td>0.83</td>
</tr>
<tr>
<td>EMA(12-26) &amp; MACD</td>
<td>-</td>
<td>0.99</td>
</tr>
<tr>
<td>EMA(12-50) &amp; MACD</td>
<td>1.7</td>
<td>2.44</td>
</tr>
<tr>
<td>RSI(70-30) &amp; BB</td>
<td>1.39</td>
<td>1.17</td>
</tr>
<tr>
<td>RSI(80-20) &amp; BB</td>
<td>1.63</td>
<td>1.22</td>
</tr>
</tbody>
</table>

5.3 Discussion 2020 Results

In this section it is discussed the overall results of 2020. Figure 5.10 shows two charts with the profit factor results for all the strategies. It is possible to observe that the single indicators strategies had a profit factor lower than the combined strategies, which were less profitable than the strategies with two indicators combined.

Analyzing each currency pair individually, we can say that for the EUR/USD currency pair, the single indicator strategy with a high-profit factor was the EMA 12-day and EMA 50-day period crossover, followed by the RSI strategy with wide parameters. While for the combined strategies, the most profitable was the combination of the EMA 12-day period and EMA 50-day period crossover with the MACD, with a profit factor of 1.78.

The most profitable single indicator strategy in the GBP/USD currency pair was the EMA 12-day period and 50-day period crossover. The preferred strategy was the only single strategy with profit, once
all the other ones had a profit factor below one. Also, as for the EUR/USD pair, the combined strategy more profitable to GBP/USD was the EMA 12-day period and 50-day period crossover with MACD.

For both currency pairs, the strategy with the worst results was the Bollinger Bands, and the combined strategy was the EMA 12-day period and 26-day period crossover with MACD. Comparing the results with an initial capital of $100,000, they overcome the lower capital results. The less profitable strategies with the higher capital had a profit factor above or equal to 1. The reason why the profit factor increased is that the losses could be supported with higher capital. However, the results were very similar with both capitals in terms of strategy efficacy.

We can conclude that the combined indicators strategies were more profitable than the single strategies, which was the study’s objective. Although the number of trades realized was far less with the combined indicators, as it is possible to see in the Figure 5.11, the strategies were more robust, leading to more winner trades and fewer losses.
Unfortunately, we did not get results for more than two indicators combined, which was the study’s primary goal. The trend indicators (EMA and MACD) never matched with the momentum (RSI) and volatile (BB) indicators, and the momentum indicators only matched with the volatile ones. There are various reasons for the lack of combinations had happened. One of the reasons is the small data set, we only analyzed the strategies during one year, and if we had higher data set, we could have triggered more trades with the different indicators categories.

5.4 Summary

This chapter was presented all the computational results from the indicators strategies, alone and combined, for the year 2020. We can conclude that the combined strategies achieved better results than the single ones. However, we will discuss the computational results in detail in the next chapter 6.
Computational Results - 2016 to 2020

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Computational Results Discussion - 2016 to 2020

This section will be discussed the overall results for the last 5 years, as well as with different signal strategies. The chapter is divided in the following sections:

- EMA(12-50) crossover AND MACD results (section 6.1);
- Results for the last 5 years (section 6.2);
- Results for the last 5 years with different signals (section 6.3); Results Discussion (section 6.4);

6.1 Analyzing Results for the EMA (12-50) crossover & MACD

The combined strategy with EMA 12-day and 50-day period crossover with MACD stood out from the others, with better results in both currencies. To evaluate the strategy efficiency, we re-ran the strategy for the last 5 years only with the lower initial capital. However, the results were inconclusive. There were years when the strategy was successful, such as 2020 and 2017, but there were also years with negative results, as shown in Table 6.1.

Table 6.1: Profit Factor for EMA(12-50) AND MACD strategy for the last 5 years

<table>
<thead>
<tr>
<th>Year</th>
<th>EUR/USD</th>
<th>GBP/USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>1.70</td>
<td>2.44</td>
</tr>
<tr>
<td>2019</td>
<td>0.43</td>
<td>1.15</td>
</tr>
<tr>
<td>2018</td>
<td>0.90</td>
<td>0.73</td>
</tr>
<tr>
<td>2017</td>
<td>2.63</td>
<td>2.48</td>
</tr>
<tr>
<td>2016</td>
<td>0.71</td>
<td>0.30</td>
</tr>
</tbody>
</table>

To understand the granularity effect on the strategy results, we ran the strategy using a shorter timeframe of 15 minutes. Still, there was no significant difference in the results obtained. These inconclusive results led us to analyze all the strategies for the last 5 years as well.

