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Currency Risk Management
Predicting the EUR/USD Exchange Rate

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1 Abstract

This project provides a simple, yet comprehensive approach to predicting movements in the exchange rate between the Euro and the U.S. Dollar through the development of a linear regression model and further fitting the errors by using momentum signals. The predictions generated are compared to the forward rates in order to develop a hedging strategy for deciding when to use a forward contract or wait to use the spot exchange rate. Finally, we analyze the payoffs obtained by using this strategy.

2   Executive Summary

This Major Qualifying Project aims to understand some of the hedging techniques used in the foreign exchange market, and to develop a simple model to predict the exchange rate between the Euro (EUR) and the US Dollar (USD), i.e. the EUR/USD exchange rate. The prediction results are used to help investors hedge against short term exchange rate risk, and tested empirically.

There are three main investment strategies used by currency traders in the Foreign Exchange market, which is also known as FX and Forex. One is Carry, which prioritizes buying currencies that pay high interest rates and selling currencies with low interest rates in order to obtain the difference between interest rates as the payoff. The second strategy is called Valuation, and rises from the long-run currency tendencies to reach their "fair value". Thus, traders buy undervalued currencies since their price is expected to go up, and sell overvalued currencies. Finally, Momentum is a strategy that arises from a common characteristic observed in the Forex market in which exchange rates tend to maintain a positive or negative trend for a relatively long period of time. Therefore, traders buy currencies that have been performing well while selling badly performing currencies.

Based on the theories behind these investment strategies, a linear regression model to predict the EUR/USD exchange rate was built by choosing the Purchasing Power Parity (PPP), which represents Valuation, Basis SWAP Libor rates, which represents Carry, and historical volatility, as the risk measure, to be the predictor variables. We then incorporate a Momentum signal from the difference of two EWMA's to improve the accuracy of our predictions by using another linear regression model to fit the error obtained in our previous model.

To confirm the effectiveness of our predictions we generate a trading strategy to decide whether we should wait until next month to make the transaction or enter a forward contract based on the comparison between the predictions and the corresponding forward rates. We obtain the payoff given by always entering the forward contract, choosing to enter according to our first model, and choosing to enter according to our improved model. We find that in both latter cases we generate a positive profit, confirming the effectiveness of this approach to predict the EUR/USD exchange rates.

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4 Introduction

Assume a U.S. based company wants to import a product from Europe. This company enters a business contract with the provider in which they have to pay in Euros. In other words, the institution needs to exchange their U.S Dollars (USD) to obtain Euros (EUR) and pay for the product. For this, the company faces two options: they can wait until the transaction date and use the spot rate of the EUR/USD, or they can enter a forward contract, with zero cost, in which they lock a previously agreed EUR/USD exchange rate and use that rate at the transaction date. How can this company decide which action to take? Obtaining an accurate prediction of the future exchange rates between the Euro and the U.S. Dollar can be the element to facilitate this decision making.

Predicting events on the future based on past events is not an exact science. Nevertheless, being able to detect small patterns or movements that may influence the outcome of an event may go a long way in generating profit, preventing unfavorable situations from happening, or at least preparing for what is to come. For example, with the help of satellites, aircraft and radars, it is possible now to project hurricane formations as well as areas affected, strength and length of the hurricane. These predictions generate a warning signal, and that signal is all that is needed to take actions, find refuge, and avoid major repercussions a hurricane may cause.

In the financial market, more specifically, the foreign exchange market (Fx, Forex), where currencies from all over the world are continuously traded, our risk exposure comes from exchange rate fluctuations. We are concerned about monetary losses originating from transaction, translation, contingent, and default risk which will be further explained in the next section. For our company, specifically, we are exposed to transaction risk. Thus, we need to explore existing strategies used to predict trends in currency pairs in order to develop a model to forecast the exchange rate of the EUR/USD pair, and furthermore provide courses of actions by using these predictions to decide to enter a forward contract or wait and use the spot rate at the transaction date.

As globalization increases, the need for currency risk management becomes more and more important, since major companies and organizations need to get involved in international business contracts in order to compete in the market. The exchange rate risk is managed by companies such as QCAM (Swiss), Perreard Partners Investment, The ECU Group, and Russel Investments, which provide currency overlay services to clients. Moreover, major banks and companies such as the Deutsche Bank and HSBC contain a currency risk management department in charge of monitoring exchange rates and making decisions to buy and sell currencies based on their strategies.

This paper provides some insight of the strategies these companies and/or departments apply to manage currency risk arising from fluctuations in exchange rates. One of these is Carry, which

prioritizes buying currencies that pay high interest rates and selling currencies with low interest rates in order to obtain the difference between interest rates as the payoff. The second strategy is called Valuation, and rises from the long-run currency tendencies to reach their "fair value". Thus, traders buy undervalued currencies since their price is expected to go up, and sell overvalued currencies. Finally, Momentum is a strategy that arises from a common characteristic observed in the Forex market in which exchange rates tend to maintain a positive or negative trend for a relatively long period of time. Therefore, traders buy currencies that have been performing well while selling badly performing currencies.

Most of the existing signals developed that aim to forecast currency trends are generated through scenarios involving numerous factors and currencies. These signals are then merged into one complex signal, which is difficult to understand and modify accordingly, that is later used for investing in a set of currency pairs. For example the Deutsche Bank Currency Returns' strategy is built by using 20 years of data and applying three trading strategies: Carry, Momentum, and Valuation. The DBCR index is then generated by investing in each of the 3 indices corresponding to these trading strategies. Moreover, the rebalancing date varies in each of the indices [4]. This whole procedure to generate an index is an example that reflects a mathematically complex way of generating possible returns from investing in the currency market.

This project explores the development of a prediction model to detect fluctuations in exchange rates by using a simpler and straightforward approach through the use of a linear regression combined with momentum. The model chosen works for predicting monthly change in exchange rate of a currency pair. In order to generate a "good" prediction, a model needs to be complex enough so as to include the necessary information, nonetheless simple enough to be understood and replicated. For this, we want to consider sufficient variables to explain the currency pair's behavior, but we do not want to over fit the data with more information than needed.

To generate this model we start by using a linear regression to predict the EUR/USD exchange rate. The predictor variables used are the Purchasing Power Parity index, or the distance from equilibrium between currencies according to their purchasing power, the Basis SWAP Libor rates, accounting for interest rates, and the Historical volatility, or variance of the currency pair. The data for these three variables was collected from the Bloomberg Terminal, and corresponds to data found under the function WCRS. Once we generate these predictions, we improve the model by fitting the errors by using a momentum component, consisting of difference between two EWMA'S, by running another linear regression.

To confirm the effectiveness of our predictions we generate a trading strategy to decide whether we should wait until next month to make the transaction or enter a forward contract based on the comparison between the predictions and the corresponding forward rates. We obtained the payoff

given by always entering the forward contract, choosing to enter according to our first model, and choosing to enter according to our improved model. We find that in both latter cases we generate a positive profit, confirming the power of this approach in predicting the EUR/USD exchange rates.

Some of the advantages of using this approach include accessibility, cost efficiency, good results for the predictions, and positive profits from our strategy. Given that the data is collected from Bloomberg, it is public and accessible for any individual with a license, compared to other models that use private data. Additionally, there is no need to hire an expert, given that it is a method that can be easily replicated. Thus, small companies, like the one in our example, who are exposed to a specific currency exchange movement through reasons like: foreign contracts, trading, and/or traveling can benefit from using this model.

5　Background

In this section we provide an overview of the dynamics in the Foreign Exchange Market along with common terms that are referred to throughout this paper. We explore how currencies are traded and the risk associated to them. Moreover, we address techniques for risk management, such as forward contracts, currency pegging and options. Finally we describe common investment strategies in the FX market, such as Carry, Momentum, Valuation, and Fundamental. All these information will be used to develop a forecasting model to predict the EUR/USD exchange rate and furthermore generate a hedging strategy by using these predictions.

5.1　Foreign Exchange Market

Foreign exchange market is the global market in which currencies can be virtually traded [5]. Also known as Forex, or FX, the Business Dictionary defines it as "the system of trading in and converting one country's currency into that of another" [6]. With over 2 trillion trades, FX is the largest financial market in the world and unlike other financial markets, it does not have a centralized location. In other words, there is no unique exchange market in which all orders are executed. Thus, traders can search for diverse competing rates across the world, with financial institutions including banks, and individual traders acting as the supply and demand parties. Similarly, the vast size of the market prevents large entities such as banks to exercise too much control over it.

Currencies are traded in pairs in FX. A currency is abbreviated with three letters, for example the U.S. Dollar is USD. The ticker for every currency pair is formed by using the abbreviation of the base currency, or the currency being bought, followed by the abbreviation of the quote currency, or the currency being sold. For example, the ticker for the currency pair between the Swiss Franc and the Euro would be CHFEUR. Here, the Swiss Franc (CHF) is the base currency and the Euro (EUR) the quote currency. Thus CHFEUR is the amount of Euros it takes to buy one Swiss Franc, and is known as the exchange rate between these two currencies. If the CHFEUR ticker marks 0.85, then I would need 0.85 Euros to buy 1 Swiss Franc.

