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A Cointegration Trading Strategy for Currency Exchange Rates

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The views stated in this thesis are those of the author and not necessarily those of the supervisor, second assessor, Erasmus School of Economics or Erasmus University Rotterdam.

Abstract

In this paper a cointegration trading strategy for currency exchange rates is developed and tested. Using the data of 27 different currency exchange rates over a period starting begin 2000 until the end of 2019. In the first 10-year period, currencies are tested on cointegration. A total of 351 tests are performed, which found 23 different combinations of currency exchange rates that are significantly cointegrated with each other. These combinations, or pairs, are then used in the second 10-year period, to evaluate a trading strategy. Based on trading rules, set in this paper. 38 Different positions were opened and closed, resulting in an average realized return of 6,5% over 10 years. The return on the strategy significantly differs from zero, at a 1% significance level.

1. Introduction

According to Malkiel (2019), the stock market follows a random walk in which change in price cannot be predicted using information from the past. The Efficient market hypothesis [EMH] takes this one step further and hypothesize, depending on the form of efficiency, that an asset price reflects all available information in the long run (Fama, 1970). This means that in the short-run anomalies can exist and the market can be inefficient. But if the EMH holds in the strong form and thus all information, public and private, is incorporated into the price, investors shouldn't be able to outperform the market. Concluding that a long-run equilibrium exists.

It's generally accepted that the EMH does not hold short-term. Since it takes time for the price to update when new information comes available, so the actual price can differ from its long-run equilibrium. A possible way to make use of this short-term inefficiency, is by using a pairs trading strategy. This strategy consists of finding suitable pairs and investing in those pairs. A suitable pair consists of two assets which are highly correlated with each other and 'move together'. Meaning that the prices of those assets diverge and converge over an extended period. When the prices of the assets are about to converge, the investor takes a long position in the lower valued stock and a short position in the higher value stock. Since the prices are going to converge the lower valued asset will raise in value, compared to the higher valued asset, which will decrease in value. After the prices cross each other, both positions are closed and a profit is realized.

1.1. FOREX market

The previous example describes how pairs behave on the stock market. The Stock market is not the only market within the financial markets. Another one being the FOREX market, which stands for Foreign Exchange market. On this market currencies are traded instead of stocks. Of all the financial markets the FOREX market has one of the largest capitalisations. Bloomberg reported a highest-ever trading level of $6,6 trillion on 16 September 2019 (Bloomberg, 2019). Since currencies are traded, its liquidity risk is one of the lowest. Alongside having a high capitalisation, trading on the FOREX market makes for interesting opportunities. One of those opportunities being pairs trading, which is explored in this paper.

When trading within financial markets there're two kind of analyses which an investor can use to predict the future value of the traded asset, namely technical and fundamental analysis. Technical analysis uses the past performance of an asset to predict its future value. Even though the EMH states that even in the weakest form this should not be possible since all historic information should be reflected into the price. Fundamental analysis uses the underlying valuation of the asset to predict its future value. There is strong evidence that currencies are directly influenced by interest rates. On this topic multiple theories exist: uncovered interest rate parity, covered interest rate parity, purchasing power parity, law of one price, etc. With the expected change in interest rates, the expected value of a currency can be predicted.

Taylor & Allen (1992) and Oberlechner (2001) researched the use of technical and fundamental analyses in trading, on the FOREX market. Their findings were that traders tend to use technical analysis for shorter trading horizons and fundamental analyses for longer trading horizons. But both of them found that most traders use a combination of both types of analysis. Lui & Mole (1998) also researched the use of both types of analysis on the Hong Kong FOREX market and found similar results. But they added that technical analysis is more useful in predicting turning points and works better when used with moving averages or other trend-following systems.

Both technical and fundamental analysis are methods which try to predict the future value of currencies, but this paper does not necessarily focus on predicting the true value of the currency in the future. But it tries to predict how two currencies are going to behave relative to each other. This paper takes the idea of pairs trading, which is used on the stock market, and applies it on the FOREX market. It can be seen as a technical way of predicting relative value and not as a fundamental way.

Because the focus of this paper is on how the assets behave relative to each other, the direction the individual assets have, is irrelevant. The strategy works when the assets move together and eventually converge. There is no need to predict the true future price nor the absolute returns, only how they behave relative to each other.

In this paper a trading strategy is developed and its returns are computed by applying the strategy on actual changes in currency prices over the period begin 2010 till end 2019. The main question, which this paper seeks to answer: Is the trading strategy, based on pairs trading within the FOREX market, a viable investment strategy? To be able to answer this question the definition of viable needs to be stated. The strategy is viable if its return significantly differs from zero. If this is not the case it is not viable. To answer the main question two sub-questions are compiled:

1. Which currency exchange rates form a pair?
2. What is the average return of all pairs over the period begin 2010 till end 2019?

In this paper a form of a pairs trading strategy is explored within the FOREX market. Not a lot of research has been done on pairs trading within the FOREX market, especially compared to other financial markets. This paper can be used to get a better understanding of the FOREX markets and its long-run equilibria. Which can be useful for investors who want to diversify their portfolios.

In the following chapters the theory behind the trading strategy is discussed as well as other papers about pairs trading. Thereafter the data is described, the paper continues with discussing the methodology for applying the theory to practice, presenting the results, drawing conclusions, and commenting on its limitations.

2. Literature

Caporale, Gil-Alana and Plastun (2017) searched for inefficiencies in currency exchange rates [CER] and tried to capture these inefficiencies into a trading strategy. They based their strategy on certain rules and executed multiple trades within one day. Those rules were based on the foreign exchange market not being as efficient as Fama (1970) describes it to be in his

Efficient Market Hypothesis. In this section the literature for developing a comparable trading strategy, using cointegration, is reviewed. As well as the statistical phenomenon cointegration.

Gatev, Goetzmann & Rouwenhorts (1998) published a paper in which they tested a pairs trading investment strategy on the stock market. They used data spanning a 35-year period. Within this period, they arbitrarily choose an 18-month period which is split into two smaller periods. The first 12 months are used as a formatting period for finding suitable pairs and the remaining six months are used to trade these pairs. To find suitable pairs, they look for two assets by minimizing the sum of squared deviations between them. The lower this sum the higher the chance the assets move together and form a pair. They based this strategy on input from investors who have experience in pairs trading. The investors claim that pairs who 'move together' are best used for a pairs trading strategy.

Gatev, Goetzmann and Rouwenhorts compiled trading rules for when to open and when to close positions in the trading period, being the latter period of the 18 months. The opening of a position starts when the two assets diverge by more than two times the historical standard deviation. The position closes when the prices are both at the same level. When the trading period ends all open positions are closed. They find that their strategy is uncorrelated with the S&P 500, but does exhibit sensitivity to the spread between high and low price-to-earnings stocks, and exhibit sensitivity to the spread between high and low book-to-value stocks. The results of the strategy are on average 12% annually.

Gatev, Goetzmann & Rouwenhorts (2006) revisited their paper from 1998. They found that the profitability has decreased since hedge funds are more prominent in use of pairs trading. An alternative explanation is that arbitrageurs have taken more interest in pairs trading and therefor profitability has decreased. They also found that the sensitivity to price-to-earnings and book-to-value stocks has decreased.

As mentioned previously, according to the consensus of the interviewed investors the assets that work best in pairs trading, are assets that 'move together'. Herlemont (2003) tries to capture this movement of different stocks to develop his own pairs trading strategy. The starting point of his strategy are stocks that have had trading patterns that where similar in the past. He assumes that if they had similar trading patterns in the past, they will inhibit this pattern in the future. To identify pairs, he looks for stocks with mean-reverting properties.

To test if the stocks move together, he uses a Dickey-Fuller test to test for stationarity of the stock prices. The reason being that if the prices are non-stationary, it means they cannot be predicted by using their past performance. Generally stock prices are seen as a non-stationary time series. Herlemont finds that the stock price data is indeed non-stationary and therefor contains a unit root with one order of integration I(1). Herlemont transforms the data to a stationary dataset by taking the first difference of the original data. He continues with finding pairs by looking for stocks that move together.