6.2 Results for the last 5 years

The results from the tests ran in the strategies for the different years are displayed in the Table 6.2. The values in green represent the strategies with a profit factor above 1, meaning profitable strategies, the values in yellow represent the strategies without realized trades, and the red values are not strategy representative, because of the small number of trades triggered
Once more, the results were inconclusive, there were good years, like 2020 and 2017, but the rest of the years had bad strategy performances. The EMA 12-day and 50-day period crossover with the MACD remained the best strategy, followed by the combined strategy of RSI (80-20) with the BB.

There were combined strategies that had never triggered trades in all the 5 years tested, which was the case of the EMA (all parameters) crossover with the RSI (all parameters), the EMA (all parameters) crossover with the BB, the MACD with the RSI (all parameters), and the MACD with the BB.

Comparing the results of 2020 and 2017, the latter year had better performance results than the former. In 2017 the profit factor was higher in almost all the strategies than in 2020. The worst years, 2016 and 2018, practically didn’t have any good strategy performance, with the profit below one.
Table 6.2: Profit Factor for all the strategies in the last 5 years

* this values are not considered because the strategy only had four trades in the all year

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EUR/USD</td>
<td>GBP/USD</td>
<td>EUR/USD</td>
<td>GBP/USD</td>
<td>EUR/USD</td>
</tr>
<tr>
<td>EMA(12-26)</td>
<td>0.67</td>
<td>0.87</td>
<td>0.45</td>
<td>0.74</td>
<td>0.79</td>
</tr>
<tr>
<td>EMA(12-50)</td>
<td>0.70</td>
<td>1.1</td>
<td>0.56</td>
<td>0.89</td>
<td>0.80</td>
</tr>
<tr>
<td>EMA(50-200)</td>
<td>1.41</td>
<td>0.90</td>
<td>0.93</td>
<td>1.50</td>
<td>0.79</td>
</tr>
<tr>
<td>MACD</td>
<td>0.80</td>
<td>0.88</td>
<td>0.54</td>
<td>0.86</td>
<td>0.83</td>
</tr>
<tr>
<td>RSI (70-30)</td>
<td>0.80</td>
<td>0.85</td>
<td>0.51</td>
<td>0.76</td>
<td>0.59</td>
</tr>
<tr>
<td>RSI (80-20)</td>
<td>1.28</td>
<td>0.84</td>
<td>0.84</td>
<td>0.66</td>
<td>0.80</td>
</tr>
<tr>
<td>BB</td>
<td>0.62</td>
<td>0.83</td>
<td>0.45</td>
<td>0.58</td>
<td>0.64</td>
</tr>
<tr>
<td>EMA(12-26) &amp; MACD</td>
<td>-</td>
<td>0.99</td>
<td>0.22</td>
<td>-</td>
<td>0.43</td>
</tr>
<tr>
<td>EMA(12-50) &amp; MACD</td>
<td>1.70</td>
<td>2.44</td>
<td>0.43</td>
<td>1.15</td>
<td>0.90</td>
</tr>
<tr>
<td>EMA(50-200) &amp; MACD</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>EMA &amp; RSI</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EMA &amp; BB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MACD &amp; RSI (70-30)</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MACD &amp; RSI (80-20)</td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
<td>MACD &amp; BB</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RSI (70-30) &amp; BB</td>
<td>1.39</td>
<td>1.17</td>
<td>0.86</td>
<td>0.94</td>
<td>0.64</td>
</tr>
<tr>
<td>RSI (80-20) &amp; BB</td>
<td>1.63</td>
<td>1.22</td>
<td>0.78</td>
<td>0.76</td>
<td>0.69</td>
</tr>
</tbody>
</table>
6.3 Results for the last 5 years with different signals strategies

Since we had so many strategies without any trades performed, we decided to test a different approach. Instead of the combined strategies that only triggered orders when both signals are true, now we would test with contrary signals, meaning that one indicator had a signal to buy and the other a signal to sell. The results from the testes ran in the strategies for the different years are displayed in the Table B.1 in the Appendix A.