5.1.1　Trading hours

Forex market provides great accessibility for traders to trade at any time since it is open 24 hours a day, 5 days a week. As one major Forex market opens, another one closes, making it a worldwide

market. Table 1 summarizes the Forex trading hours for each of the following regions. The London and New York trading sessions overlap between 8:00 AM and 12:00 PM, which corresponds to the busiest trading period in a day due to the high volume of transactions occurring, of about 50% of all trades throughout the day. Active trading is usually beneficial for traders since currencies are easily bought and sold, meaning there is high liquidity, a concept that will be discussed further in the paper. Nonetheless, a busy trading period comes with high volatility in the exchange rate, and risk arises.

Table 1: FX Trading Hours by Region

	Open (EST)	Close (EST)
Sydney, Australia	5:00 PM	2:00 AM
Tokyo, Japan	7:00 PM	4:00 AM
Zurich, Switzerland	2:00 AM	11:00 AM
London, Great Britain	3:00 AM	12:00 PM
New York, United States	8:00 AM	5:00 PM

5.1.2 Spot and Forward Rates

The spot rate and forward rate are the two common prices used for foreign exchange contracts. Spot transactions trade using the current exchange rate between two currencies. These transactions usually take two business days two settle, nevertheless the contract uses the exchange rate at the moment the order is placed. On the other hand, forward contracts lock a previously agreed exchange rate between two currencies and use this price to trade a contract in the future. Moreover, the two parties involved in a forward contract enter it with zero cost. The way a forward price is established is by considering the spot rate plus or minus forward points that represent the difference in interest rates between the two currencies and the maturity of the deal, or the date the trade will be executed. We use the term forward premium when points are added to the spot price, and forward discount when these are subtracted. Forward points are commonly quoted as a bid and offer, such as 7/10. This means that if the offer (10) is larger than the bid (7), then we will add points to the spot rate, while if the offer is lower than the bid we will subtract points from the spot rate. For example, if the EUR/USD spot rate is 1.1995, and the forward points on the offer side are +10, then the forward rate is 1.2005, since this pair is quoted to four decimal points.

Given that currency pairs may experience frequent movements in a short period of time, spot

trading can be very volatile. Therefore, when entering a business contract that will be settled sometime in the future, forward contracts may be a better choice. In other words, forward rates serve as a hedging tool in currency trading, since they reduce the risk of sudden price movements. For example, in China there has been a significant demand growth for Malaysian pineapples, with an import rate expected to double to RM320 million annually by 2020 [7]. A small Malaysian pineapple farm decides to export their products to China for the next harvesting season. As of January 17, 2018, the exchange rate between these two countries' currency is 1 Malaysian Ringgit (MYR) to 1.6252 Chinese Yuans (CNY) [8]. This farm could wait and sell their products, receive CNY, and change to MYR at the exchange rate marked on the harvest date, or they could lock the currency in a forward rate established now by using a forward contract. By using this latter strategy, the farm eliminates the risk of currency fluctuation. Nevertheless, if the farm owners are risk-seeking and expect that there will be a favorable exchange rate in the future, they may choose to wait and use the spot rate later on. Through the development of this project, we aim to provide suggested course of action to scenarios similar to this one based on the predicted exchange rates generated by our model.

5.1.3 Liquidity

"The degree to which an asset can be quickly bought or sold in the market without affecting the asset's price is known as liquidity" [9]. In other words, liquidity describes how easy it is to convert an asset into cash, given that this last one is the most liquid asset and the basis for comparing all other assets. On the other hand, real estate is considered one of the least liquid asset, since it can take a long time to sell.

One common measure of liquidity is the bid/ask spread, or the difference between the price of the demand and the price of the supply. A bid price is the highest price the market is willing to pay for an asset, while the ask price is the lowest price the market is offering to sell it for [10]. The price for an asset falls within the bid/ask spread and corresponds to the price at which a previous transaction took place. A trade happens when the bid price and the ask price overlap. For liquid assets, this spread is often very small, of less than 2% of the price. Let's use the Credit Suisse Group AG's stocks (CS) as an example. The bid price for this stock on February 16, 2018 was $18.77 while the ask price is $18.79, subtracting these two, we get a bid/ask spread of $0.02 [11].

On the other hand, illiquid assets often show big bid/ask spreads, mostly because they are harder to set a fair price to or because they have a lower demand. For example, an artist who just finished a painting and is ready to sell it in the market. She might think that her art is worth $1000, nevertheless, after showing it in a gallery, she only receives offers around $500. Here, the

bid/ask spread is \$500, 50% of the price the artist is asking for her work. This big spread leads to a harder time selling the painting and converting it into cash, since both parties, demand and supply, need to reach an agreement in order for the transaction to take place, making this asset very illiquid. An example of an asset with low liquidity in the financial market are low rated bonds, since they present high bid/ask spreads and low market volumes (short demand and supply).

In the Forex market, a currency pair with high liquidity corresponds to a pair that is frequently traded, such as the EUR/USD, or the Japanese Yen and the U.S. Dollar (JPY/USD). On the other hand, a pair consisting of two currencies that are not regularly traded can be considered a low liquidity pair. For example, the Bolivian boliviano and the Nigerian naira.

5.2   Risk Management

One fundamental element to consider when trading in Forex is to set the amount of risk the party is willing to take. It is true that riskier strategies may receive higher pays, but these may come at a higher cost. Similarly, a low risk exposure is not necessary good, since it will not generate a significant reward. Thus, it is essential to set a level of risk tolerance according to how much one is willing to lose given that things go wrong. As Paul Tudor Jones, an American investor and hedge fund manager once said, "I always think about losing money as opposed to making money. Don't focus on making money, focus on protecting what you have" [12].

Managing risk is what separates a trader from a gambler. Nevertheless, "the biggest risk is not taking a risk. In a world that's changing really quickly, the only strategy that is guaranteed to fail is not taking risks" (Mark Zuckerberg) [13]. Therefore, it is important to take some risk and control it by using risk management tools appropriate to the asset being traded. An investment that reduces the risk of adverse price movements in an asset is called a hedge. In other words, hedging is equivalent to buying an insurance to protect an asset.

In this section, we will present the principal measures of risk, such as the variance, standard deviation and the value at risk. Then, we will address the types of risk exposure in the FX market, followed by a description of common risk management techniques including forward contracts, options, or currency-hedged funds. For this project, the risk management tool we incorporate is the use of forward contracts.

5.2.1   Measures of risk

Some of the most commonly used risk measures are standard deviation, Value at Risk and expected shortfall.

Standard Deviation

The standard deviation measures how far away from the expected value, or mean, the data is distributed. Thus, a high standard deviation implies that there is more spread in the data and that values fall away from the mean. On the other side, a small standard deviation is obtained when data is distributed close to the expected value. This measurement is commonly used to calculate the historical volatility of an asset, which is correlated to the risk of an asset based on its returns. For example, an exchange rate with a high standard deviation implies that there is higher volatility, and thus, a higher risk associated to the pair of currencies.

The standard deviation is commonly represented by the greek letter sigma (σ) and is calculated through formula (1), where $\overline{x}$ is the arithmetic mean from the sample, x_i corresponds to each observation, and N is the total number of data points, in this case, the number of months we obtained data from.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \overline{x})^2}{N - 1}} \tag{1}$$

Value at Risk (VaR)

The Value at Risk, or VaR, is a statistical measure that calculates the expected loss from an investment given a degree of confidence (α) and a period of time. For example, if a company has a 6% probability of loosing more than \$10,000 over one year, then this company has a one year 6% VaR of \$10,000. Mathematically, VaR is defined as the following:

$$VaR_\alpha(X) = -\inf\{x \in \mathbb{R} : F_X(x) > \alpha\} \tag{2}$$

$$VaR_\alpha(X) = F_Y^{-1}(1 - \alpha) \text{ if F is invertible} \tag{3}$$

Expected Shortfall (CVaR)

The expected shortfall, also known as the conditional value at risk (CVaR), is the average of all losses which are greater or equal than the VaR. In other words, it is the average loss in the worst (1-α) cases.

5.2.2 Foreign Exchange Risk Exposure

There are several types of risk, arising from fluctuation in the exchange rates, an investor in the foreign exchange market is exposed to. The type of risk we use for this project is transaction risk. Nevertheless, in this section we explain some other common types of risk, which include: translation, contingent, and default.

Transaction Risk

A common risk in the foreign exchange world is due to transactions. This occurs when two parties with different domestic currencies enter a contract with a pre-established exchange rate and expiration date. Nevertheless, this contract does not account for the volatility on the currency pair, and at the date and time the transaction takes place the exchange rate might not be the same, harming one of the parties in the contract.

Translation Risk

Translation risk appears mostly on financial statements. These reports are published for multi-national purposes, therefore, the translation of significant figures from one currency to another occur using a non-constant exchange may imply foreign exchange risk, since it can affect the reported statements, such as the total losses of a company over a course of a year. Moreover, if the translation exposure was beneficial in one period of time, it can get reversed in the next one.