The paper continues with developing trading rules for when to open and when to close positions. His trading rules are aimed to minimise the possible loss from a position. Herlemont (2003) also mentions that the timing of opening and closing positions is an important issue. Opening too early or too late will limit the potential profit. Herlemont uses two metrics to clarify for when to open a position. The first being the *price ratio* and the second being *twice the standard deviation*. The *price ratio* is the prices of the stocks that form a pair divided by each other. Since these prices are found to move together the *price ratio* should stay within a certain range over a long-run period. The second metric, *twice the standard deviation*, is computed using a 130-day rolling mean. This means that mean of the *price ratio* is calculated every day using the previous 130 days. The standard deviation is multiplied by two and computed for every day. When this metric equals the *price ratio*, for the second time, a position is opened. By mentioning; for the second time, Herlemont assumes that the *price ratio* deviates from the mean before converging again. Meaning that the distance between the mean and the *price ratio* increases and increases until a certain point. From there on the distance will start to decrease until the *price ratio* equals the mean. When the *price ratio* increases, it can exceed the level which is *twice the standard deviation*. When the *price ratio* starts to decrease, it will cross the same level again. When *twice the current standard deviation* crosses with the *price ratio* for the second time (so the distance has started to converge), that is when Herlemont opens a position. The position is closed when either one of the following happens: The *prices ratio* equals the mean, the loss equals or is greater than 20%, or the maximum holding period exceeds 50 trading days.

The intend of the research paper by Herlemont is not necessarily to create the best possible trading strategy for pairs trading, but rather to explore multiple ways to test for finding pairs and to minimise potential loss by such a strategy. He also states that the potential profit is limited by the number of arbitrageurs active on the market, and by not being a bull market. Since the strategy relies on a neutral state of the market[1] in which no major shocks occur. A bull market is generally not associated with a market in which no major shocks occur.

Elliott, Hoek & Malcolm (2005) introduced a more quantitative approach to pairs trading. They state that this strategy should be possible on every financial market that is out of equilibrium. They try to find pairs, just as Herlemont, that are market neutral. The portfolio with two stocks, which is market neutral and form a pair, is called a spread. They must inhibit the following behaviour: that the return process of the spread is mean-reverting. When the actual value deviates by a certain amount from the mean, Elliot et al. open a position. To estimate the true state of the spread and thus to find when the value deviates a certain amount from the mean, a Kalman filter is used. They show that, when all assumptions are met, the strategy should work on any occasion when markets are in disequilibrium.

In the past a lot of research has been done on if markets stay in equilibrium. With the introduction of the European Monetary System [EMS] a new currency was introduced; the Euro. Cheng (1995) researched if the Purchasing Power Parity [PPP] holds within the new EMS. Cheng tested his hypothesis of long-run PPP over the floating exchange rate period for five countries participating in the EMS. To test his hypothesis, he tested if cointegration, between the nominal exchange rates and price indices of the five countries, is present. Because more than two variables were used in the testing for cointegration, Cheng choose to use the Johansen procedure to test for cointegration instead of the more often used Engle and Granger test for cointegration.

Cheng states that if the hypothesis is not rejected, the PPP holds for those five countries. Therefor the real exchange rates are stationary and the different currencies are cointegrated. This in turn implies that short-run deviations from the long-run equilibrium are indeed short-run deviations and will converge in the future. Cheng does reject his hypothesis in some cases, but in most cases the PPP does hold. Concluding that the long-run PPP relationship does not change with the advent of the EMS.

[1] With neutral state Herlemont means that the assets must have the opposite sensitivity (β) to the market and thus the sum of β's equals zero for the pair.

Koronidis (2013) researched if pairs trading is possible on the FOREX market and used the EUR/USD and GBP/USD to test his hypothesis. Koronidis ran into the same problem as Herlemont, being that currency price levels are non-stationary. To find pairs he used the 2-step approach for cointegration, developed by Engle and Granger (1987). When the EUR/USD and the GBP/USD both were I(0) (no unit root) and are cointegrated, he could use them to test his strategy. Unfortunately, he could not conclude that the two currencies were indeed cointegrated. But, just as Elliot et al., he stated that the theory should be able to work in practice if all assumptions were met.

2.1. Hypothesis

To answer the main question: Is an exchange rate trading strategy, based on pairs trading, a viable strategy? And to answer the sub-questions: which exchange rates form a pair and what are the returns of these pairs? A couple of alternative hypotheses are tested.

1. Within the FOREX market, currency exchange rate pairs do exist.
2. The average return of the trading strategy is larger than zero.

3. Data

In this section the data is described starting with the explanation to why all currencies are denoted in Dollars for the purpose of this paper. Following the structure of the data and concluding with how the data is divided into a formation and into a trading period.

3.1. Dollar as base currency

To make it easier to understand and interpret the results all currencies are denoted in USD. If this was not the case the dataset would have to be enormous. Since to be able to perform one test four different currencies need to be evaluated and two different exchange rates need to be tested on cointegration. Changing one of these currencies has to be done by a completely new currency. Otherwise the same test would be performed in a different perspective. This can be clarified by the following example. Let’s say the EUR/USD is tested on cointegration with the CAD/NZD. The following relationship that is going to be tested is the EUR/CAD with the NZD/USD. For these two tests four different datasets need to be used. If all currencies are denoted in USD, a lot less datasets are required. The EUR/USD can be tested on the CAD/USD and the NZD/USD, only requiring three datasets for four possible tests (fourth being CAD/USD on NZD/USD).

Table 1
List of used currencies ordered per continent

America		Europe		Africa		Asia		Oceania	
Currency	Abbr.	Currency	Abbr.	Currency	Abbr.	Currency	Abbr.	Currency	Abbr.
American Dollar	USD	British Pond	GBP	Central African CFA franc	XAF*	Chinese Yuan Renminbi	CNY*	Australian Dollar	AUD
Argentine Peso	ARS*	Bulgarian Lev	BGN*	Moroccan Dirham	MAD	Emirati Dirham	AED*	Fiji Dollar	FJD
Brazilian Real	BRL*	Croatian Kuna	HRK	South African Rand	ZAR	Hong Kong Dollar	HKD*	New Zealand Dollar	NZD
Canadian Dollar	CAD	Czech Koruna	CZK	West African CFA franc	XOF*	Indian Rupee	INR		
Colombian Peso	COP	Danish Krone	DKK*			Japanese Yen	JPY		
Costa Rica Colon	CRC	Euro	EUR			Malaysian Ringgit	MYR		
Mexican Peso	MXN	Icelandic Krona	ISK			Saudi Arabian Riyal	SAR*		
		Norwegian Krone	NOK			Singapore Dollar	SGD		
		Polish Zloty	PLN			Syrian Pound	SYP*		
		Romanian Leu	RON			Turkish Lira	TRY		
		Russian Ruble	RUB			Vietnamese Dong	VND		
		Swedish Krona	SEK						
		Swiss Franc	CHF						
		Ukrainian Hryvnia	UAH						

Currencies with a * are pegged with a different currency and therefore not used.

3.2. Data structure

The data that will be used to answer the main- and sub-questions are the daily spot currency exchange rates over the period begin 2000 – end 2019. For this paper 39 major different exchange rates will be evaluated. These CER are selected to represent at least two currencies from every continent. This will result in a more diverse portfolio which should be more robust against idiosyncratic risk. However, 11 of those CER are pegged with a different currency and are excluded from the tests. A pegged currency is a currency that is artificially hold within a certain range from a foreign currency. One of the reasons a central bank can choose to peg its currency is to reduce volatility and help with boosting their own economy. Including a pegged currency into the dataset should, by definition, be cointegrated with the foreign currency. So, for example including the BGN into the dataset would result in most currencies that are cointegrated with the EUR also be cointegrated with the BGN. This could make for an interesting investment strategy but is not what this paper is focussed on. The last currency that is excluded is the USD, since it's used as currency in which all other currencies are denoted. It makes no sense to test the USD on a possible pair with the USD.

By eliminating the 11 pegged currencies from the list, and the USD, only 27 remain. This results in testing 351 (26+25+24+…+1) possible pairs on cointegration, see table 1.

3.3. Formation and trading period

The dataset is, arbitrarily, divided into two 10-year periods. The first 10-year period, ranging from begin 2000 till the end of 2009, is used to find CER that are cointegrated and form a pair. The second 10-year period is the trading period and used to test the strategy. This means that when the trading rules suggest a position should open a fictional position can be opened, and the results can be measured since the actual price levels are known. This way the average return can be computed and the performance can be evaluated.

