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Carry Trades

In a portfolio context

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Executive Summary

This report provides a performance and risk analysis of both carry trades and equity strategies during the time-period of 2002-2016. The measured time-period is divided into three sub-periods showing different economic circumstances to see how both performance and the relationship between carry trades and equities evolve. This is to explore the possibility of carry trades working as a complement to an equity based portfolio and to determine if it can create diversification during the time of need. The method of analysis includes applying the principles of modern portfolio theory to carry trades and equities, while trying to create efficient portfolios using Markowitz' efficient frontier. The findings of the analysis show how traditional thoughts of carry trades' crash risk are put into perspective, as neither equities nor carry trades show a normal distribution. Carry trade portfolios show high Sharpe Ratios but have increasing correlations with equities during the time of crisis, which makes it less desirable for reasons of diversifications. Further results show how the implementation of transaction costs can lead to the added suffering of carry trades during increased financial uncertainty. The traditional saying regarding carry trades "going up by stairs and down by elevators" further gains momentum through the paper's results of maximum drawdown duration risk and much lower median returns for carry trades than equities.

1. Thesis Introduction

The first part of the thesis introduces the topic of the paper and my personal inspiration for writing about it; hereafter I am presenting my problem statement and how it will be operationalized.

1.1 Background

The current financial landscape has seen large increases in all equities since the financial crisis exemplified by record levels in major indices such as the Dow Jones Industrial Average index (Rushe, 2017). During this period, the interest rates have been at historically low levels due to the expansive monetary policies by central banks. Due to the pursuit of returns, the interest rates have, in some opinions, driven up the price for equities, leaving doubt about further future price increases (Plesner, 2014). These macro-economic developments have an impact on the topic of this paper, carry trades, in two ways. Firstly, the low-interest environment has made carry trades less intriguing in the last few years. Secondly, the current price level in equities can push investors towards seeking alternative risk premiums – such investment could be carry trades.

Fed increased the interest rate for the United States in December 2016 (Neate, 2016) for only the second time since 2008, while increasing inflation figures for other areas such as the Eurozone (Jones and Wagstyl, 2017) puts pressure on central banks to change their monetary policies. This could cause larger spreads between interest rates, which in turn could truly spark a comeback to the carry trade.

A carry trade, which will be further elaborated upon, is an investment in a high-interest currency by borrowing in a low-interest currency. This strategy through interest spreads could, therefore, be a sign of market neutrality, as the apparent exposure to equities is non-existing. Market neutral investment strategies are obviously popular due to the fact they can generate returns in all market conditions; however, the lack of transparency in these strategies can also cause major losses. A great example is the rise and fall of Long-Term Capital Management – a fund managing to earn prolific returns before crashing four years later, showing underlying risks not known to the investors prior to the investment (Lowenstein, 2001)**.** This is comparable with carry trades in the concept of Taleb (2007)'s theory of "Black Swans", who recognized that the apparent risk is not always known, due to the occurrence of unlikely events. For a carry trade, the underlying risks lie in the exchange rate movements, which can be impacted in many ways. The historic presence of "Black Swans" and possible currency crashes in exchange rates can be derived from the often-used saying regarding carry trades: "Going up by the stairs and down by the elevator" (Brunnermeier, Nagel, and Pedersen 2008, p. 314), indicating many small profits and few large losses.

The theme of the dissertation is carry trade as either an investment alternative or complement to an equity portfolio. In contrast to Koijen, Moskowitz, Pedersen, and Vrugt (2013), I will focus exclusively on currency carry strategies within the most frequently traded currencies, rather than focusing on carry trades across different asset classes.

This will be done in the context of modern portfolio theory by looking at carry strategies as single assets. However, as Taleb's "Black Swans" defies the normal distribution often assumed in modern portfolio theory, I will test the normal distribution through the empiric returns and see if there are other underlying risk factors to be considered when investing in carry trades. The results from carry trades will then, throughout the paper, be compared to S&P 500, to see how they fare against equities.

1.2 Personal Motivation

The field of finance has a myriad of interesting aspects and stories, which offers both academic research and countless real life issues. Its diversity and ever-growing knowledge are only a few of the reasons why I have become so passionate about it. While studying finance, it has become clear how much focus modern portfolio theory puts on equities, which makes sense from both a current and historic perspective. However, the principles of modern portfolio theory are interesting to apply to other assets, which is why I have chosen carry trades.

I have found carry trades interesting due to several factors. The foreign exchange market is the largest financial market in the world (Shapiro and Moles, 2014, p. 255). A global market such as this, which is affected by everything from macro-economic developments to political events, is something I find extremely intriguing. Due to the abundant number of factors influencing the exchange rates, it therefore seems plausible that exchange rates develop differently than predicted by the uncovered interest parity, thereby making carry trade a profitable investment strategy.

Another element I find intriguing about carry trades is concerning the market dynamics. Where traditional theories, such as the efficient market hypothesis, dictate that assets are correctly priced due to the market mechanics (Bodie, Kane, and Marcus, 2015, p. 351), carry trades can instead be self-fulfilling. This is due to selling funding currency against buying investment currency assists in appreciating the investment currency leading to a profitable carry trade.

These factors have led to my interest in looking at carry trades against the traditional equity in a modern portfolio theory context, a context where I will be looking at how carry trade performs against equity but also if it can help create better risk-adjusted returns through portfolio optimization.

1.3 Problem

Due to investors' desire for expected returns while trying to avoid variance (risk) as much as possible (Markowitz 1952, p. 77), carry trades need to either create superior returns or generate diversification for it to be considered in a portfolio. While performance and underlying risks need to be tested, the underlying hypothesis of the dissertation is that carry trades are indeed profitable and do not correlate perfectly with the equity market, creating the opportunity for diversification. The notion of carry trades' profitability is supported by the negative correlations between forward prices and future spot exchange rates found by Fama (1984) and the overall high Sharpe Ratios in carry trades proved by Koijen, Moskowitz, Pedersen, and Vrugt (2013). The overall problem statement for the thesis is described as:

"Carry trades across developed countries' currencies serve as a profitable strategy and possible complement to an equity based portfolio."

Through modern portfolio theory, individual carry trades can be used as single assets, which allows the use of modern portfolio theory principles to analyze carry trades as both single assets and as a portfolio of multiple assets. The idea is then to check if a carry trade portfolio can complement equities by expanding the efficient frontier created by Markowitz (1959).

Inspired by "Black Swans" and Long-Term Capital Management, carry trades could entail risk factors, which are not transparent by use of mean-variance statistics. This idea is strengthened by the saying returns "Go up by the stairs and down by the elevator", implying an underlining crash risk involving carry trades (Laborda, Laborda, and Olmo 2014). The chosen time-period of 2002-2016 becomes interesting, as Melvin & Shand (2017) depict carry trades to have had their worst performance during the recent financial crisis. This poses the question of how different economic environments impact the performance of carry trades and thereby also their contributions to an overall portfolio.

The problem statement will, therefore, be operationalized through these following research questions:

1. How can a carry trade strategy be back-tested to form a representative data series of its return and whether it is profitable?
2. How would a carry trade strategy perform against a passive equity strategy across different economic environments?
3. Are normal portfolio measures useful for carry trades or how could underlying risks be explained?
4. Could a carry trade strategy by means of diversification contribute to an equity based portfolio and create a better risk-adjusted return?

1.4 Significance of Study

The contribution to the field of finance and carry trades is done by looking at carry trades across different economic periods, but especially by looking at the relationship between carry trades and equities.

Analyzing the relationship and the comparative performance between carry trades and equities can give perspective to previous carry trade findings by testing it against a benchmark of stocks. Hopefully, it can challenge the current perception of carry trades instead of merely validating existing findings. By using a fresh and slightly different perspective on the subject, I will attempt to avoid the temptation of simply confirming existing results through *naive empiricism,* as described by Taleb (2007, p. 53).

"By a mental mechanism I call naive empiricism, we have a natural tendency to look for instances that confirm our story and our vision of the world – these instances are always easy to find."

In addition to expanding the academic knowledge on the subject, the results are meant to enlighten any potential investors on the underlying performance and risk of carry trades, how it differs from equities, and whether carry trades could serve as a diversification tool by adding it to an equity portfolio.

1.5 Demarcation

The following section presents the assumptions for the thesis and the possible biases these assumptions and simplifications bring. It is beyond the scope of the thesis to stress them all.

<u>Transaction Costs & Interest Margins</u>

Throughout the return series, and in the creation of the optimal portfolios, transaction costs for exchanging currencies, together with the different interest margins between bid and ask rates, are not considered. These costs will only be measured approximately in the latter part of the thesis to help give an overall picture of their relative size. The inclusion of these in the return series would likely have a negative impact on the overall return results and are to be considered by any potential investor. The difference in return could, thereby, also change the overall weights in optimal portfolio creation.

<u>The Risk-Free Rate</u>

The 3-month LIBOR rate is used as the proxy for the risk-free rate. I will not engage in discussions on whether this can be considered risk-free or not, a discussion that has gained more momentum since the credit crisis in 2008 and the Euro crisis in 2011.

Liquidity & Credit Risk

By assuming a risk-free rate and using the most traded currencies, credit risk, in terms of deposit, and liquidity risk of entering and exiting strategies will not be further investigated. Using transactions costs would help reflect some of these risks, as they impact the spread between bid and ask rates. Pedersen, Nagel & Brunnermeier (2009) argued that the return on carry trade could be a premium for providing liquidity, a paper giving further insight into the potential liquidity risk and cycles when doing carry trades.

Time-period

The chosen time-period of 2002-2016 and the subsequent periods of 2002-2006, 2007-2011 and 2012-2016 have been chosen to show arguably a full economic cycle, where each sub-period show a different economic phase. I will not engage in further discussions regarding characteristics of the time-period other than identifying them as the prosperous period (2002-2006), the financial crisis (2007-2011), and the economic recovery (2012-2016).

Required Return

When evaluating the return of an investment strategy, the required return would be a way to see if investments create or destroy value. The required return can be impacted by things such as liquidity risk, credit risk, the degree of market risk, and whether the investment is leveraged or not. The return series are created based on the investor already having one unit of currency in hand, borrowing one unit at the risk-free rate and investing two units at the risk-free rate for the investment currency. Thereby being “one long” in the risk-free rate and “one long” in the carry trade. A further discussion of the degree of required return will not be discussed but would be relevant if comparing the results to other investment types.

Choice of Currencies

I have included the four most traded currencies (Desjardins, 2016): United States Dollar (USD), Euro (EUR), Great British Pound (GBP), and Japanese Yen (JPY). In addition to these, I have also included Swiss Franc (CHF), since it is an interesting case due to both being historically stable and being unpegged from the Euro in 2015. Common for all is that they are developed countries, which means no developing countries have been included in the analysis. Emerging markets, although excluded from the analysis, would be interesting to include in a carry trades, as the difference in economic development might cause their exchange rate to behave differently than developed markets. However, if the analysis had included emerging markets, it is important to note the increased political and legal risks, as these countries might show risks not limited to limitations on foreign exchange trades and rapid changes in monetary policies.

All return series have been created from an American investor's point of view, and thereby against USD, which means all currencies either have a long or short[1] position. This is different from other studies such as Koijen, Moskowitz, Pedersen, and Vrugt (2013) and Melvin and Shand (2017)**,** where long (short) positions are only taken for currencies with interest rates in the higher (lower) end of the scale, leaving neutral positions for currencies with average-sized interest rates.

Outside Risk Factors to Carry Trades

There are many things impacting the exchange rate besides the overall macro-economic period; some of the major ones in my analysis include the CHF unpegged from the Euro in 2015 and the Euro Crisis in 2011. Outside factors impacting the exchange rate will not be further discussed; instead, the focus will be on the defined three time-periods 2002-2006, 2007-2011, and 2012-2016. Using quantitative data to estimate correlations between carry trades and equities during the specific time-periods, the results may miss out or under-estimate how specific political, or other major events, temporarily impact exchange rates and thereby carry trade returns.

Creation of Optimal Portfolios

- *Long Only*

In creating the optimal portfolio, I am restricting the portfolio not to include short positions in any of the assets. This is done as I want to measure how traditional carry trades fare during all times, wherefore a short position goes against the overall purpose of the analysis. For the use of short positions in carry trades I refer to the findings of Laborda, Laborda, and Olmo (2014), who found optimal portfolio strategies to include going short in currency carry trades during periods of financial uncertainty.

- *Expected Utility and Risk Aversion*

In modern portfolio theory, the efficient (optimal) portfolios will maximize utility at a given risk aversion (Markowitz 1959, p. 129). As risk-aversion can differ both between investors and change over time, especially during poor economic times, I will not attempt to identify any specific degree of risk aversion. I will instead assume risk aversion to be the same as the identified weighted equity portfolio, which is a weighted portfolio between equities and the risk-free asset. The optimal portfolio is thereby identified as the portfolio with the highest risk-adjusted return based on the same risk as the weighted equity portfolio, which consists of 70% equities and 30% in the risk-free asset.

[1] See Concept Definitions

Tax

This paper will refrain from including taxation in the analysis. As carry trades involve several legal jurisdictions, it is too complex for this sort of analysis and will only complicate the results. Instead, I will presume a marginal tax of 0%.

Investor Base

I will not engage in the restrictions on which investors can enter carry trade strategies and the impact hereof. However, this is naturally something to take into consideration, as restrictions can affect the liquidity of carry trades as well as impacting the degree of the perfect capital market. A carry trade often needs high margins or large transactions, as the case is with future and forward contracts. This limits the number of private investors, whereas the professional investor is often measured against an equity index benchmark (Bodie, Kane, & Marcus, 2014, p. 838), which would make them less inclined towards strategies with low market correlations.

1.6 Limitations & Critique

Selection Bias and Data Snooping of Currencies and Time-Period

In choosing only five different currencies to create the carry trade strategies, there is an argument to be made for selection bias, which also comes to show when it is only developed countries. Choosing the Swiss Franc due to its known historic stability up until 2015, after which it greatly appreciated, can be argued to be data snooping. In regards to the chosen time-period of 2002-2016, it represents recent financial history, while it arguably also represents a full economic cycle. It can be further argued that the recency of the observations makes it more representative than previous studies, as the financial world is constantly evolving leading to potential outdated data. The critique of this, however, is that a time-period including one of the worst crisis in recent memory might not be representative for years to come.

Using Historic Observations

By using past observations for portfolio optimization, it is also assumed that correlations between strategies are constant; however, with thoughts to the random walk theory (Malkiel, 1973), these correlations might not remain constant in the future.

Tradability of the Simulated Strategies

The carry trade strategies have been constructed manually by borrowing one unit of currency from the funding currency and investing it in the investment currency at the risk-free rate, while closing each position at the end of each month. This strategy is not as tradeable a carry trade as it is selling and buying forward contracts of currency, since the higher number of transactions makes it more complex and time-consuming.

Risk-Aversion in Creating the Optimal Portfolio

In creating the optimal portfolio, the risk-free rate is substituted with a certain weight of carry trade strategy to create a portfolio with the same underlying risk, as the weighted equity portfolio. While this assumes same risk-aversion, it is doubtful whether a risk-averse investor would truly allow a risk-free rate to be substituted with a carry trade and feel the same risk-exposure, as it can affect other risk-measures than the sheer variance. This critique is in line with the argument by Statman (1987, p. 362), saying: *"Alternative approaches to portfolio construction exists. One is the framework in which investors are concerned about the skewness of the return distribution as well as with the mean and variance"*.

Data Limitations

- *Data Frequency*

The returns series are created with monthly frequency using the end of the month prices, hereby assuming it is representative of the overall correlations, risk measurements, and performance. However, changing the frequency of observations will likely have an impact on the overall results, as shown in section 4: "Challenging the Assumptions".

- *LIBOR Rates*

The 3-month LIBOR rates have been calculated from a yearly yield down to a monthly yield, assuming a flat yield curve. Subsequently, it is assumed the relative spread between two countries interest rate is the same for both yearly and monthly figures.

1.6 Concept Definitions

Carry Trade	The strategy of borrowing at the risk-free rate in the funding currency and investing in the risk-free rate in the investment currency, thereby earning the "Carry". The four single carry Trades in this paper will be described as: USD/EUR, USD/GBP, USD/JPY, and USD/CHF.
Investment & Funding Currency	In carry trades, the investment currency is the high-interest currency, where the funding currency is the low-interest currency.
Long & Short positions in carry trades	A long (short) carry trade is therefore borrowing (investing) in the funding currency and investing (borrowing) in the investment currency.
Exchange Rate	All exchange rates are cross currency rates against USD in direct quotation, meaning USD/EUR shows the number of USD per unit EUR.
Weighted Carry Trade	The weighted carry trade is a portfolio equally weighting the four single carry trade strategies as four independent assets.
Weighted Equity Portfolio	The portfolio, which is deemed the standard portfolio for the investor in terms of risk-aversion, consists of 70% equities and 30% in the risk-free asset. Equities are measured as the equity index Standard and Poor's 500 (S&P 500) and the risk-free rate as the USD 3-month LIBOR rate.
Optimal Portfolio	The portfolio created through the analysis, attempting to give the highest risk-adjusted return through a combination of weighted carry trade and equities, while assuming the same apparent risk as the weighted equity portfolio measured in standard deviation.

Kindly see data section for elaborate descriptions of the data used for the thesis.

2. Methodology

2.1 Introduction

In this section, I will detail the methodology used for the analysis, including the theory of modern portfolio theory and the current studies made on carry trades. The data used for the analysis will be presented and explained before describing in detail how I am building the carry trade and portfolio optimization models.

2.2 Paradigm

The entire thesis is based on a positivistic approach, which views reality as an objective truth. I will be using this view when deducting results based on quantitative historic data to assume the performance of various strategies in the future. However, keeping in mind the assumptions and limitations of the thesis, the result of the analysis might not be exactly transferable to reality, but instead closely mirror it. This idea leans more towards post-positivism, as described by Guba (1990, p. 20).

"*… Postpositivism moves from what is now recognized as a "naive" realist posture to one often termed* critical realism*. The essence of this position is that, although a real world driven by real natural causes exists, it is impossible for humans truly to perceive it with their imperfect sensory and intellective mechanisms."*

A critique of the paper is the lack of other paradigms than positivism and post-positivism, as a constructivist approach would help shed light on how social structures affect carry trades during different liquidity cycles and how political changes might affect the overall exchange rates. Despite this, the post-positivist approach is deemed most applicable as it allows the results to be applied for other time-periods and future analysis, which is the core purpose for back-testing an investment strategy.

2.3 Modern Portfolio Theory

In the following section, I will discuss modern portfolio theory (MPT) and how I will apply it in the context of carry trades. However, prior to going in depth with the theory, I will describe in detail what the carry trade entails and how the returns are measured.

2.3.1 Anatomy of the Carry Trade

As mentioned by Koijen, Moskowitz, Pedersen, & Vrugt (2013); In carry trades, as with any type of financial asset, the return can be decomposed into:

$$R = Carry + E(\Delta Price) + Unexpected\ \Delta Price$$

Where R is the return, "E(ΔPrice)" is the expected price change, and "Unexpected ΔPrice" is the unexpected price shock to the underlying security, which in this instance is the exchange rate.

This paper focuses on carry trades using the fixed income and spot currency market; however, it can also be done through the forward market using forward currency contracts between the investment and funding currency. Assuming the covered interest parity holds (Shapiro & Moles, 2014, p. 161), the forward prices are a direct reflection of the interest-rate spread between the countries creating a forward premium (discount) for the currency with the lowest (highest) interest-rate. The carry trade investor then sells the forward with a forward premium (funding currency) and buys the forward with forward discount (investment currency).

$$f_t > e_t = Sell\ forward$$
$$f_t < e_t = Buy\ forward$$

Where f_t is the forward exchange rate and e_t is the spot exchange rate.

The return of the carry strategy would therefore be:

$$R_i = Carry + \Delta Price$$

Where the carry would be the spread between the risk-free rate between the funding and investment currency.

$$Carry = r_{investment} - r_{funding}$$

The carry can be accurately estimated ex-ante, since the investor will know the risk-free rate for the following period. In contrast, the change in price can only be observed ex-post, when knowing the development in the exchange rate.

$$\Delta Price = \frac{\frac{e^1_{Investment}}{e^1_{funding}}}{\frac{e^0_{Investment}}{e^0_{funding}}} - 1$$

The expected total return, therefore, depends on how investors expect the development in future spot price to be. The three scenarios below detail whether the return will be greater, less than or equal to the carry. The origin behind these views will be further detailed in the carry trade literature review.

$Uncovered\ Interest\ Parity$:	$E(r) = 0$
$e_o \rightarrow e_1$:	$E(r) = Carry$
$-_{Corr}(f_1, e_1)$:	$E(r) > Carry$

2.3.2 Return, expected return and standard deviation of single assets

Return

In estimating the expected return, modern portfolio theory, in the lack of better alternatives, often uses the historic average (Bodie et al., 2014, p. 130). Consequently, it is assumed that past returns are an indicator of future returns. The two most common methods for historic averages are the arithmetic and geometric mean. The arithmetic average is the mean of the sum of all returns throughout a time series.

$$\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i$$

For a carry trade, it can be calculated as:

$$\bar{R} = \frac{\sum_{i=1}^{N} Carry + E(\Delta Price) + Unexpected\ \Delta Price}{N}$$

Where $\bar{R}$ is the arithmetic average and N is the total number of observations.

Another way to estimate the past and future returns is by using the geometric average. Where arithmetic average uses the sum of the observations, the geometric average uses the product of the values. By using the geometric average, the analyst can calculate the average return on assets that are compounded over multiple periods.

$$G_{\bar{R}} = (1 + R_c)^{\frac{1}{N}} - 1$$

Where $G_{\bar{R}}$ is the geometric mean and R_c is the cumulative return over N periods.

During this analysis, the geometric average is used for historic and expected future return, as it takes into consideration cumulative return and thereby incorporates the time-factor; this is also in line with common financial practice (Bodie et al., 2014, p. 131). Therefore, in this analysis: $G_{\bar{R}}^{i} = E(R_i)$. The arithmetic average will instead be used for risk-measure purposes, such as calculating standard deviations, further detailed below, and as the mean for the normal distribution.

Risk

On the risk side, total risk is measured as the variance and decomposed into the standard deviation to ensure unit comparability with the returns. The variance is the measure of the dispersion of a random variable and the expected value of the squared deviation from the mean (Bodie et al., 2014, p. 132). The standard deviation is the square root of the variance, and hence the expected value of the deviation from the mean. Standard deviation also takes the units of measure of the data it represents, which ensures comparability.

$$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}[R_i - \bar{R}]^2$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(R_i - \bar{R})^2}$$

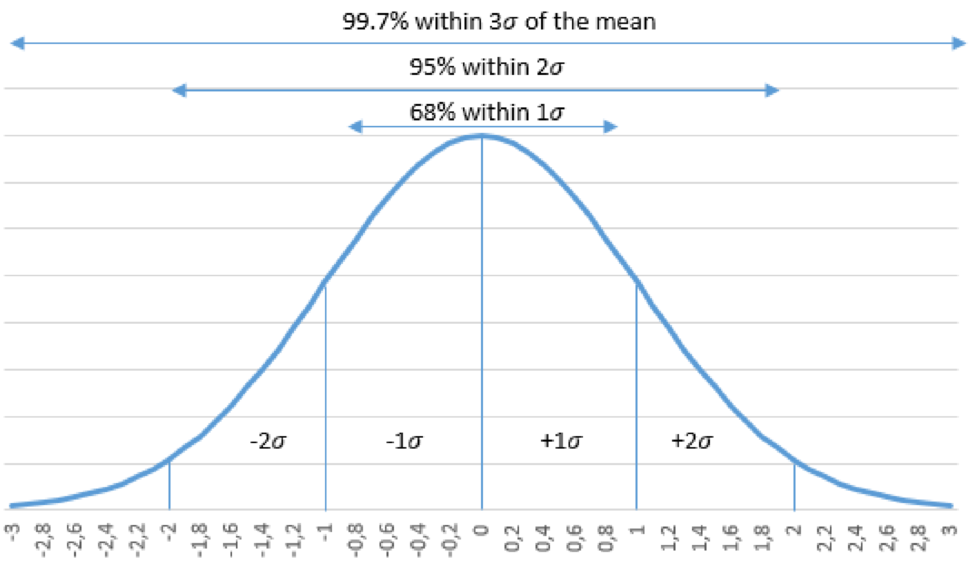
Where σ^2 denotes the estimated variance based on N number of observations and σ is the standard deviation.