Once more, 2017 stood out with the best strategies performances, having a profit factor above 1 in almost all the strategies. The EMA 50-day and 200-day period crossover with a signal for sell with the RSI (80-20) with a signal for buy in 2017 was by far the strategy with a higher profit factor of 5.73. The strategies with the combination of EMA crossover with a signal for sell and RSI with a signal for buy had great performances. The year 2020 continuously having good strategy performance again as well. Regarding the years less profitable, were once more the 2018 and 2016.

![Currency Markets of 2017](a) EUR/USD 2017 (b) GBP/USD 2017

**Figure 6.1: Currency Markets of 2017**

6.4 Discussion 2016 - 2020 Results

We concluded that years with great strategy performance, like 2020 and 2017, had an uptrend market almost all the year, and the years with a weak performance, as 2018 and 2016, had a downtrend market.

Looking at the Figures 6.2(a) and 6.2(b) it is possible to observe that 2020 was in a major part of the year an uptrend market, except at the beginning of the year for the GBP/USD that had a sharp drop. That difference between the currency pairs had consequences in the profit factor results. The EUR/USD pair had a higher profit factor in the strategies than the GBP/USD, perhaps because of that price drop. As for the year 2017, in the Figures 6.1(a) and 6.1(b), although there was a significant uptrend for both
currency pairs, the EUR/USD at the end of the year experienced a sideways market. And in fact, the EUR/USD had lower profit factors in the strategies comparing with the GBP/USD pair.

The year with the worst strategies performances was by far 2018, followed by 2016. Comparing the strategy results with the market performance through the year, we can see in the Figures 6.3 and 6.4 that the worst results correspond to a downtrend market. Looking at the year of 2016, in the Figures 6.4(a) and 6.4(b), the GBP/USD had a sideways market at the beginning of the year followed by a downtrend until the year, as for the EUR/USD was an inconsistent market with highs and lows all over the year, and as well a downtrend at the end of the year. Compared with the strategy performance results, the EUR/USD had a higher profit than the GBP/USD, which matches the market behavior.
### 6.5 Summary

In conclusion, it is difficult to predict with the technical indicator such unpredictable market as Forex. However, looking at the results, it is possible to recognize a pattern. Markets with uptrend behavior, as 2017 and 2020, usually tend to have better performance results with combined technical indicators than markets in a downtrend, 2016 and 2018 behavior. The table 6.3 shows a sample of the results of combined strategies for the last five years. The years 2020 and 2017 had better profit factors (above 1) than the years 2018 and 2016 (below 1). As already stated, when the profit factor is above 1, the strategies are favorable so that they will be profitable. The results from all the strategies are displayed in detail in the Appendix B.

The next chapter will be presented the conclusions.
7

Conclusion

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Conclusions

The purpose of this study is to evaluate the efficiency of combined different types of technical indicators in forecasting the Forex market for the two major currency pairs, EUR/USD and GBP/USD. In this context, four technical indicators were tested (Exponential Moving Average, Moving Average Convergence Divergence, Relative Strength Index, and Bollinger Bands) and combined in a dataset of 30 minutes timeframe, initially for the all year of 2020, and then for the last five years.

The results in the Tables 6.2 and B.1 confirm that the combined strategies are more profitable than the single ones. Note that using combined strategies generates much fewer trades. For example, within the 12 different combined strategies used, only four generated trades.

To understand if the good results achieved correspond to a strong strategy, we ran the same strategies for the last five years. Surprisingly, the newer results do not corroborate the 2020’s results. The strategies with a good performance in 2020 are unprofitable in other previous years. Regarding this outcome, we modified the strategies; one indicator had a signal to buy and the other a signal to sell, and they were tested for the last five years. Once again, the results achieved did not bring any conclusion. The same strategy could have a good and bad performance, depending on the dataset. The only difference noticed is that we performed trades in all the combinations with this type of strategy.

Looking at the last five years’ results, it is possible to recognize that most of the tested strategies achieved the best results for 2020 and 2017. On the other hand, 2018 and 2016 have shown the worst results. When comparing these results with the market’s trend, one can conclude that they are deeply related. Like 2020 and 2017, an uptrend market year leads to better strategies performance, while a downtrend market produces the opposite effect. Therefore, we can conclude that forecasting the trend direction in such an unpredictable market like Forex is a hard task that requires further investigation.