However, using the first 10-year period for formation and the second period for trading, the following problem can arise. A currency pair that is formed in the formation period may no longer be a pair under the same assumptions in the trading period.

4. Methodology

Even though pairs trading is well-known strategy and often used, not much research has been done for the application on the FOREX market. Elliot et al. (2005) showed confidence that the theory should be able to work in any market that is in disequilibrium and Koronidis (2013) shared the same thought. One reason the research on pairs trading in the FOREX market is scare can be related to the fact that it is hard to establish when the portfolio with the two currencies are market neutral. Herlemont (2003) and Elliot et al. both stated that when the βeta of the pair equals zero the portfolio was in the best state to be able to produce positive returns. One of the easiest ways to calculated the βeta is by using the CAPM formula and estimating the βeta with an OLS. However, this requires to have observations about the market return. Which can be problematic for the FOREX market since, in essence, it's a zero-sum game.

To illustrate let's take the following hypothetical situation, the world only has two currencies, EUR and USD. The market return consists of the cumulative return of all currencies. But when the USD appreciates compared to the EUR, both returns are opposite. So, the summation of returns, and thus the market return, equals zero. This is also the driving factor behind the PPP.

In this section the framework is described which is used to be able to answer the main- and sub-questions. Starting with how the pairs are found and formed which are used in the trading period to calculate the average returns and concluding, with how the return is tested of being different from zero.

4.1. Formation period

As previously mentioned, the best assets to form a pair are assets that move together. Following this logic for currencies, the currencies should somehow be related. But before any test, which measure any form of correlation, can be used on the dataset, it first must be proven that the dataset is useable. Time series data of stock prices tend to be non-stationary. Meaning historic prices have limited explanatory value for future prices. This implies that when someone wants to predict the future price, he/she should find factors other than historic prices. It's assumed to be true for CER as well. If this is the case, the panel data for CER contains a unit root and needs to be extracted. Extracting the unit root can be done by differencing the price levels and is called a unit root process (Brooks, 2014). Differencing price levels means taking the delta from the price levels, in other words, the return on the CER. The order of integration tells how many times the data needs to be differenced. When panel data is I(1) (one order of integration) differencing one time is necessary to eliminate the unit root and get I(0).

4.1.1. Unit root

When working with two or more time series a possibility exists that the two-time series move together, appear to be correlated, but are in fact not correlated. This is called a spurious relationship and can happen when both time series contain a unit root (Simon, 1954). The time series is seen as non-stationary (Brooks, 2014).

To test if this is the case, an Augmented Dickey-Fuller [ADF] test can be used. Which has a null hypothesis in which the dataset contains a unit root and an alternative hypothesis of not containing a unit root (Dickey & Fuller, 1976). It can also be used to test if the unit root process was successful. After differencing the dataset, the ADF should reject the null hypothesis which means that the unit root process was successful. One thing to consider when using the ADF test and rejecting the null-hypothesis is that the alternative hypothesis is not established. In this case, it means that extracting the unit root and thus eliminating the non-stationary, does not prove that the data is stationary, only that the data does not contain significant non-stationarity.

After testing all CER on unit root, all of them contain at least one order of integration I(1) and thus a unit root. As can be seen in Figure 1.

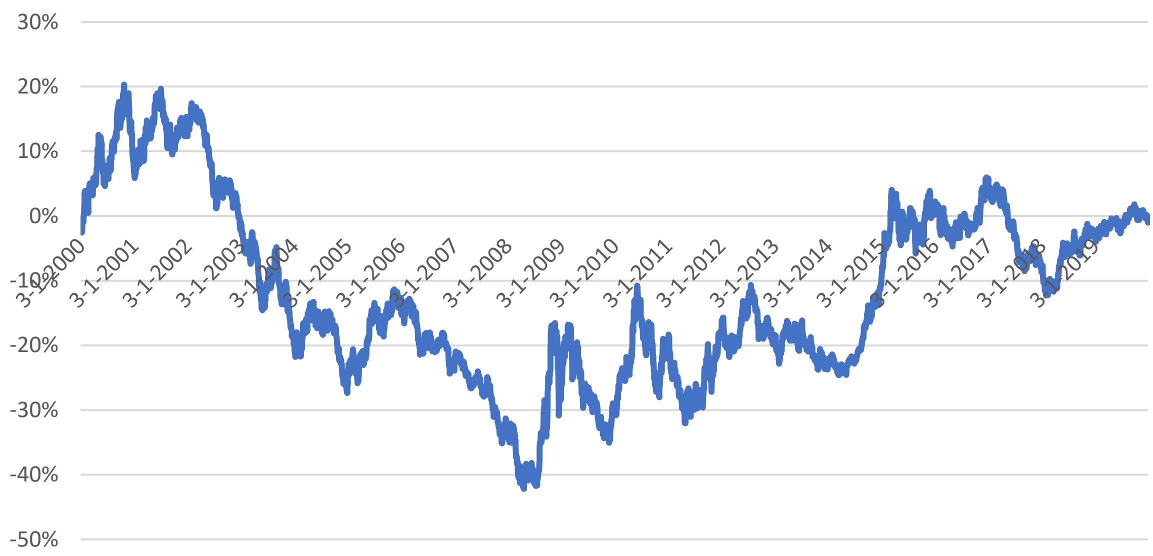

Figure 1 Cumulative return on the USD/EUR I(1), for the period 2000-2019.

To eliminate the unit root from the time series a unit root process is used. This process needs to be repeated until zero orders of integration is achieved I(0) and the unit root is successfully extracted. The results can be seen in Figure 2.

When the ADF test is used to test the currency returns on unit root, all of the CER have a significant z-statistic. This means that the p-value is not significantly different from zero and the null hypothesis can be rejected. The time series no longer contains a unit root and can be used to find pairs. The results of the ADF can be found in appendix I.

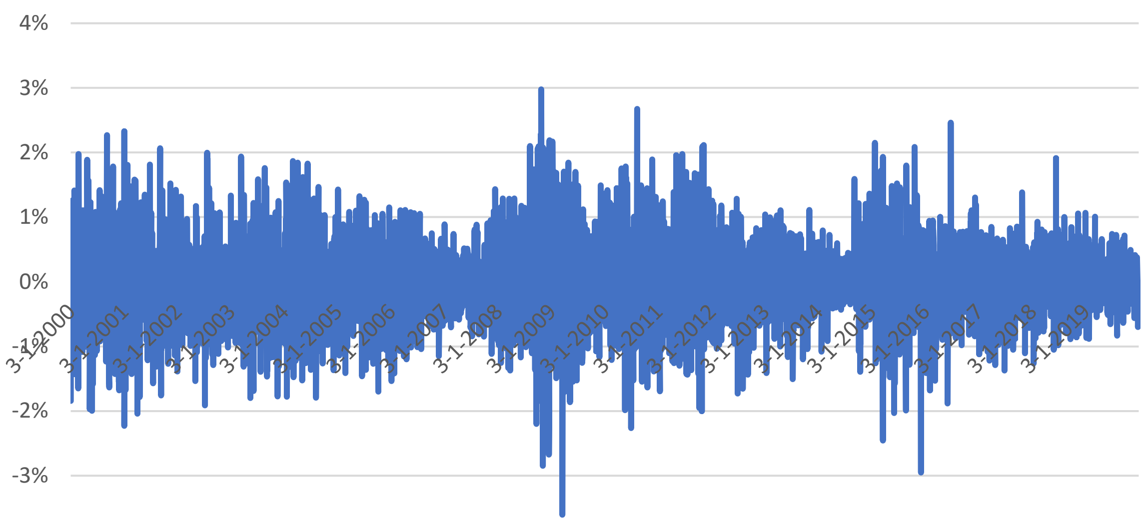

Figure 2 Distribution of the return's USD/EUR I(0), for the period 2000-2019.

Not only can the conclusion be drawn that the time series no longer contains an unit root. Another conclusion can be drawn: that the original dataset is I(1). Would this not be the case and instead be I(2), the dataset cannot be stationary after differencing only once. In the following subsection cointegration will be discussed. The test that is used only works when the data is I(1), which has just been confirmed to be the case.