The standard deviation as a measure of total risk assumes that the returns follow the normal distribution, which I will be testing whether they do or not. The testing of the normal distribution can thereby show whether standard deviation is a valid measure of the total risk.

2.3.3 The Normal Distribution

While modern portfolio theory is a tool for analyzing both single assets and entire portfolios, it assumes a normal distribution by using the standard deviation as a risk-measure (Bodie et al., 2014, p. 135). Before elaborating on performance measures, asset pricing models and portfolio optimization, it is therefore important to understand the underlying assumption regarding the normal distribution and which complications it creates if the returns are not normally distributed.

The normal distribution is a bell-shaped distribution, which characterizes the distribution pattern of many natural phenomena. It outlines how most of the observations will tend to fall close to the mean, where larger deviations from the mean are less probable.

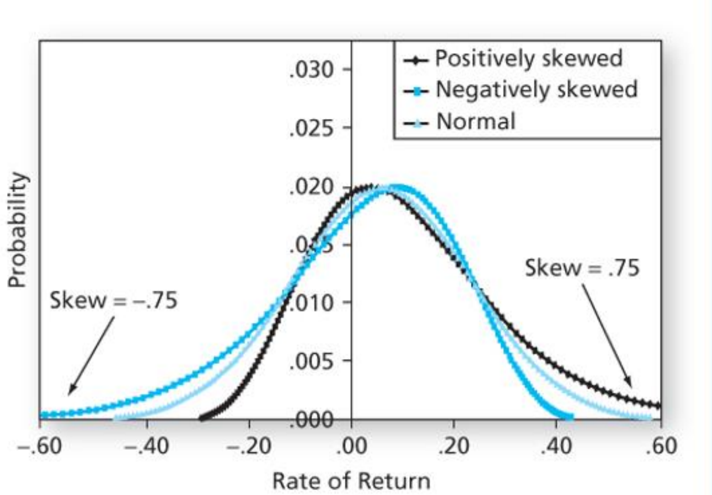


The normal distribution (own creation).

In the normal distribution, the standard deviation therefore shows the risk of extreme observations. The symmetry on each side of the mean in the normal distribution shows how the normal distribution has a skewness of 0. Skewness measures the asymmetry of the distribution by the ratio of the average cubed deviations from the mean. Positive (negative) skewness indicates the distribution is skewed to the right (left) of the mean, which in an investment perspective gives the investor a better idea of possible extreme returns and, thereby, the risk associated with the asset or investment strategy.

$$Skewness = Average\left[\frac{(R_i - \bar{R})^3}{\sigma^3}\right]$$

A negatively skewed distribution of returns show larger extreme negative returns than dictated by the normal distribution, and can thereby be an indicator of crash risk of the underlying asset.

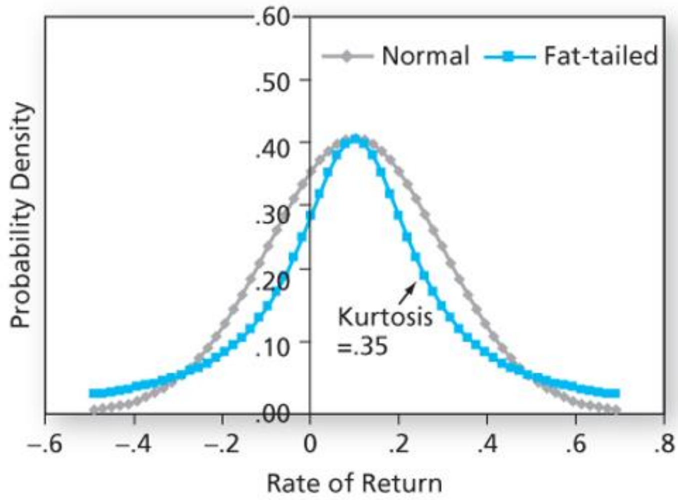


From "Investments", Bodie, Kane, Marcus (2014).

Kurtosis is another way to measure the distribution of observations, as it measures if there are any "fat tails", meaning more extreme observations than dictated by the normal distribution. As kurtosis in the normal distribution has a value of 3, the excess kurtosis can be calculated as follows:

$$Excess\ Kurtosis = Average\left[\frac{(R_i - \bar{R})^4}{\sigma^4}\right] - 3$$

The standard deviation can be used to measure the probability of extreme returns. Therefore, a distribution with a high kurtosis can undermine this risk-measure, as the extreme returns are more frequent than under the normal distribution and its subsequent standard deviation. A great example of where this is applicable in financial theory, is the common use of Value at Risk (VaR). The one-day 95% VaR defines the maximum value a portfolio can lose in a single day with 95% probability. However, since this measure assumes a normal distribution, it will not reflect the true risk for a portfolio with a high excess kurtosis.[2]



From "Investments", Bodie, Kane, Marcus (2014).

Median

The median is defined as the middle value of a data set, when observations have been sorted in the order of size. In a normal distribution, the median would equal the mean, but when a distribution is not normally distributed, the extreme returns will have a larger impact on the arithmetic mean than on the median. Throughout this paper, the median will be used to give an indication of the distribution of data, as large deviances between the mean and the median show shortfalls of mean-variance techniques.

2.3.4 Jarque-Bera Test

A way to test the normality of a distribution is through the Jarque-Bera (JB) test (Lhabitant, 2004, p. 48). Here, the null hypothesis is that observations are normally distributed, whereas the alternative hypothesis is that observations do not fall within the normal distribution. JB tests the distribution based on the skewness and excess kurtosis, which under a normal distribution have values of 0.

$$Jarque\ Bera = \frac{T}{6}\left[Skewness^2 + \frac{Kurtosis^2}{4}\right]$$

Where T is the number of observations.

[2]VaR further detailed in section 2.3.5

JB follows a distribution with two degrees of freedom and the critical values of 9.21 and 5.99 show the 1% and 5% level of significance respectively. I will focus on the 5% significance level throughout the analysis. If the calculated JB value is greater than the critical value, the null hypothesis of a normal distribution is rejected.

2.3.5 Value at Risk (VaR)

Value at Risk (VaR) is, as previously mentioned, a common measure of total risk for the investment (Lhabitant, 2004, p. 53). It is based on the concept of standard deviation and normal distribution measuring the maximum loss an investor can incur at a given level of probability. The 95% VaR, which measures the maximum loss with 95% certainty, is calculated as:

$$VaR = -1.65 * \sigma_i$$

Where the time measure for the standard deviation is the same as the measured VaR, e.g. monthly. Often the investment value is multiplied to show VaR in dollar figures; however, in this paper VaR will be expressed in percentage.

2.3.6 Drawdown & Expansion

Drawdown is a risk measure and can be used for assets to determine the risks using the cumulative return of an asset or, in my case, a carry trade strategy. Drawdown is defined as the difference between the assets cumulative value and its historical high measured in percentage, which can be calculated as:

$$DD(t) = \max[0, max_{t\in(0,T)} \frac{CT_t}{CT_T} - 1]$$

Where CT_t is the cumulative return and CT_T is the historical high. The drawdown is therefore measured as the relative difference between the current cumulative return and its peak value. Expansions are defined as the times drawdown equals 0, which signals new historic highs. Drawdown duration is the length of time between expansions; i.e. from peak to peak. Maximum drawdown measures the “peak to valley”; i.e. the largest drawdown over the analyzed period, where maximum drawdown duration is defined as the longest time-period between expansions. Drawdown as a risk measure can be easier to interpret than standard deviations and can be applied to distributions not following a normal distribution. As Lhabitant (2004, p. 56) says:

“Drawdowns have one major advantage over volatility: they refer to a physical reality, and as such they are less abstract.”

2.3.7 Portfolio consisting of N assets

In the analysis, all single carry trade strategies will be viewed as independent assets, which are then used to form portfolios of multiple assets. Having a portfolio consisting of N number of assets, the expected return of the portfolio is calculated by the sum of the weighted returns (Bodie et al., 2014, p. 208).

$$E(R_p) = \sum_{i=1}^{N} W_i * E(R_i)$$

Where $Wi\ x\ Ri$ is the weight and return of each asset.

Matrices will be used when calculating optimal portfolio weights, and using matrix notation the return of the portfolio is calculated as:

$$E(R_P) = (w_1 \quad w_2 \quad w_n) * \begin{pmatrix} R_1 \\ R_2 \\ R_N \end{pmatrix}$$

Assuming a normal distribution, the variance of the portfolio will be calculated as:

$$\sigma_p^2 = w_m^2 * \sigma_m^2 + w_i^2 * \sigma_i^2 + 2 * w_i * w_m * \sigma_{im}$$

With the standard deviation being the root of the formula.

$$\sigma_p = \sqrt{w_m^2 * \sigma_m^2 + w_i^2 * \sigma_i^2 + 2 * w_i * w_m * \sigma_{im}}$$

By using the correlation instead of the covariance, the formula can be written as follows:

$$\sigma_p = \sqrt{w_m^2 * \sigma_m^2 + w_i^2 * \sigma_i^2 + 2 * w_i * w_m * \sigma_i * \sigma_m * P_{im}}$$

These specific formulas are critical, as they show the value created by diversification. They show how correlation and covariance between the individual assets impact the overall risk of the portfolio.

The covariance measures the joint variability of two assets, where the sign of the covariance indicates the tendency in the linear relationship between the assets. If the covariance is positive, the assets tend to show similar behavior, which means asset A gives positive returns at the same time as asset B. The covariance between two assets can be calculated as:

$$Cov_{A,B} = \sigma_{A,B} = \frac{\sum_{i=1}^{n}\left(R_i^A - E(R_A)\right) - \left(R_i^B - E(R_i^B)\right)}{N-1}$$

Where N denotes the number of paired observations.

To calculate the covariance between assets, I will be making a covariance matrix, which proves useful when calculating the optimal portfolio strategies. The covariance will be calculated for N assets as seen below; the covariance of asset 1 and 1 will be the variance of the actual asset, which is also illustrated as follows:

$$Covariance\ Matrix = \begin{bmatrix} \sigma_{1,1} & \sigma_{1,2} & \sigma_{1,N} \\ \sigma_{2,1} & \sigma_{2,2} & \sigma_{2,N} \\ \sigma_{N,1} & \sigma_{N,2} & \sigma_{N,N} \end{bmatrix}$$

The linear relationship can also be seen in the sign of the correlation coefficient. A negative correlation means asset A tends to increase when asset B decreases. The strength of this tendency is determined by the value of the correlation coefficient, where a high value equals a strong tendency.

The correlation coefficient between two assets can be derived as:

$$\rho_{A,B} = \frac{Cov_{A,B}}{\sigma_A * \sigma_B}$$

Remembering the formula for portfolio variance, the correlation determines whether there is a reduction of total risk by pooling assets together in a larger portfolio, which is the concept of diversification.

To illustrate the reduction of risk, I will use the following three examples: perfect positive correlation, zero correlation, and perfect negative correlation.

Imagine two assets, where asset A could be a carry trade strategy and asset B could be the SP500 index.

$$\rho_{A,B} = +1 \rightarrow Perfect\ positive\ correlation$$
$$\rho_{A,B} = \quad 0 \rightarrow zero\ correlation$$
$$\rho_{A,B} = -1 \rightarrow Perfect\ negative\ correlation$$

2.3.8 Correlations and diversification

Perfect Positive

If the carry trade strategy and the SP500 have a correlation coefficient of positive one, there will be zero diversification, which can be showed as:

$$\sigma_P^2 = w_A^2 * \sigma_A^2 + w_B^2 * \sigma_B^2 + 2 * w_A * w_B * \sigma_A * \sigma_B * P_{A,B}$$

If the correlation is +1, it can be re-written as:

$$\sigma_P^2 = w_A^2 * \sigma_A^2 + w_B^2 * \sigma_B^2 + 2 * w_A * w_B * \sigma_A * \sigma_B$$

$$\Downarrow$$

$$\sigma_P^2 = (w_A * \sigma_A + w_B * \sigma_B)^2$$

The total risk is, therefore, a product of the weighted risk of each asset; i.e. no diversification benefit.

Zero Correlated Assets

If the assets are uncorrelated with a correlation coefficient of zero, the portfolio variance formula will be:

$$\sigma_P^2 = w_A^2 * \sigma_A^2 + w_B^2 * \sigma_B^2$$

The lack of a linear relationship creates a diversification benefit, which can be seen from the formula above.

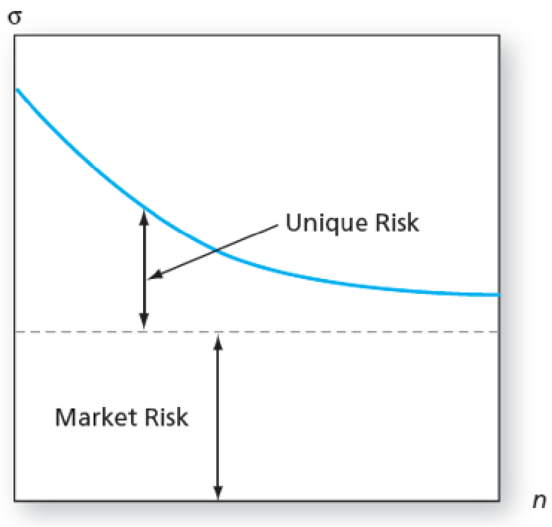
Perfect Negative Correlation

If the two assets have a perfect negative correlation, the assets will always move in the opposite way of each other; i.e. if asset A increases, asset B will always decrease.

The formula for the portfolio variance will therefore be:

$$\sigma_P^2 = (w_A * \sigma_A - w_B * \sigma_B)^2$$

By having the perfect negative correlation, the portfolio can, in theory, have a variance (risk) of zero, if weighted properly.



Diversification

Assuming correlations less than +1, the risk of portfolios can therefore be reduced by increasing the number of assets, which is the core concept of diversification. This illustration shows how the overall risk is reduced with increasing number of assets, as the exposure to the unique risk of each asset (unsystematic risk in CAPM[3]) is reduced, so most risk exposure is to the overall market (systematic risk in CAPM).

From "Investments", Bodie, Kane, Marcus (2014).

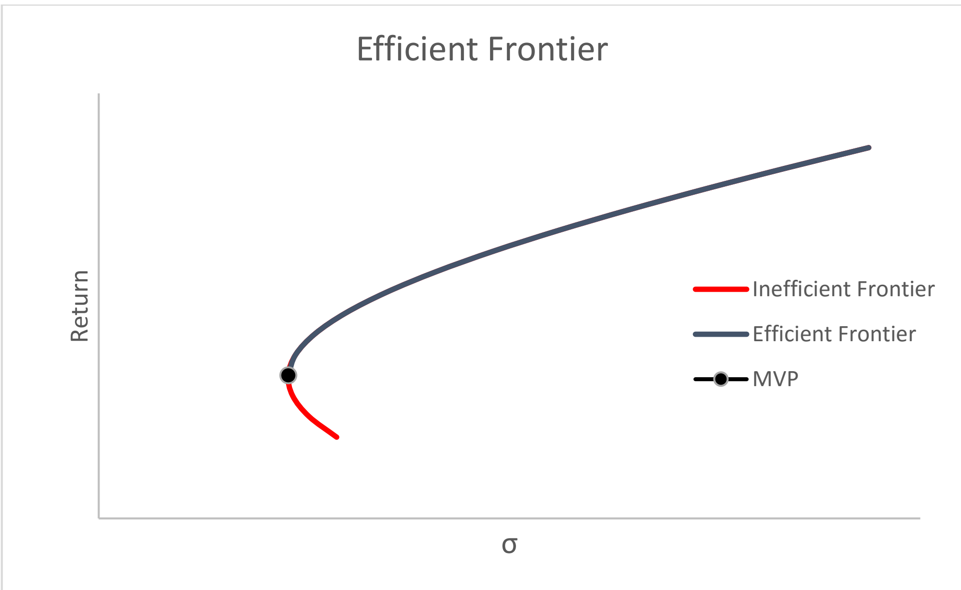
[3] CAPM is further defined in section 2.3.12.

<u>Note: Portfolio of N Assets in Carry Trade Context</u>

In this paper, a portfolio of N assets and the diversification it brings will be applied in two contexts. Firstly, the weighted carry trade is a portfolio consisting of all four analyzed carry trade strategies, which attempts to reduce the idiosyncratic risk each strategy has. The idiosyncratic risk is characterized by being unique; for a carry trade, it could be either political or economic factors such as the balance of payments for that specific currency. The interpretation of risk can differ a bit from the systematic risk of CAPM, as a carry trade's risk premium is not necessarily created through systematic risk measured in its beta. It can instead be created through things such as crash risk and liquidity premium as argued by Brunnermeier et al. (2008). Secondly, the weighted carry trade is used in a portfolio together with equities creating "the optimal portfolio", which tries to increase the risk-adjusted return through a correlation less than +1 between equities and carry trades.

2.3.9 The Efficient Frontier

Markowitz (1952), a pioneer of the modern portfolio theory, developed the concept of the efficient frontier. This frontier represents the portfolios giving the highest return at any given risk measured in the standard deviation and the correlations between the assets play a large role, as they are what "pushes" the frontier to the left and thereby decreasing risk while maintaining return. The efficient frontier starts at the minimum variance portfolio and moves up along the solid line, which represents the efficient portfolios available at different risk intervals. By excluding a risk-free asset, a rational investor will invest along the efficient frontier depending on individual risk aversion, as discussed by Markowitz (1959).



The efficient frontier (own creation with inspiration from Markowitz).

I will be using the efficient frontier to identify the optimal portfolios, where the combination of carry trades and equities will make up the efficient frontier starting from the minimum variance portfolio. The minimum variance portfolio (MVP) of two assets is calculated as (Bodie et al., 2014, p. 213):

$$w_{A,MVP} = \frac{\sigma_B^2 - \sigma_{A,B}}{\sigma_A^2 + \sigma_B^2 - 2 * \sigma_{A,B}}$$

To follow the example from earlier, if a carry trade strategy and an equity based portfolio have a correlation of less than 1, it can by combination create a higher risk-adjusted return than independently.

Tobin (1958), contributed by including a risk-free asset to the analysis. The use of the risk-free rate in portfolio optimizations means the investor can identify the tangent portfolio having the highest Sharpe Ratio and leverage the portfolio depending on risk-aversion. This line is called the capital market line (CML) and although I am not making any assumptions about future risk-free rates and subsequently nor any assumptions regarding tangent portfolios, I will be using its related Sharpe Ratio for performance measure, which is the slope of CML.

2.3.10 Sharpe Ratio

The Sharpe Ratio, introduced by William Sharpe (1964), measures the risk premium per unit of total risk measured by standard deviation.

$$SR = \frac{R_p - R_f}{\sigma_p}$$

Where R_p is the return of the portfolio and R_f is the risk-free rate.

The Sharpe Ratio is a common use for performance measures of both single assets and entire portfolios, as it is easy to both apply and comprehend, although an important note is that normal distribution is assumed when using standard deviation as a measure of total risk.

2.3.11 M2

M2 is an adjustment of the Sharpe Ratio proposed by Franco Modigliani and his granddaughter Leah (Modigliani & Modigliani, 1997). M2 adjust the returns to the same risk of the benchmark portfolio by using the product of the Sharpe ratio and the benchmark standard deviation. By doing this, it ensures the portfolios are in the same position on the horizontal axis of the efficient frontier or CML:

$$M2 = (Sharpe\ Ratio * \ \sigma_{Benchmark}) + R_f$$

In this paper, M2 will be used to help interpret results with negative Sharpe Ratios, as M2 risk adjusts returns to the same standard deviation.

2.3.12 CAPM

The foundation of Capital Asset Pricing Model (CAPM) was laid out by Sharpe (1964), Lintner (1965), and Mossin (1966), who build upon the work done by Markowitz & Tobin.

CAPM is a model used to divide risk into unsystematic (unique) and systematic (market) risk, and uses the idea of the market portfolio, which all investors should hold. Expected return is based on the amount of systematic risk, measured in the assets beta value. The beta value, which shows how the asset tends to correlate with the market, can be derived from:

$$\beta_i = \frac{\sigma_{i,M}}{\sigma_M^2}$$

and the total systematic risk of the asset is:

$$\sigma_{sys}^2 = \beta_i^2 * \sigma_M^2$$

With total risk (variance) being:

$$\sigma_{total}^2 = \sigma_{sys}^2 + \sigma_{usys}^2$$

The statistical significance of beta will be shown through its T-stat values, which signals how many standard deviations the approximated value is from zero. A T-stat value of more than 2 would, thereby, make it significant with 95% certainty.

CAPM is based on the following conditions, outlined by Bodie et al. (2014, p. 303-304):

- Investors are rational, and mean variance optimizers.
- Investors have homogenous expectations.
- All assets are publicly traded (both long & short) and investors can borrow and lend at the risk-free rate.
- There are no transaction costs nor taxes.

In this paper, CAPM will exclusively be used for performance and risk-measure purposes, where beta illustrates whether an asset is exposed to the overall market (systematic) risk. Treynor Ratio is then used to measure the risk premium per unit of systematic risk exposure:

$$Treynor\ Ratio = \frac{R_P - R_f}{\beta}$$

2.3.12 Critique & Limitations of Modern Portfolio Theory

Mean-variance as risk-measure

MPT assumes volatility to be a good measure of risk. However, in addition to the complications surrounding the assumed normal distribution, it can prove to be a rather inadequate view of risk due to several factors. By using sheer volatility, upwards price movement is deemed to be just as risky as downside movement, although few investors would deem an asset increasing all the time as particularly risky. Furthermore, these volatilities expected returns and covariance between assets are based on historic observation, despite these might be a poor predictor of future observations based on Malkiel's random walk theory. In the concept of the efficient frontier, the optimal portfolios are created from past performances, which not necessarily represent the future. An example of this is the heat MPT received in the aftermath of the financial crisis, where portfolios did not show the level of diversification they were presumed to have, since correlations increase during the time of crisis. This increase in correlation throughout the financial sector has since been backed up by Sandoval & Franco (2012) in their paper on correlations during the financial crisis. Lastly, as previously mentioned, a normal distribution underestimates the probability of statistically unlikely events such as Taleb's "Black Swans".

The Critique by Roll & Fama

Roll's (1977) empirical research and especially his critique of the "Market Portfolio" in CAPM took away some credibility of the pricing model. The critique notes the lack of realism in terms of replicating the market portfolio, as it consists of all assets in the world, such as commodities, real estate, human capital, etc. Fama (1992) added fuel to the fire with his research, showing beta to have little explanatory power in terms of historic returns, which laid the foundations for the multi-factor model Fama-French (1996).

Perfect Capital Markets

The models used from MPT assume perfect capital markets, which in respect of CAPM also means everything is correctly priced and return only comes from the systematic risk. In this paper, where possible market neutral strategies are estimated, these theories serve as a poor indicator of expected return as they do not make room for market imperfections. Pedersen (2015, p. 4) argues that these markets are only efficient due to the presence of major investors who provide the liquidity needed for efficient markets. Thereby, arguing markets are not efficient in themselves but only nearly efficient due to heavy trading on pricing anomalies.

Despite these shortcomings, MPT is still widely used today and CAPM is still widely popular with its use of beta and concept of diversification, while having the benefit that a one-factor model is easy to comprehend. It will be interesting to see whether financial institutions, with a larger focus on big-data, are closing in on new pricing theorems or whether CAPM and mean-variance portfolio theory has become institutionalized to such a degree that it will continue its foothold in financial institutions. However, for this paper, it will not be discussed into further details.

Using Historic Returns as Expected Returns During Time of Crisis

In creating efficient portfolios, the historic return is used as the expected return. However, when having a financial crisis and possibly negative returns, it does not make sense. A rational investor would naturally want to avoid negative returns. This complicates the matter of optimizing portfolios using data from financial difficulties.

2.4 Carry Trade Literature Review

The Uncovered Interest Parity and the Forward Premium “Puzzle”

As earlier mentioned, the unknown factor in carry trades is the future spot price. The uncovered interest rate parity (UIP) states that expected change in future spot price is equal to the difference in exchange rates between the countries’ currencies (Shapiro and Moles, 2014, p. 163). This is:

$$UIP: \frac{1 + r_h}{1 + r_f} = \frac{e_t}{e_0}$$

Where r_h is the home currency’s risk-free rate, r_f the foreign currency’s risk-free rate, e_t is the future spot rate, and e_0 is the current spot exchange rate.