The technical analysis believes that past pattern prices can be used to predict future prices. This type of analysis uses a systematic, graphical approach to identify patterns of historical trading prices and market movements and then create predictions that possibly generate significant returns. Analysis of past pattern repetitions leads an investor/trader to conclude that the patterns have some regularity and are predictable. Nevertheless, there remains a question, and if we look closely at any random walk chart plotted against time, it is always possible to find repetition patterns. This makes investor’s predictions utterly useless. If the patterns are not random, they are either driven by fundamentalists, undermining the entire art of technical analysis, or driven by technical analysts.

There is no correct answer about which analysis is better for predicting the Forex market, and each one has its pros and cons. Regarding technical analysis, more specifically to technical indicators, it is possible to have good results with the right strategies; however, it is not reliable to beat the market in the long run. It is essential to consider other factors that may influence the market, such as macroeconomic aspects, news, understanding market behavior better, and making more well-informed decisions.
In the end, this work brings the following conclusions:

1. As purposed in the objectives, combining different indicators is more profitable than using a single indicator. Combining the EMA double crossover with the MACD and the RSI with the BB showed efficient strategies with good results.

2. The market trends it is related to the efficiency of the technical indicators. It was noticed that the years that we achieved better results, 2017 and 2020, were the years when the market was in uptrend. On the other hand, the years less profitable, 2016, 2018, and 2019 were when the market was on a downtrend.

3. Trading in the Forex market with initial higher capital has better outcomes than lower capital. A possible reason is that with higher capital, it is possible to recover from massive drawdowns.

The Forex market, as already stated, it is very unpredictable. Due to that, relay only in the technical analysis and therefore in technical indicators is unreliable. When the market is in a downtrend, it is not easy to have good results only with the technical indicators. Having good knowledge about economic factors and combining them with technical analysis tools is a more trustworthy strategy.

7.1 Limitations

This work was based only on studying four technical indicators, discarding other indicators more recent and possibly more efficient. The dataset tested represented a small sample, and it would be interesting to study the behavior of the indicators in a large dataset, for example, in the last twenty years and with different timeframes.

Future developments would be interesting to analyze the technical indicators in conjunction with fundamental indicators, and study their efficiency in predicting the Forex market.
Bibliography


Plots and Code of the Project

The Appendix A shows the strategies performance plots, some pieces of code used to test the strategies, and strategy equity curves.

A.1 EMA Plots

In this section are displayed the performance plots of EMA strategy, with the different parameters analyzed. The plots shows the closing prices of 30 minutes timeframe for the GBP/USD pair in year 2020. The green signals correspond to an entry orders and the red ones to exit orders. Besides that, in the plot it is possible to observe the positions in the market, the cumulative Profit and Loss, and the drawdown. The EMA 50-day and 200-day period, it was the only that had positive returns, all the other strategies had a weak performance.

A.1.1 EMA12 & EMA26 Strategy

The Figure A.1 shows a strategy performance for the EMA 12-day and 26-day period crossover.
A.1.2 EMA12 & EMA50 Strategy

The Figure A.1 shows a strategy performance for the EMA 12-day and 50-day period crossover.
A.1.3 EMA50 & EMA200 Strategy

The Figure A.1 shows a strategy performance for the EMA 50-day and 200-day period crossover.

A.2 MACD Listings and Plots

Here are displayed a piece of code used in the MACD strategy and the performance plot.

A.2.1 MACD Rules Strategy

In the Listing A.1 shows the order rules for entry and exit the market. When the MACD line and MACD signal are above zero triggers an order to buy and enter in the market. An order to sell is triggered when the MACD line and the MACD signal are bellow zero. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
Listing A.1: Add MACD rules to strategy

```r
# Create an entry rule to enter in a Long position when all the conditions are TRUE
add_rule("macd",
  name = 'ruleSignal',
  arguments = list(sigcol="signal.gt.zero", sigval=TRUE, orderside='long',
                  ordertype='stoplimit', prefer='High', treshold=.threshold,
                  orderqty=+.orderqty, replace=FALSE),
  type = 'enter',
  label='EnterLONG')

# Create an entry rule to enter in a Short position when all the conditions are TRUE
add_rule("macd",
  name = 'ruleSignal',
  arguments = list(sigcol='signal.lt.zero', sigval=TRUE, orderside='short',
                  ordertype='stoplimit', prefer='Low', treshold=.threshold,
                  orderqty=-.orderqty, replace=FALSE),
  type = 'enter',
  label= 'EnterSHORT')

# Close long positions when the signal.gt.zero column is True
add_rule("macd", name = 'ruleSignal',
  arguments = list(sigcol="signal.gt.zero", sigval=TRUE,
                  orderside='short', ordertype='market',
                  orderqty='all', TxnFees=.txnfees, replace=TRUE),
  type = 'exit',
  label = 'Exit2LONG')

# Close Short positions when the signal.lt.zero column is True
add_rule("macd", name = 'ruleSignal',
  arguments = list(sigcol='signal.lt.zero', sigval=TRUE,
                  orderside='long', ordertype='market',
                  orderqty='all', TxnFees=.txnfees, replace=TRUE),
  type = 'exit',
  label = 'Exit2SHORT')
```