4.1.2. Cointegration

The test that will be used to evaluate different CER, in the formatting period, is the 2-step error correction test for cointegration [2-step approach] developed by Engle and Granger (1987). If two CER are cointegrated it means they have a long-run relationship but may differ in the short-term. This means that CER can deviate from each other but are bound by some relationship in the long-run (Brooks, 2014). Because the two assets are somehow bound, they return to a situation in which they are in equilibrium again. So, if an investor chooses the right time to invest, when the assets are in disequilibrium, a profit is expected to be made. The driving factor behind the return to the equilibrium is the Purchasing Power Parity as mentioned in the literature section (Cheng, 1995).

PPP is defined that a price for a basket of goods in the domestic country must equal the same price in a foreign country with a couple factors taken into account. Would this be the case, then an arbitrageur can make a profit by buying the domestic basket of goods and sell it in the foreign country for a higher value.

The trading strategy, that is developed in this paper, relies on the fact that CER will converge back to its equilibrium. For this to happen two CER need to be cointegrated, this is tested in the formatting period. In this paper cointegrated CER in the formatting period are assumed to be cointegrated in the trading period. To test if CER are cointegrated, the null-hypothesis of the 2-step approach needs to be rejected. H_0: *CER are not cointegrated* and H_A: *CER are cointegrated*. The testing period, begin 2000 till end 2009, is used for finding pairs and the trading period, begin 2010 till end 2019, is used to apply the strategy. The 2-step approach works as follows, when variables γ ($currency_1$) and χ ($currency_2$) are suspected to be cointegrated a simple regression is compiled:

$$\gamma_t = \beta_0 + \beta_1 \chi_t + \upsilon_t \tag{1}$$

The next step is to predict the residual:

$$\hat{\upsilon}_t = \gamma_t - \hat{\beta}_0 - \hat{\beta}_1 \chi_t \tag{2}$$

And test the residual for stationarity. Through the rewriting of the formula the predicted residual becomes a linear combination of the variables. The variables can only be cointegrated if they themselves are I(1), but the linear combination of the two must be I(0). To test if this is the case, the predicted residual is tested on stationarity. If the predicted residual is stationary, meaning it's I(0). The combination of the linear I(1) variables is cointegrated (Brooks, 2014).

The original model by Engle & Granger (1987) goes further and gives coefficients to calculate a long-run error correction model, but this is not relevant for this paper. Since cointegration itself is important for the strategy and not if one or the other currency can predict or influence the other currency in the long-run.

The first 10-year period is used to find pairs, based on the 2-step approach for cointegration. The second 10-year period is used to develop and evaluate the trading strategy.

4.2. Trading period

The pairs that are found in the formatting period are used in the trading period to test if the strategy's returns are different from zero. Since it's known that certain CER prices are cointegrated and will converge when they're in disequilibrium, an investor can open a position which profits from this convergence. The positions that need to be opened depend on which currency is valued higher relative to the other. Since they are expected to converge the higher valued currency decreases relative to the other currency and vice versa.

4.2.1. Trading rules

Herlemont (2003) mentioned the importance of timing for opening positions. The optimal time to open a position is when the CER are the furthest apart from each other. If the distance between the two CER is at its largest the prices will change with greater absolute value. This is illustrated by the following example: Let's say it known that the USD/EUR and the USD/GBP are cointegrated and form a pair EUR:GBP. They're in equilibrium when the distance between the USD/EUR and the USD/GBP is zero, meaning a Dollar exchanged for Euros, exchanged for British Pounds, and exchanged for Dollars should equal the starting amount. In this example, this is not the case and the USD/EUR are higher valued than in its equilibrium. Since the USD/EUR and USD/GBP are cointegrated the USD/EUR is expected to decrease in value relative to the USD/GBP. The further the USD/EUR is from its equilibrium the greater the relative price will decrease. An investor who had a short position in the USD/EUR and a long position in the USD/GBP will make a larger profit, the larger the distance between the USD/EUR and the equilibrium-price.

In the previous paragraph the distance between the pairs is emphasized and plays a crucial part for the trading rules for opening a position. But what exactly is the distance? This is a parameter that measures how far the currency is from its equilibrium.

Even though all the currencies are denoted in Dollars they cannot be compared to each other. Take the USD/HRK and USD/EUR for example, USD/HRK has an average exchange rate of around $5,8. USD/EUR has an average exchange rate of around $0,7. Those price levels are expected to never cross each other, even though they're cointegrated. Since its known that a long-run PPP exists, when this PPP holds, the CER are in equilibrium. In this paper it's assumed that a five-year average is long enough for the PPP to hold. Meaning that if the price level equals the five-year average price level, for both currencies, it should be impossible to create arbitrage profit by traditional means.

In the previous section the method for forming pairs is described, since they're cointegrated the have a long-run equilibrium from which they can deviate. The distance captures this deviation. To calculate the long-run equilibrium a moving average is used. For every day of the trading period, the average of both currency price levels over the last five years is calculated. This average excludes the price for that day, but the price level of that day is used to calculate deviation from its equilibrium. The current price minus the rolling average is divided as whole by the rolling average. This is done to standardise the data.

$$Deviation_{currency} = \frac{(current\ price - average\ previous\ 5\ years)}{average\ previous\ 5\ years} \quad (3)$$

To calculate the distance between the CER that form a pair, the deviation from both currencies is subtracted from each other. The smaller deviation is always subtracted from the larger deviation. This results in, always having a positive value for the distance.

$$Distance = deviation_{currency1} - deviation_{currency2} \quad (4)$$

When $currency_1 > currency_2$.

$$Distance = deviation_{currency2} - deviation_{currency1} \quad (5)$$

When $currency_2 > currency_1$.

The distance is calculated for every day of the trading period and for the last five years of the testing period. A rolling standard deviation for the distance is calculated, computed over the previous five years. This results in the ability to compare the current distance between the pairs with a rolling standard deviation of the distance, over the previous five years.

Gatev, Goetzmann and Rouwenhorts (2006) present in their paper about pairs trading, a trading rule which opens a position when the distance between price levels ≥ 2 times the standard deviation. Herlemont (2003) does the same, except using a dynamic standard deviation which changes over time and only opens when the distance ≥ 2 times the standard deviation for two consecutive days, for the second time (as explained in section 2).

In this paper, when the current distance is greater than twice the standard deviation a position is opened. This position is held until the CER converge and the distance between them returns to zero. This is illustrated by Figure 3. In which the course of the deviations of the pair HRK:EUR is shown for the period 2015 – 2018. When the distance is twice the five-year standard deviation a position is opened, shown in the figure as the grey line increasing. When the deviations cross each other, the position is closed and a profit is realized.

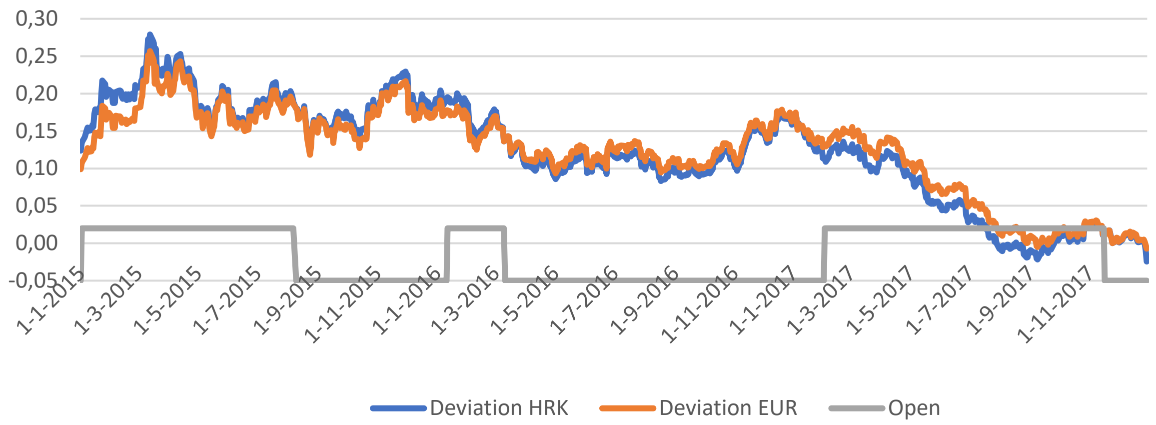

Figure 3 The course of the deviations of the HRK and EUR from its five-year average, including when a position is opened and closed. Over the period 2015 – 2018.