Contingent Risk

Given that currency exchange rates are continuously changing, a party that is negotiating the terms of a foreign contract can be affected by the contingent risk of the currency pair. In other words, the exchange rate can be one value the day the contract is presented, but it may change over the course of the negotiation process and until the negotiation is finally settled. Thus, the party is exposed to risk by the fluctuation on the currency pair until the contract is finally determined.

Default Risk

A type of risk always prevailing when trading is default, which is the failure to pay what was promised. Since in the foreign exchange market there are two parties involved in the trade, an

opportunity of default by one of the parties is usually present. This is why some government parties may choose to look into credit rating agencies such as the S&P Global and Moody's to detect the other government party's ability to pay back their debt. One major example of default occurred with Greece. When they adopted the Euro in 2001, their economy was already unstable. By 2012, the country fell into the biggest sovereign debt-restructure in history, and two years later the default came. Greece only represents 2.5% of the European Union's economy, nevertheless this default contributed to a stagnant economy across Europe and a weakening Euro against the U.S. Dollar.

5.2.3   Risk Management Tools

Currency Pegging

Globally speaking, one common strategy that countries use for risk management is currency pegging. A currency peg is a country's agreement to attach, or peg, the central bank's exchange rate to another country's currency. This exchange rate policy allows stability in long-term business contracts, since the exchange rate between the two countries is fixed and no surprise comes from volatile rates. Some examples of countries that are pegged to the U.S. dollar include Hong Kong, since 1983, and Saudi Arabia, since 2003. On the other hand, Denmark is an example of a country pegged to the Euro since 1982. Additionally, other countries, such as China, Malaysia and Singapore are linked to a basket of currencies.

Unfortunately, an issue that arises with pegs, is that central banks must deploy foreign reserves by buying and selling in currency markets to keep exchange rates stable. Thus, if the country cannot back up, the peg will slip or break, causing major impacts in the country's economy [14]. Some examples of broken pegs include the British pound in 1992, the Russian Ruble in 1997, and the Argentinian corralito in 2002.

Despite this risk, the fostering in trading that these pegs bring imply major benefits, such as trading agreements, to both countries that make assuming this risk worth it. One example of two countries benefiting from a peg is China and the United States, with a peg of China's Yuan (CNY) to the U.S. Dollar. Moreover, as an attempt to compete with the Chinese market, other countries with big trade volumes with China might also peg their currency to the U.S. Dollar.

Forward Contracts

Forward contracts lock a previously agreed exchange rate between two currencies and use this price to trade a contract in the future. The two parties involved in a forward contract enter it with zero cost. The main advantage of using a forward contract is that the party knows in advance the rate they will pay on the transaction date, and thus there are no surprises. The only loss that arises from forward contracts occur from the spot rate going down.

Currency Options

In the FX market, as well as in the stock market, it is possible to buy and sell call and put options. A call option gives the holder the right but not the obligation to purchase a currency pair at a specific exchange rate on or before a certain date. On the other hand, a put option gives the holder the right but not the obligation to sell a currency pair at a specific exchange rate on or before a certain date. We will refer to the last possible date as the expiration date, and to the exchange rate established as the strike price [15].

For example, on May 29, 2017, an investor thinks that the AUD/USD (Australian dollar vs. U.S. dollar) pair will head upwards in the next two months, i.e. the AUD will appreciate relative to the USD. The current exchange rate is 0.7438. The investor decides to go to a broker to buy an AUD call option, also known as an AUD call/USD put, with a strike price of 0.7600, an expiry of July 29, 2017 and a premium of 10 USD pips (0.0010). Two months later, the investor finds that the AUD/USD pair is now 0.7990, so he decides to exercise the option, giving a result of 380 USD pips profit (0.7990 − 0.7600 − 0.0010 = 0.0380) [16].

The main advantage of using call options as a risk management tool is that the downside risk is limited only by the option premium, while the potential profit is unlimited. Additionally, the trader decides what strike price and expiration date to use in the contract for call/put options. Furthermore, the advantage of purchasing one is the protection it provides. For example, a call option can be used to protect against an increase in the exchange rate. On the other hand, a put option would be used to protect against a drop in the exchange rate. Thus, the choice of call and put depends on the perceived future trend of the currency pair. On the other hand, some disadvantages of call/put options are high premiums, affecting the risk/reward ratio, and difficulty in accurately predicting the time period and price.

5.3 FX Investment Strategies

There are four main investment strategies in the Forex market based on different theories and factors that affect the changes in exchange rates, they are: Carry, Momentum, Valuation, and Fundamental.

5.3.1 Carry

Carry trading is referred to buying a currency that pays a high interest rate compared to a low interest rate currency, and selling the currency that pays a lower rate compared to a higher interest rate currency. Using this strategy, the trader obtains the difference between the interest rates of the two currencies, which depending on the volume of the trade can generate a significant amount. Table 2 shows a list of some currencies and their interest rate. Here, we can see that using the Carry strategy, investors would buy the Argentinian peso (26.25%) against the Swiss franc (-0.75%). Nevertheless, the pay from interest differentials is not too big relative to the amount of risk taken. An issue with Carry is that the currencies with very high interest rates usually present strong reactions to global news. In general, if the economy is stable, this strategy will rise and pay, but when bad news arise unexpectedly, they will drop fast and drastically, possibly causing to blow up all the gains in a blink [17].

5.3.2 Momentum

A common characteristic among the Forex market is a continuous trend of an exchange rate over a long period of time. In other words, if an exchange rate is favorable for one currency, this positive trend will likely continue for relatively long period of time. Thus, using the Momentum strategy, the trader buys currencies that have been performing well and sells currencies that have been performing badly. An example of Momentum is displayed in Figure 1. Here, we can see that the trend of exchange rate between the Singaporean Dollar (SGD) and the USD starts going up at the beginning of 2017 and continues this upward trend towards 2018.

5.3.3 Valuation

Valuation rises from the long-run currency tendencies to reach their "fair value", or the rational and unbiased estimate of the potential market price of an asset. Here, the trader looks for "undervalued" currencies to buy, since their price is expected to go up, and "overvalued" currencies to

Table 2: List of Countries and Central Bank Interest Rates in 2017 [3]

Country/Currency Union	Central Bank Interest Rate (%)
Argentina	26.25
Ghana	21.00
Egypt	18.75
Mexico	7.00
Indonesia	4.75
Australia	1.50
Hong Kong	1.50
United States	1.25
Eurozone	0.00
Denmark	-0.65
Switzerland	-0.75

Figure 1: SGD/USD Exchange Rates from April 19, 2016 to April 19, 2018 [1]

sell. This strategy is usually profitable in the medium to long terms, thus it is not recommended for intraday trading.

An example of Valuation can be shown with the CNY/USD exchange rate. In 2015, the People's Bank of China initiated the devaluation of its currency in order to promote it's exports and maintain it's GDP growth. Given this devaluation and under the Valuation strategy, one would expect this exchange rate to raise back to its fair value. Looking at Figure 2, we can see

that after the beginning of 2017 the exchange rate starts rising, and this is exactly what we expect by using the Valuation strategy.

Figure 2: CNY/USD Exchange Rates from April 18, 2008 to April 15, 2018 [2]

5.3.4 Fundamental

The Fundamental strategy is mostly used for cautious investors, since it relies on following countries' news and buy the currencies of countries of strengthening economic trends against those with weakening economies. The difficulty behind the Fundamental method is understanding the several economic indicators and reports, and comparing them among countries.

Throughout these sections we have an overview of how currencies are trade in the Forex market, the types of risk prevailing as well as techniques to manage them, and the the main FX investment strategies. With all these information, we now want to develop a forecasting model to predict the exchange rate between the Euro and the U.S. Dollar and furthermore develop a trading strategy to reduce risk and generate profit. We want to generate a model that incorporates all the information and theories behind the strategies we learned in this section, but at the same time stays parsimonious to prevent over fitting. The construction and components of this forecasting model are described in the next section.

6 Methodology

This section describes the process followed to construct the model to predict the EUR/USD exchange rates and the hedging strategy developed by using the predictions obtained. Here, we start by giving an overview of the currencies selected, followed by a description of the linear regression along with the predictor variables chosen. Next, we explain how the predictions given from the model are improved by using another regression to fit the error. Finally, we discuss the construction of a strategy to decide whether to enter a forward contract, or wait until the transaction date and use the spot rate.

6.1 Currencies Selected

The currencies selected for this project are the Euro and the U.S Dollar, more specifically, the EUR/USD exchange rate. We choose this pair given that they are both mainly affected by macroeconomic factors, but not not affected by news or political issues, which are not modeled into this project.

6.2 Linear Regression

The exchange rate forecast of the currency pair is obtained by developing a linear regression using predictor variables related to the pair. In this section, we explain the methods behind a linear regression as well as the predictor variables chosen and their connection to the currency pair.