For a carry trade this would result in the positive return on carry exactly equaling the loss on the exchange rate, which naturally does not lead to a profitable strategy. However, Fama (1984) tested the relationship between forward premiums and actual future spot rates and found a negative correlation between the two, implying that not only does UIP not hold but the *reverse* of UIP’s prediction tends to happen. For carry traders this would mean a positive return on *both* the interest spread and the exchange rate. Later findings (Koijen, Moskowitz, Pedersen, and Vrugt 2013) have shown that this correlation factor is instead zero, meaning the high-interest currency tend to neither appreciate nor depreciate. These recent finding further support Meese and Rogoff’s (1983) findings, saying exchange rates follow the same “Random walk” as stocks do (Malkiel 1973).

The forward premium “puzzle” has attempted to be further explained since, concluding currency returns are impacted by things other than merely the interest-spread between countries. Consumption risk (Lustig and Verdelhan 2007), the crash risk of the underlying currency (Brunnermeier, Nagel and Pedersen 2008) liquidity risk (Brunnermeier et al., 2008), and financial uncertainty (Laborda, Laborda, and Olmo 2014) are some of these factors. These findings do not even include the political and economic risks we have seen lately with the unpegging of the Swiss Franc against the Euro and also the recent Euro-crisis.

Performance and Risks in Carry Trades

Studies within carry trade returns have seen how carry trades overall create a high Sharpe Ratios, negative skewness and excess kurtosis (Brunnermeier et al, 2008). Brunnermeier et al. continues to argue decreased risk-tolerance among investors can lead to the unwinding of carry trades, which then leads to currency crashes. This exposure to the overall market uncertainty has been elaborated on by regressing it against the VIX[4] index. These findings have shown positive correlations leading to investment propositions of underweighting carry trades when the VIX index is high (Laborda, Laborda, and Olmo, 2014).

The concept of carry trades being heavily affected by global risk factors is further highlighted by Lustig, Roussanov, and Verdelhan, (2011, p. 2) in their "Common Risk Factors in Currency Markets":

"By investing in high interest rate currencies and borrowing in low interest rate currencies, US investors load up on global risk."

All these findings indicate the greater risk in carry trades during the economic crisis, which due to negative skew and excess kurtosis might not be measured using normal mean-variance analysis within modern portfolio theory. Melvin & Shand (2017) tested the worst episodes of carry losses in the past decades and unsurprisingly found the largest drawdown to be during the recent financial crisis. Furthermore, they found carry drawdowns to be increasingly likely to persist the further they carried on, something they conclude to be highly relevant for potential investors. This drawdown risk in carry trades further supports the saying of "Going up by stairs and down by the elevator", as one would have to "climb many stairs" before reaching the peak from before the elevator.

The reason why the focus lies exclusively within risk-factors concerning exchange fluctuations is because almost the entire variance of carry trades comes from the exchange rate. A study (Rangvid 2003) decomposing the variance for investing Danish Crowns (DKK) in American bonds showed the exchange rate fluctuations made up 98.8% of the entire variance.

My analysis is made to build upon the current literature within carry trade, where I am testing carry trades across the most recent financial period, while testing them across three sub-periods entailing different economic environments. These results are held against the performance of equities, which is where I will

[4] VIX Index measures the implied volatility of S&P 500 index options.

attempt to expand on the current literature, as the findings will explore whether these strategies are profitable and whether they can complement equities to a higher risk-adjusted return.

2.5 Data and Model Creation

2.5.1 Introduction

All data for this paper has been gathered from Bloomberg and represents quantitative data used for financial and statistical processes. The results are then, in accordance with the deductive methodology, used to approximate future expected observations, an approach in line with the overall positivistic paradigm of this paper. Due to the quantitative nature of the data and the fact it reflects actual objective historic observations, the data set is viewed as a great reflection of reality. Furthermore, Bloomberg is viewed as having a high credibility within the financial landscape, which further increases the reliability of the data.

The following sections outline the origin of the used data and exactly how I am building the models of return series and portfolio optimization used for the analysis.

2.5.2 Data

<u>LIBOR Rates</u>

3-Month LIBOR rates using closing prices (PX_LAST) with monthly frequencies for all currencies and with both monthly and daily frequency for EUR 3-month LIBOR rate. The yearly LIBOR rate yields are made into monthly yields for return series purposes.

The LIBOR rate is the interbank offered rate (Bloomberg).

- USD Bloomberg ticker code: US0003M Index
- EUR Bloomberg ticker code: EUR003M Index
- GBP Bloomberg ticker code: BP0003M Index
- JPY Bloomberg ticker code: JY0003M Index
- CHF Bloomberg ticker code: SF0003M Index

<u>EUR/USD Deposit Rate</u>

The Eurodollar deposit rate used as closing prices (PX_LAST) for both bid- and ask-price (PX_BID/PX_ASK) with monthly frequency.

- EUR/USD Bloomberg ticker code: EDDR03M Index

Exchange Rates

Mid-price currency crosses between USD and the four other currencies; all prices are closing prices (PX_LAST) and with monthly frequencies, while USD/EUR is both monthly and daily frequency.

- USD/EUR Bloomberg ticker code: USDEUR Curncy
- USD/GBP Bloomberg ticker code: USDGBP Curncy
- USD/JPY Bloomberg ticker code: USDJPY Curncy
- USD/CHF Bloomberg ticker code: USDCHF Curncy

I will also be using bid- and ask-price (PX_BID/PX_ASK) for USD/EUR, using monthly frequency to test possible transaction costs.

S&P 500

The major American stock index S&P 500, all observations are closing prices (PX_LAST) with monthly frequency.

- S&P 500 Bloomberg ticker code: SPX Index

2.5.3 Model Creation

This sections details exactly how I have performed the analysis and how the return series for each strategy has been created. The analysis consists of three major return series, which are single strategies, weighted strategies, and the optimal strategy. All these strategies will be analyzed both in terms of their performance, but also to disclose the underlying risks associated with the strategies, modern portfolio theory will be used for both purposes. There will be a short sub-conclusion for each of the three return-series to highlight the most important observations and lessons.
All returns are calculated for the period of 2002-2016, where they are categorized into four different time-periods to see how each economic period affects returns:

- 2002-2016: The entire period.
- 2002-2006: The prosperous economic period.
- 2007-2011: The economic crisis.
- 2012-2016: The economic recovery.

Single Strategies

The return series are made based on opening the carry position at the beginning of the month and closing at the end of the month, which creates the monthly returns. The return-series assume the investor has raised one unit of currency and invests it in the investment currency's risk-free rate, while performing a carry trade simultaneously, thereby having the risk exposure towards the carry trade and its exchange rate exposure. The investment and funding currency is identified prior to the commencement of each period and the return series can therefore be calculated as:

$$R = r^I + \frac{(1 + r^I) * e_{t-1}}{e_t} - (1 + r^F)$$

Where r^I and r^F are the risk-free rate for the investment currency and funding currency respectively. e_{t-1} is the spot exchange rate at the beginning of the month and e_t for the end of the month.
The return series for the S&P 500 is simply calculated as the return from month to month.

Weighted strategies

The weighted carry trade uses the return series from the single carry trade strategies and weighs them 25% each.

$$Weighted\ Carry\ Trade\ Return = \sum_{n}^{i=1} W_{CT}^{i} * R_{CT}^{i}$$

The weighted equity portfolio consists of 70% weight in the S&P 500 index and 30% weight in the risk-free USD rate.

$$Weighted\ Equity\ Portfolio\ Return = \frac{7}{10} * R_{S\&P} + \frac{3}{10} * R_f^{USD}$$

Optimal Portfolios

The optimal portfolio is a combination-portfolio between the weighted carry trade and S&P 500. I will be creating optimal portfolios for both the entire period of 2002-2016 and each sub-period to see if the weights differ across different time-periods. The idea of the optimal portfolios is to see if the risk-adjusted return can increase through a combination of carry trades and equities compared to the alternative portfolio, which uses only equities and the risk-free rate (weighted equity portfolio).
The optimal portfolios are therefore based on maximizing the Sharpe Ratio, while having the same apparent risk exposure as the weighted equity portfolio. Practically, I am doing this by using Excel's solver program to find the optimal weights by setting criteria of not going short in any carry trades or equities and having the exact same standard deviation as the weighted equity portfolio for that time-period. The optimal weights are then used to create the return-series for the optimal portfolios.
Additionally, I am finding the minimum variance portfolio, as this helps to identify and illustrate the efficient frontier.

Challenging the Assumptions

In the latter part of the analysis, the paper tries to show the possible effect of transaction costs and what the effect of daily observations would be.

The return series for daily observations are created using the same principles as the monthly return series. However, as official trading days can vary between the United States and Europe, the data have been cleansed to only show trading days where both markets are open.

The transaction costs are estimated using bid-ask spreads for the USD/EUR exchange rate and the EUR/USD deposit rate. These are then analyzed on average spreads, minimum, and maximum spreads.

Calculations

For a further interest in how the models and calculations have been practically applied, I kindly refer to appendix 1 "Calculations Excel Guide".

2.6 Reliability & Validity

This section serves to explore the validity and reliability (Saunders, Lewis, & Thornhill, 2009, p. 156-157) of my analysis and the data I have used for model creation.

Reliability

The reliability refers to the repeatability of the analysis and whether it could consistently be done a second time. The data collection technique is based on using historic observations as data input, and applying return-series based on the same criteria across each time-period. Despite the data-snooping and selection bias detailed in the thesis' critique, the quantitative data is per definition extremely objective and, thereby, avoids observer bias, which is why the reliability of the analysis is estimated to be very high.

Validity

The validity refers to whether the results reflect what the paper intends to analyze. In my analysis, I look at carry trades and equities in a vacuum by excluding things such as transaction costs and taxes. In this, I use historic performance as an indicator of future returns, which can be a threat to the validity of the results regarding portfolio optimization for future investments, since historic performance might not be a good indicator. However, with these assumptions in mind, the credibility of the research is judged as high. The analysis measures the parameters it intends to explore by using the field of finance to elaborate on each investment strategy, which is the same field in where I try to broaden the current literature on carry trades.

3. Analysis

3.1 Introduction

The performance and risk analysis will start with all single strategies before looking at the weighted strategies and the optimal portfolios. The analysis has been structured to show the results of the overall period followed by results for each sub-period. All tables and illustrations in the analysis are using commas as the decimal mark, which is to be viewed as periods to avoid misunderstandings.

3.2 Single Carry & S&P 500 Strategies

3.2.1 Performance Analysis

2002-2016

The average monthly arithmetic average of the US 3-month LIBOR rate for 2002-2016, which is used to calculate the Sharpe Ratio, is 0.1385%. During the single strategies performance analysis, where there is a total of five different strategies, color codes have been used for convenience; ranging from dark green as the best and dark red as the worst performer.

2002-2016					
	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Geomean	0,396%	0,310%	0,247%	-0,030%	0,383%
Standard Deviation	2,977%	2,619%	2,804%	3,126%	4,149%
Sharpe	0,086	0,066	0,039	-0,054	0,059
Beta	0,196	0,144	0,142	-0,149	1,000
Beta t-stat	3,772	3,112	2,860	-2,692	0,000
Treynor	1,315%	1,194%	0,765%	1,131%	0,244%
Correlation With S&P	0,2728	0,2278	0,2102	-0,1983	1

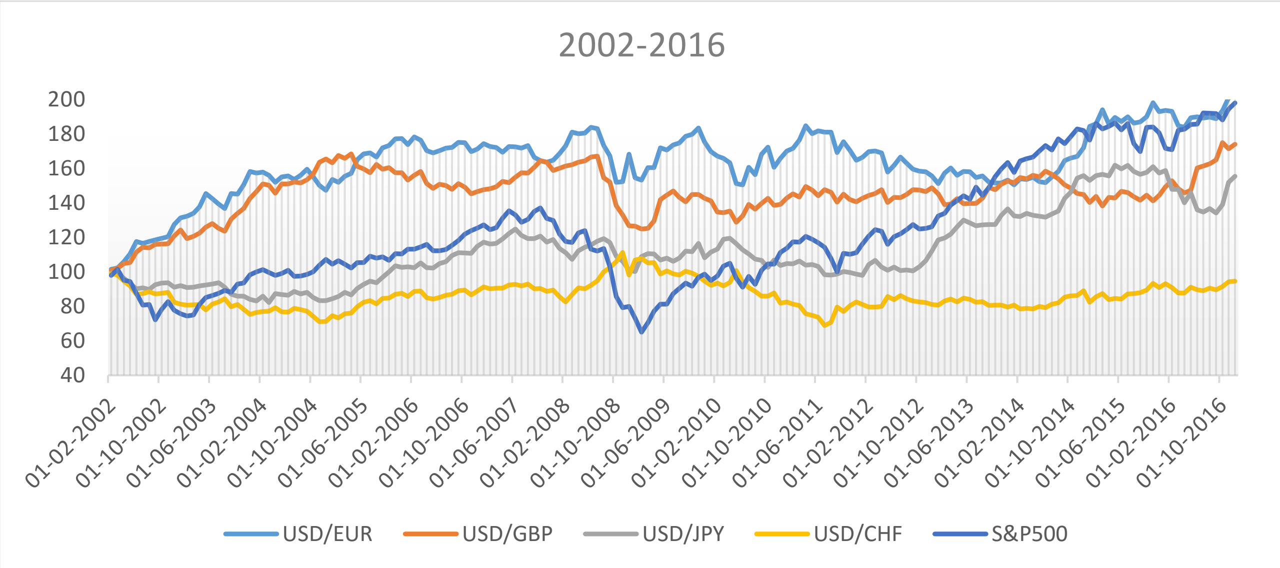
Performance statistics 2002-2016 based on monthly frequency.

USD/EUR had both the highest average return (geomean) and the highest Sharpe Ratio with 0.396% and 0.086 respectively. The second highest Sharpe Ratio was USD/GBP, while S&P 500 delivered third best Sharpe and overall second highest average monthly return with 0.383%. It is worth noting the significantly higher standard deviation in S&P 500, compared to all carry trades.

Other than showing how the underlying asset tends to correlate with the market, beta shows the degree of systematic risk, which for performance measure can be used in the Treynor Ratio. Looking at the t-stats, all beta values are statistically significant (95% quantile) and show a positive exposure to the overall market, with exception of USD/CHF showing a reversed exposure, which is also evident by its negative correlation with S&P 500.

A quick note is that the negative correlation and beta by USD/CHF is interesting for portfolio purposes; however, it loses most of its allure as it delivers a negative return. These betas and correlations need to be kept in mind to understand the mechanisms behind the optimal portfolio strategy, which I will investigate later.

Due to the low beta values, the top performing carry strategies show a very good Treynor Ratio. The Treynor Ratio can, unfortunately, be hard to interpret without knowing the overall risk; hence the weights of systematic and unsystematic risk and the possibility for diversification will be presented in the risk analysis.



	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Indexed Return	203%	174%	156%	95%	198%

Cumulative returns from 2002-2016 starting from index 100.

The cumulative returns show a similar story as the average historic returns measured in the geometric mean. The volatility, for better or worse, of S&P 500 is clearly shown with the large fall during the 2008 crash and how rapid the equity index increased finishing with the second-highest indexed return of 198% only outdone by USD/EUR at 203%. The graph also tells how poorly USD/CHF has performed in contrast to all other strategies.

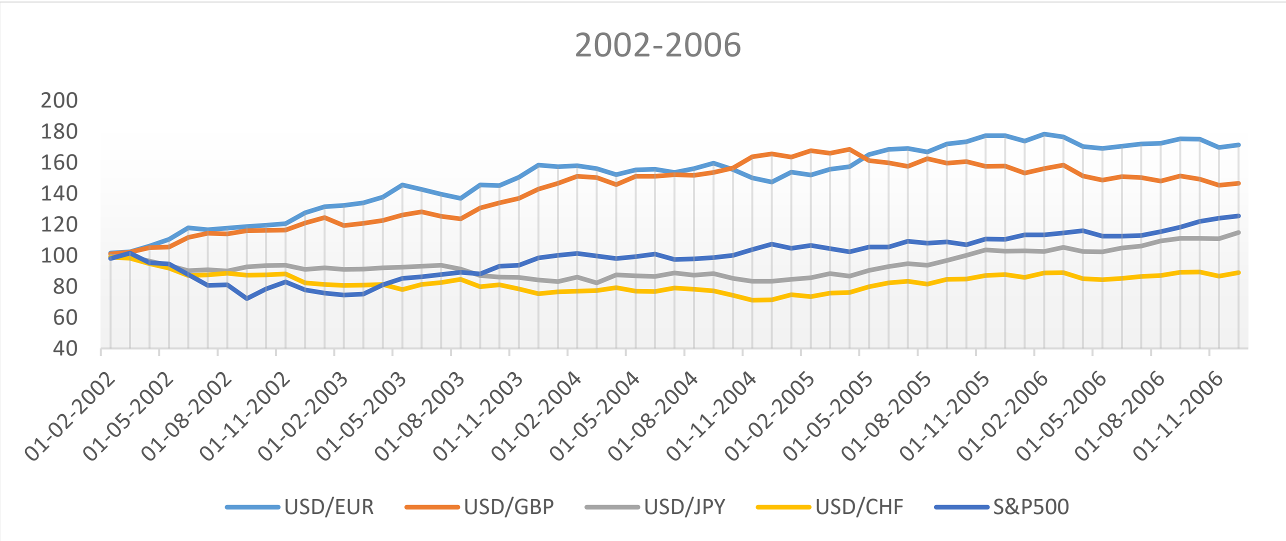
2002-2006

The average arithmetic average of the US 3-month LIBOR rate for 2002-2006, which is used to calculate the Sharpe Ratio, is 0.2269%.

2002-2006					
	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Geomean	0,917%	0,650%	0,234%	-0,199%	0,386%
Standard Deviation	2,507%	2,367%	2,323%	2,701%	3,590%
Sharpe	0,275	0,179	0,003	-0,157	0,044
Beta	-0,105	-0,100	0,053	0,123	1,000
Beta t-stat	-1,149	-1,153	0,615	1,250	0,000
Correl. With S&P	-0,1505	-0,1510	0,0812	0,1633	1

Performance statistics 2002-2006 based on monthly frequency.

During the more stable period of 2002-2006, it is the two carry trades USD/EUR and USD/GBP delivering by far the best returns, which stems from a much higher return together with a standard deviation far below S&P500. The two outperforming strategies USD/EUR and USD/GBP show a negative correlation with S&P500 together with a negative beta. However, these betas are not statistically significant, wherefore I have not found it reasonable to calculate the Treynor Ratio.



	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Indexed Return	171%	147%	115%	89%	125%

Cumulative returns from 2002-2006 starting from index 100.

The strong performance of USD/EUR and USD/GBP is signaled from the high positive returns from the start with both finishing with the two highest cumulative returns, while S&P 500 finishes as 3rd.

2007-2011

The monthly arithmetic average of the US 3-month LIBOR rate for 2007-20011, which is used to calculate the Sharpe Ratio, is 0.1565%

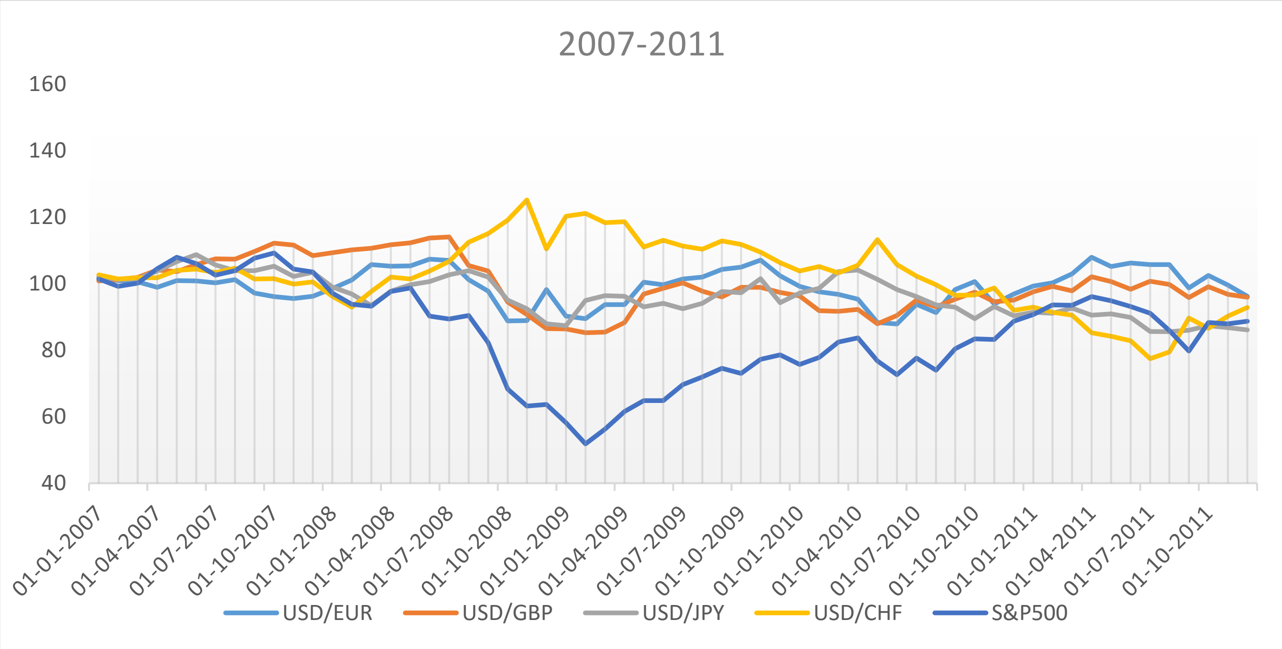
2007-2011					
	USD/EUR	**USD/GBP**	**USD/JPY**	**USD/CHF**	**S&P500**
Geomean	-0,065%	-0,069%	-0,250%	-0,124%	-0,200%
Standard Deviation	3,779%	2,987%	2,951%	4,038%	5,457%
Sharpe	-0,059	-0,075	-0,138	-0,070	-0,065
M2	-0,163%	-0,255%	-0,595%	-0,223%	-0,200%
Beta	0,370	0,262	0,114	-0,271	1,000
Beta t-stat	4,821	4,160	1,641	-3,000	0,000
Correl. With S&P	0,5348	0,4794	0,2107	-0,3665	1

Performance statistics 2007-2011 based on monthly frequency.

It is clear the financial crisis impacts the overall return during this period seeing all strategies generating negative returns. Due to negative returns, the Sharpe Ratio is also negative, which can be tough to comprehend. Therefore, I have in this example also used M2 to show returns where all strategies have been risk-adjusted to match S&P 500.

Another interesting observation is all betas being statistically significant in crisis, where they were not during the more economic stable period, 2002-2006. This supports research that carry trades are affected by the overall financial uncertainty (Laborda et. Al 2014; Melvin & Shand 2017). USD/CHF still manages to deliver a loss, despite its negative beta and negative correlation with S&P 500 throughout the time of crisis.

The cumulative indexed return shows the same return picture with all strategies losing value and only a single carry trade strategy, USD/JPY, being less profitable than the S&P 500.



	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Indexed Return	96%	96&	86%	93%	89%

Cumulative returns from 2007-2011 starting from index 100.