To maximise the potential profit the position is not closed until the CER do cross each other. Even though this theoretically maximise profit from the trade, it does not take into account the time value of money and its opportunity costs. Perhaps a position can be closed earlier and yield a lower profit, but the profit can be realized earlier which outweighs the later higher profit.

Since the CER are cointegrated and converge, one can argue that after crossing the price levels will continue to diverge, and holding the positions for longer can increase the potential profit. But since this is not statistically tested this is not included into the strategy.

Only closed positions are taken into account since positions that are not closed at the end of the trading period, haven't had time to return to their equilibrium. If these positions are included, it would cloud the evaluation of the strategy. The strategy can only be evaluated if the included positions follow the set trading rules. Otherwise the trading rules are not evaluated. The strategy is built on the assumption that cointegrated CER do eventually converge and has not stop-loss parameters built in. Therefore, closing positions earlier does not occur.

4.3. Comparing returns

On first thought every position should result in a profit if the pairs do converge. However, if the convergence of the price takes a long time, there is a possibility for the positions to return a loss. This could happen when currency prices change drastically over time. Resulting in a large change in the five-year average. When this happens and the deviation returns back to its five-year average, a negative return can be achieved. So, with more volatility comes more uncertainty.

To evaluate the trading strategy, the returns are compared against being different from zero. If this is the case the strategy is seen as viable. To test if this is true, a one sample t-test is performed.

$$t - statistic = \frac{\bar{\chi} - \mu}{\sigma/\sqrt{n}} \tag{6}$$

Where $\bar{\chi}$ equals the average measured return of all the currency pairs, μ equals the threshold being zero, σ equals the standard deviation of the return per closed position and n is the amount of closed positions in the trading period.

5. Results

In this section the different CER are tested on cointegration within the formation period after which pairs are formed. The section continues with calculating the returns of the trading strategy within the trading period. And concludes with the testing of the hypothesis if the returns are different from zero.

5.1. Finding pairs

The 2-step approach is performed for a total of 351 tests, which statistics can be found in appendix II. The significant currency pairs are tabulated in table 2.

The first hypothesis can be confirmed, since there’re existing CER pairs within the FOREX market, based on statistically significant cointegration.

Table 2
Engle-Granger 2-step test for cointegration for different significant exchange rate pairs with base currency USD, for the period begin 2000 until end 2009.

Currency pairs	**Observations**	**Z-value**
CAD:AUD	2.609	-3,485**
CHF:AUD	2.609	-3,339**
CRC:CHF	2.609	-3,152*
EUR:AUD	2.609	-3,802**
GBP:FJD	2.609	-3,964***
HRK:AUD	2.609	-3,773**
HRK:CHF	2.609	-3,853**
HRK:EUR	2.609	-5,528***
MAD:AUD	2.609	-4,052***
MAD:HRK	2.609	-3,329*
MXN:JPY	2.609	-3,477**
NOK:AUD	2.609	-3,389**
NOK:HRK	2.609	-3,438**
NZD:NOK	2.609	-3,389**
PLN:CAD	2.609	-3,255*
RON:MYR	2.609	-3,181*
RON:PLN	2.609	-3,087*
RUB:FJD	2.165	-3,141*
RUB:GBP	2.165	-3,225*
RUB:INR	2.165	-3,146*
RUB:RON	2.165	-3,313*
SEK:AUD	2.609	-4,455***
SEK:FJD	2.609	-3,916***
SEK:NZD	2.609	-4,244***
TRY:RUB	2.609	-4,084***
UAH:ISK	2.609	-3,702**
VND:MXN	2.609	-3,329*

Note: *P < 0,10; **P < 0,05 and ***P < 0,01.

5.2. Return on the strategy

A total of 27 pairs where found. Between those 27 pairs, 50 different positions were opened, but only 38 were closed. The remaining 12 positions were still open when the end of the dataset was reached, 31st of December 2019. As discussed in the end of the previous section, these positions are excluded from the overview. Those 12 positions yielded an average loss of 7,7%. Bringing down the return to 3,1% across all pairs and positions for the trading period. The results of the 50 positions are tabulated in table 3.

Table 3
Consolidated results trading strategy for the period begin 2010 – end 2019 including all opened positions.

Currency pairs	Z-value	Positions Opened	Arithmetic Return Strategy	Days Position Opened	Return p. day
CAD:AUD	-3,485**	3	9,6%	499	0,019%
CHF:AUD	-3,339**	1	-17,4%	1.335	-0,013%
CRC:CHF	-3,152*	3	27,6%	565	0,049%
EUR:AUD	-3,802**	3	23,0%	1.514	0,015%
GBP:FJD	-3,964***	2	6,6%	1.176	0,006%
HRK:AUD	-3,773**	2	14,8%	861	0,017%
HRK:CHF	-3,853**	1	16,5%	661	0,025%
HRK:EUR	-5,528***	4	7,1%	925	0,008%
MAD:AUD	-4,052***	2	7,1%	764	0,009%
MAD:HRK	-3,329*	3	9,1%	761	0,012%
MXN:JPY	-3,477**	2	8,5%	1.197	0,007%
NOK:AUD	-3,389**	2	14,3%	769	0,019%
NOK:HRK	-3,438**	1	-7,1%	1.317	-0,005%
NZD:NOK	-3,389**	1	-1,2%	907	-0,001%
PLN:CAD	-3,255*	2	10,5%	256	0,041%
RON:MYR	-3,181*	1	10,9%	720	0,015%
RON:PLN	-3,087*	4	9,9%	508	0,020%
RUB:FJD	-3,141*	1	-1,4%	1.183	-0,001%
RUB:GBP	-3,225*	1	21,9%	589	0,037%
RUB:INR	-3,146*	1	1,9%	1.169	0,002%
RUB:RON	-3,313*	1	6,5%	1.136	0,006%
SEK:AUD	-4,455***	2	18,4%	438	0,042%
SEK:FJD	-3,916***	1	-8,6%	1.307	-0,007%
SEK:NZD	-4,244***	2	16,4%	509	0,032%
TRY:RUB	-4,084***	2	5,6%	1.278	0,004%
UAH:ISK	-3,702**	1	-41,0%	1.175	-0,035%
VND:MXN	-3,329*	1	-13,3%	1.303	-0,010%
Average		1,7	3,1%	496	0,035%

Note: *P < 0,10; **P < 0,05 and ***P < 0,01.

If the positions, which were still open at the end of dataset are removed, the realized return would be 6,5% and is tabulated in table 4. For all returns, see appendix III.

Table 4
Consolidated realized results trading strategy for the period begin 2010 – end 2019, including only closed positions.

Currency pairs	Z-value	Positions Opened	Arithmetic Return Strategy	Days Position Opened	Return p. day
CAD:AUD	-3,485**	2	12,9%	149	0,086%
CRC:CHF	-3,152*	3	27,6%	565	0,049%
EUR:AUD	-3,802**	2	21,6%	1.051	0,021%
GBP:FJD	-3,964***	2	6,6%	1.176	0,006%
HRK:AUD	-3,773**	1	14,2%	384	0,037%
HRK:CHF	-3,853**	1	16,5%	661	0,025%
HRK:EUR	-5,528***	3	6,3%	407	0,016%
MAD:AUD	-4,052***	1	7,1%	421	0,017%
MAD:HRK	-3,329*	3	9,1%	761	0,012%
MXN:JPY	-3,477**	1	17,7%	167	0,106%
NOK:AUD	-3,389**	2	14,3%	769	0,019%
NZD:NOK	-3,389**	1	-1,2%	907	-0,001%
RON:MYR	-3,181*	1	10,9%	720	0,015%
RON:PLN	-3,087*	3	12,6%	258	0,049%
PLN:CAD	-3,255*	2	10,5%	256	0,041%
RUB:FJD	-3,141*	1	-1,4%	1.183	-0,001%
RUB:GBP	-3,225*	1	21,9%	589	0,037%
RUB:INR	-3,146*	1	1,9%	1.169	0,002%
RUB:RON	-3,313*	1	6,5%	1.136	0,006%
SEK:AUD	-4,455***	2	18,4%	438	0,042%
SEK:NZD	-4,244***	2	16,4%	509	0,032%
TRY:RUB	-4,084***	1	38,9%	502	0,078%
UAH:ISK	-3,702**	1	-41,0%	1.175	-0,035%
Average		1,5	6,5%	404	0,048%

Note: *P < 0,10; **P < 0,05 and ***P < 0,01.