The linear regression model aims to understand how the response variable Y, in this case the exchange rate of the EUR/USD, is affected by a set of predictor variables $X_1, ..., X_n$, which in our case correspond to the Purchasing Power Parity (PPP) index, Basis SWAP Libor, and historical volatility. The model is defined by the following form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon \tag{4}$$

Where:

- ϵ is the value representing the error from our predictions by using the X_i's.

- X_1, X_2, X_3 correspond to our predictor variables: PPP index, Basis SWAP Libor and historical volatility respectively.

- β_0 is the intercept and the expected value of Y when the X_i's are zero.

- $\beta_1, \beta_2, \beta_3$ are the coefficients and corresponding slopes of X_1, X_2, X_3. In other words, β_j indicates the change in the expected value of Y by a unit change of X_j

The estimates of the β's are the values that minimize the sum of squared errors for the sample, which quantifies how much the data points vary around the estimated regression line.

6.2.1 Predictor Variables

Purchasing Power Parity (PPP) Index

The first predictor variable is the Purchasing Power Parity index. PPP states that exchange rates between currencies are in equilibrium when the purchasing power is equivalent between the two countries [18]. Thus, if the exchange rate between these two countries is equal to the ratio of the two countries' price level of a fixed basket of goods, then there exists an equilibrium between these two countries. In other words, PPP explains the relation between inflation and exchange rates, since if prices are increasing due to inflation, the country's exchange rate needs to depreciate to return to PPP. Therefore, one of the variables to predict a given exchange rate will be how far the PPP index between two countries is away from an equilibrium.

Nevertheless, there are a few considerations to keep in mind when using PPP as a predictor variable. The first one is that it only applies to tradeable goods. The second consideration is that both countries must have comparative markets for the goods used to calculate PPP. Without this, the difference in demand will cause prices to move without affecting the exchange rate between these countries. Additionally, PPP does not account for legislations and transportation/transaction costs that may cause difference in the pricing of the goods from one location to another. Finally, it is important to acknowledge that reverting back to a PPP may take a long time, thus using this factor as a predictor variable may not be as efficient for short-term forecasting.

The data collected to represent PPP was downloaded from the WCRS function in Bloomberg Terminal. In general, as a rule of thumb, Bloomberg suggests that currencies over or undervalued beyond 20% will often persist for several years before reverting. Likewise, currencies within a 10% value of their PPP estimate are considered to be fair valued. Bloomberg covers four options to calculate Purchasing Power Parity, including Consumer, Producer, BigMac, and OECD. We selected our base range to cover all data available, and then downloaded the data from January 2013 until December 2017 for the first two options. We then find that PPP Producer resulted in a higher correlation with the historical exchange rates, and thus we selected this option. Finally,

the formula used in Bloomberg to calculate PPP is given by formula (5), where the base currency is the USD.

$$PPP(t) = AverageExchangeRate * \frac{ForeignCPI(t)}{ForeignCPI(average)} * \frac{BaseCPI(average)}{BaseCPI(t)}, \quad (5)$$

CPI, or Consumer Price Index, is the monthly measurement of a country's prices for the majority of household goods and services such as food, housing, transportation, and medical care [19]. It is calculated by taking the average of the price changes in the basket of goods (i.e, the set of consumer products and services) [20]. Because of this, the CPI is considered a measure of inflation, a factor that commonly affects exchange rates.

Basis SWAP Libor

We use LIBOR as our estimated interest rates for each currency. LIBOR stands for London interbank Offered Rate, which is a benchmark rate of estimated interest rates used for short-term loans. To calculate these rates, the banks are asked the following question: "At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11 am London time?". Thus, it considers the lowest perceived rate at which each bank could obtain funding in a reasonable market for a given maturity and currency. These rates are quoted as an annualized rate (i.e. the total interest that would be paid over 365 days) with 5 decimal places, and are calculated using a trimmed arithmetic mean. This means that the submissions are ranked in descending order and the highest and lowest 25% of them are excluded before calculating the average in order to exclude outliers. LIBOR is also considered a "good" measure of the "health" of the banking system and market expectation for future central bank interest rates. LIBOR rates are calculated for different borrowing periods, such as overnight, and one year. Nevertheless, they are only available for five currencies: USD, CHF, EUR, GBP, and JPY.

Using the theory behind the Carry investment strategy, one of the factors selected to predict the EUR/USD exchange rate movement is the difference between interest rates of these two currencies. In general, we want to buy the currency with the high interest rate and sell the one with a low interest rate. The data used to represent this variable in our model was also downloaded from Bloomberg's WCRS function under the name Basis SWAP Libor. A positive number in the data implies that foreign interest rates were higher than the base rates for that particular period. The fluctuation of this difference translates into one of the currencies appreciating against the other, consequently affecting the exchange rate between these two.

Historical Volatility

Volatility in the financial world describes how much the price of an asset, or in this case the exchange rate of a currency pair, fluctuates over time. It is usually calculated using the standard deviation or variance of the returns of a said asset. In general, the higher the volatility, the riskier the asset [21]. There are two types of volatility, historical, which is derived from past behavior, and implied volatility, which is what traders think will happen. Historical volatility is commonly used to predict future volatility.

Volatility can be measured for minute return, hourly return, daily return, monthly return, or longer time frames returns. An intraday trader may measure volatility minutely, while a long term investor may only consider monthly volatility in a specific currency pair. In the FX market, a given currency pair can experience higher volatility in the hours where most people are trading it, since there is high supply and demand and the prices are moving rapidly to meet these. For example, the EUR/USD is more volatile when when either London or New York are open, and even more volatile when they are both open (between 1 pm and 4 pm EST).

In this model, we use the data from WCRS in Bloomberg for historical volatility of the foreign currency versus the base currency. We neglected the implied volatility since it had a smaller correlation with the historical exchange rates compared to the historical volatility.

6.3 Improving the model: fitting the error

Recall the linear regression from the previous section:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon \tag{6}$$

For the next model, we attempt to decrease the error term (ϵ) by implementing another linear regression using a momentum signal as the predictor variable. This way, we aim to fit the error from the last regression model by generating a new regression of the form:

$$\epsilon = \lambda_0 + \lambda_1 S + \eta \tag{7}$$

Where:

- ϵ is the error of the prediction from the previous section

- S corresponds to our predictor variable, momentum.

- λ_0 is the intercept and the expected value of ϵ when the S is zero.

- λ_1 is the coefficient and corresponding slope of S. In other words, λ_1 indicates the change in the expected value of ϵ by a unit change of S

- η is the new error of the model

Therefore, our combined model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \lambda_0 + \lambda_1 S + \eta \qquad (8)$$

Predictor variable: Momentum

Following the concept of momentum, we choose our predictor variable to be the crossover of two exponentially weighted moving averages (EWMA) of different length of the EUR/USD exchange rates, in order to fit the error found from the last model.

An EWMA is an infinite impulse response filter with exponentially decaying weights. This approach is used when there is a belief that recent data points are more relevant than past ones, and thus are given more weight. The following formula shows the recursive calculation.

$$EWMA_t(X, \alpha) = \begin{cases} X_0 & t = 0 \\ \alpha * X_t + (1 - \alpha) * EWMA_{t-1}(X, \alpha) & t > 0 \end{cases} \qquad (9)$$

Where:

- X_t is the EUR/USD exchange rate at time t

- α is the weighting coefficient

- $EWMA_t$ is the value of the EWMA at any time period t.

To generate the momentum signal, we used the MATLAB function tsmovavg:

$$\text{output} = \text{tsmovavg(vector,'e',timeperiod)} \qquad (10)$$

Here, the first input is a vector, corresponding to the historical exchange rates for the currency pair, followed by the letter 'e', representing the method of exponentially weighted moving average, and finally the timeperiod, calculated using the formula shown below.

$$\alpha = \frac{2}{timeperiod + 1} \qquad (11)$$

The two timeperiods we chose for the short (ms) and long (ml) EWMA's are 2 and 3, corresponding to α's of 33.33% and 25%. Once we computed these two averages, we subtracted the long EWMA (ml) from the short EWMA (ms), resulting in the vector sml. Here, positive values in the vector indicate a positive trend (i.e. there was an upward movement in the short time vs. the long time), while negative values represent a negative trend. A value of 0 denotes the crossover of the short and long EWMA's, meaning a change of direction in the trend. The timeperiods were chosen by trial and error, looking at the behavior of the short-minus-long vector and selecting a pair of α's that resulted in the maximum number of crossovers. Therefore, our predictor variable for the new model corresponds to the short-minus-long vector.

6.4   Constructing a Strategy with the Predicted Values

As an application of the predictions generated by the linear regression, we compared each of them to the corresponding forward rates with one month expiration date and either waited for the next month or entered a forward contract depending on which one is lower. This way, if the forward rate is greater or equal to the predicted rate, we choose to not enter the forward contract and wait until the next month to use the spot rate then. On the other hand, if the forward rate is smaller than the predicted rate we enter the forward contract. Here our payoff could be either 0, meaning what investor actually pays the spot exchange rate in one month, for our first case. Or the payoff would be the difference between the spot rate at the moment and the forward rate of the transaction for the second case.