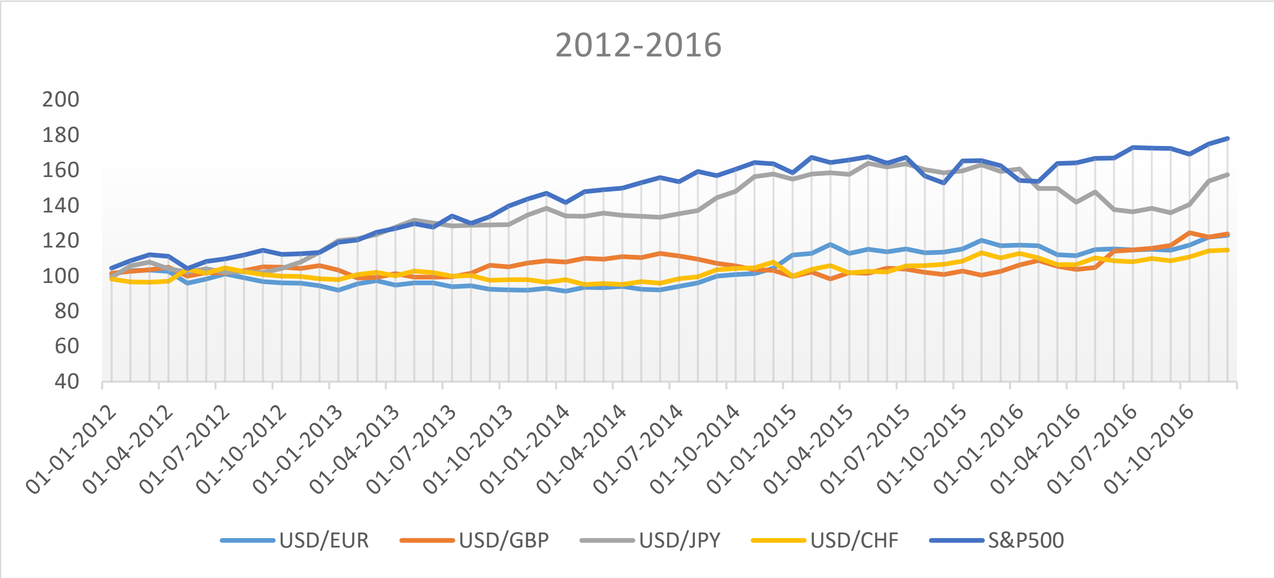
<u>2012-2016</u>

The monthly arithmetic average of the US 3-month LIBOR rate for 2012-2016, which is used to calculate the Sharpe Ratio, is 0.034%

2012-2016					
	EUR/USD	**USD/GBP**	**USD/JPY**	**USD/CHF**	**S&P500**
Geomean	0,346%	0,356%	0,759%	0,229%	0,966%
Standard Deviation	2,412%	2,452%	3,032%	2,432%	2,987%
Sharpe	0,130	0,132	0,239	0,080	0,312
Beta	0,032	0,079	0,311	-0,158	1,000
Beta t-stat	0,300	0,735	2,450	-1,508	0,000
Correl. With S&P	0,0393	0,0961	0,3062	-0,1943	1

Performance statistics 2012-2016 based on monthly frequency.

In the aftermath of the financial crisis the S&P500 shows the best absolute return followed by USD/JPY. Carry strategies, except for USD/JPY being slightly higher, have an overall lower standard deviation than S&P 500. USD/CHF has its only positive return during this period, while still having a negative correlation with S&P 500.



	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Indexed Return	123%	124%	157%	115%	178%

Cumulative returns from 2007-2011 starting from index 100.

The graphed returns show how S&P 500 and USD/JPY followed each other until USD/JPY's late dip, which resulted in the higher absolute return for S&P 500.

Performance Measure Conclusion

By looking at the performance of carry trades, it looks evident that they can be profitable and produce high Sharpe Ratios. CHF showed to be the worst performer, while all other strategies were profitable. The performance was affected by the economic period with all strategies delivering losses during the financial crisis, which supports the current literature on carry trade performance during financial uncertainty. This is backed by all carry trade betas being statistically significant during 2007-2011, which does not bode well for any potential diversification, as it coincides with the worst return on equities.

3.2.2 Underlying Risk Analysis

<u>2002-2016</u>

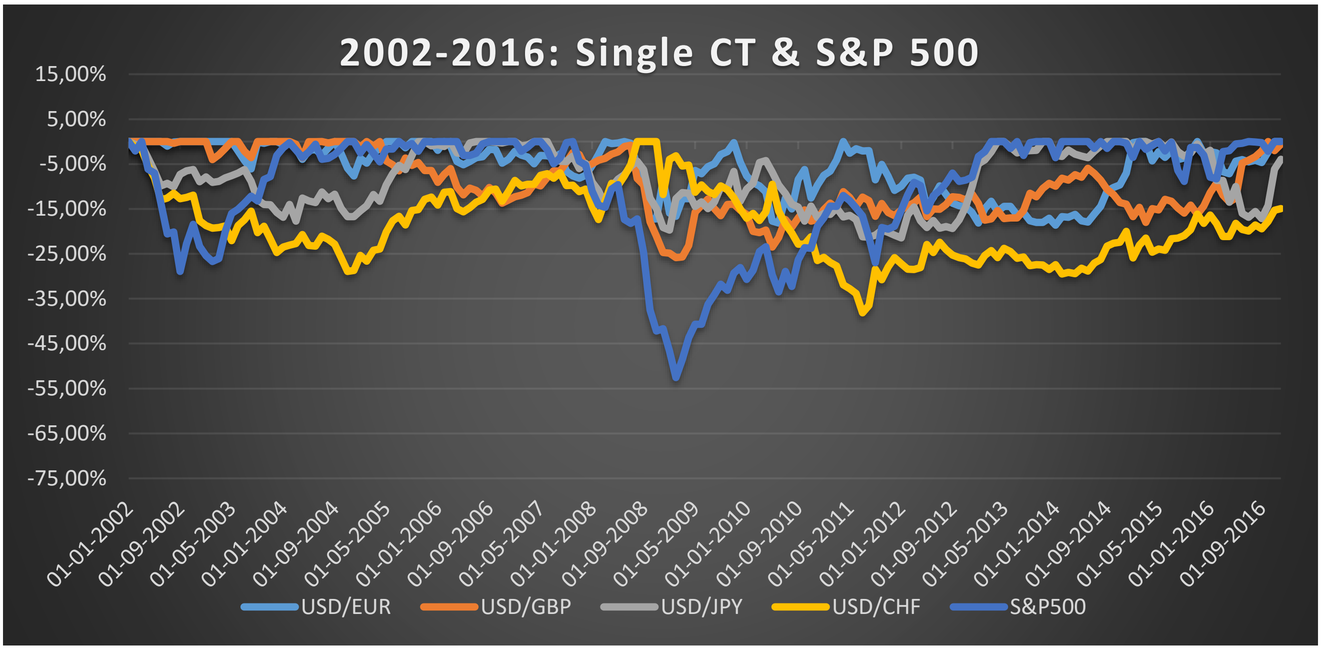
Excess kurtosis is present in both carry trades and equities, and the Jarque-Bera value shows normal distribution with 95% certainty can be rejected for all strategies, with the exception of USD/JPY.

2002-2016					
	USD/EUR	**USD/GBP**	**USD/JPY**	**USD/CHF**	**S&P500**
Mean (Arit. Avg)	0,440%	0,344%	0,286%	0,018%	0,470%
Median	0,367%	0,515%	0,289%	0,226%	0,998%
Standard Deviation	2,977%	2,619%	2,804%	3,126%	4,149%
Excess Kurtosis	1,244	1,568	0,580	2,028	1,676
Skewness	-0,064	-0,051	0,087	0,037	-0,697
Min. Observed return	-9,160%	-9,051%	-7,092%	-11,772%	-16,942%
Max observed return	10,491%	9,623%	9,365%	12,744%	10,772%
Max loss with 95% (VaR)	-5,394%	-4,789%	-5,211%	-6,109%	-7,663%
Systematic Risk	7%	5%	4%	4%	100%
Unsystematic Risk	93%	95%	96%	96%	0%
Jarque-Bera value	11,67	18,41	2,73	30,72	35,45
Normality	Rejected	Rejected	Not Rejec.	Rejected	Rejected

Summary risk statistics for 2002-2016, based on monthly frequency.

The 5% VaR, which is higher for S&P 500 due to its higher standard deviation, shows larger potential losses in equities, which is also shown by the larger minimum observed return. The potential for extreme losses is further outlined by S&P 500 having the largest negative skew of all strategies. This crash risk is further shown by S&P 500's median of 0.998% and its large discrepancy from the mean, which show an overweight of high positive returns for S&P 500, but also how the mean is influenced by large negative observations.

The systematic/unsystematic risk, calculated with the significant betas from the performance analysis, shows the massive overweight of unsystematic risk for all carry trades, which is expected for a strategy attempting to be market neutral.



Drawdown 2002-2016.

Drawdown	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
No. of Expansions	33	27	20	4	37
Maximum Drawdown	-18,62%	-25,85%	-21,46%	-38,14%	-52,56%
Max. Drawdown Duration (MDD)	46	138	71	98+[5]	65

Drawdown Statistics, MDD is shown in months.

Looking at the drawdown graph, the financial crisis is easy to spot through drawdowns for all strategies. The maximum drawdown for S&P500 is much higher than any of the other strategies; however, the maximum drawdown period is only second shortest to USD/EUR. S&P 500 reached a new peak before all but one of the carry trade strategies, despite losing more than 50% from "peak to valley". All this speaks to the high volatility of equities found in the performance analysis and the summary risk statistics.

[5] "+" Shows drawdown period is still on-going.

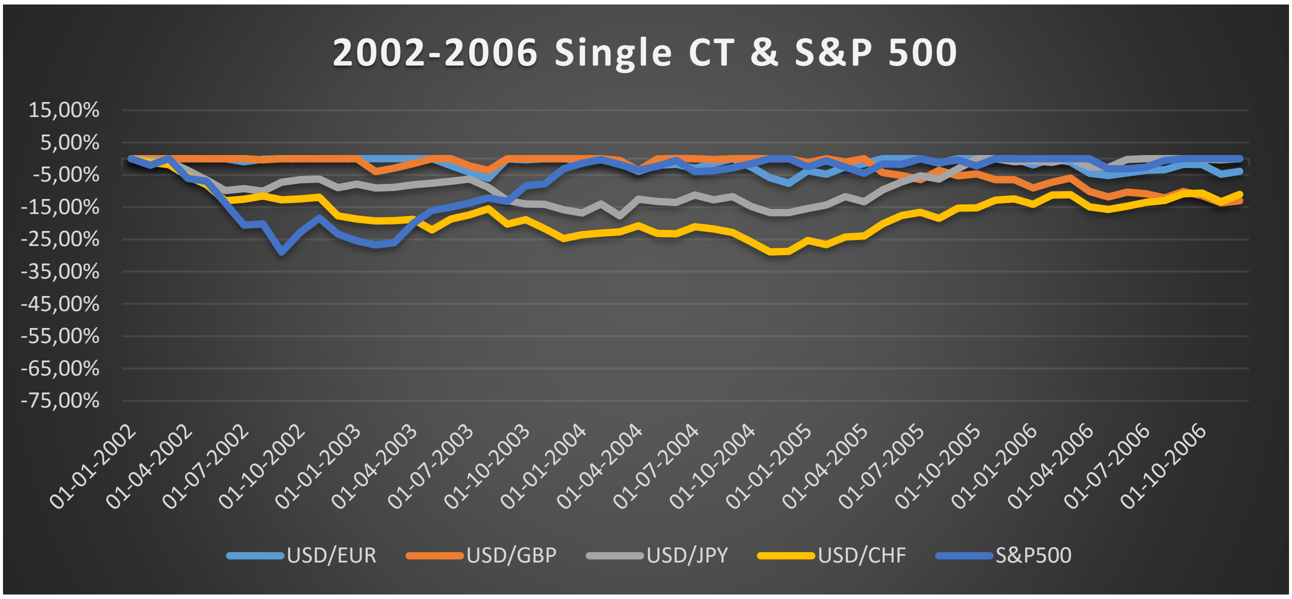
2002-2006

2002-2006					
	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Mean (Arit. Avg)	0,947%	0,677%	0,261%	-0,162%	0,450%
Median	0,798%	0,973%	0,200%	0,289%	0,936%
Standard Deviation	2,507%	2,367%	2,323%	2,701%	3,590%
Excess Kurtosis	-0,334	-0,275	-0,341	-0,448	1,550
Skewness	0,391	-0,096	0,087	-0,308	-0,638
Min. Observed return	-3,507%	-4,418%	-4,452%	-6,544%	-11,002%
Max observed return	6,563%	5,922%	6,234%	4,958%	8,645%
Max loss with 95% (VaR)	-3,967%	-3,962%	-4,293%	-5,457%	-6,586%
Systematic Risk	2%	2%	1%	3%	100%
Unsystematic Risk	98%	98%	99%	97%	0%
Jarque-Bera value	1,78	0,28	0,36	1,42	9,91
Normality	Not Rejec.	Not Rejec.	Not Rejec.	Not Rejec.	Rejected

Summary risk statistics 2002-2006, based on monthly frequency.

The Jarque-Bera value shows that normal distribution with 95% certainty can only be rejected for S&P500 for 2002-2006, and cannot for any of the carry trades. This is also evident by the large excess kurtosis of 1.550 and negative skewness of -0.638. The carry trades are again both negatively and positively skewed, whereas all carry trades show to have thinner tails than the normal distribution during 2002-2006. None of the betas were significant for this time-period, which is why the levels systematic and unsystematic are questionable.

The results during this period speak to research that carry trades perform well during economic stable times, as the relatively low maximum losses show the lack of currency crashes, which is further supported by the thin tails and skewness being between low negative values to positive values.



Drawdown 2002-2006.

Drawdown	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
No. of Expansions	25	26	6	0	13
Maximum Drawdown	-7,65%	-13,71%	-17,72%	-28,88%	-28,94%
Max. Drawdown Duration (MDD)	10	20	46	N/A	32

Drawdown Statistics, MDD is shown in months.

The drawdown graph shows the relatively low drawdown throughout the period by all three profitable carry strategies; USD/EUR, USD/GBP, and USD/JPY, while S&P 500, similarly to the entire period, shows much larger maximum drawdown, although the equity index still recovered from its 28.94% maximum drawdown. USD/CHF again showed its terrible performance by never reaching an expansion.

2007-2011

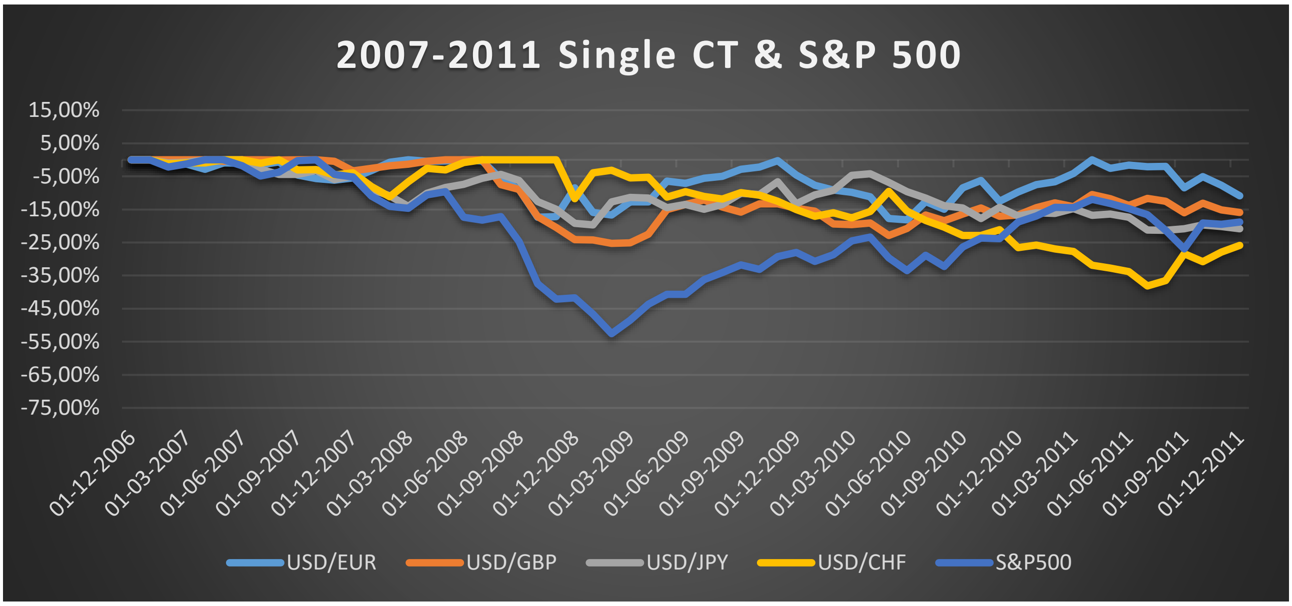
2007-2011					
	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
Mean (Arit. Avg)	0,006%	-0,025%	-0,207%	-0,044%	-0,050%
Median	-0,060%	0,355%	-0,151%	0,021%	0,818%
Standard Deviation	3,779%	2,987%	2,951%	4,038%	5,457%
Excess Kurtosis	0,776	2,108	0,584	1,638	0,504
Skewness	0,003	-0,211	0,150	0,199	-0,514
Min. Observed return	-9,160%	-9,051%	-7,092%	-11,772%	-16,942%
Max observed return	10,491%	9,623%	8,685%	12,744%	10,772%
Max loss with 95% (VaR)	-7,401%	-5,880%	-5,990%	-7,958%	-10,747%
Systematic Risk	29%	23%	4%	13%	100%
Unsystematic Risk	71%	77%	96%	87%	0%
Jarque-Bera value	1,50	11,55	1,08	7,10	3,28
Normality	Not Rejec.	Rejected	Not Rejec.	Rejected	Not Rejec.

Summary risk statistics 2007-2011, based on monthly frequency.

The effect of the financial crisis is clearly shown in the arithmetic average of all strategies. The median of S&P 500 is still more than 0.8%, which means more than half of the returns are high but also how large negative returns affect the mean negatively. In contrast, two of the carry trades had negative medians showing many negative returns. Interestingly this shows long periods of poor returns, which does not correspond to the "stairs and elevators" saying of carry trades, but instead indicate many losses, rather than just a few large ones.

The large minimum return and the negative skewness of S&P 500 instead show the poor performance here could be due to a few very bad returns or "black swans". Compared to 2002-2006, the carry trades demonstrate much thicker tails showing more tail risk. The heightened volatility of both carry trades and S&P 500 can also be seen by increased standard deviations compared to both 2002-2006 and 2012-2016.

The concept of carry trades having increased correlations with the market during poor economic times are also evident by the increasing share of systematic risk compared to the other time-periods.



Drawdown 2007-2011.

Drawdown	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
No. of Expansions	4	11	4	9	4
Maximum Drawdown	-18,15%	-25,26%	-21,32%	-38,14%	-52,56%
Max. Drawdown Duration (MDD)	34	41+	54+	37+	50+

Drawdown Statistics, MDD is shown in months.

The drawdown shows S&P500 being much more prone to a large maximum drawdown during the time of crisis, whereas the graph also shows its ability to rapidly recover. USD/CHF showed its possible diversification benefits by experiencing expansions while all other strategies had growing drawdowns. USD/EUR was the only strategy reaching a new expansion during this period after the financial crisis.

2012-2016

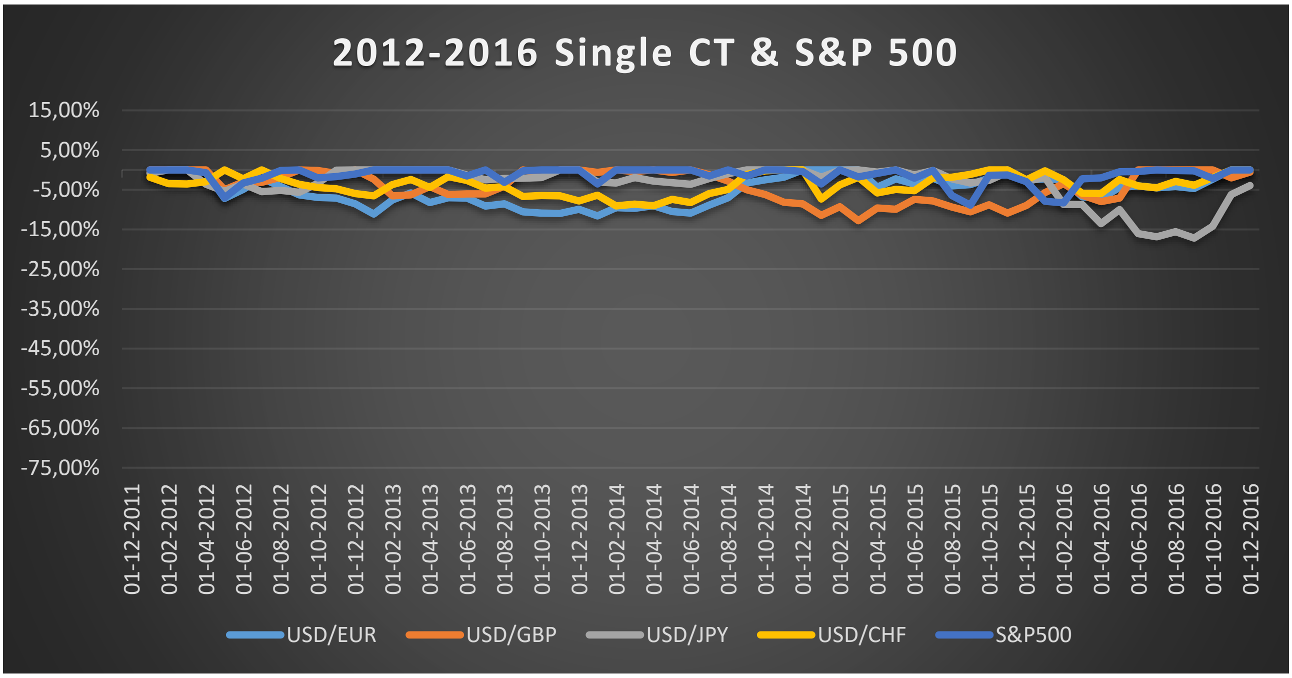
2012-2016					
	USD/EUR	**USD/GBP**	**USD/JPY**	**USD/CHF**	**S&P500**
Mean (Arit. Avg)	0,375%	0,386%	0,804%	0,258%	1,010%
Median	0,363%	0,499%	0,765%	0,239%	1,183%
Standard Deviation	2,412%	2,452%	3,032%	2,432%	2,987%
Excess Kurtosis	0,835	1,622	0,847	1,009	0,181
Skewness	-0,057	0,530	-0,002	-0,066	-0,272
Min. Observed return	-6,522%	-4,977%	-6,873%	-7,341%	-6,265%
Max observed return	7,237%	8,858%	9,365%	7,103%	8,298%
Max loss with 95% (VaR)	-4,353%	-4,420%	-5,139%	-4,509%	-4,844%
Systematic Risk	0%	2%	33%	5%	100%
Unsystematic Risk	100%	98%	67%	95%	0%
Jarque-Bera value	1,773	9,393	1,793	2,586	0,819
Normality	Not Rejec.	Rejected	Not Rejec.	Not Rejec.	Not Rejec.

Summary risk statistics 2012-2016, based on monthly frequency.

During this time-period, all carry strategies experienced larger kurtosis than S&P 500, while normal distribution could not be rejected for any strategies except USD/GBP.

The only significant beta for this time-period is USD/JPY, which interestingly has a high amount of systematic risk. However, as it is the only carry trade showing this tendency in any period not being the financial crisis, it could be a coincidence of both USD/JPY and S&P 500 just being very profitable overall during this period (and relatively small sample size).

The dominance of S&P 500 is evident when looking at maximum drawdown and MDD, where S&P 500 clearly outperformed all the strategies. USD/JPY shows the highest drawdown despite having the second-best performance in the performance analysis, which is indicative of the relatively high volatility compared to the rest of the carry strategies during this time-period.



Drawdown 2012-2016.

Drawdown	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500
No. of Expansions	10	17	16	8	26
Maximum Drawdown	-11,58%	-12,79%	-17,17%	-9,06%	-8,89%
Max. Drawdown Duration (MDD)	33	24	19	28	14

Drawdown Statistics, MDD is shown in months.

Risk Analysis Conclusion

The risk-analysis results clearly show S&P 500 to be a much riskier investment based on mean-variance analysis, as it has a higher standard deviation and VaR for the entire period, where its lowest VaR period of 2012-2016 still only brings S&P 500 at the same level, as carry trades. However, I believe an important observation is to be found in the median, which for S&P 500 is 0.998% for 2002-2016, where the best carry trade, USD/GBP, only has around half at 0.515%. This speaks to the distribution of the returns, where there are a lot of "small" returns for carry trades, in contrast to the decently sized positive returns for S&P 500. At the same time, the discrepancy between median and mean show how S&P 500 is heavily affected by large losses, which can be attributed to especially the "Black Swans" from the financial crisis. This difference in return distribution between equity and carry trades is further shown in drawdown statistics. The overweight of high positive returns, as seen in the median, makes equities better equipped to recover from drawdowns compared to carry trades. This is illustrated by S&P 500 only having the second shortest MDD, despite S&P500 having much larger maximum drawdown than any of the carry trades. This finding supports the results from Melvin & Shand (2017) that drawdown is key importance when looking at the risks associated with carry trades. Additionally, they also found the Swiss Franc to be a major contributor to poor drawdown, which I can only recognize from my results.

None of the return series proved to be normally distributed. A comment to this is the chosen period, with the largest financial crisis in the past 100 years making up almost a third of the time-period. Therefore, it can be questioned whether it is truly representative of future returns.