5.3. Analysing the results

20 Of the realized positions yield a positive return. The longest opened position was 1.183 days and the shortest was 33 days. If the positions were ranked based on days open, the top 25% of longest open positions contain the only three different pairs which return a loss (RUB:FJD, UAH:ISK, and RUB:RON). Realizing an average return of -5,7%. Two of the top 25% positions (RUB:INR and GBP:FJD[2]), have an individual return lower than 2%. The pair (RUB:RON) which is the only unmentioned position in the top 25% of longest days open, yielded a return of 6,5% over 1.136 days.

[2] GBP:FJD had two positions opened and closed, one of them returned 1,2% over an 865-day period.

The above mentioned CER almost all contain the RUB. The RUB is involved in five total opened positions and all of them are special. Three of them are already mentioned, the remaining two (TRY:RUB and RUB:GBP) have the highest and second highest returns of all the positions. This is the result of the RUB crashing in around July 2014. The crash resulted in the five-year average changing drastically, from around $30 in July 2014 to above $60 at the end of 2019. Because of the drastic change there is a possibility the five-year average no longer represents the true value of the currency and thus the PPP no longer holds.

5.3.1. Trading strategy without cointegration

Even though positive returns are realized and cointegration is significant, that doesn't mean that the strategy doesn't work when pairs are not cointegrated. To test this the 20 pairs with the highest z-value are also tested. This resulted in the testing of 23 currency pairs that are not cointegrated. Of those 23, six positions were still open at the end of the dataset. When this happened with pairs that are cointegrated they got removed. In this case, there should be no long-run equilibrium and the pairs could very well never close again. A pair that hasn't closed at the end of the dataset could be proof this. But of these six, four opened only recently, less than 200 days ago. Including these into the sample would cloud the results in favour of the strategy not working without cointegration. Therefor the four positions which are open for less than 200 days are eliminated from the sample without cointegration. See table 5 for the results.

When analysing the returns from the trading strategy without cointegration there are six negative returns, all of these six positions have more than 1.100 days between opening and closing. The average days a position is opened in the strategy with cointegration is 404 days, the average for the strategy without cointegration is 818 days.

If the positions are again ranked based on days open, the top 25% consist of seven positions, which are open for more than 1.100 days and yield -19,0% of the average total return. Excluding them gives an average return of 9,4%. Concluding that positions that are opened for too long make up for most of the negative returns.

Table 5
Consolidated realized results trading strategy, without cointegration, for the period begin 2010 – end 2019, sorted by z-value.

Currency pairs	**Z-value**	**Positions Opened**	**Arithmetic Return Strategy**	**Days Position Opened**	**Return p. day**
VND:CRC	-0,788	1	4,6%	185	0,025%
ISK:CHF	-0,816	1	11,7%	448	0,026%
GBP:CHF	-0,818	2	-6,6%	2.070	-0,007%
RUB:CRC	-1,047	1	2,2%	1.102	0,002%
RON:CRC	-1,050	1	5,3%	608	0,009%
INR:CRC	-1,051	1	6,2%	415	0,015%
VND:MYR	-1,083	1	5,2%	645	0,008%
RON:CHF	-1,107	1	14,6%	782	0,019%
RUB:CHF	-1,135	1	-12,1%	1.311	-0,009%
VND:NZD	-1,254	1	16,2%	267	0,061%
UAH:CHF	-1,259	1	-33,6%	1.260	-0,027%
UAH:MYR	-1,266	1	-19,3%	1.215	-0,016%
INR:CHF	-1,269	1	12,4%	576	0,022%
UAH:CRC	-1,273	1	-32,3%	1.193	-0,027%
UAH:SGD	-1,282	1	-29,4%	1.248	-0,024%
VND:AUD	-1,290	1	12,8%	529	0,024%
GBP:CRC	-1,299	1	5,2%	495	0,011%
Average		1,1	-3,5%	818	0,005%

Note: no significant values.

Table 6
Return on the 9 CER pairs that yielded a negative return under the original trading rules, including both strategies. When trading period is artificially shortened.

	Original return	**50 days max**	**Return when period shortened by:**			
Pairs			*100 days*	*200 days*	*300 days*	*500 days*
RUB:FJD	-1,4%	-4,5%	-4,7%	-8,8%	-10,5%	-0,9%
NZD:NOK	-1,2%	-4,5%	-4,0%	-1,5%	-8,6%	-7,7%
UAH:ISK	-41,0%	-18,9%	-47,3%	-47,4%	-56,8%	-63,4%
GBP:CHF	-8,5%	-3,6%	-11,6%	-12,1%	-13,8%	-13,5%
RUB:CHF	-12,1%	-21,2%	-16,6%	-12,6%	-14,5%	-10,9%
UAH:CHF	-33,6%	-8,8%	-37,2%	-37,8%	-38,7%	-37,1%
UAH:MYR	-19,3%	-36,5%	-23,2%	-26,4%	-25,9%	-28,2%
UAH:CRC	-32,3%	-28,9%	-32,8%	-33,2%	-37,7%	-36,0%
UAH:SGD	-29,4%	3,3%	-33,8%	-37,8%	-37,0%	-37,5%

5.3.1. Shortening trading period

Concluding from the application of the strategy on cointegrated pairs and pairs without cointegration, it seems that positions that are open for more than 900 days make up for most of the negative returns. It could be beneficial to artificially close positions that are opened for more than a certain period. To test if this is true the positions which were open longer than

900 days are cut short. Herlemont (2003) did the same in his paper, he closed positions which were open for more than 50 days. The return of the pairs that originally yielded a negative return are evaluated twice. The first after being open for 50 days and the second being when their period is shortened by 100, 200, 300, and 500 days. Yet artificially closing these positions early, does not always yield a better return, as can be seen in table 6.

Only the pair UAH:SGD did have a positive return after 50 days opened and only the RUB:FJD and RUB:CHF perform better if their position is shortened by 500 days. So, generally, the strategy does not improve by manual intervention.

5.4. Viable trading strategy

To conclude of the trading strategy is viable for the purpose of this paper, the second hypothesis is tested. The average return of the trading strategy is significantly greater than zero. This significance is tested by using a t-test:

$$t - statistic = \frac{6{,}5\% - 0\%}{11{,}7\%/\sqrt{38}} = 3{,}339 \tag{7}$$

The corresponding p-value is 0,0004, which means the return is significantly greater than zero. The same t-test is performed for the average return of all opened positions in the trading period. This includes the positions that were still open at the end of the trading period. The average return of these positions is 3,1%.

$$t - statistic = \frac{3{,}1\% - 0\%}{12{,}1\%/\sqrt{50}} = 1{,}812 \tag{8}$$

The corresponding p-value is 0,0352. Since the hypothesis is one-sided the null-hypothesis of the average return being less or equal to zero, can be rejected at a 5% significance, but cannot be at a 1% significance. If the alternative hypothesis states that the average return differs from zero, and thus being two-sided. The hypothesis cannot be rejected at the 5% significance level, but only at the 10%.

6. Conclusion

In this research paper a trading strategy based on the statistical phenomenon of cointegration is tested, for which the 2-step approach is used. This test can only work if the dataset consists of CER that are I(1). An Augmented Dickey-Fuller test was used and the null-hypothesis was rejected, meaning the first difference of the CER is I(0). Thus, the CER themselves are I(1).

A total of 351 possibilities are tested and of those 351 possibilities, 27 CER are cointegrated with at least a 10% significance. This was computed using the first 10-year period of the dataset. For these pairs a trading strategy was developed. The strategy describes trading rules for when to open and when to close a position. The opening and closing of positions were executed in the second 10-year period. A total of 50 positions were opened, of those, 12 were still open at the end of the dataset; 31/12/2019 and excluded from the realized returns. The remaining 38 pairs yielded an average realized return of 6,5%. Meaning that an investor who would invest into an equally weighted portfolio consisting of only the cointegrated CER, would yield an average return of 6,5% over the trading period. The null-hypothesis of the average realized return being less or equal to zero is rejected. But including the 12 positions that were still open at the end of the dataset would give another conclusion. Including these positions, which gave an average return of 3,1%, the hypothesis of the average return being greater than zero can only be confirmed at a 5% significance level, not at 1% significance. If, again, all 50 positions are included and a hypothesis of the average return being different from zero is tested. The hypothesis can only be confirmed with a significance of 10%. The main question: Is a currency exchange trading strategy, based on pairs trading, a viable investment strategy? Is positively answered.