For example, if we wanted to compare the prediction for November 2015, we would look at the forward rate of the currency standing on October 2015 and with a one month expiration. For this date in particular, we find that the predicted EUR/USD exchange rate is 1.06, while the forward rate is 1.12. This means that in the first case, we would have to pay $1.06 in order to get 1 Euro, and in the second case we would pay $1.12 to get 1 Euro. Therefore, according to this particular prediction, we would prefer to wait until the next month to exchange USD for EUR rather than settling for a forward contract, since we believe that it will be cheaper to make this exchange later. Then, at the expiration date, we will receive a payoff of $0, since the transaction will be using the spot rate.

On the other hand, in June 2015, the predicted rate is 1.11 and the forward rate is 1.10, therefore, we choose to lock the forward contract this month. Then, when July comes, we look at the actual exchange rate and find that it is actually 1.12, which means that by entering the forward contract we prevented a loss of 0.02 USD.

We repeat this process for the predicted exchange rates and the one month forward rates from

January 2014 until December 2017, looking at the difference between these rates and deciding if we should wait until the next month or enter the forward contract.

We obtained the Forward rates from the Bloomberg terminal using the function FRD. The pricing date selected was a specific month starting from December 2013, and using this as our base, we obtained the forward prices for the next month, January 2014. We repeated this process to obtain the one-month forward rates until December 2017.

7 Results

In this section we will summarize the results obtained by using the two models previously described. We will discuss the fitness of the models as well as the accuracy and application of the predictions.

7.1 Predicting the EUR/USD Currency Pair

7.1.1 Regression Analysis

As explained in the previous section, a linear regression follows the following form:

$$EUR/USD = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon \tag{12}$$

After obtaining all the data from our predictor variables and the response variable, we used MATLAB to generate a linear regression fitting this data and obtained the results shown in Table 3 (see the MATLAB code in the A Appendix):

Table 3: Linear Regression Results

```
Linear regression model:
    y ~ 1 + x1 + x2 + x3

Estimated Coefficients:
                    Estimate          SE         tStat        pValue

                   _____    _____    _____    _____

    (Intercept)        1.2788      0.013926      91.828     6.5176e-52
    x1              0.0092838    0.00052927      17.541     1.7625e-21
    x2             -0.0050673     0.0011575     -4.3779     7.2851e-05
    x3              0.0010878    0.00040156      2.7089      0.0095828


Number of observations: 48, Error degrees of freedom: 44
Root Mean Squared Error: 0.0177
R-squared: 0.979,  Adjusted R-Squared 0.978
F-statistic vs. constant model: 686, p-value = 6.11e-37
```

Thus, adding the corresponding coefficients and the intercept, the linear regression for this set of data is given by the following:

$$Y = 1.2788 + 0.009284 X_1 - 0.005067 X_2 + 0.001088 X_3 \tag{13}$$

The β coefficient represents the degree of change in the outcome variable for every unit of change in the corresponding predictor variable. A positive sign of β implies that there is a positive correlation, thus the exchange rate will increase by the value of the given β for every unit increase of its predictor variable. On the other hand, a negative value means that the exchange rate will decrease by the value of the given β for every unit increase of its predictor variable. Looking at the β's, we have that both the PPP and the historical volatility hold a positive correlation with our dependent variable. On the other hand, the β corresponding to the Basis SWAP Libor rates is negative, meaning that by every unit increase of this predictor, the exchange rate will decrease by a value of 0.005067.

Correlation Coefficient/R-squared

The coefficient of determination (R-squared) measures the strength of the linear relationship between two variables. R-squared can be interpreted as the percent of variance in the outcome that can be explained by the given set of predictor variables. In this case, we calculated R-squared, between the 4 years of exchange rates and the values obtained from our regression over this time period. The formula used to calculate R-squared is given by calculating the SSE and the SSTO, see formula (16). SSE is the sum of squared error and quantifies how much the data points y_i vary around the estimated regression line $\widehat{y_i}$. On the other hand, SSTO is the total sum of squares, which quantifies how much the data points y_i vary around their mean $\overline{y}$.

$$SSE = \sum_{i=1}^{N}(y_i - \widehat{y_i})^2 \tag{14}$$

$$SSTO = \sum_{i=1}^{N}(y_i - \overline{y})^2 \tag{15}$$

$$R - squared = 1 - \frac{SSE}{SSTO} \tag{16}$$

In general, the higher the R-squared, the better the variance in the outcome can be explained by the given set of predictor variables. For this model, we find an R-squared value of 0.979, meaning that 97.9% of the variance in the exchange rates can be explained by our set of predictor variables.

P-value

The p-value found by running a linear regression corresponds to the answer to the question "how likely are we to get an extreme test statistic t as we would get if the null hypothesis were

true?". To answer this question, we first need to run a t-test for testing the correlation. The null hypothesis for this scenario corresponds to the correlation having a value of zero, while the alternative hypothesis is that the correlation is not equal to zero. After running the test statistic and finding the p-value, there are two possible conclusions. If the p-value is greater than the given significance level (α), we fail to reject the null hypothesis and conclude that "there is not enough evidence at the (α) level to conclude that there is a linear relationship between the predictor variable and the response variable". On the other hand, if the p-value is smaller than the given significance level (α), we reject the null hypothesis and conclude that "there is sufficient evidence at the α level to conclude that there is a linear relationship between the predictor variable and the response".

For this project in particular, we use a significance level of 0.05, and thus a p-value below 0.05 indicates that we reject the null hypothesis and that there is sufficient evidence to conclude that there is a linear relationship between the predictor and response variables. According to Table 3, we can see that all three predictor variables' p-value fall under 0.05. Therefore, all three of them hold linear relationships with the response variable. Moreover, we can see that the model is significant with a p-value of 6.11e-37

Residuals

Figure 3 shows a histogram of the Raw Residuals obtained from the linear regression from January 2013 to December 2016. Here we can see that the residuals follow a normal distribution and fall between -0.05 and 0.04.

Figure 3: Residuals from initial model
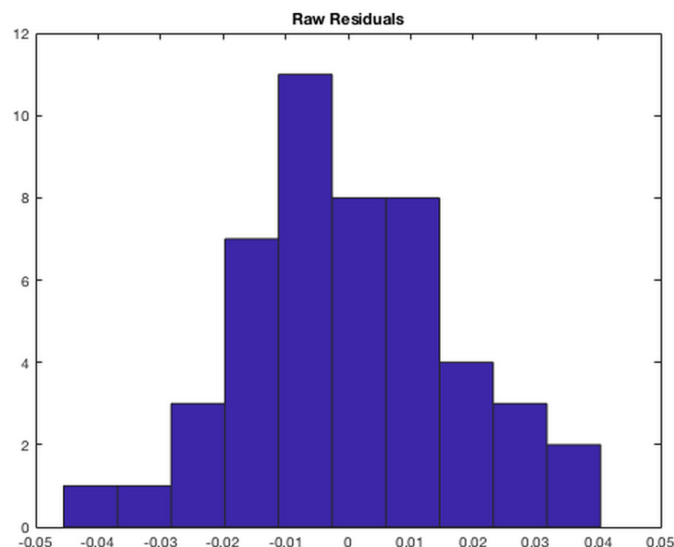
Regression Plot

Figure 4 displays the actual values (blue) for the exchange rate (EUR/USD) between January 2013 and December 2016 compared to the values generated by the linear regression (orange). We can see that the values obtained by our prediction are very close to the actual values.

Figure 4: Regression vs. Actual Exchange Rates from January 2013 to December 2016
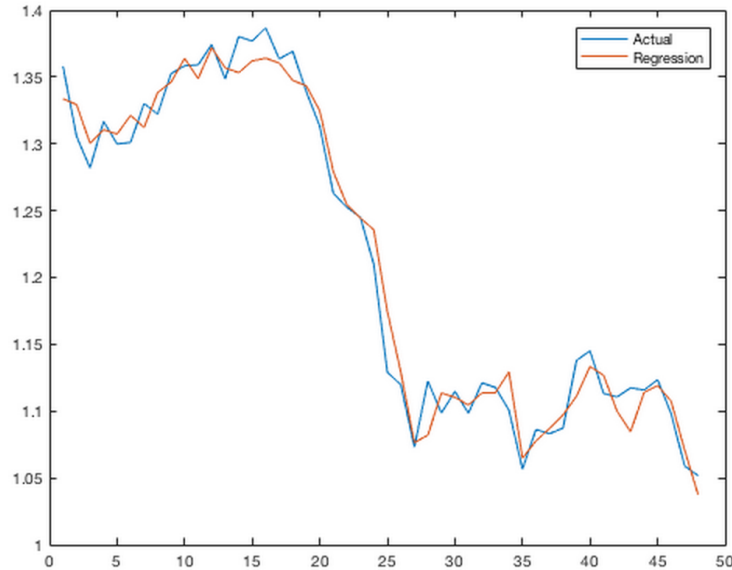
7.1.2 Predicted Values

Figure 5 shows the predicted values (orange) for the EUR/USD exchange rate from January 2017 until December 2017 compared to the real values (blue). Again, we can see that our predictions are relatively close to the real values.