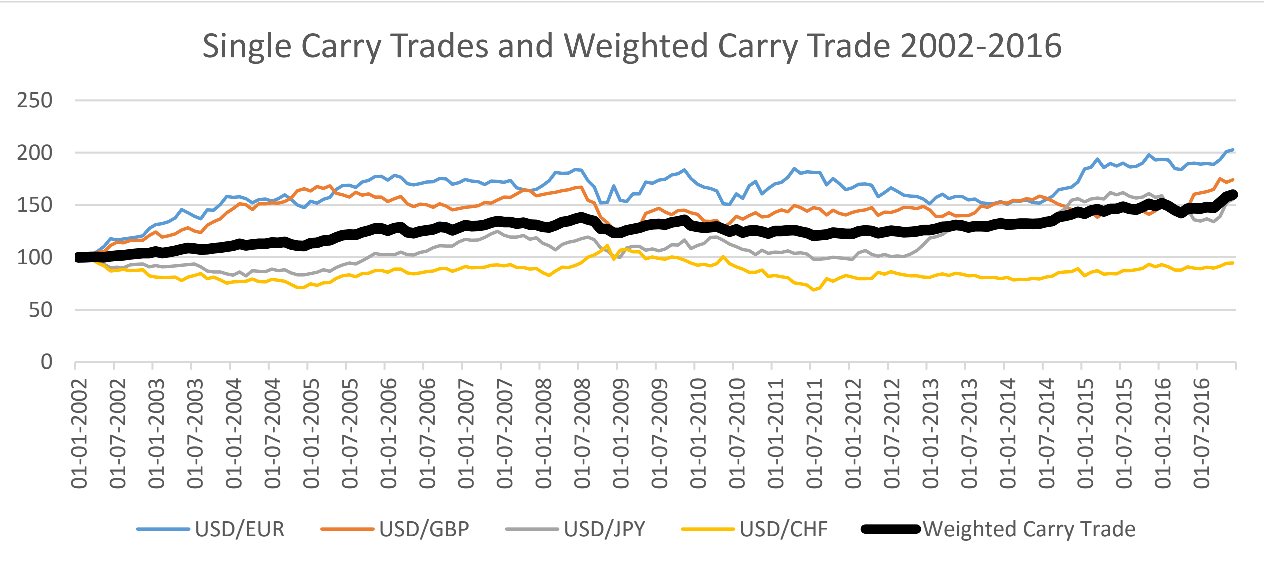
3.3 The Weighted Carry Trade Strategy and Equity Index Strategy

3.3.1 Performance Analysis

2002-2016

Looking at the graphed cumulative return, one quickly notices the 'flatness' of the weighted carry trade, which is shown through a standard deviation of merely 1.366% in contrast to the lowest of the single carry trades being USD/GBP at 2.619% (From section 3.2.1). This, in turn, also gives the weighted carry trade a higher Sharpe Ratio than all the single carry trades. The lower standard deviation and higher Sharpe clearly signal the benefits of diversification by lessening some idiosyncratic risk on the part of single carry trades. In that sense, the theory of increasing risk-adjusted returns by pooling assets together (diversification) seems valid.

The correlation between the weighted carry trade and S&P 500 is close to the level of the single carry trades at 0.252 but the much lower beta and the low volatility show that each movement is rather small.



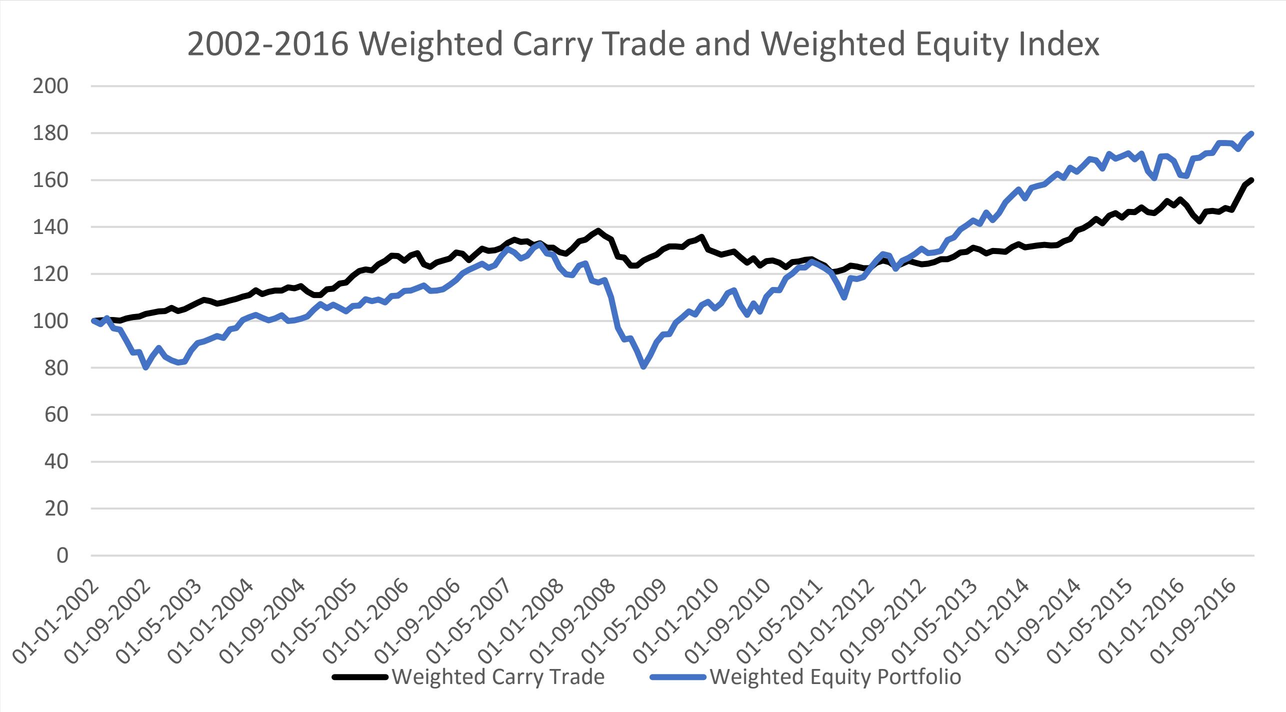
	USD/EUR	USD/GBP	USD/JPY	USD/CHF	Weighted CT
Indexed Return	203%	174%	156%	95%	160%

Cumulative Returns 2002.2016: Single carry trades (thin lines) and the weighted carry trade (thick line).

2002-2016		
	Equal Weight CT	Weighted Equity PF
Geomean	0,263%	0,328%
Standard Deviation	1,366%	2,900%
Sharpe	0,091	0,065
Beta	0,083	0,7
Beta t-stat	3,467	0
Treynor	1,497%	0,271%
Correl. With S&P 500	0,252	1

Performance statistics: weighted portfolios 2002-2016, based on monthly frequency.

The comparative performance between the portfolios show the weighted carry trade to give inferior total returns but a superior Sharpe Ratio due to the much lower standard deviation. The low beta and thereby low systematic risk again makes the Treynor Ratio high, relative to equities. The low beta of the weighted carry trade can also be derived from the below graph of cumulative returns, where the cumulative return looks to be rather stable over the entire period but interestingly also looks rather stale in the aftermath of the financial crisis, indicating a sort of "lagged effect" for carry trades.



	Weighted Carry Trade	Weighted Equity Portfolio
Indexed Return	160%	180%

Cumulative Returns: Weighted portfolios 2002-2016.

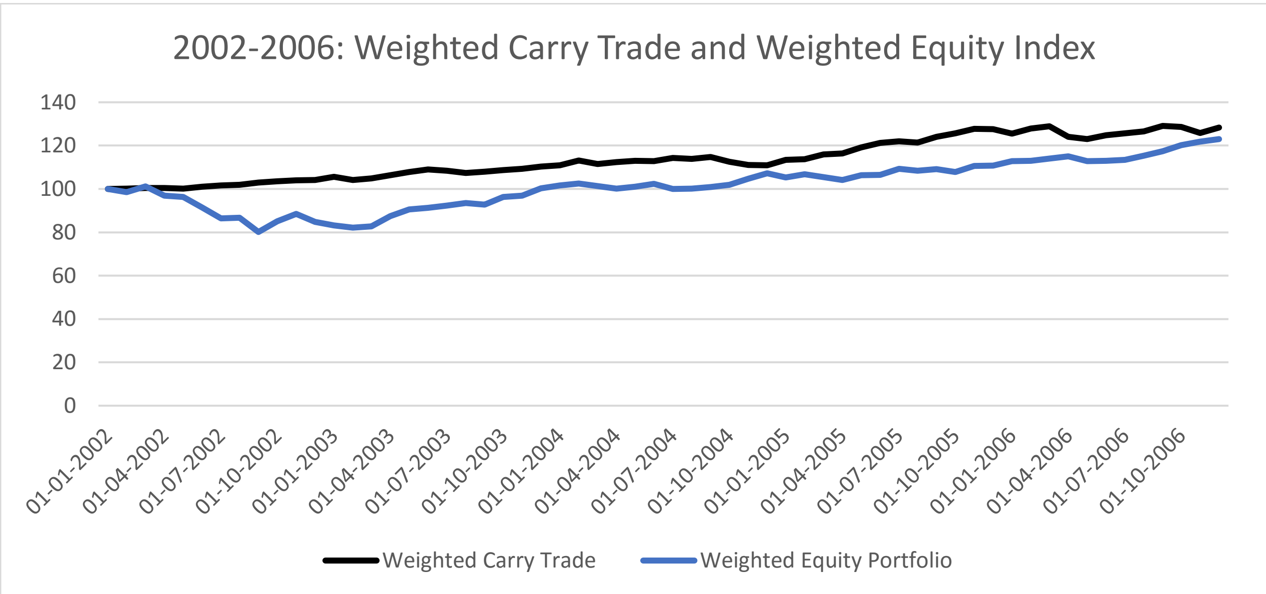
2002-2006

During the economic prosperous period of 2002-2006, the weighted carry trade was a superior strategy both in terms of risk (standard deviation) and average return, which is shown in the far higher Sharpe Ratio of 0.094 compared to the 0.016 of the weighted equity portfolio. As with the single strategies, the weighted carry trade did not show a significant beta during this period and the correlation between the carry trade and S&P 500 was extremely close to zero, which is a great sign for possible diversification.

2002-2006		
	Weighted CT	Weighted Equity PF
Geomean	0,340%	0,268%
Standard Deviation	1,202%	2,515%
Sharpe	0,094	0,016
Beta	-0,007	0,7
Beta t-stat	-0,165	0
Correl. With S&P 500	-0,022	1

Performance statistics: Weighted portfolios 2002-2006, based on monthly frequency.

The economic stability is evident during this period, where neither strategy showed any major signs of weakness.



	Weighted Carry Trade	Weighted Equity Portfolio
Indexed Return	129%	123%

Cumulative return: Weighted portfolios 2002-2006.

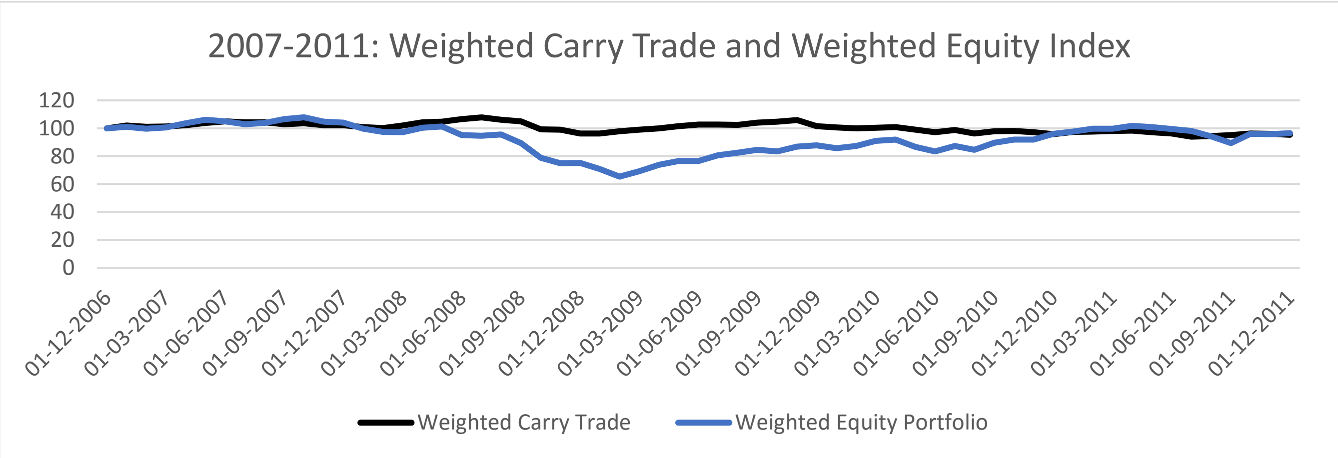
2007-2011

During the period of the financial crisis both portfolios showed negative returns, while having their most volatile period. The carry trade was slightly outperformed by the weighted equity portfolio despite having a lower risk measured in standard deviations. 2007-2011 was also the only period where the weighted carry trade showed to have a significant beta, which can also be seen from the increased correlation towards the S&P 500 of 0.430, indicating that even weighted carry trades tend to have higher correlation during times of crisis, which decreases any potential diversification possibilities.

2007-2011		
	Weighted CT	Weighted Equity PF
Geomean	-0,162%	-0,144%
Standard Deviation	1,509%	3,812%
Sharpe	-0,211	-0,079
M2	-0,010	-0,003
Beta	0,119	0,7
Beta t-stat	3,626	0
Correl. With S&P 500	0,430	1

Performance statistics: Weighted portfolios 2007-2011, based on monthly frequency.

The immediate impact of the financial crisis can especially be seen in the equity portfolio, where the weighted carry trade takes a dip but also continue a poor performance from the end of 2009 and onwards. In contrast, the equities show rapid improvement in the aftermath of the financial crisis.



	Weighted Carry Trade	Weighted Equity Portfolio
Indexed Return	95%	96%

Cumulative Returns: Weighted portfolios 2007-2011.

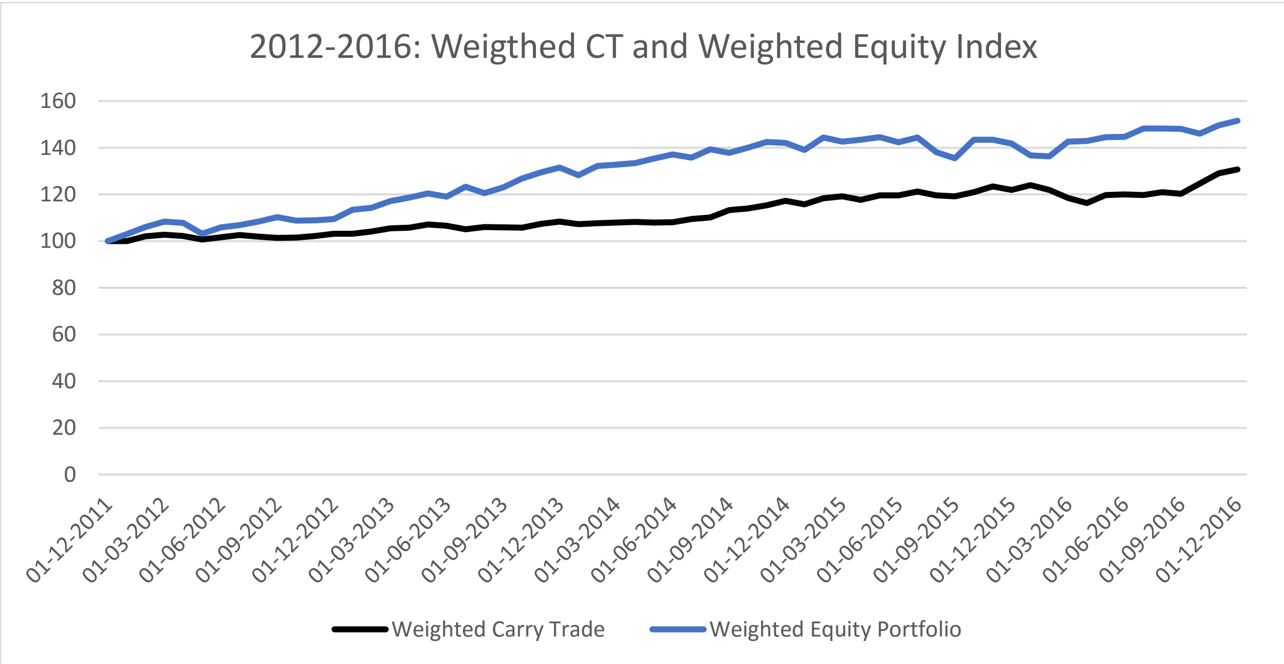
2012-2016

The latter period in the analysis, 2012-2016, shows good performance by both strategies where the far superior absolute returns by the weighted equity portfolio cause a slightly higher Sharpe Ratio compared to the weighted carry trade. The correlation between carry trades and S&P 500 of 0.149 is lower than during the crisis and beta is statistically insignificant.

2012-2016	Weighted CT	Weighted Equity PF
Geomean	0,364%	0,612%
Standard Deviation	1,324%	2,091%
Sharpe	0,250	0,277
Beta	0,066	0,7
Beta t-stat	1,144	0
Correl. With S&P 500	0,149	1

Performance statistics: Weighted portfolios 2007-2011, based on monthly frequency.

The cumulative returns show the same story of positive returns by both portfolios. However, it is clear how much better equities performed throughout this sub-period.



	Weighted Carry Trade	Weighted Equity Portfolio
Indexed Return	131%	152%

Cumulative returns: Weighted portfolios 2012-2016.

3.3.2 Underlying Risk Analysis

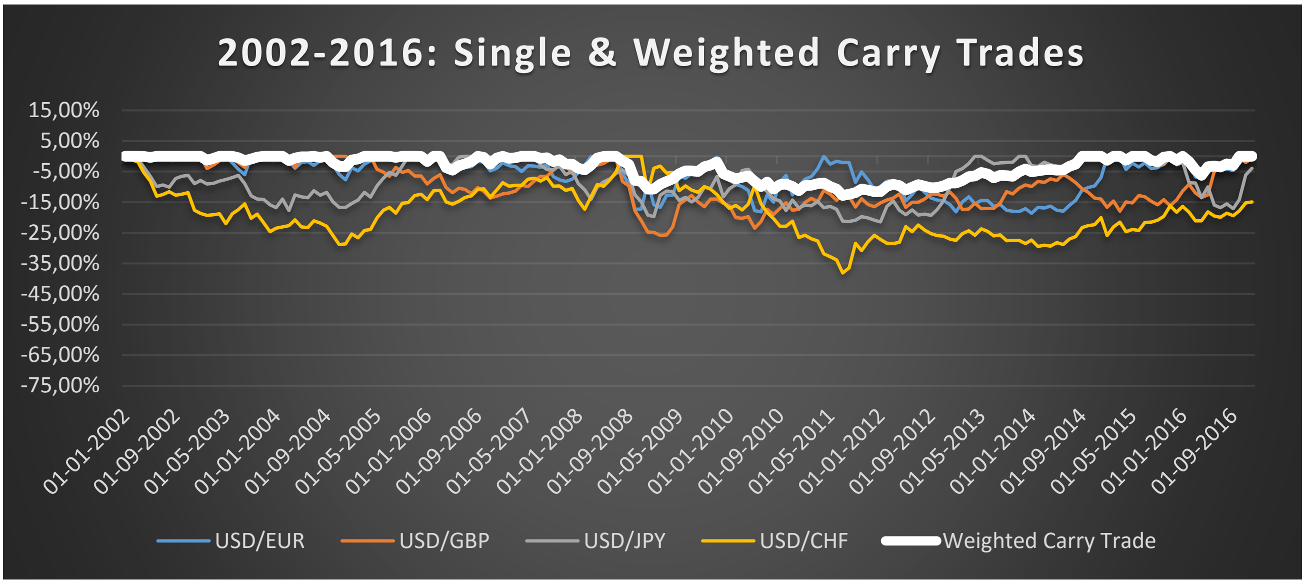
2002-2016

2002-2016		
	Weighted CT	**Weighted Equity PF**
Mean (Arit. Avg)	0,272%	0,370%
Median	0,477%	0,741%
Standard Deviation	1,366%	2,900%
Excess Kurtosis	1,472	1,666
Skewness	-0,708	-0,703
Min. Observed return	-5,384%	-11,784%
Max observed return	3,584%	7,551%
Max loss with 95% (VaR)	-2,405%	-5,314%
Andel Sys. Risiko	6%	100%
Andel Usys. Risiko	94%	0%
Jarque-Bera value	31,116	35,465

Summary risk statistics: weighted portfolios 2002-2016, based on monthly frequency.

The summary risk statistics clearly indicates the overall risk being lower measured by the standard deviation and the VaR by including all four carry trades in one portfolio. However, normal distribution is rejected for both portfolios, as shown by their JB-value, as both strategies show fat-tail risk through excess kurtosis, while being negatively skewed. The overall systematic risk measured under the guidelines of CAPM shows approximately the same level of systematic risk as the single strategies. This contradicts with the theoretical idea that pooling assets together decreases the weight of unsystematic risk for a portfolio. This result, however, is deemed being more a product of CAPM and its assumptions not being a great fit for analyzing a strategy attempting to be market neutral. Instead, we see the overall risk measured in standard deviation decreases, indicating a decrease in idiosyncratic risk.

The weighted equity portfolio naturally shows the same pattern, although to a lesser degree, as S&P 500. However, the results for the weighted equity portfolios are illustrated to compare the two portfolios, as the weighted equity portfolio is the risk-benchmark portfolio used for the portfolio optimization.

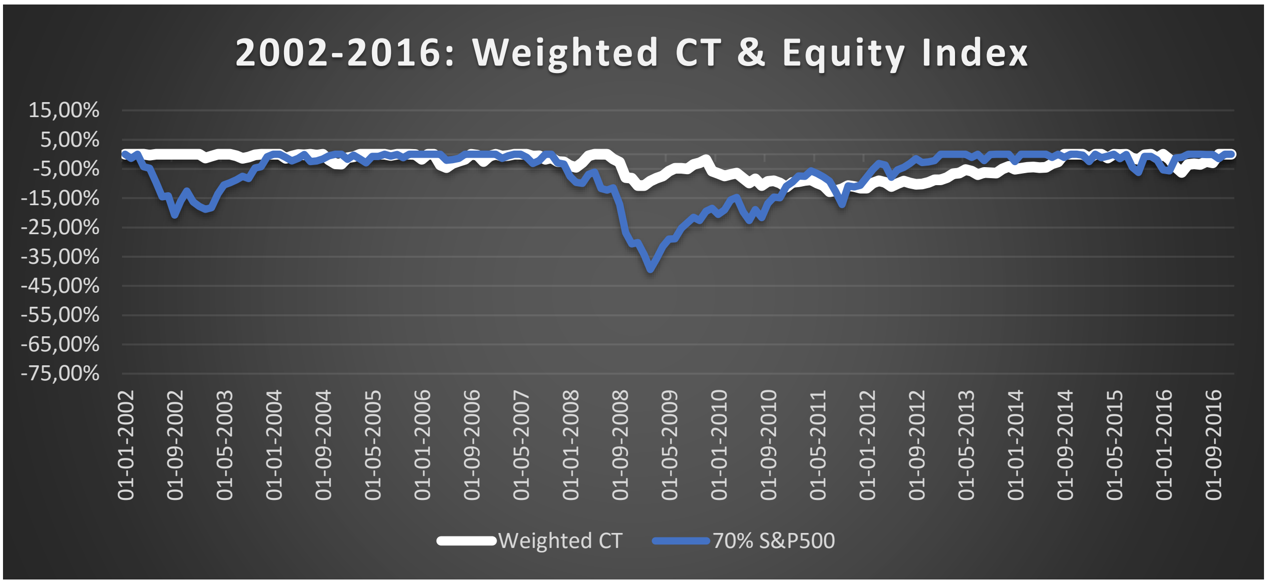


Drawdown 2002-2016: Single carry trades (thin lines) and the weighted carry trade (thick line).

Drawdown	USD/EUR	USD/GBP	USD/JPY	USD/CHF	S&P500	Weighted CT
No. of Expansions	33	27	20	4	37	49
Maximum Drawdown	-18,62%	-25,85%	-21,46%	-38,14%	-52,56%	-12,82%
Max. Drawdown Duration (MDD)	46	138	71	98+	65	74

Drawdown statistics 2002-2016: Single & weighted carry trades, MDD Shown in months.