Source: Author

A.2.2 MACD Strategy

The Figure A.4 shows a strategy performance for the MACD. This strategy had a weak performance for both currency pairs, with a negative returns.

A.3 RSI Listings and Plots

In this section are displayed the performance plots and Listings of RSI strategy, with the different parameters analyzed.

A.3.1 RSI rules

In the Listing A.2 shows the order rules for entry and exit the market. When the RSI is oversold (20/30) triggers an order to buy and enter in the market. An order to sell is triggered when the RSI is overbought (70/80) are bellow zero. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs. The example in the listing, is a strategy for the GBP/USD currency pair, with the parameters of 30 for oversold, and 70 for overbought.
Listing A.2: Add rules to strategy

```r
#Create an entry rule to enter in a Short position when all the conditions are TRUE
add.rule("rsi", name="ruleSignal",
arguments = list(sigcol="RSI.gt.70", sigval=TRUE, orderqty=+.orderqty,
otype='stoplimit', prefer='Low', treshold=.threshold,
orderside="short", replace=FALSE),type = 'enter',
label = 'enterShort')

# Close Short positions when the RSI.lt.30 column is True
add.rule("rsi", name="ruleSignal",
arguments = list(sigcol="RSI.lt.30", sigval=TRUE, orderside='short',
ordertype='market',orderqty='all',TxnFees=.txnfees,
replace=TRUE),type = 'exit',
label = 'exitShort')

#Create an entry rule to enter in a Long position when all the conditions are TRUE
add.rule("rsi", name="ruleSignal",
arguments = list(sigcol="RSI.lt.30", sigval=TRUE, orderqty=+.orderqty,
otype='stoplimit', prefer='High', treshold=.threshold,
orderside="long", replace=FALSE),type = 'enter',
label = 'enterLong')

#Close long positions when the RSI.gt.70 column is True
add.rule("rsi", name="ruleSignal",
arguments = list(sigcol="RSI.gt.70", sigval=TRUE, orderside='long',
ordertype='market',orderqty='all',TxnFees=.txnfees,
replace=TRUE),type = 'exit',
label = 'exitLong')
```

Source: Author

A.3.2 RSI (30 & 70) Strategy

The Figure A.5 shows a strategy performance for the RSI, with parameters of 30 for oversold, and 70 for overbought. This strategy had an bad performance, with negative returns for both currency pairs.
A.3.3 RSI (20 & 80) Strategy

The Figure A.6 shows a strategy performance for the RSI, with parameters of 20 for oversold, and 80 for overbought. This strategy had a strong performance for the EUR/USD currency pair. However, for the GBP/USD this strategy doesn’t fit, showing a weak performance and negative returns.

A.4 BB Listings and Plots

Here are displayed a piece of code used in the BB strategy and the performance plot.

A.4.1 BB rules

In the Listing A.3 shows the order rules for entry and exit the market. When close price is above the upper band of the BB, a sell signal is triggered to enter in the market, and when the close price is bellow the lower band, a buy signal is triggered and place an order to enter in the market. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
Listing A.3: Add rules to strategy

```r
#add rule to enter short
add.rule("bbands", name = 'ruleSignal',
  arguments = list(sigcol="Cl.gt.UpperBand", sigval=TRUE,
  orderqty=-.orderqty, treshold=.threshold,
  ordertype='market', orderside=NULL), type = 'enter',
  label = 'BBSELL')

#add rule to enter long
add.rule("bbands", name = 'ruleSignal',
  arguments = list(sigcol="Cl.lt.LowerBand", sigval=TRUE,
  orderqty= .orderqty, treshold=.threshold,
  ordertype='market', orderside=NULL), type = 'enter',
  label = "BBBUY")

#add rule to exit positions
add.rule("bbands", name = 'ruleSignal',
  arguments = list(sigcol="Cross.Mid", sigval=TRUE, orderqty="all",
  TxnFees=.txnfees, ordertype='market', orderside=NULL), type='exit')
```