Table 4 provides the real value of the exchange rates as well as numerical predictions and their percent error. Overall, we have that the percentage errors all fall below 2.9%.

7.2 Model Improvement

7.2.1 Error Regression Analysis

Using the momentum signal of the short-minus-long EWMA as the predictor variable and the errors as the response variable, we find the results shown in Table 5.

Figure 5: Predicted values from January to December 2017
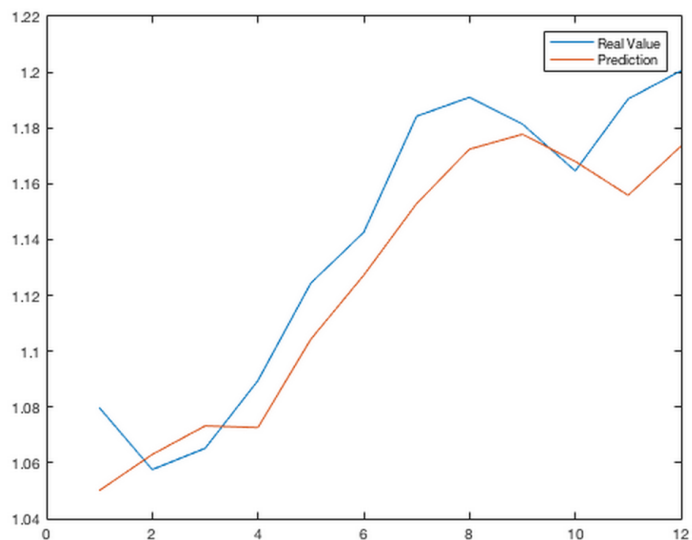
Table 4: Predicted values from January to December 2017

Date	Real	Predicted	PercentError
'Jan 2017'	1.0798	1.0501	0.027526
'Feb 2017'	1.0576	1.063	0.0051044
'Mar 2017'	1.0652	1.0732	0.0075537
'Apr 2017'	1.0895	1.0727	0.015459
'May 2017'	1.1244	1.1043	0.017878
'Jun 2017'	1.1426	1.1272	0.013458
'Jul 2017'	1.1842	1.1529	0.026429
'Aug 2017'	1.191	1.1724	0.015621
'Sep 2017'	1.1814	1.1777	0.0031017
'Oct 2017'	1.1646	1.168	0.002925
'Nov 2017'	1.1904	1.1559	0.02901
'Dec 2017'	1.2005	1.1735	0.022495

Thus, our linear regression using these data is the following:

$$\epsilon = 0.00290 + 1.2525 S_1 \tag{17}$$

From the chart, we can see that the R-Squared value is 0.271, meaning that 27.1% of the variance in the response can be explained by the momentum signal. Moreover, we find that the predictor's p-value is 0.00015, implying that a linear relationship with the response variable is hold.

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Table 5: Linear Regression: Error Results

```
Linear regression model:
    y ~ 1 + x1

Estimated Coefficients:
                  Estimate        SE        tStat       pValue
                  _____    _____    _____    _____

    (Intercept)   0.0029039   0.0022467    1.2925        0.20263
    x1               1.2525     0.30313    4.1319     0.00015043


Number of observations: 48, Error degrees of freedom: 46
Root Mean Squared Error: 0.0148
R-squared: 0.271,  Adjusted R-Squared 0.255
F-statistic vs. constant model: 17.1, p-value = 0.00015
```

Residuals

Figure 6 shows the histogram of the Raw Residuals from the error regression. Compared to the residuals obtained in the previous model, we can see that these values now fall between -0.03 and 0.04, and that most of them are concentrated very close to 0.

Figure 6: Residuals from improved model
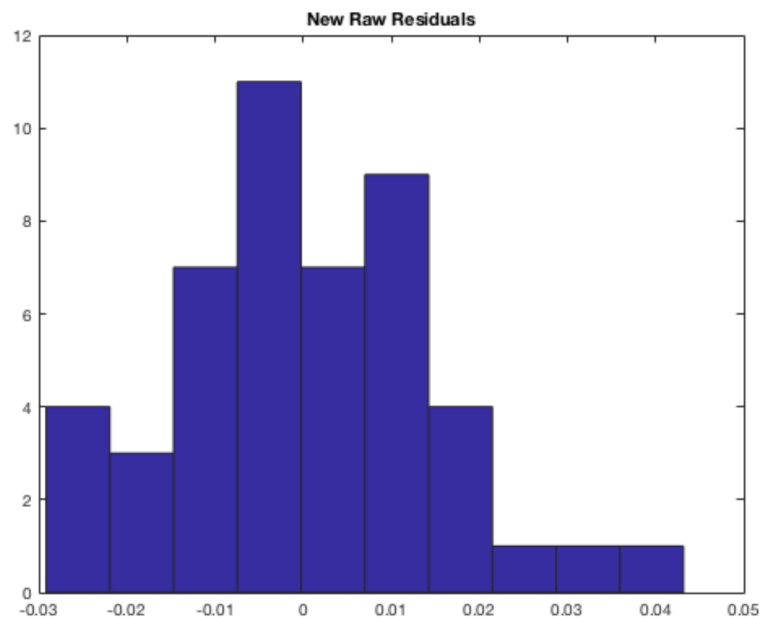
7.2.2   Predicted Values

In Figure 7, we can see the actual values (blue) for the exchange rate (EUR/USD) between January 2017 and December 2017 compared to the predicted values generated by our initial model

(orange) and the predicted values generated by our improved model including the error fitting portion (yellow). Here we can see that our predictions fall much closer to their actual values by using the latter model, implying that it was beneficial to include momentum in our model in order to generate better predictions.

Figure 7: Actual values, predictions from the initial model, and predictions from the improved model from January to December 2017
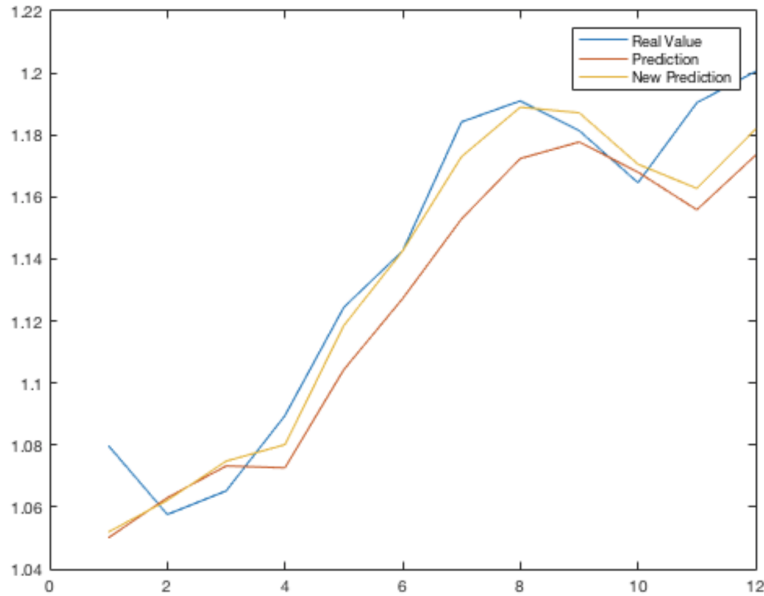
Table 6 presents the numerical comparison between the actual exchange rates for the EUR/USD, the predicted rates using our initial model, and the predicted rates obtained with the improved model. Again, we can see that the values obtained with the improved model are closer to the real exchange rates compared to the values obtained with the initial model.

Table 7 shows the percentage errors derived from the initial predictions and the predictions found using the improved model. We can see that using our new model the percent errors fall below 2.3%, with most of them actually being less than 0.09%, much lower than the errors we obtained from our initial model.