When using the trading strategy on pairs that are most likely not cointegrated, it did not yield a positive return. But when only evaluating the five most unlikely to be cointegration pairs and the 10 most unlikely cointegrated pairs, they did yield a positive return. Including more pairs, that are most likely not cointegrated, reduced the profit. Further research is needed to explain this result.

One trend that came apparent in both strategies, is that the longer a position is held to more likely it is to yield a negative return. The positions which belong in the top 25% of longest held positions almost always yielded a negative return. But shortening this period did generally not increase the chance at profitability.

7. Limitations

Even though the trading strategy was carefully constructed and readjusted, the model does have some limitations.

Not every day of the trading period is utilized. In total there're 27 possible pairs. With a trading period consisting of 10 years, 2.610 possible trading days exist in the trading period. Multiply that by 27, a hypothetical total of 70.470 possible trades could occur. Of these 70.470 only 15.353 days had an open position (utilizing only 21,8% of the trading period). The reported average return of 6,5% is only achieved over the days on which positions were opened. There're a lot of unutilized days present in the trading period, therefor reserving the capital for when a position does open can come with a serious opportunity cost.

For the testing for cointegration and applying of the strategy, different 10-year periods were used. It is possible that a pair that was cointegration in the first period no longer is cointegrated in the second period. To optimize the strategy a rolling window for the 2-step approach could have been used.

To improve the realized returns, a portfolio could be constructed which includes only the best pairs. This can be based on a mean-variance optimizing portfolio which uses the Sharpe Ratio, popularised by Markowitz (1952) to further improve the trading strategy.

The returns that are given on the trading strategy do not take into account the following: the presence of transaction cost, the bid-ask-spread, and other costs that may occur when trading and holding currencies.

In the same regard, the reported realized returns are not discounted. However, the amount of days between opening and closing positions is taken into account.

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9. Appendix I – Results Dickey-Fuller test on returns

Table 7
Results Dickey-Fuller test for unit root one order of integration

Currency	Z-statistic	Observations	1% Critical Value	5% Critical Value	10% Critical Value
AUD	-76,441***	5.217	-3,430	-2,860	-2,570
BGN	-73,387***	5.217	-3,430	-2,860	-2,570
CAD	-74,426***	5.217	-3,430	-2,860	-2,570
CHF	-74,281***	5.217	-3,430	-2,860	-2,570
COP	-68,160***	5.217	-3,430	-2,860	-2,570
CRC	-84,044***	5.217	-3,430	-2,860	-2,570
EUR	-73,639***	5.217	-3,430	-2,860	-2,570
FJD	-84,867***	5.217	-3,430	-2,860	-2,570
GBP	-70,729***	5.217	-3,430	-2,860	-2,570
HRK	-73,653***	5.217	-3,430	-2,860	-2,570
INR	-71,401***	5.217	-3,430	-2,860	-2,570
ISK	-73,150***	5.217	-3,430	-2,860	-2,570
JPY	-75,540***	5.217	-3,430	-2,860	-2,570
MAD	-75,538***	5.217	-3,430	-2,860	-2,570
MXN	-75,746***	5.217	-3,430	-2,860	-2,570
MYR	-70,414***	5.217	-3,430	-2,860	-2,570
NOK	-73,702***	5.217	-3,430	-2,860	-2,570
NZD	-73,118***	5.217	-3,430	-2,860	-2,570
PLN	-72,747***	5.217	-3,430	-2,860	-2,570
RON	-73,070***	5.217	-3,430	-2,860	-2,570
RUB	-69,699***	4.773	-3,430	-2,860	-2,570
SEK	-75,633***	5.217	-3,430	-2,860	-2,570
SGD	-74,852***	5.217	-3,430	-2,860	-2,570
TRY	-76,937***	5.217	-3,430	-2,860	-2,570
UAH	-85,336***	5.217	-3,430	-2,860	-2,570
VND	-83,966***	5.217	-3,430	-2,860	-2,570
ZAR	-75,290***	5.217	-3,430	-2,860	-2,570

Note: *P < 0,10; **P < 0,05 and ***P < 0,01.

10. Appendix II – Results Engle Granger 2-step test for Cointegration

UAH	VND	ZAR
-2,330		
-2,218	-2,153	

INR	ISK	JPY	MAD	MXN	MYR	NOK	NZD	PLN	RON	RUB	SEK	SGD	TRY
-1,575													
-1,592	-2,174												
-1,115	-0,463	-1,968											
-1,337	-1,794	-3,477	-2,546										
-0,971	-0,911	-1,574	-1,802	-1,329									
-1,412	-0,710	-1,702	-2,388	-2,093	-1,861								
-1,427	-0,460	-1,576	-2,626	-1,881	-1,399	-3,389							
-1,778	-1,150	-1,882	-2,565	-1,964	-2,797	-2,675	-2,266						
-2,928	-2,569	-2,448	-2,765	-2,445	-3,181	-2,690	-2,680	-3,087					
-3,146	-1,822	-1,496	-1,711	-1,628	-1,643	-2,062	-2,110	-2,350	-3,313				
-1,825	-0,900	-1,811	-2,962	-2,080	-1,892	-2,579	-4,244	-2,363	-1,293	-3,008			
-0,210	-0,419	-1,723	-1,838	-2,004	-2,811	-1,454	-0,911	-2,388	-0,397	-0,487	-1,130		
-2,706	-2,762	-2,696	-2,785	-2,676	-2,722	-2,883	-2,829	-2,701	-2,571	-4,084	-2,787	2,784	
-1,614	-3,702	-3,041	-1,295	-2,967	-1,291	-1,166	-1,126	-1,158	-1,216	-1,618	-1,131	1,565	-1,299
-0,098	-1,065	-2,435	-1,401	-3,329	-1,021	-1,234	-0,894	-0,989	-0,368	-0,670	-0,882	2,123	-0,393
-2,704	-2,378	-2,297	-2,404	-2,253	-2,189	-0,319	-2,547	-2,245	-2,062	-2,113	-2,520	2,189	-1,987

Currency	AUD	BGN	CAD	CHF	COP	CRC	EUR	FJD	GBP	HRK
AUD										
BGN	-3,852									
CAD	-3,485	-2,662								
CHF	-3,339	-3,286	-2,427							
COP	-1,821	-1,783	-2,172	-1,761						
CRC	-2,975	-3,022	-2,740	-3,152	-1,995					
EUR	-3,802	-27,708	-2,688	-2,925	-1,054	-2,947				
FJD	-2,376	-2,477	-2,269	-2,149	-1,509	-2,041	-2,470			
GBP	-1,559	-1,216	-1,461	-1,116	-1,382	-1,557	-1,196	-3,964		
HRK	-3,773	-5,304	-2,801	-3,853	-1,161	-3,042	-5,528	-2,166	-0,806	
INR	-1,885	-1,838	-1,973	-1,773	-1,632	-1,774	-1,840	-2,582	-2,822	-1,852
ISK	-0,366	-0,516	-0,497	-0,611	-0,826	-0,763	-0,515	-1,070	-1,131	-0,558
JPY	-2,344	-2,287	-2,309	-2,407	-1,778	-2,550	-2,277	-1,693	-1,588	-2,309
MAD	-4,052	-3,285	-3,037	-2,505	-1,132	-2,893	-2,869	-2,016	-0,631	-3,329
MXN	-2,429	-2,518	-2,222	-2,766	-1,327	-2,628	-2,512	-1,628	-1,450	-2,467
MYR	-1,813	-1,643	-1,953	-1,665	-2,301	-1,547	-1,647	-1,067	-0,934	-1,672
NOK	-3,389	-2,854	-2,553	-2,938	-1,257	-2,691	-2,713	-2,504	-1,228	-3,438
NZD	-2,572	-2,965	-2,101	-2,818	-1,022	-2,171	-2,948	-2,803	-1,838	-2,871
PLN	-2,779	-2,466	-3,255	-2,357	-2,127	-2,682	-2,506	-2,265	-1,514	-2,640
RON	-2,719	-2,695	-2,992	-2,609	-2,764	-2,649	-2,696	-2,754	-2,839	-2,700
RUB	-1,973	-1,706	-1,890	-1,534	-1,733	-1,520	-1,709	-3,141	-3,225	-1,747
SEK	-4,455	-2,773	-2,820	-2,343	-1,377	-2,522	-2,682	-3,916	-2,243	-2,865
SGD	-1,676	-1,573	-2,192	-1,859	-1,303	-2,539	-1,576	-0,503	-0,039	-1,771
TRY	-2,810	-2,827	-2,716	-2,823	-2,352	-2,519	-2,827	-2,754	-2,728	-2,790
UAH	-1,206	-1,275	-1,222	-1,386	-1,236	-1,496	-1,276	-1,256	-1,434	-1,274
VND	-1,535	-1,331	-1,126	-1,906	-0,408	-1,206	-1,334	-0,150	-0,126	-1,268
ZAR	-2,396	-2,379	-2,457	-2,349	-2,133	-2,330	-2,386	-2,624	-2,719	-2,375