Source: Author

A.4.2 Bollinger Bands Strategy

The Figure A.7 shows a strategy performance for the BB. This strategy had a weak performance, with negative returns for both currency pairs. Comparing with the other single indicators strategies, the BB was the worst strategy among them.
A.5 Combined Strategies Plots and Listings

In this section are represent the performance plots and listings of some combined strategies. We only display the strategies that had trades, which are the EMA 12-day and 26-day period crossover with the MACD, the EMA 12-day and 50-day period crossover with the MACD, the RSI (80-20) with the BB, and the RSI (70-30) with the BB.

A.5.1 EMA 12-26 Crossover & MACD

In the Listing A.4 shows the order rules for entry and exit the market. When the fast EMA (12) is above the slow EMA(26) and the MACD line and MACD signal are above 1, a signal to buy is triggered. When the fast EMA (12) is bellow the slow EMA (26) and the MACD line and MACD signal are bellow 1, is triggered a signal to sell. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
The Figure A.8 shows a strategy performance for the EMA 12-day and 26-day period crossover with the MACD. This strategy had a profit factor of 1, meaning that it is a profitable strategy, but not a strong one. The end equity was higher than the initial equity.

### A.5.2 EMA 12-50 Crossover & MACD

In the Listing A.5 shows the order rules for entry and exit the market. When the fast EMA (12) is above the slow EMA(50) and the MACD line and MACD signal are above 1, a signal to buy is triggered. When the fast EMA (12) is bellow the slow EMA (50) and the MACD line and MACD signal are bellow 1, is triggered a signal to sell. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
Listing A.5: Add EMA 12-50 & MACD rules to strategy

```r
#add rule for entry long
add.rule("ema.macd", name = "ruleSignal",
    arguments = list(sigcol="Buy", sigval=TRUE,
    orderqty=+.orderqty,
    ordertype='stoplimit', prefer='High', treshold=.threshold,
    orderside="long", replace=FALSE
    ),
    type = 'enter',
    label = 'enterLong')

#add rule for exit long
add.rule("ema.macd", name = "ruleSignal",
    arguments = list(sigcol="Sell", sigval=TRUE,
    orderqty='all',
    ordertype='market',
    TnxFees=.txnfees,
    replace=TRUE
    ),
    type = 'exit',
    label = 'exitLong')

#add rule for entry short
add.rule("ema.macd", name="ruleSignal",
    arguments = list(sigcol="Sell", sigval=TRUE, orderqty=+.orderqty,
    ordertype='stoplimit', prefer='Low', treshold=.threshold,
    orderside="short", replace=FALSE
    ),
    type = 'enter',
    label = 'enterShort')

#add rule for exit short
add.rule("ema.macd", name="ruleSignal",
    arguments = list(sigcol="Buy", sigval=TRUE, orderqty=+.orderqty,
    ordertype='market',
    TnxFees=.txnfees,
    replace=TRUE
    ),
    type = 'exit',
    label = 'exitShort')
```

Source: Author
The Figure A.9 shows a strategy performance for the EMA 12-day and 50-day period crossover with the MACD. This was the best strategy among all the other, the profit factor was above 2 for the GBP/USD and 1.50 for the EUR/USD.

A.5.3 RSI 70-30 & BB

In the Listing A.6 shows the order rules for entry and exit the market. When the RSI is oversold at 30 and the close price is below the lower band of the BB, a buy signal is triggered. When the RSI is overbought at 70 and the close price is above the upper band of the BB, a sell signal is triggered. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
Listing A.6: Add RSI 70-30 & BB rules to strategy

```r
#add rule for entry long
add.rule("rsi.bb", name = "ruleSignal",
  arguments = list(sigcol="Buy", sigval=TRUE,
    ordertype='stoplimit', prefer='High', treshold=.threshold,
    orderside="long", replace=FALSE
  ),
  type = 'enter',
  label = 'enterLong')

#add rule for exit long
add.rule("rsi.bb", name = "ruleSignal",
  arguments = list(sigcol="Sell", sigval=TRUE,
    orderside='long',
    ordertype='market',
    orderqty='all',
    TxnFees=.txnfees,
    replace=TRUE
  ),
  type = 'exit',
  label = 'exitLong')

#add rule for entry short
add.rule("rsi.bb", name="ruleSignal",
  arguments = list(sigcol="Sell", sigval=TRUE, orderqty=+.orderqty,
    ordertype='stoplimit', prefer='Low', treshold=.threshold,
    orderside="short", replace=FALSE
  ),
  type = 'enter',
  label = 'enterShort')

#add rule for exit short
add.rule("rsi.bb", name="ruleSignal",
  arguments = list(sigcol="Buy", sigval=TRUE, orderqty=+.orderqty,
    ordertype='market',
    orderqty='all',
    TxnFees=.txnfees,
    replace=TRUE
  ),
  type = 'exit',
  label = 'exitShort')
```