7.3 Evaluating the Payoff obtained by Using the Strategy from the Predicted Values

Table 8 summarizes the payoffs and variances obtained by using different strategies regarding entering the forward contract or waiting for the next month using the spot rate. The first strategy corresponds to always entering the forward contract, which means that the payoff is obtained by subtracting the forward rate from the actual rate. The profit over the four year period that we

Table 6: Actual values, predictions from the initial model, and predictions from the improved model from January to December 2017

| Date	Real	Predicted	NewPredicted
'Jan 2017'	1.0798	1.0501	1.0519
'Feb 2017'	1.0576	1.063	1.0622
'Mar 2017'	1.0652	1.0732	1.0748
'Apr 2017'	1.0895	1.0727	1.0801
'May 2017'	1.1244	1.1043	1.1185
'Jun 2017'	1.1426	1.1272	1.1426
'Jul 2017'	1.1842	1.1529	1.173
'Aug 2017'	1.191	1.1724	1.189
'Sep 2017'	1.1814	1.1777	1.1872
'Oct 2017'	1.1646	1.168	1.1706
'Nov 2017'	1.1904	1.1559	1.1628
'Dec 2017'	1.2005	1.1735	1.1819

Table 7: Percentage error of the predictions using the initial and improved model from January to December 2017

T =

12×4 table

Date	Real	PercentError	PercentErrornew
'Jan 2017'	1.0798	0.027526	0.025812
'Feb 2017'	1.0576	0.0051044	0.0043189
'Mar 2017'	1.0652	0.0075537	0.0090124
'Apr 2017'	1.0895	0.015459	0.0085989
'May 2017'	1.1244	0.017878	0.005229
'Jun 2017'	1.1426	0.013458	3.3419e-06
'Jul 2017'	1.1842	0.026429	0.0094616
'Aug 2017'	1.191	0.015621	0.0017084
'Sep 2017'	1.1814	0.0031017	0.0048744
'Oct 2017'	1.1646	0.002925	0.0051162
'Nov 2017'	1.1904	0.02901	0.023206
'Dec 2017'	1.2005	0.022495	0.01549

found under this strategy is -0.3430. The second strategy is given by always waiting for the next month and using the spot rate for the transaction, thus, generating a profit of 0. Next, we have the profit of 0.5194, obtained by deciding if we should wait until the next month or enter the forward contract according to the predictions given by our initial model, the linear regression. Following, we computed the profit acquired by using this strategy with our improved predictions, generated with the error fitting component, in which we find a profit of 0.5203. Finally, we generated the

payoffs of what would be the optimal strategy, in an unrealistic situation that we know the spot exchange rate one month before, and thus know if we should enter the forward contract or just wait. Using this latter strategy, we obtain a profit of 0.5853.

Table 8: Profit generated using the different strategies

Strategy	Payoff	Variance
Always entering the one-month-forward contract	-0.343003	0.001640312
Always waiting for the next month	0	0
Choosing to enter the forward contract or to wait according to the predicted exchange rates	0.519405	0.000361998
Choosing to enter the forward contract or to wait according to the predicted exchange rates from our new model	0.520295	0.00036163
Entering the forward contract given the information that the actual exchange rate will increase	0.585292	0.00034511

We can see that overall the payoffs obtained by using this strategy according to our predictions are much better than if we always enter the forward contract or always wait for the next month. The payoff from our improved model is slightly better than that of our initial model, showing that including momentum does enhance our predictions. Moreover, we can see that the variance given by using our predictions is less compared to the initial one. This is a good sign, since a lower variance implies a lower risk. Finally, it is important to note that these payoffs are computed by using the unit of 1 Euro, and thus, a bigger investment will produce a greater payoff.

8   Conclusions

This simple approach to forecasting the movement of a currency pair provides an alternative to more complex and outdated strategies. The results obtained proved to be very good and the trading strategy based on our predictions generate a positive profit. Nonetheless, there are several recommendations and suggestions to improve on this model.

The first recommendation concerns data length and frequency. For this project, we used monthly data for a period of 5 years. This frequency implies that daily predictions of exchange rate movements are not taken into account. Thus, this signal would not be able to predict if a pair will suffer a drastic movement during the course of a few days. Instead, it will give an average of the expected change for the next month. Therefore, using a similar approach on daily data may be helpful in anticipating short term behavior in the currency pair. Moreover, using a longer time frame for the data, say 20 years, would result in more information of the currencies' past behavior that could affect the predictions generated through this model.

The next recommendation focuses on information, or news regarding factors that may affect the currency pair exchange rates. This approach is not commonly incorporated into mathematical models, since news can occur from one day to another and they are also difficult to foresee. Nevertheless, paying attention to "news" and information concerning the currency pair being traded might result in a good indicator of exchange rate movements.

Moreover, this approach was only tested for the EUR/USD pair. For different currency pairs, there are many other factors that can influence price fluctuations, including change in political dynamics, GDP, debt, shifts in supply and demand, economic cycles and even weather [22]. Therefore, it is recommended to test this model and trading strategy for different currency pairs for future studies.

As a final remark, in this project we incorporated the three main concepts used to explain changes in exchange rates, Carry, Valuation, and Momentum. Nevertheless, it is important to note that even though each strategy contributes towards the prediction of the behavior of a currency pair, it alone may not fully explain the complete behavior. Thus, it is important to consider a combination of these strategies in order to develop a forecasting model.

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A Appendix: MATLAB Code

MATLAB Code

```matlab
clc
clear ALL
close all
disp('-------------------------')
disp(' ')
disp('Predicting EUR/USD')
disp('all together')
disp(' ')
disp('-------------------------')
disp(' ')

%% 1-Data
% import data

MomEx = ExchangeRate; %this is for momentum 2013-2017
EURUSDO=Reg(1:48,:);
EURUSDN=Reg(49:end,:);

Exchange  = EURUSDO(:,1);
PPPP  = EURUSDO(:,2);
HistVol = EURUSDO(:,3);
SWAP = EURUSDO(:,4);

n=length(Exchange);

%% 2-Linear Regression

X=[PPPP HistVol SWAP];
lm = fitlm(X,Exchange)
Linreg = lm.Fitted;

%% 3-ANOVA

an1=anova(lm)

% The model is good if the predictors are significant at the 5%
% significance level given the other terms in the model, i.e.
their pValue
% is less than 0.05.


%% 4- Residuals

epsHat=Exchange-Linreg;

figure
```

```matlab
hist(epsHat)
title('Raw Residuals')


%% 5- Comparing the actual and predicted values

figure
plot(1:n, Exchange, 1:n, Linreg)
legend('Actual','Regression')

%% 6- Predict next 12 months and plot predictions
real=[];
pred=[];
for i=1:12
    r = EURUSDN(i,1);
    real = [real;r];
    p = predict(lm,EURUSDN(i,[2:4]));
    pred = [pred;p];
end
m=length(real);

figure
plot(1:m, real, 1:m, pred)
legend('Real Value','Prediction')

%% 7- Plot of all the points

figure
plot(1:(n+m), [Exchange;real], 1:(n+m), [Linreg;pred])
legend('Real Values','Regression')

%% 8- Residuals for predicted values

error=abs(pred-real);
E=sum(error);
profit=sum(pred-real);

figure
hist(error)
title('Prediction errors')


%% 9- Table of Real vs. Predicted Exchange Rates
chg=[];
for i=1:length(pred)
    m=(abs(real(i)-pred(i)))/(real(i));
    chg=[chg,m];
end
```

```matlab
Date = {'Jan 2017';'Feb 2017';'Mar 2017';'Apr 2017';'May
2017';'Jun 2017';'Jul 2017';'Aug 2017';'Sep 2017';'Oct
2017';'Nov 2017';'Dec 2017'};
Real = [real];
Predicted = [pred];
PercentError = [transpose(chg)];
T = table(Date,Real,Predicted,PercentError)

%% 10- Momentum

%vector length
lmom=length(MomEx);

EWMA1 = tsmovavg(MomEx,'e',2,1); %short-more weight to first
value
EWMA2 = tsmovavg(MomEx,'e',3,1); %long-more weight to past data

figure()
plot(1:lmom,MomEx,1:lmom,EWMA1,1:lmom,EWMA2)
legend('Actual Exchange Rate','EWMA1 (short)','EWMA2 (long)')
title('Actual vs. Moving Averages')

sml = EWMA1 - EWMA2;
figure()
plot(1:lmom,sml)
title('Short minus Long EWMA')


%% 11- Regression on Errors
y=sml(13:60); %momentum signal: short-minus-long for 2013-2016
Predictions = Linreg;
Exrate = MomEx(13:60);
Error= Exrate-Predictions;

lmerror = fitlm(y,Error)
RegError = lmerror.Fitted;

%% 12- New model adding back predictions for errors

Ynew = Predictions + RegError;
lyn=length(Ynew);

figure
plot(1:lyn, Exchange, 1:lyn, Linreg, 1:lyn, Ynew)
legend('Real Value','Prediction', 'New Predictions')
```

```matlab
%% 13- New Residuals

epsnew=Exchange-Ynew;

figure
hist(epsnew)
title('New Raw Residuals')

%% 14- Predict next 12 months and plot predictions with new
model

newerr=[];

for i=1:12
    pn = predict(lmerror,sml(60+i));
    newerr = [newerr;pn];
end

newpred = newerr + pred;

mn=length(newpred);

figure
plot(1:mn, real, 1:mn, pred, 1:mn, newpred)
legend('Real Value','Prediction','New Prediction')


%% 15- Table of Real vs. Predicted Exchange Rates and real vs.
percent errors
chgnew=[];
for i=1:length(newpred)
    per=(abs(real(i)-newpred(i)))/(real(i));
    chgnew=[chgnew,per];
end
Date = {'Jan 2017';'Feb 2017';'Mar 2017';'Apr 2017';'May
2017';'Jun 2017';'Jul 2017';'Aug 2017';'Sep 2017';'Oct
2017';'Nov 2017';'Dec 2017'};
Real = [real];
Predicted = [pred];
NewPredicted = [newpred];
T = table(Date,Real,Predicted, NewPredicted)

PercentError = [transpose(chg)];
PercentErrornew = [transpose(chgnew)];

T = table(Date,Real,PercentError,PercentErrornew)
```