Using maximum drawdown clearly paints the picture that a portfolio of carry trades is less risky than a single carry trade. The weighted strategy's maximum drawdown is only -12.82%, which is only around 2/3 of the very best of the single carry trade strategies. Despite the relatively low maximum drawdown, the weighted carry trade is still fairly slow at recovering, as shown by MDD. The drawdown duration of the weighted carry trade is longer than two of the single carry trades and also longer than the weighted equity portfolio, despite the maximum drawdown being less than 1/3 of the maximum drawdown of the weighted equity portfolio. This again supports the findings that drawdown duration is a primary concern in carry trades. It also speaks to the earlier notion of the relatively low median indicating many small returns and can be further viewed upon as "stairs" compared to "elevators". The overweight of small returns makes carry trades more vulnerable to "Black Swans" due to their inability to quickly recover.



Drawdown 2002-2016: Weighted strategies.

Drawdown	Weighted CT	Weighted Equity PF
No. of Expansions	49	46
Maximum Drawdown	-12,82%	-39,38%
Max. Drawdown Duration (MDD)	74	63

Drawdown statistics 2002-2016: Weighted strategies, MDD shown in months.

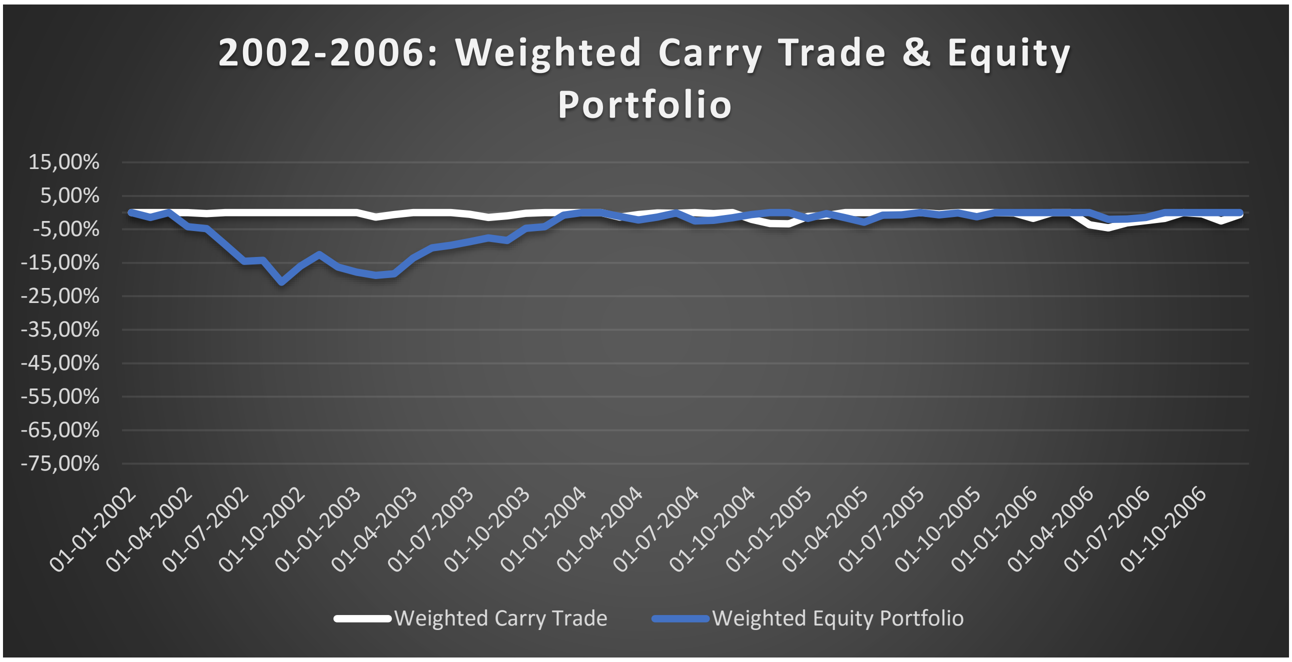
The ability to recover is clear when looking at MDD, where the weighted equity portfolio has a shorter MDD despite having maximum drawdown more than three times greater. The much larger median for equities still shows how the distribution of returns are higher overall, but are dragged down by some extreme losses. The combination of high losses and high profits speak to the volatile nature of equities, which can be seen by their much greater standard deviation.

2002-2006

The normal distribution can be rejected for both weighted portfolios during this period. Both portfolios also show risks outside the normal distribution with distributions being leptokurtic through excess kurtosis, while having negative skewness. While the weighted carry trade does show a larger negative skew, it is interesting to look at the discrepancy between the median and the mean. This indicates larger negative returns have a higher impact on equities' arithmetic average return than for the weighted carry trade. Simultaneously, it also shows how 50% of the returns are generally higher for the equity portfolio during this period.

2002-2006		
	Weighted CT	**Weighted Equity PF**
Mean (Arit. Avg)	0,431%	0,383%
Median	0,568%	0,706%
Standard Deviation	1,202%	2,515%
Excess Kurtosis	1,399	1,552
Skewness	-0,913	-0,659
Min. Observed return	-3,685%	-7,657%
Max observed return	2,471%	6,094%
Max loss with 95% (VaR)	-1,926%	-4,547%
Jarque-Bera value	13,015	10,196

Summary risk statistics 2002-2006: Weighted portfolios, based on monthly frequency.



Drawdown 2002-2006: Weighted portfolios, based on monthly frequency.

Drawdown	Weighted CT	Weighted Equity PF
No. of Expansions	30	17
Maximum Drawdown	-4,56%	-20,79%
Max. Drawdown Duration (MDD)	6	22

Drawdown statistics 2002-2006: Weighted portfolios, MDD shown in months.

The drawdown graph shows the extremely low level of drawdown the weighted carry trade portfolio experience during the positive economic period of 2002-2006. This is indicative of the overall good performance seen from the performance analysis as well.

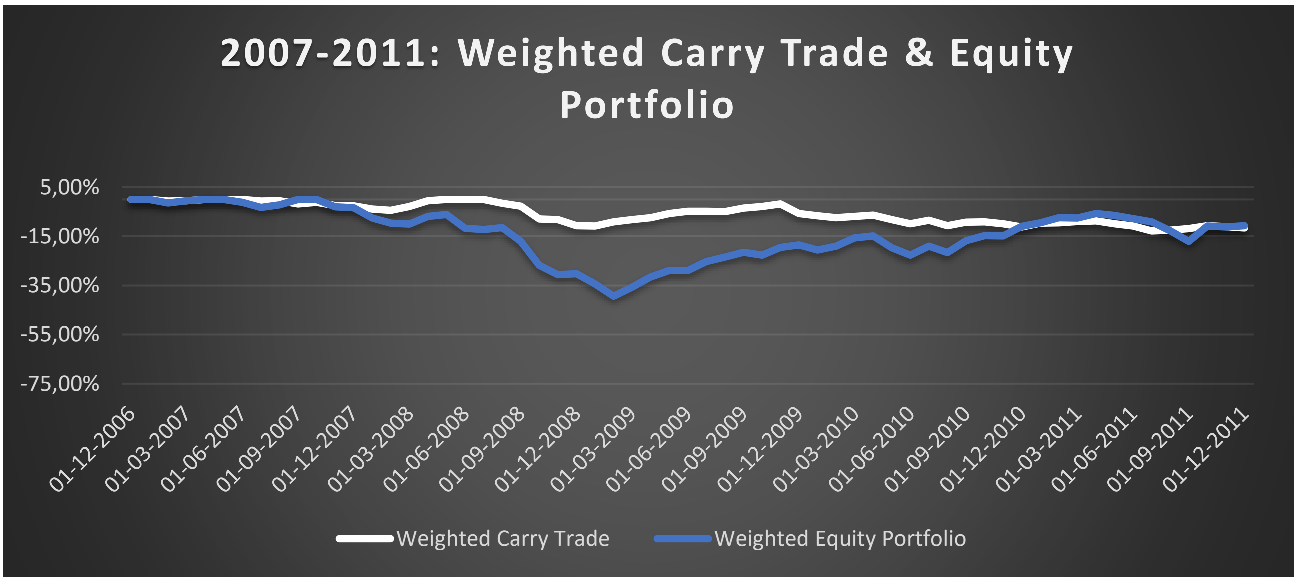
2007-2011

The negative returns from the performance analysis looks to be heavily influenced by some extreme negative observations for both portfolios, as both seen in the negative skewness and in the discrepancy between the mean and the median. Here both portfolios have positive median, which through the negative skew and extreme observations create a lower mean. The saying of "Stairs and elevators" looks applicable in that sense, as the median returns of carry trades are low and positive (stairs), while the distribution reveals a large negative skew, which implies crash risk (elevator). The same trend shows in the weighted equity portfolio, but with a much higher median indicating its ability to recover, and a smaller skew, despite having a very poor minimum return.

Interestingly, normal distribution cannot be rejected for the weighted equity portfolio, despite the presence of excess kurtosis and negative skewness. Whether this is simply a matter of too few observations is uncertain but seems plausible.

2007-2011		
	Weighted CT	**Weighted Equity PF**
Mean (Arit. Avg)	-0,068%	0,012%
Median	0,207%	0,597%
Standard Deviation	1,509%	3,812%
Excess Kurtosis	1,666	0,500
Skewness	-1,021	-0,522
Min. Observed return	-5,384%	-11,784%
Max observed return	2,369%	7,551%
Max loss with 95% (VaR)	-3,026%	-7,461%
Jarque-Bera value	17,357	3,348

Summary risk statistics 2007-2011: Weighted portfolios, based on monthly frequency.



Drawdown 2007-2011: Weighted portfolios.

Drawdown	Weighted CT	Weighted Equity PF
No. of Expansions	6	5
Maximum Drawdown	-12,82%	-39,38%
Max. Drawdown Duration (MDD)	41	50

Drawdown statistics 2007-2011: Weighted strategies, MDD shown in months.

The drawdown statistics show how an equity portfolio gives much higher maximum drawdown risk, as this is more than triple the maximum drawdown of the weighted carry strategy. What is shown by the drawdown graph is instead the development in the drawdown, where it can be seen how the weighted equity portfolio decreases its drawdown to finish with less drawdown than the carry trade portfolio at the end of the period. This, although neither strategy reaches a new expansion during this time-period, points out the possible drawdown duration risk with carry trades, as it clearly does not show the same ability to rapidly recover.

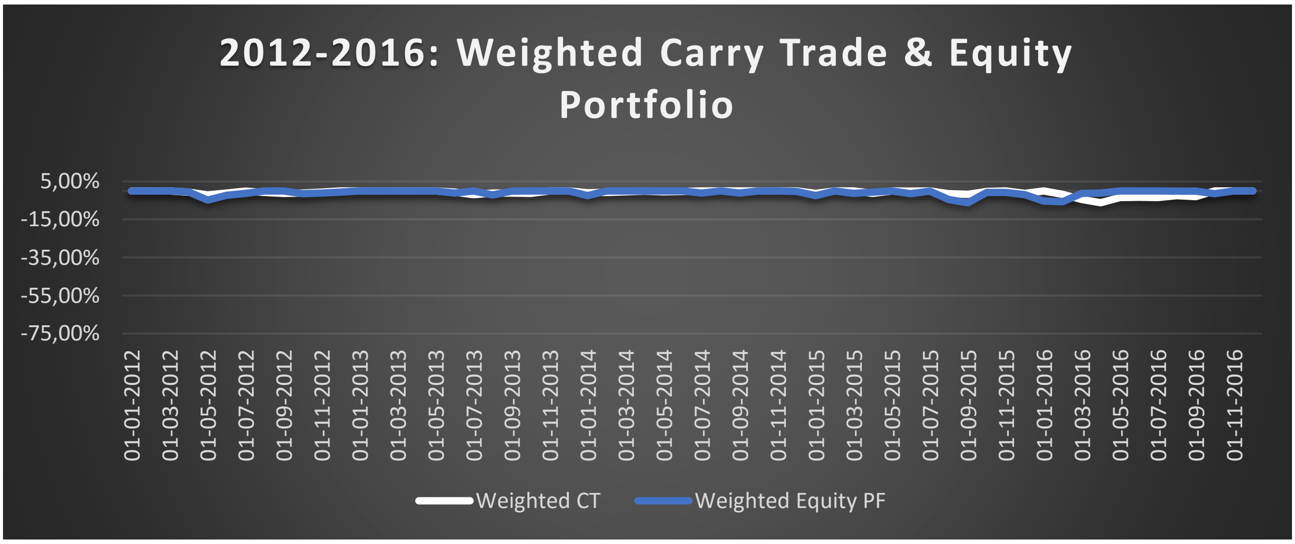
2012-2016

The normal distribution cannot be rejected for either portfolio during the period of 2012-2016. The lack of risks outside those measured by the standard deviation is also shown by almost no excess kurtosis and no negative skewness. The median and arithmetic mean are also quite close during this period, showing very little impact on the mean by extreme observations, which simultaneously indicates a normal distribution.

2012-2016		
	Weighted CT	**Weighted Equity PF**
Mean (Arit. Avg)	0,456%	0,717%
Median	0,447%	0,837%
Standard Deviation	1,324%	2,091%
Excess Kurtosis	0,0433	0,1811
Skewness	0,0433	0,1811
Min. Observed return	-2,719%	-4,374%
Max observed return	3,584%	5,817%
Max loss with 95% (VaR)	-2,139%	-3,381%
Jarque-Bera value	0,0235	0,4100

Summary risk statistics 2012-2016: Weighted portfolios, based on monthly frequency.

The drawdown shows similarity to that of 2002-2006, where especially the weighted carry trade had very little drawdown risk. During 2012-2016, there is little to no difference in the drawdown risk between the weighted portfolio, which is clearly shown by the below graph and the drawdown statistics.



Drawdown 2012-2016: Weighted portfolios.

Drawdown	Weighted CT	Weighted Equity PF
No. of Expansions	26	29
Maximum Drawdown	-6,20%	-6,22%
Max. Drawdown Duration (MDD)	9	12

Drawdown statistics 2012-2016: Weighted portfolios, MDD shown in months.

Weighted Strategies Sub-conclusion

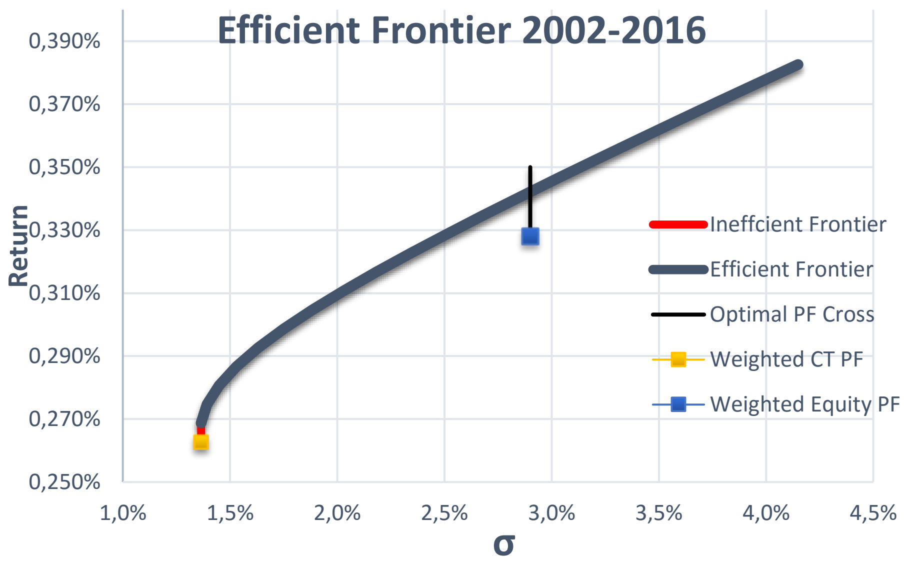
The weighted carry trade overall delivers a high Sharpe Ratio over the entire period compared to the weighted equity portfolio, which is through a clear overperformance in 2002-2006 and an almost identical performance in 2012-2016. 2007-2011 delivers a worse result for carry trades than the weighted equity portfolio, despite an overall lower volatility. The weighted carry trade shows a much lower volatility than any of the single carry trades speaking to the diversification of idiosyncratic risk. The correlation with S&P 500 is very low for the good economic periods, but increases during the crisis. Drawdown analysis shows how maximum drawdown duration is a larger risk-factor for carry trades than equities, due to their inability to recover from a relative to equities low maximum drawdown after a time of economic crisis. For comparison, the weighted carry trade only reached a new expansion in September 2014, where the weighted equity portfolio did that in January 2013.

3.4 Optimal Portfolio Strategy

The optimal portfolio is defined as the investment alternative to the weighted equity portfolio, where I am weighing the weighted carry trade and the S&P 500 in such combination that the standard deviation *exactly* equals the standard deviation of the weighted equity portfolio.

3.4.1 Optimal Portfolio Performance Analysis

2002-2016



	Weights
Weighted CT	33,7%
S&P 500	66,3%

Efficient frontier 2002-2016, including weights of the optimal portfolio.

The efficient frontier is illustrated as above, starting from the minimum variance portfolio all the way to the top, which is a 100% investment in S&P 500. The weighted equity portfolio is illustrated as being below the efficient frontier and thus an inferior portfolio.

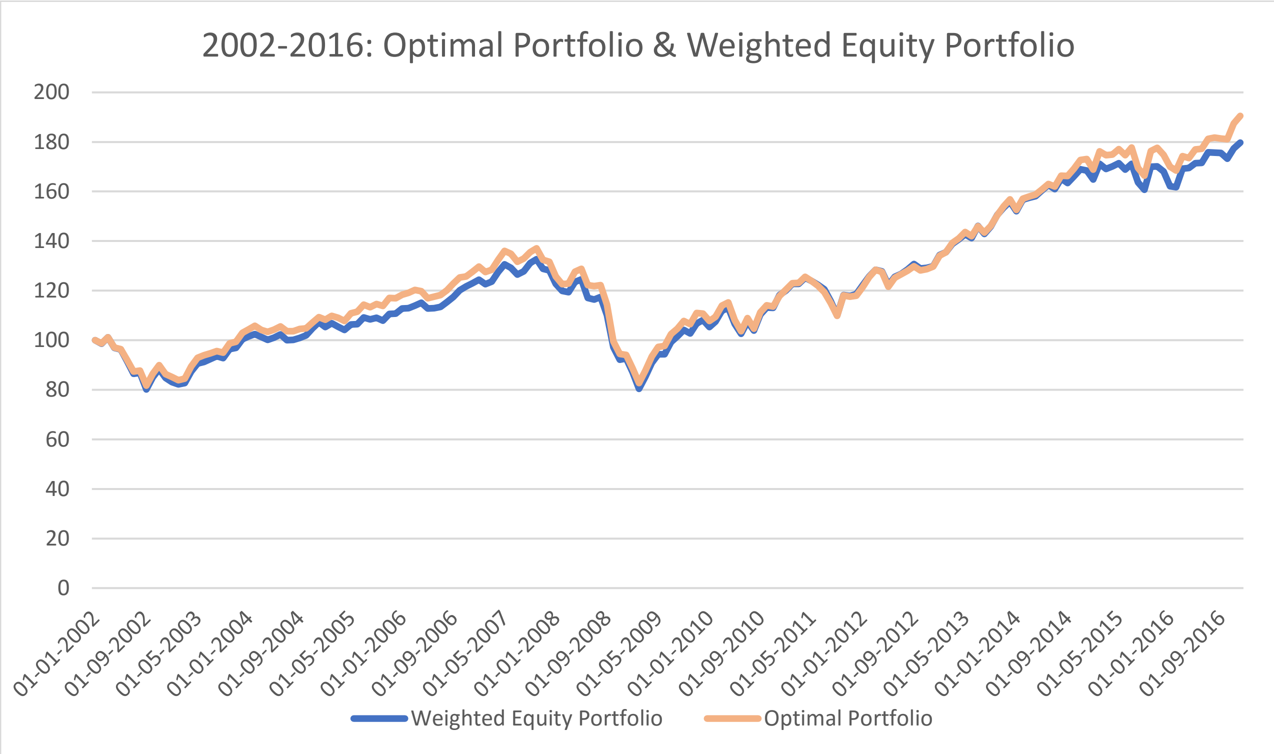
S&P 500 and the weighted carry trade have during the entire period a correlation of 0.252 (Section 3.3.1), with the correlation being less than +1, the efficient frontier has the well-known "curved" look.

The weights for the efficient portfolio, with a standard deviation equal to that of the weighted equity portfolio, is approximately 2/3 equities and 1/3 in the weighted carry trade.

Looking at the performance of the optimal portfolio, it follows that of the weighted equity portfolio. However, both looking at the graphed return and the geometric mean the optimal portfolio is slightly better both during the lows in 2009 and during the highs of 2002-2006 and ends up at an indexed return of 191% compared to the 180% of the weighted equity index. The better performance can also be seen by the slightly better Sharpe Ratio.

2002-2016				
	Weighted CT	Weighted Equity PF	Optimal PF	S&P500
Geomean	0,263%	0,328%	0,342%	0,383%
Standard Deviation	1,366%	2,900%	2,900%	4,149%
Sharpe	0,091	0,065	0,070	0,059

Performance statistics 2002-2016, based on monthly frequency.



	Optimal Portfolio	Weighted Equity Portfolio
Indexed Return	191%	180%

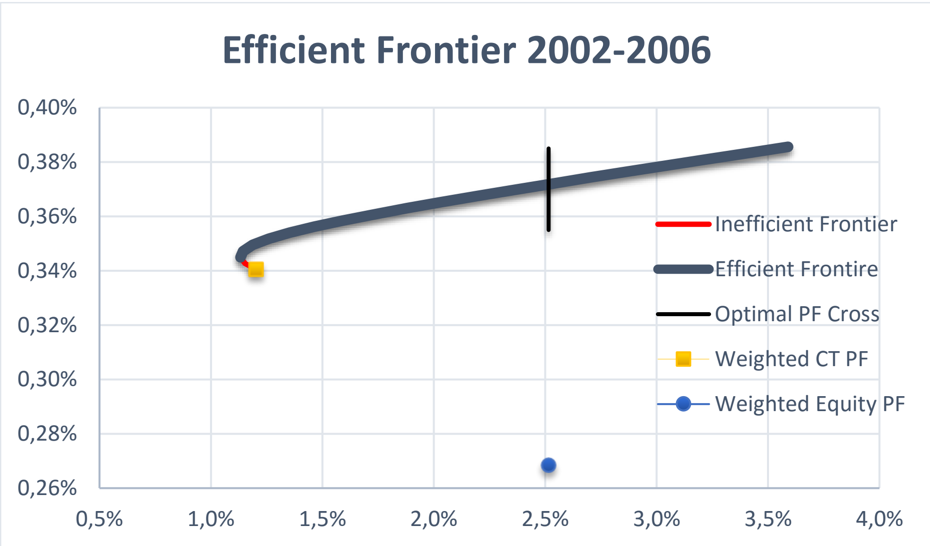
Cumulative returns 2002-2016: Optimal portfolio and weighted equity portfolio.

2002-2006

During the booming economy in 2002-2006, it is clearly shown by the efficient frontier how an investor loses out by investing 30% of the portfolio in the risk-free rate compared to the mixture of carry trade and S&P 500. Given the same standard deviation, the higher average return gives a significant higher Sharpe Ratio with levels of 0.016 and 0.058 respectively. The weights for the optimal portfolio are comparable to the weights for the entire period with only 3.2 percentage point higher allocation in S&P 500. The correlations factor between the weighted carry trade and the weighted equity index is -0.022 (Section 3.3.1) indicating great possibilities for diversification.