11. Appendix III – Results trading strategy

Currency	Positions	Opening date	Closing date	Short position	Long position	Return 1	Return 2	Strategy	Days	return p.day
CAD:AUD	1	10-7-15	18-12-15	AUD	CAD	10,25%	-3,67%	6,57%	116	0,0567%
CAD:AUD	2	27-5-16	12-7-16	AUD	CAD	0,18%	6,12%	6,30%	33	0,1911%
CAD:AUD	3	29-8-18	31-12-19	AUD	CAD	0,65%	-3,95%	-3,30%	350	-0,0094%
CHF:AUD	1	19-11-14	31-12-19	AUD	CHF	1,16%	-18,53%	-17,37%	1.335	-0,0130%
CRC:CHF	1	15-1-15	6-3-15	CRC	CHF	0,39%	14,91%	15,31%	37	0,4137%
CRC:CHF	2	22-5-17	4-5-18	CRC	CHF	2,43%	2,72%	5,15%	250	0,0206%

CRC:CHF	3	1-11-18	25-11-19	CRC	CHF	7,70%	-0,54%	7,16%	278	0,0258%
EUR:AUD	1	20-12-10	31-7-13	EUR	AUD	1,37%	10,59%	11,96%	683	0,0175%
EUR:AUD	2	21-8-15	17-1-17	AUD	EUR	6,31%	3,35%	9,66%	368	0,0263%
EUR:AUD	3	23-3-18	31-12-19	AUD	EUR	10,18%	-8,78%	1,40%	463	0,0030%
GBP:FJD	1	16-12-14	23-2-16	FJD	GBP	12,30%	-6,90%	5,40%	311	0,0174%
GBP:FJD	2	24-6-16	17-10-19	GBP	FJD	-5,77%	7,00%	1,22%	865	0,0014%
HRK:AUD	1	24-8-15	9-2-17	AUD	HRK	7,70%	6,51%	14,22%	384	0,0370%
HRK:AUD	2	5-3-18	31-12-19	AUD	HRK	10,18%	-9,58%	0,60%	477	0,0013%
HRK:CHF	1	15-1-15	27-7-17	HRK	CHF	4,12%	12,43%	16,55%	661	0,0250%
HRK:EUR	1	2-1-15	10-8-15	HRK	EUR	-6,45%	8,91%	2,45%	157	0,0156%
HRK:EUR	2	12-1-16	11-3-16	HRK	EUR	4,14%	-2,64%	1,50%	44	0,0340%
HRK:EUR	3	2-2-17	16-11-17	EUR	HRK	-7,03%	9,40%	2,37%	206	0,0115%
HRK:EUR	4	5-1-18	31-12-19	EUR	HRK	7,60%	-6,79%	0,80%	518	0,0016%
MAD:AUD	1	8-7-15	15-2-17	AUD	MAD	3,32%	3,77%	7,09%	421	0,0168%
MAD:AUD	2	7-9-18	31-12-19	AUD	MAD	1,18%	-1,20%	-0,02%	343	-0,0001%
MAD:HRK	1	2-1-15	11-4-16	HRK	MAD	5,46%	-2,59%	2,87%	332	0,0086%
MAD:HRK	2	17-11-16	21-3-17	HRK	MAD	-0,12%	3,36%	3,23%	89	0,0363%
MAD:HRK	3	21-7-17	8-11-18	MAD	HRK	0,05%	2,92%	2,96%	340	0,0087%
MXN:JPY	1	2-1-15	24-8-15	JPY	MXN	15,98%	1,76%	17,73%	167	0,1062%
MXN:JPY	2	20-1-16	31-12-19	MXN	JPY	-2,15%	-7,11%	-9,27%	1.030	-0,0090%
NOK:AUD	1	6-1-15	1-9-15	NOK	AUD	-6,52%	15,18%	8,66%	171	0,0506%
NOK:AUD	2	1-12-15	15-3-18	NOK	AUD	11,76%	-6,08%	5,68%	598	0,0095%
NOK:HRK	1	15-12-14	31-12-19	NOK	HRK	-14,76%	7,68%	-7,08%	1.317	-0,0054%
NZD:NOK	1	21-11-14	14-5-18	NOK	NZD	14,04%	-15,26%	-1,22%	907	-0,0013%
PLN:CAD	1	24-11-17	2-10-18	CAD	PLN	5,47%	-0,84%	4,62%	223	0,0207%
PLN:CAD	2	31-12-18	13-2-19	CAD	PLN	3,01%	2,89%	5,90%	33	0,1789%
RON:MYR	1	24-8-15	25-5-18	MYR	RON	3,86%	7,08%	10,95%	720	0,0152%
RON:PLN	1	8-2-16	31-3-16	PLN	RON	-1,78%	6,58%	4,80%	39	0,1231%
RON:PLN	2	1-12-16	1-2-17	PLN	RON	-0,17%	5,33%	5,17%	45	0,1149%
RON:PLN	3	1-11-17	2-7-18	RON	PLN	-1,09%	3,76%	2,66%	174	0,0153%
RON:PLN	4	16-1-19	31-12-19	RON	PLN	-3,63%	0,93%	-2,69%	250	-0,0108%
RUB:FJD	1	11-12-14	24-6-19	RUB	FJD	-9,89%	8,49%	-1,39%	1.183	-0,0012%
RUB:GBP	1	4-12-14	7-3-17	RUB	GBP	-6,57%	28,44%	21,87%	589	0,0371%
RUB:INR	1	29-12-14	20-6-19	RUB	INR	-7,29%	9,19%	1,89%	1.169	0,0016%
RUB:RON	1	11-12-14	18-4-19	RUB	RON	-11,74%	18,26%	6,52%	1.136	0,0057%
SEK:AUD	1	24-8-15	8-7-16	AUD	SEK	4,02%	5,72%	9,74%	230	0,0423%
SEK:AUD	2	27-10-16	14-8-17	SEK	AUD	11,95%	-3,32%	8,62%	208	0,0415%
SEK:FJD	1	29-12-14	31-12-19	SEK	FJD	-16,07%	7,50%	-8,57%	1.307	-0,0066%
SEK:NZD	1	13-11-14	24-8-15	SEK	NZD	-9,94%	21,63%	11,68%	203	0,0575%
SEK:NZD	2	24-6-16	25-8-17	SEK	NZD	6,18%	-1,47%	4,71%	306	0,0154%
TRY:RUB	1	15-12-14	15-11-16	RUB	TRY	38,49%	0,42%	38,92%	502	0,0775%
TRY:RUB	2	10-1-17	31-12-19	TRY	RUB	-36,32%	3,03%	-33,29%	776	-0,0429%
UAH:ISK	1	2-1-15	4-7-19	UAH	ISK	-38,70%	-2,32%	-41,02%	1.175	-0,0349%
VND:MXN	1	2-1-15	31-12-19	MXN	VND	8,35%	-21,65%	-13,30%	1.303	-0,0102%

Note: Rows that are coloured in red are those whose position are still opened at the end of the dataset, 31/12/2019.