B Appendix: Linear Regression Data

Exchange Rate	PPP Producer	Historical Volatility	Basis Swap LIBOR
1.3579	12.56	7.579130435	-21.52608696
1.3057	12.31	8.124	-20.75
1.2819	9.94	8.872380952	-23.7047619
1.3168	10.43	8.055454545	-22.35
1.2999	9.39	7.398636364	-19.53863636
1.301	10.87	7.641428571	-18.1252381
1.3302	10.41	8.82173913	-17.07130435
1.3222	11.57	6.392380952	-14.24666667
1.3527	12.09	6.249090909	-12.16636364
1.3584	13.35	5.78173913	-8.813043478
1.3591	12.19	7.1425	-6.5065
1.3743	13.4	5.067826087	-5.177391304
1.3486	11.94	5.725909091	-3.586818182
1.3802	11.82	5.95	-4.761
1.3769	12.48	5.594545455	-3.946818182
1.3867	11.66	4.253636364	-1.356818182
1.3635	11.29	3.866666667	-3.326190476
1.3692	10.42	3.715	-8.561363636
1.339	9.79	3.226521739	-9.154347826
1.3132	8.2	3.47047619	-11.64285714
1.2631	5.58	6.953636364	-14.87727273
1.2525	3.97	9.489090909	-12.05681818
1.2452	2.58	8.646190476	-13.23952381
1.2098	1.72	8.398695652	-15.30826087
1.1291	-3.54	9.497619048	-21.37047619
1.1196	-5.67	13.4375	-26.5875
1.0731	-10.73	14.28347826	-27.93869565
1.1224	-10.37	13.85	-27.92227273
1.0986	-8.34	12.01238095	-24.77380952
1.1147	-7.96	13.45909091	-24.25227273
1.0984	-10.16	10.43045455	-24.91681818
1.1211	-9.39	10.46772727	-22.97909091
1.1177	-7.49	12.99318182	-27.34227273
1.1006	-7.66	9.627142857	-27.2052381
1.0565	-13.03	10.58545455	-36.25136364
1.0862	-11.14	12.88608696	-29.77043478
1.0831	-12.74	8.006666667	-30.32
1.0873	-10.3	9.97	-32.68952381
1.138	-9.6	8.803043478	-31.2
1.1451	-8.56	6.6665	-29.558
1.1132	-8.89	7.050434783	-31.03173913

1.1106	-9.2	10.49863636	-37.00136364
1.1174	-10.33	9.94	-44.15047619
1.1158	-8.93	6.933478261	-42.99956522
1.1235	-9.25	6.095714286	-39.40380952
1.0981	-10.83	5.630454545	-38.93
1.0589	-12.93	7.782272727	-44.58954545
1.0517	-15.38	9.256666667	-47.56571429
1.0798	-14.32	8.963913043	-46.32608696
1.0576	-14.56	7.173	-40.742
1.0652	-14.11	7.728636364	-32.57318182
1.0895	-14.61	7.09952381	-31.77761905
1.1244	-10.62	8.083478261	-32.16
1.1426	-8.98	6.65047619	-31.75761905
1.1842	-6.05	7.680909091	-28.35590909
1.191	-3.8	7.604782609	-29.99304348
1.1814	-3.22	7.4975	-30.534
1.1646	-4.31	6.983478261	-32.57
1.1904	-5.22	7.210909091	-34.90454545
1.2005	-3.88	5.886666667	-36.30333333

C   Appendix: Error Regression Data

Exchange Rate	Direction	Error
1.3084	-0.0009	-0.0082
1.3325	0.0037	0.027
1.3343	0.0027	0.0148
1.3239	0.0033	0.0226
1.2365	-0.0016	0.0031
1.2667	-0.0009	0.0218
1.2304	-0.0055	-0.0044
1.2579	-0.0088	-0.0115
1.286	-0.0147	-0.0161
1.296	-0.0126	-0.002
1.2986	-0.0092	0.0006
1.3193	-0.0115	-0.0258
1.3579	-0.0215	-0.0455
1.3057	-0.0176	-0.0096
1.2819	-0.0188	-0.0034
1.3168	-0.0045	0.0404
1.2999	-0.0046	-0.015
1.301	-0.0004	0.0043
1.3302	-0.0023	-0.0062
1.3222	0.0019	0.0075
1.3527	0.0014	0.004
1.3584	-0.002	-0.0287
1.3591	-0.0092	-0.0083
1.3743	-0.0024	0.0085
1.3486	-0.001	-0.0039
1.3802	0.0003	-0.0098
1.3769	0.0088	0.0268
1.3867	0.0085	0.0117
1.3635	0.0003	-0.0136
1.3692	-0.0016	0.0106
1.339	-0.0003	0.0329
1.3132	-0.0002	0.0018
1.2631	0.0012	0.0043
1.2525	-0.0032	-0.0093
1.2452	-0.0094	-0.012
1.2098	-0.0085	0.0143
1.1291		
1.1196		
1.0731		
1.1224		
1.0986		

D   Appendix: Actual, Predicted, and Forward Exchange Rates

	Exchange Rates	Predicted Rates From Initial Model	Predicted Rates From Improved Model	Forward Rates
Jan-13	1.3579	1.3336	1.3501	
Feb-13	1.3057	1.3294	1.3314	
Mar-13	1.2819	1.3004	1.2953	
Apr-13	1.3168	1.3105	1.3142	
May-13	1.2999	1.3073	1.3086	
Jun-13	1.301	1.3213	1.323	
Jul-13	1.3302	1.3122	1.3205	
Aug-13	1.3222	1.3384	1.3443	
Sep-13	1.3527	1.3462	1.3571	
Oct-13	1.3584	1.3639	1.3741	
Nov-13	1.3591	1.3487	1.3566	
Dec-13	1.3743	1.3719	1.3809	
Jan-14	1.3486	1.3568	1.3585	1.354096
Feb-14	1.3802	1.3532	1.3608	1.367141
Mar-14	1.3769	1.3621	1.3683	1.352464
Apr-14	1.3867	1.3641	1.371	1.373348
May-14	1.3635	1.3604	1.3613	1.379199
Jun-14	1.3692	1.3474	1.3492	1.386698
Jul-14	1.339	1.3434	1.3394	1.35953
Aug-14	1.3132	1.3247	1.3166	1.368014
Sep-14	1.2631	1.2792	1.2637	1.342782
Oct-14	1.2525	1.2545	1.2416	1.313502
Nov-14	1.2452	1.2446	1.2359	1.262424
Dec-14	1.2098	1.2356	1.2241	1.248271
Jan-15	1.1291	1.1746	1.1506	1.247211
Feb-15	1.1196	1.1292	1.1101	1.200473
Mar-15	1.0731	1.0765	1.0558	1.134259
Apr-15	1.1224	1.082	1.0792	1.118586
May-15	1.0986	1.1136	1.1107	1.076547
Jun-15	1.1147	1.1104	1.1128	1.114977
Jul-15	1.0984	1.1046	1.1046	1.093065
Aug-15	1.1211	1.1136	1.119	1.105713
Sep-15	1.1177	1.1137	1.1184	1.095387
Oct-15	1.1006	1.1293	1.1298	1.131847
Nov-15	1.0565	1.0648	1.0561	1.119945
Dec-15	1.0862	1.0777	1.0776	1.101883
Jan-16	1.0831	1.087	1.0887	1.064298
Feb-16	1.0873	1.0971	1.1004	1.083843
Mar-16	1.138	1.1112	1.1251	1.089469
Apr-16	1.1451	1.1334	1.147	1.087602
May-16	1.1132	1.1268	1.1301	1.139873
Jun-16	1.1106	1.1	1.1009	1.154229

Jul-16	1.1174	1.0845	1.0871	1.116171
Aug-16	1.1158	1.114	1.1167	1.11447
Sep-16	1.1235	1.1192	1.1236	1.117419
Oct-16	1.0981	1.1074	1.1063	1.120816
Nov-16	1.0589	1.0709	1.062	1.122525
Dec-16	1.0517	1.0374	1.0296	1.106534
Jan-17	1.0798	1.0501	1.0519	1.067592
Feb-17	1.0576	1.063	1.0622	1.045921
Mar-17	1.0652	1.0732	1.0748	1.077805
Apr-17	1.0895	1.0727	1.0801	1.056133
May-17	1.1244	1.1043	1.1185	1.068211
Jun-17	1.1426	1.1272	1.1426	1.094281
Jul-17	1.1842	1.1529	1.173	1.122833
Aug-17	1.191	1.1724	1.189	1.137942
Sep-17	1.1814	1.1777	1.1872	1.18184
Oct-17	1.1646	1.168	1.1706	1.187162
Nov-17	1.1904	1.1559	1.1628	1.175001
Dec-17	1.2005	1.1735	1.1819	1.163471