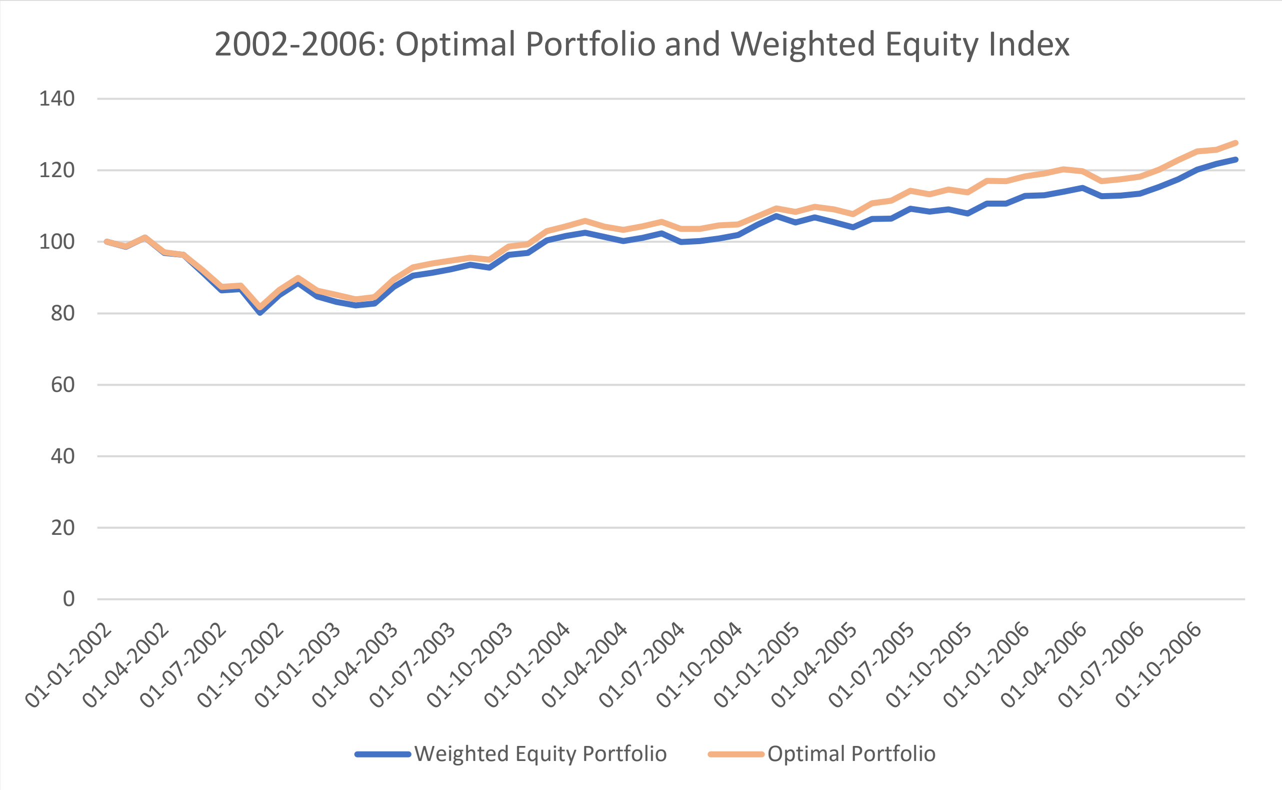
2002-2006				
	Weighted CT	Weighted Equity PF	Optimal PF	S&P500
Geomean	0,340%	0,268%	0,372%	0,386%
Standard Deviation	1,202%	2,515%	2,515%	3,590%
Sharpe	0,094	0,016	0,058	0,044

Performance statistics: 2002-2006, based on monthly frequency.



Optimal PF	Weights
Weighted CT	30,5%
S&P 500	69,5%

Efficient frontier 2002-2006 including weights of the optimal portfolio.

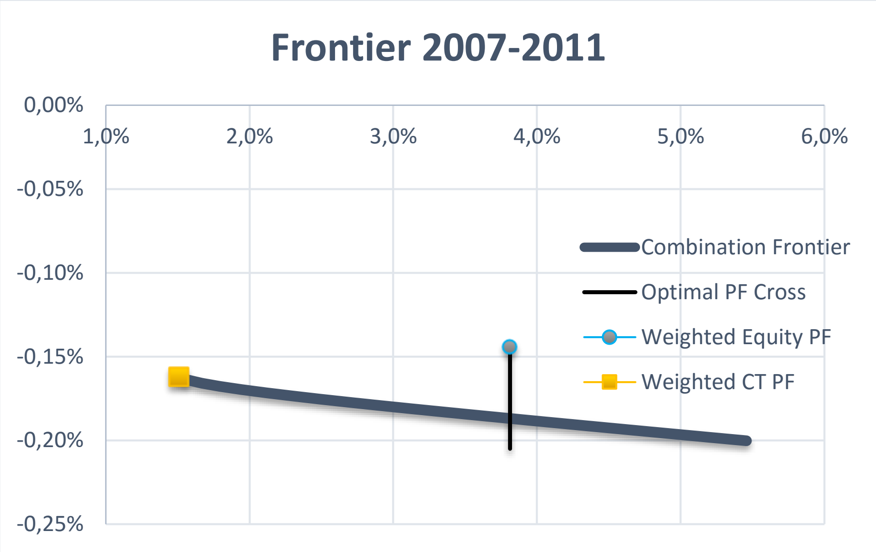


	Optimal Portfolio	Weighted Equity Portfolio
Indexed Return	128%	123%

Cumulative returns 2002-2006: Optimal portfolio and weighted equity portfolio.

The cumulative return of the optimal portfolio follows that of the overall weighted equity portfolio, due to the overweight of S&P500 for each strategy; however, the optimal portfolio performs overall better than the weighted equity index as seen in the above performance analysis table and the below graphed returns.

2007-2011



Optimal PF	Weights
Weighted CT	34,8%
S&P 500	65,2%

"Efficient" frontier 2007-2011, including weights of the optimal portfolio.

During the financial crisis, the "optimal" portfolio, meaning the highest return for the combination of the weighted carry strategy and the S&P 500, does not show to be particular "optimal".

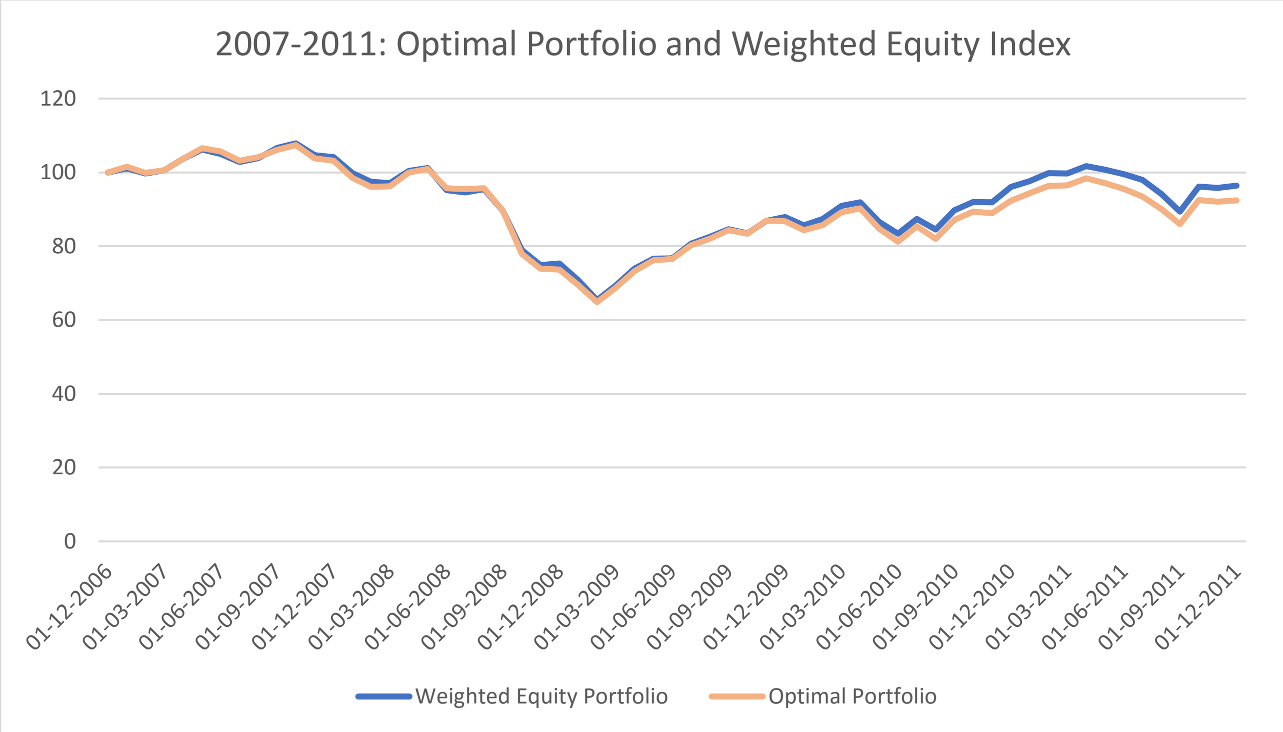
This is a critique of the model and the assumptions used in CAPM and modern portfolio theory, where historic returns are used as expected returns. By using observations from a financial crisis the expected returns will be negative, which is bound to create problems when creating an optimal portfolio based on a level of risk-aversion. In a negative-return environment, the investor gets higher returns by avoiding risk altogether, which is contradictory to the assumption that an investor is rewarded by taking on "market" risk. This model fault can be seen by the "optimal" portfolio being inferior to both the carry trade and weighted equity portfolio.

The correlation factor of 0.430 (Section 3.3.1) between S&P 500 and the weighted carry trade during this period is the highest correlation for any of the periods, which supports the earlier results of carry trades having stronger correlations with market movements during times of economic difficulties.

2007-2011				
	Weighted CT	Weighted Equity PF	Optimal PF	S&P500
Geomean	-0,162%	-0,144%	-0,187%	-0,200%
Standard Deviation	1,509%	3,812%	3,812%	5,457%
Sharpe	-0,211	-0,079	-0,090	-0,065

Performance statistics: 2007-2011, based on monthly frequency.

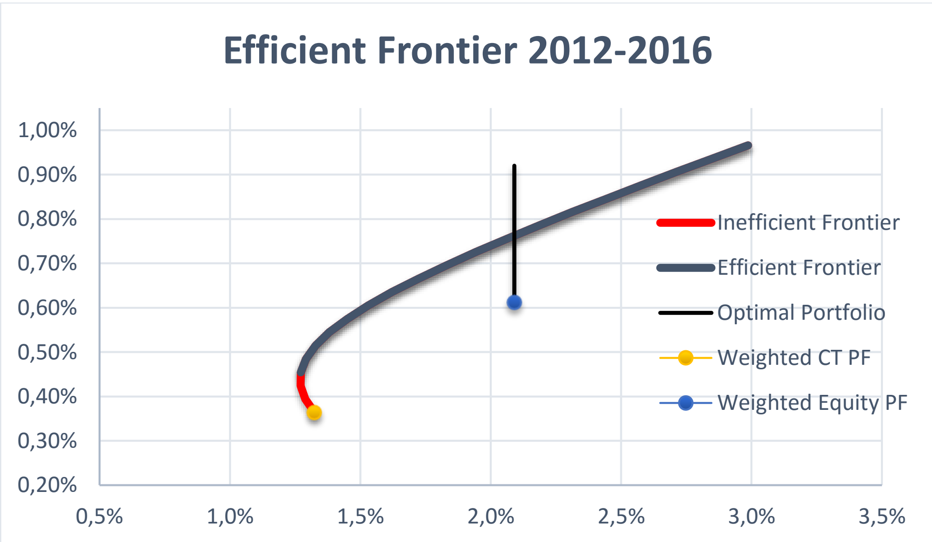
The poor performance can also be seen from the cumulative graph showing the optimal portfolio and the weighted equity portfolio ending at 92% and 96% respectively.



	Optimal Portfolio	Weighted Equity Portfolio
Indexed Return	92%	96%

Cumulative returns 2007-2011: Optimal portfolio and weighted equity portfolio.

<u>2012-2016</u>



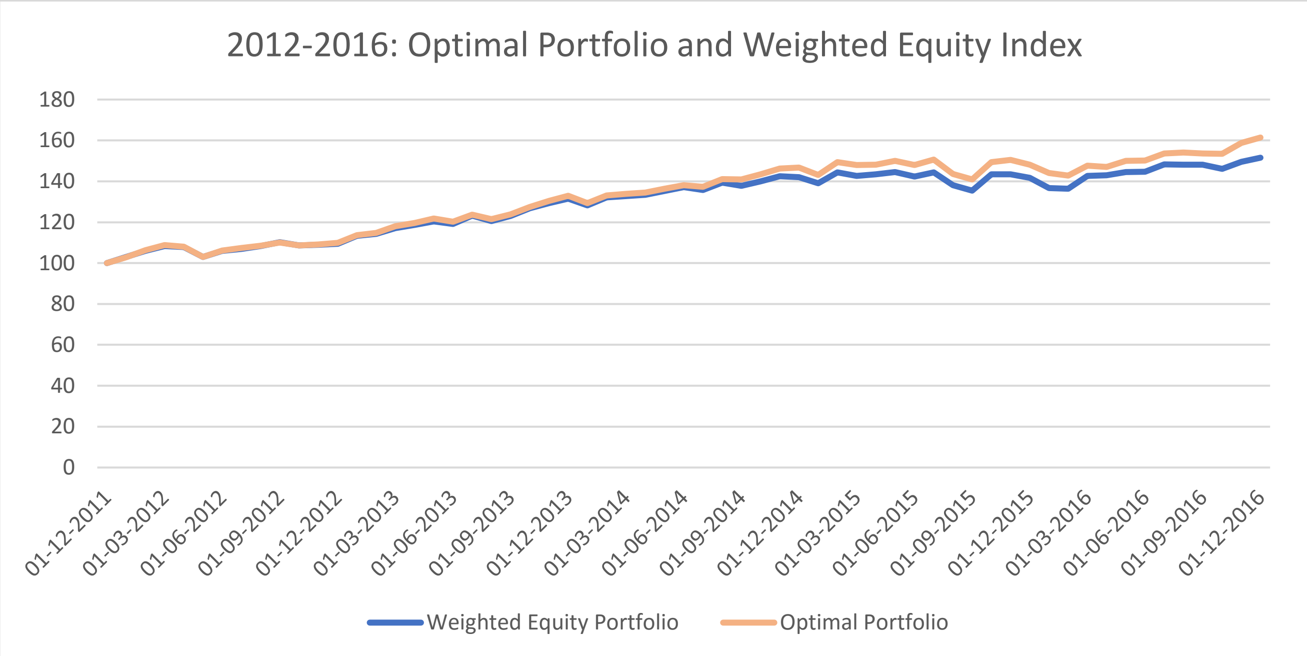
Optimal PF	Weights
Weighted CT	33,8%
S&P 500	66,2%

Efficient frontier 2012-2016, including weights of the optimal portfolio.

The post-financial crisis period showed positive results for both strategies with the optimal portfolio being the superior strategy with a Sharpe Ratio of 0.349 compared to the 0.277 of the weighted equity portfolio. The correlation between the weighted carry trade and the S&P 500 was 0.149 (Section 3.3.1) during this period, showing good diversification possibilities. The weights of the assets are again around the same 2/3 and 1/3 mark as during earlier time-periods.

2012-2016				
	Weighted CT	Weighted Equity PF	Optimal PF	S&P500
Geomean	0,364%	0,612%	0,762%	0,966%
Standard Deviation	1,324%	2,091%	2,091%	2,987%
Sharpe	0,250	0,277	0,349	0,312

Performance statistics: 2012-2016, based on monthly frequency.



	Optimal Portfolio	Weighted Equity Portfolio
Indexed Return	161%	152%

Cumulative returns 2012-2016: Optimal portfolio and weighted equity portfolio.

3.4.2 Optimal Portfolio Risk Analysis

As shown, the weights between the weighted carry trade and the weighted equity portfolio are fairly constants through all periods. This section then serves to see if there is any underlying difference in risk, since the standard deviation is the same.

2002-2016

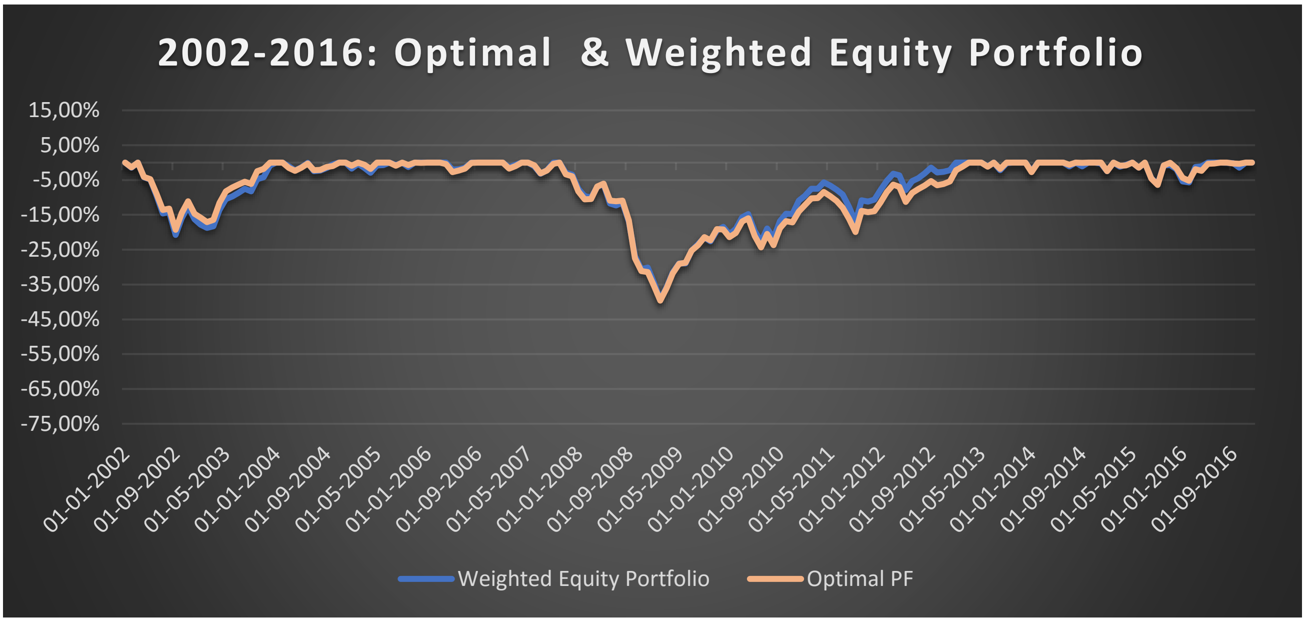
The optimal portfolio's Jarque-Bera value is further from its critical value of 5.99 than that of the weighted S&P 500, indicating a less normally distributed series of return through a larger excess kurtosis and negative skew. The larger negative skewness for the optimal portfolio also comes to show in the minimum observed return, which despite having the same standard deviation, is more than a percentage point worse than that of the weighted equity portfolio. The optimal portfolio also has a much greater kurtosis showing associated tail-risk, which together with the increased negative skewness show potential currency crash-risk.

2002-16	Optimal PF	Weighted Equity PF
Mean	0,403%	0,370%
Median	0,736%	0,741%
Standard Deviation	2,900%	2,900%
Excess Kurtosis	2,255	1,666
Skewness	-0,776	-0,703
Minimum	-13,04%	-11,78%
Maximum	7,58%	7,55%
Max loss with 95% (VaR)	-5,282%	-5,314%
Jarque-Bera value	55,89	35,46

Summary risk statistics 2002-2016: optimal portfolio and weighted equity portfolio.

Drawdown

The drawdown for the two strategies is very similar, with the actual figures of expansions, maximum drawdown and maximum drawdown period being close to identical. The results, however, again show that carry trades do not give much diversification when needed during financial downturns. The inclusion of carry trade instead of the risk-free rate does not indicate much added risk when looking at the overall drawdown, the added risk is instead slightly seen in the distribution, which shows larger negative skewness and fatter tails, a risk that also shows up in the minimum observed values. Due to the higher correlation between carry trades and equities during periods of crisis, the potential for negative returns is higher than with the inclusion of the risk-free rate.



Drawdown 2002-2016: Optimal portfolio and weighted equity portfolio

Drawdown	Weighted Equity PF	Optimal PF
No. of Expansions	46	47
Maximum Drawdown	-39,38%	-39,63%
Max. Drawdown Duration (MDD)	63	65

Drawdown statistics 2002-2016, MDD measured in months.

<u>2002-2006</u>

The performance analysis showed particular good performance during this sub-period and the risk metrics do not show the optimal portfolio to be a riskier investment during this period. The normal distribution can be rejected for the weighted equity portfolio with 99% certainty and optimal portfolio with 95% certainty, as showed by the Jarque-Bera test's critical values, which indicates mean-variance risk-measures can be considered questionable. Keeping this in mind, the rest of the risk-metrics are quite even, where the weighted equity portfolio only shows a bit more risk overall.

2002-2006	Optimal PF	Weighted Equity PF
Mean	0,444%	0,383%
Median	0,669%	0,706%
Standard Deviation	2,515%	2,515%
Excess Kurtosis	1,356	1,552
Skewness	-0,523	-0,659
Minimum	-7,320%	-7,657%
Maximum	6,178%	6,094%
Max loss with 95% (VaR)	-4,486%	-4,547%
Jarque-Bera value	7,204	10,196

Summary risk statistics 2002-2006: Optimal portfolio and weighted equity portfolio.

Drawdown	Weighted Equity PF	Optimal PF
No. of Expansions	17	19
Maximum Drawdown	-20,79%	-19,27%
Max. Drawdown Period (MDD)	22	21

Drawdown statistics 2002-2006, MDD measured in months.

The graphed drawdown, as seen in appendix 2. shows the optimal portfolio to have the same pattern as the weighted equity portfolio, with exception to generally having a bit less drawdown. This is supported by the drawdown statistics showing all-around lesser drawdown risk; more expansions, less maximum drawdown, and shorter MDD.

<u>2007-2011</u>

Keeping in mind the optimal portfolio performed worse than the weighted equity portfolio during 2007-2011, it is backed up by the risk-metrics as a riskier investment as well. Despite the same standard deviation during the financial crisis, the maximum loss is greater for the optimal portfolio, which indicates diversification tends to disappear when needed the most. Both portfolios show large tail risk, which is seen through both their negative skew and the impact of large losses on the mean compared to the median. The normal distribution cannot be rejected for either of the strategies; however, the optimal portfolio is close to the critical value and it seems probable it is merely a matter of increasing the observations.

2007-11	Optimal PF	Weighted Equity PF
Mean	-0,056%	0,012%
Median	0,220%	0,597%
Standard Deviation	3,812%	3,812%
Excess Kurtosis	0,973	0,500
Skewness	-0,573	-0,522
Minimum	-12,916%	-11,784%
Maximum	7,474%	7,551%
Max loss with 95% (VaR)	-7,528%	-7,461%
Jarque-Bera value	5,653	3,348

Summary risk statistics 2007-2011: Optimal portfolio and weighted equity portfolio.

Drawdown	Weighted Equity PF	Optimal PF
No. of Expansions	5	4
Maximum Drawdown	-39,38%	-39,63%
Max. Drawdown Period (MDD)	50+	50+

Drawdown statistics 2007-2011, MDD measured in months.

The drawdown statistics tell the same story of inclusion of carry trades during economic uncertainty, which causes in a slightly worse performance by the optimal portfolio. This can also be derived from the graphed drawdown in appendix 2.

<u>2012-2016</u>

The latter sub-period, where the optimal portfolio's Sharpe Ratio outcompeted the one of the weighted equity portfolio, shows a tad difference in the risk-metrics. However, despite the larger excess kurtosis and larger negative skew by optimal portfolio than the weighted equity portfolio, normal distribution cannot be rejected for either portfolios by their JB value. The maximum observed loss is like that of the equity portfolio and an interesting note is how the portfolio consisting carry trades has a much higher median, while its discrepancy between the mean and median is also greater. Firstly, it shows how extreme (low) observations affect the mean negatively and thereby how diversification does not seem to be present when needed. Secondly, it shows how the optimal portfolio has a relative overweight of greater returns than the weighted equity portfolio, which is also evident by the results from the performance analysis.

2012-16	Optimal PF	Weighted Equity PF
Mean	0,822%	0,717%
Median	1,123%	0,837%
Standard Deviation	2,091%	2,091%
Excess Kurtosis	0,429	0,181
Skewness	-0,422	0,181
Minimum	-4,672%	-4,374%
Maximum	5,996%	5,817%
Max loss with 95% (VaR)	-3,275%	-3,381%
Jarque-Bera value	2,243	0,410

Summary risk statistics 2012-2016: Optimal portfolio and weighted equity portfolio.

Drawdown	Weighted Equity PF	Optimal PF
No. of Expansions	29	30
Maximum Drawdown	-6,22%	-6,39%
Max. Drawdown Period (MDD)	12	12

Drawdown statistics 2012-2016, MDD measured in months.

The drawdown statistics show very little difference as also seen in the graph in appendix 2, with close to no notable differences.