Source: Author

The Figure A.10 shows a strategy performance for the RSI (70-30) with the BB. Overall this strategy had a good performance, with a profit factor above 1, and was profitable for both currency pairs.

### A.5.4 RSI 80-20 & BB

In the Listing A.7 shows the order rules for entry and exit the market. When the RSI is oversold at 20 and the close price is bellow the lower band of the BB, a buy signal is triggered. When the RSI is overbought at 80 and the close price is above the upper band of the BB, a sell signal is triggered. To exit the market, either when is a position of buy or sell, is triggered when the opposite occurs.
Listing A.7: Add RSI 80-20 & BB rules to strategy

```r
#add rule for entry long
add.rule("rsi.bb", name = "ruleSignal",
arguments = list(sigcol="Buy", sigval=TRUE,
    orderqty=+.orderqty,
    ordertype='stoplimit', prefer='High', treshold=.threshold,
    orderside="long", replace=FALSE
),
type = 'enter',
label = 'enterLong')

#add rule for exit long
add.rule("rsi.bb", name = "ruleSignal",
arguments = list(sigcol="Sell", sigval=TRUE,
    orderside='long',
    ordertype='market',
    orderqty='all',
    TxnFees=.txnfees,
    replace=TRUE
),
type = 'exit',
label = 'exitLong')

#add rule for entry short
add.rule("rsi.bb", name="ruleSignal",
arguments = list(sigcol="Sell", sigval=TRUE, orderqty=+.orderqty,
    ordertype='stoplimit', prefer='Low', treshold=.threshold,
    orderside="short", replace=FALSE
),
type = 'enter',
label = 'enterShort')

#add rule for exit short
add.rule("rsi.bb", name="ruleSignal",
arguments = list(sigcol="Buy", sigval=TRUE, orderqty="all",
    ordertype='market',
    orderqty='all',
    TxnFees=.txnfees,
    replace=TRUE
),
type = 'exit',
label = 'exitShort')
```

Source: Author
The Figure A.11 shows a strategy performance for the RSI (80-20) with the BB. Overall this strategy had a good performance, with a profit factor above 1, and was profitable for both currency pairs.

A.6 Equity Curves

In this section are displayed the strategy’s equity curves from the computational results.

A.6.1 EMA (12-50) crossover

Figure A.12(a) shows a downtrend in the equity curve with a massive drawdown at the end of the year. Figure A.12(b) has an equity curve with an uptrend until the middle of the year and remained sideways. For the pair GBP/USD, Figure A.13(a) display an uptrend at the beginning of the year but back to the end of the year started into a downtrend. Figure A.13(b) shows the best performance with an uptrend almost the year.

A.6.2 EMA (50-200) crossover

The Figures A.14(a) and A.14(b) shows an uptrend in the beginning of the year and remained stable through the year. Although for GBP/USD in the Figures A.14(a) and A.15(b) also had an uptrend in the first part of the year, the half of the year started in a downtrend with a huge drawdown.
Figure A.12: Equity Curve for EMA(12) AND EMA(50) EUR/USD

Figure A.13: Equity Curve for EMA(12) AND EMA(50) GBP/USD

Figure A.14: Equity Curve for EMA(50) AND EMA(200) EUR/USD

A.6.3 RSI 80-20

Figures A.16 and A.17 shows the equity curves for the RSI strategy. For the EUR/USD pair, the charts A.16(a) and A.16(b) shows a sideways trend at the beginning of the year, but a significant uptrend remained until the end of the year. In the GBP/USD charts A.17(a) and A.17(b) observers, a
massive drawdown at the beginning of the year, but with a slight uptrend with some highs and lows thought the rest of the year.
A.6.4 EMA (12-26) crossover and MACD

Figure A.18 shows the equity curves for the EMA and MACD strategy. Both GBP/USD pair charts are very similar, with a drawdown at the beginning of the year and an uptrend until the end of the year.

A.6.5 EMA (12-50) crossover and MACD

Figures A.19 and A.20 shows the equity curves for the EMA and MACD strategy. Both GBP/USD and EUR/USD pair charts are very similar, with a drawdown at the beginning of the year and an uptrend until the end of the year.

A.6.6 RSI(70-30) and BB

Figures A.21 and A.22 shows the equity curves for the RSI and BB combined strategy. The EUR/USD charts A.21(a) and A.21(b) have a similar equity curve, with a downtrend until May and then a strong
uptrend for the rest of the year. The GBP/USD charts A.22(a) and A.22(b), are very similar as well. It started a year with a sideways trend, followed by a significant drawdown and quick reverse. The strategy remained stable through the year.
A.6.7 RSI(80-20) and BB

Figures A.23 and A.24 shows the equity curves for the RSI and BB combined strategy. The EUR/USD charts A.23(a) and A.23(b) have an equity curve very similar, with a strong uptrend almost all year, except at the beginning of the year. For the GBP/USD pair, the charts A.24(a) and A.24(b) are very alike as well. There were no trades until March when started with a downtrend with a quick recovered and remained stable until the end of the year.
In the Appendix B is a displayed large table with the results of all strategies in the last 5 years for the both currency pairs (EUR/USD and GBP/USD), in a 30 minutes timeframe.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indicators</strong></td>
<td>EUR/USD</td>
<td>GBP/USD</td>
<td>EUR/USD</td>
<td>GBP/USD</td>
<td>EUR/USD</td>
</tr>
<tr>
<td>EMA (12-26) buy</td>
<td>1.29</td>
<td>0.94</td>
<td>0.69</td>
<td>0.85</td>
<td>0.77</td>
</tr>
<tr>
<td>EMA (12-26) sell</td>
<td>1.03</td>
<td>0.84</td>
<td>0.52</td>
<td>1.17</td>
<td>0.76</td>
</tr>
<tr>
<td>EMA (12-50) buy</td>
<td>1.23</td>
<td>0.96</td>
<td>0.65</td>
<td>0.97</td>
<td>0.79</td>
</tr>
<tr>
<td>EMA (12-50) sell</td>
<td>1.30</td>
<td>1.23</td>
<td>0.58</td>
<td>1.05</td>
<td>0.69</td>
</tr>
<tr>
<td>EMA (50-200) buy</td>
<td>1.11</td>
<td>1.70</td>
<td>0.68</td>
<td>2.06</td>
<td>0.62</td>
</tr>
<tr>
<td>EMA (50-200) sell</td>
<td>1.07</td>
<td>0.90</td>
<td>0.45</td>
<td>0.80</td>
<td>0.50</td>
</tr>
<tr>
<td>RSI (70-30) buy</td>
<td>0.62</td>
<td>0.75</td>
<td>0.39</td>
<td>0.66</td>
<td>0.48</td>
</tr>
<tr>
<td>RSI (70-30) sell</td>
<td>1.07</td>
<td>0.60</td>
<td>0.79</td>
<td>0.86</td>
<td>0.57</td>
</tr>
<tr>
<td>RSI (70-30) buy</td>
<td>1.02</td>
<td>0.87</td>
<td>1.05</td>
<td>0.67</td>
<td>0.70</td>
</tr>
<tr>
<td>RSI (70-30) sell</td>
<td>1.13</td>
<td>1.11</td>
<td>0.75</td>
<td>0.78</td>
<td>0.64</td>
</tr>
<tr>
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Table B.1: Profit Factor for all the strategies with different signals in the last 5 years.
In the Table B.1 are displayed the results for the combined strategies, with contrary signals for the last 5 years. The values in green represent the strategies with profit factor above 1, and the blue values represent the strategies with profit factor above 2, which means that were more stronger and profitable strategies. With this type of strategies we didn’t have strategies without trades, has happened with the strategies with the same signal for both indicators. The years of 2020 and 2017 still continuous to have the better results. Although, it is possible to observe that the strategies are not consistent through the years and for each currency pair.