Optimal Portfolio Sub-conclusion

A risk-weighted (optimal) portfolio of carry trades and equities do perform better overall than the weighted equity portfolio, as seen by the 191% cumulative return compared to the 180% of the equity portfolio. However, as normal distribution for both portfolios through 2002-2016 is rejected, mean-variance shows not to be a completely accurate risk-measure, which is illustrated in 2007-2011, where the optimal portfolio performs worse than the weighted equity portfolio. This is further shown by the maximum observed loss being significantly higher. So overall, the optimal portfolio performs better over the span of an economic cycle but does not show much diversification during times of crisis, which was feared due to the increasing correlation between carry trades and equities during 2007-2011. This, however, is before transactions costs, which the next section will shed some light on.

4. Challenging the assumptions

All strategies have been back tested under the assumption of no transaction costs and by using monthly observations as representative data for the return series. In this section, I will attempt to quantify the level of transaction costs and see how daily observations impact the return statistically, cumulatively, and in respect of drawdown risk.

Transaction costs are identified as the bid-ask spreads made by banks for both investing in the risk-free rate and for exchanging currencies. The interest rate cost is measured as the exact difference between the bid and ask rate, where the transaction cost for the currency exchange is measured as the bid-ask spread relative to the mid-price exchange rate. USD/EUR, which are the two most traded currencies, are used to measure these costs.

4.1 Transaction Costs

The EUR/USD deposit rate is also achievable for private business and not just the banks as the case is with the LIBOR rate. All transaction costs for interest rates are measured as monthly costs and exchange rate transaction costs are measured as the difference between bid-ask at the end of each month. All this is done to ensure comparability with the previously analyzed monthly return series.

Transaction Costs	Interest Rate	Currency	Potential Total
Lowest	0,000%	0,000%	0,000%
Average	0,012%	0,026%	0,038%
Highest	0,167%	0,202%	0,369%

As expected, the largest bid-ask difference (transaction cost) for the deposit rate is observed during the peak of the credit crisis with 0.167% and the lowest observed prior to the financial crisis, where the average interest-difference (cost) for the entire period is 0.012% per month. The average cost for the exchange rate bid-ask spread is 0.026% per transaction. A further breakdown of calculations can be found through appendix 1.

The actual cost incurred by the investor will depend on how the investment strategy is modeled. Where the interest rate spread is incurred each passing month, the currency spread is only incurred for each time the position is closed. It is thereby influenced by the investor’s investment horizon and how much the interest rates between countries fluctuate, as a change in the investment and funding currency would mean exchanging currencies. Due to these factors being unknown ex ante, I will continue the approach used throughout this paper by closing the investment position for each passing month.

	USD/EUR	S&P500	Weighted CT
Return Excl. Cost	0,396%	0,383%	0,263%
Avg. Adjusted Return	0,358%	0,383%	0,225%
Return Worst Case	0,027%		-0,106%
Standard Deviation	2,977%	4,149%	1,366%
Sharpe with avg. Costs	0,074	0,059	0,063

Table comparing performance statistics before and after transaction costs.

In the above table, the returns for the entire period of 2002-2016 are adjusted with observed transaction costs. Using the average transaction cost, the USD/EUR carry trade, which earned the highest total return, comes out with a lower total return than S&P 500. The Sharpe Ratio is still a bit higher due to the lower volatility. Applying the average transaction costs to the weighted carry trade gives a Sharpe Ratio of 0.063 compared to 0.091 excluding costs; noteworthy this new Sharpe Ratio is *lower* than the Sharpe Rate of the weighted equity portfolio at 0.065.

Using the worst-case transaction cost scenario, the costs nearly eat up the entire average return of USD/EUR and make the weighted carry trades return negative. Additionally, the transaction costs are likely to increase during times of financial crisis due to an increase in credit risk and decrease in liquidity. While results already showed lesser returns during economic instability before transactions costs, it exposes the carry trade investor to an even greater risk when including them. This risk is greater through worse carry trade performance, especially during times of crisis, and a likely higher correlation with equities, which would mean even less diversification.

4.2 Daily Observations

The daily observations are used for all trading days for the United States and Europe, which amounts to approximately 252 per year. Otherwise, all parameters are the same as for the monthly analysis, including the assumptions of no transaction costs.

In the below table, the different results are highlighted for daily and monthly observations respectively. The "Daily to Monthly" shows the key figures converted into monthly ratios for comparison (Bodie et al., 2014, p. 134); a month consists of 21 trading days on average.

$$\sigma_{monthly} = \sigma_{Daily} * \sqrt{Trading\ Days}$$

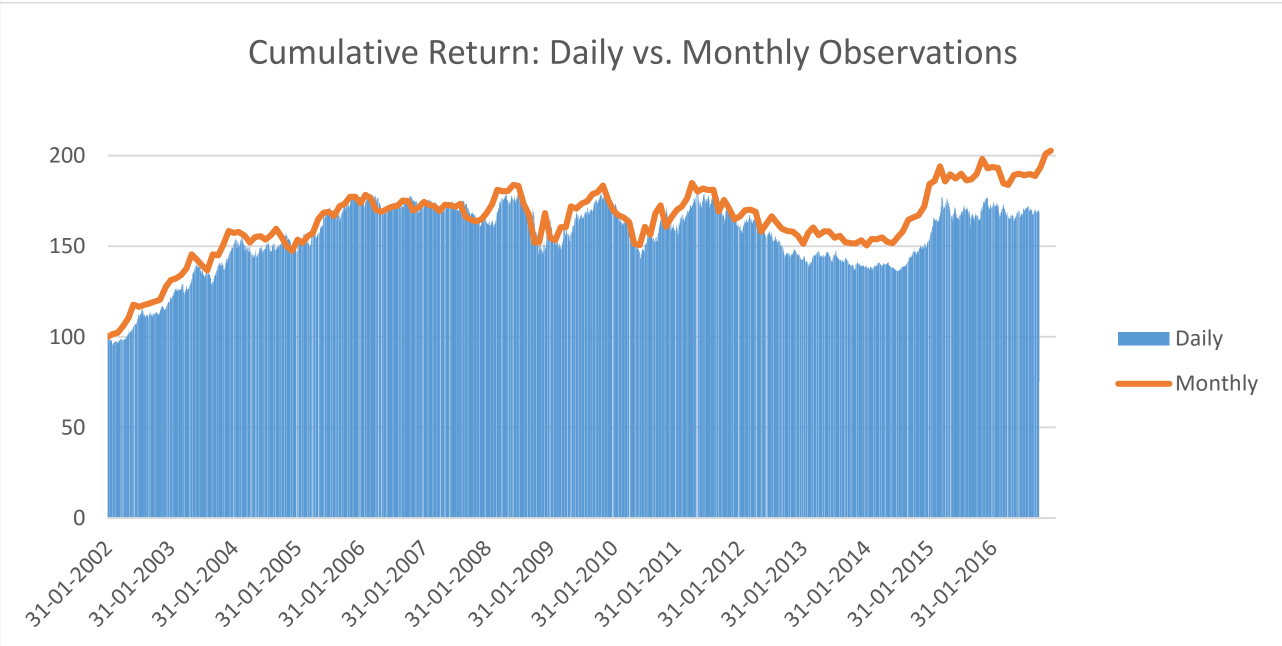
$$R_{monthly} = R_{daily} * Trading\ Days$$

The average return decreases, while the standard deviation is slightly lower but very close to the same level.

USD/EUR	Daily	Daily to Monthly	Monthly Obs.
Geomean	0,016%	0,331%	0,396%
Mean	0,018%		0,440%
Median	0,017%		0,367%
Standard Deviation	0,630%	2,886%	2,977%
Excess Kurtosis	1,656		1,244
Skewness	0,013		-0,064
Minimum	-2,957%		-9,160%
Maximum	3,552%		10,491%
Sharpe		0,067	0,086
Jarque-Bera	432,83		11,672

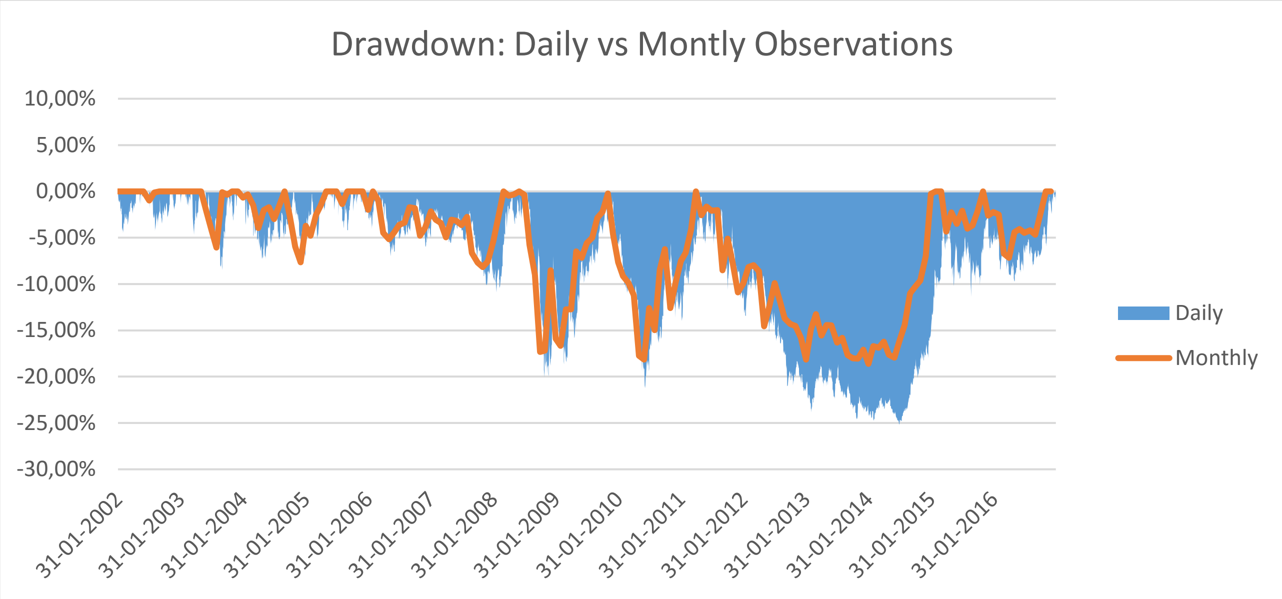
Summary Statistics USD/EUR 2002-2016, daily vs. monthly frequency.

Generally, more extreme returns are observed, as shown by the excess kurtosis, while skewness becomes positive instead of negative. As illustrated by the Jarque-Bera value, the normal distribution is rejected by an even wider margin, as expected with larger sample size. Despite the overall lower return using daily observations, the cumulative return follow the same pattern as monthly return.



Cumulative returns 2002-2016 USD/EUR, daily vs. monthly frequency.

As noted, the standard deviation is around the same and skewness is positive for the returns measured in daily observations. Having used drawdown as a risk-measure throughout the paper, it is deemed relevant to look at drawdown implications caused by daily observations and see if there are any major differences.



Drawdown 2002-2016 USD/EUR, daily vs. monthly frequency.

USD/EUR	Daily	Monthly
No. Expansion	146	33
Max Drawdown	-25,17%	-18,62%
Max Drawdown Duration in days	2126	1403
MDD in Months	101,2	46

Drawdown statistics 2002-2016 USD/EUR, daily vs. monthly frequency.

The maximum drawdown is much higher when using the daily observations, where we can see a major drawdown for the strategy during the euro crisis. This also causes a much longer MDD, which can significantly impact an investor based on the investors' time horizon. These findings give a strong indication that it impacts the overall risk assessment quite a lot whether one measures the returns on a monthly or a daily frequency. The fact that drawdown is greater by increasing frequency is in line with Lhabitant (2007), who said one should be aware of this tendency when comparing data-series with different intervals. However, this serves as an indication of the possible risks associated with an on-going investment strategy.

5. Conclusion

The paper gives strong evidence of carry trades being a profitable strategy. Three out of the four single strategies were profitable, and when equally weighted in the weighted carry trade, the carry trade delivered overall high Sharpe Ratios. The weighted carry trade had a much lower risk and higher Sharpe Ratio than any of the single strategies. Diversification among carry trades, thereby, seems evident, as the amount of idiosyncratic risk was decreased, despite not showing a lower level of systematic risk due to a very low beta.

The weighted carry trade with a monthly Sharpe of 0.091 outperformed both S&P 500 and the weighted equity portfolio. This was mainly done by its clear outperformance during 2002-2006 and almost on par Sharpe Ratio during 2012-2016. 2007-2011 showed negative returns for all strategies, where the weighted carry trade lost more than the weighted equity portfolio, despite an overall lower volatility.

The paper also highlights how carry trades are influenced by economic uncertainty, which is evident through poor performance and higher correlations with equities in times of crisis. The weighted carry trade and S&P 500 showed an overall correlation of 0.252 but where it was as low as -0.022 and 0.149 for 2002-2006 and 2012-2016 respectively, it increased to 0.430 during 2007-2011. This is also shown in the beta values, which are statistically insignificant for the good economic periods, but become significant during 2007-2011.

Currency crashes and “black swans” through negative skewness and excess kurtosis remain present in the weighted carry trade, which indicates crash risk could be somewhat correlated based on low-high interest spreads. However, the paper gives a new perspective to the relative size of crash-risk and kurtosis in carry trades, as both S&P 500 and the weighted equity portfolio show similar levels of negative skew and leptokurtic distribution. Furthermore, the normal distribution can be rejected not only for the weighted carry trade but also for both the weighted equity portfolio and S&P 500 indicating mean-variance to be a faulty risk-measure tool. The crash risk in equities is further shown in the discrepancy between the median and mean due to the impact of extreme single losses, a discrepancy that is larger for equities.

The large losses in equities can also be derived from the maximum drawdown, which is far greater for equities than for the weighted carry trade. The results lead to the underlying risk difference being the maximum drawdown duration, which is very pronounced for carry trades. Despite the maximum drawdown through 2002-2016 was -12.82% for the weighted carry trade compared to -39.38% for the weighted equity portfolio and -52.56% for S&P 500, it still took the weighted carry trade the longest to recover.

This inability to recover means carry trades are more exposed to “Black Swans” than equities, and thereby validating the “stairs” part of the saying “Going up by the stairs and down by the elevator”. The “elevator” part, which symbolizes crash risk, looks to be evident in both carry trades and equities.

Creating portfolios of carry trades and equities show that carry trade gives little to no diversification during the time of crisis compared to simply putting it in the risk-free rate. The optimal portfolio gives better returns over the entire period at indexed 191% compared to 180% of the weighted equity portfolio. This is due to overperformance during 2002-2006 and 2012-2016, as the optimal portfolio has worse performance than the weighted equity portfolio and only slightly better than a 100% investment in equities during 2007-2011.

The conclusion, therefore, seems to be that carry trades perform well and complement equities in good economic situations but do not create diversification in the time of need compared to simply including the risk-free rate in the portfolio. In case transaction costs are included, their negative impact will increase during financial uncertainty, which only hurts the portfolio and its lack of diversification during the time of crisis.

6. Discussion

The paper has helped increase mine and hopefully the reader's understanding of carry trade performance during 2002-2016 and how the different economic environments impact its performance and correlation with equities. By comparing carry trade with equities, it brings forth a new perspective, while also making it more relatable due to the daily exposure to equity everyone has through the news media.

How Results Compared to Previous Studies

My results regarding negative skewness and excess kurtosis give the same conclusion regarding potential crash risk and tail risk as Brunnermeier et al. (2008). Their findings show an even greater excess kurtosis and negative skew than mine; however, I would argue this could be due to the chosen currencies used for their analysis. They chose eight developed currencies where they shorted the three currencies with lowest interest-rates and went long in the three with highest interest-rates. If there truly is a correlation between the spread between high-interest and low-interest currencies and their crash risk, then only choosing carry trades with larger spreads would cause in higher crash risk.

Both Brunnermeier et al. (2008) and Melvin & Shand (2017) measured higher Sharpe Ratios in their carry trade portfolios, however this could again be due to both using the method of going long in the top 3 interest-rates and short in the bottom 3, leaving neutral positions in average-sized interest-rate currencies. My measured time-period is also different as they measured from 1986-2006 and 1983-2013, respectively. My results, therefore, reflect newer data, which includes the recent low-interest environment. Despite the difference in levels, the general conclusions of high Sharpe Ratios and apparent crash risk remain the same. My results also highlight the importance of maximum drawdown duration as a risk-measure in carry trades, which Melvin & Shand also concluded.

My results on increased correlations during financial uncertainty are purely based on identifying 2007-2011 as being a period of crisis. The conclusion of carry trades poor results during economic difficulties are in accordance with those Brunnermeier et al., who concluded it through positive correlations with the VIX index and TED spread.[6] The positive correlation with VIX index is further documented (Egbers and Swinkels 2013: Laborda, Laborda and Olmo 2013). An intriguing difference is found in Melvin & Shand who tested this by measuring the length of maximum drawdown duration against Financial Stress index (FSI), where they also found positive correlations for developed currencies but a negative correlation for emerging markets. It would therefore be very intriguing for a similar study as mine to test the differences in performance and diversification by including currencies from emerging markets.

[6] Difference between libor and government T-bills.

The results of this paper further expand the knowledge on the impact of transaction costs on carry trades during poor economic times, which would affect the performance negatively and thereby further support the conclusions regarding economic uncertainty's impact on carry trade returns.

Intriguing Subjects for Further Studies

Through the analysis, I have tried to expand the knowledge on performance and underlying risks of carry trades and how they compare to equities. And although the purpose of the analysis has been to find answers, results often lead to new questions.

In addition to further exploring the impact of emerging market currencies on my carry trade portfolio, my graphed cumulative return from the weighted carry trade (Section 3.3.1) gives thought to Brunnermeier et. Al's results on the impact of liquidity. Although a fall in liquidity likely affects all financial sectors after a major global financial crisis, it does pose questions regarding carry trade strategies. Firstly, it would be interesting to measure if there is any statistical evidence attributing the long period of poor "lagged" returns seen in the graphed cumulative returns to the lack of liquidity. Secondly, this could lead to testing an investment momentum strategy going long in carry trades during times of increasing liquidity and shorting once liquidity dries up. With this in mind, Mancini & Ranaldo (2013)'s paper on liquidity in foreign exchange markets and its impact on carry trade returns would have been interesting to include. Naturally, the impact of increasing transaction costs during liquidity spirals would need to be considered.

All my results are based on developed countries and not whether they have fixed or floating currency. The Swiss Franc is the only currency that had a fixed exchange rate up until 2015 and the only carry trade creating a negative return throughout the entire analyzed period. Despite a fixed exchange rate could be interpreted positively, as the restriction was on currency appreciation and Swiss Franc primarily functioned as a funding currency. It would be interesting to further investigate the implications of breaching the apparent "perfect" market of fluctuating exchange rates and whether it can be measured in carry trade returns.

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Appendices

Appendix 1: Calculations Excel Breakdown

This appendix describes the attached excel sheets and the calculation used throughout he paper.

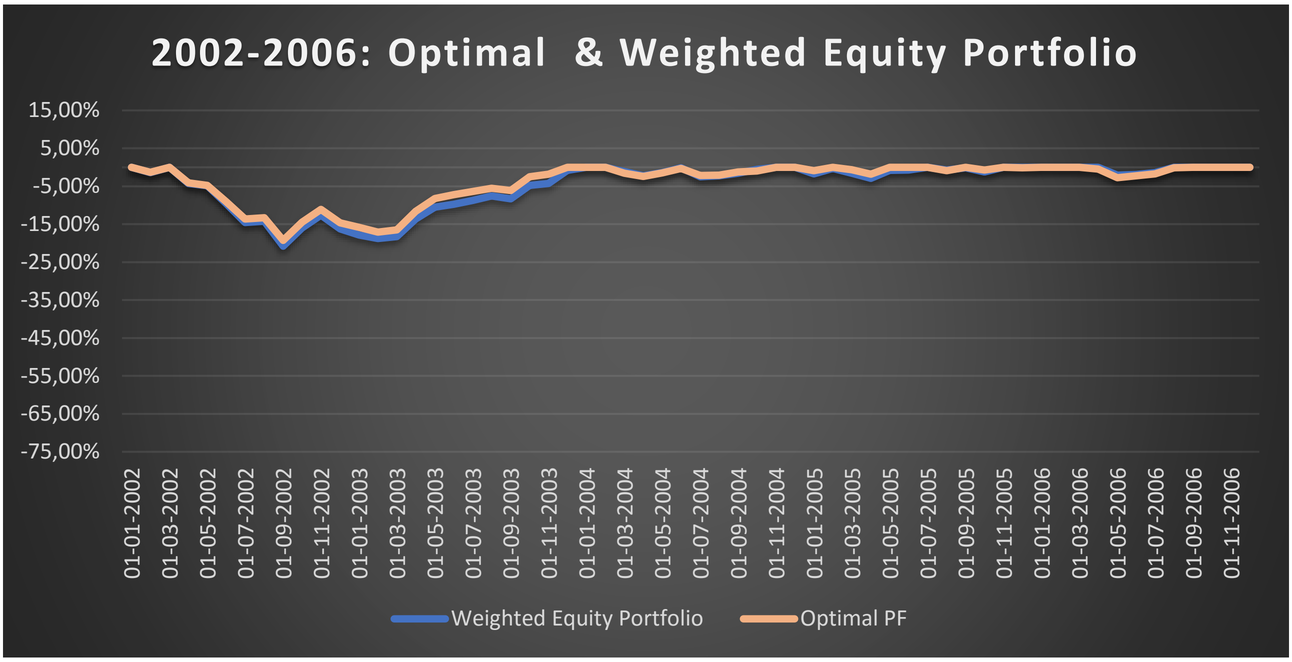
Excel Notebook Name: "Carry Trades – Return Series Analysis"

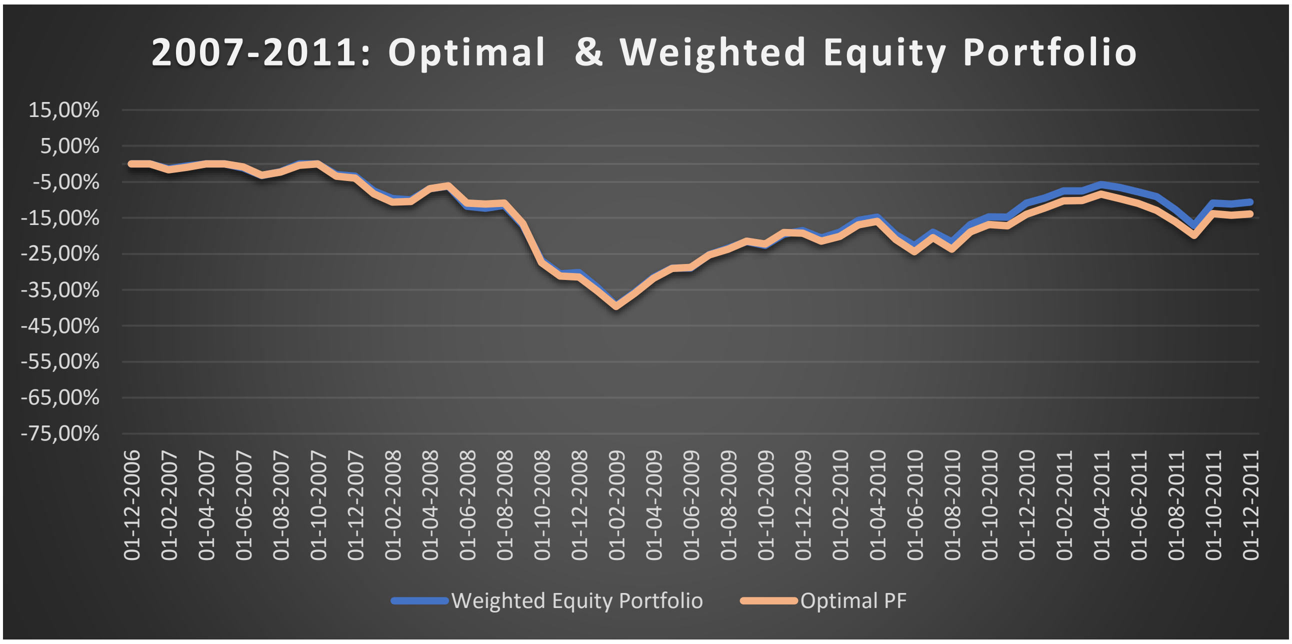
Sheet Name	Calculation Description
All Returns	All returns series for all single, weighted, and optimal strategies, including graphed cumulative returns,
Drawdown	Drawdown calculations for all strategies.
Risk Statistics Optimal PF	Summary risk statistics for all optimal portfolios
Statistics	Summary risk statistics and performance statistics for all strategies, excluding the risk statistics for the optimal portfolios.
Regressions	Regression analysis for all strategies against S&P 500.

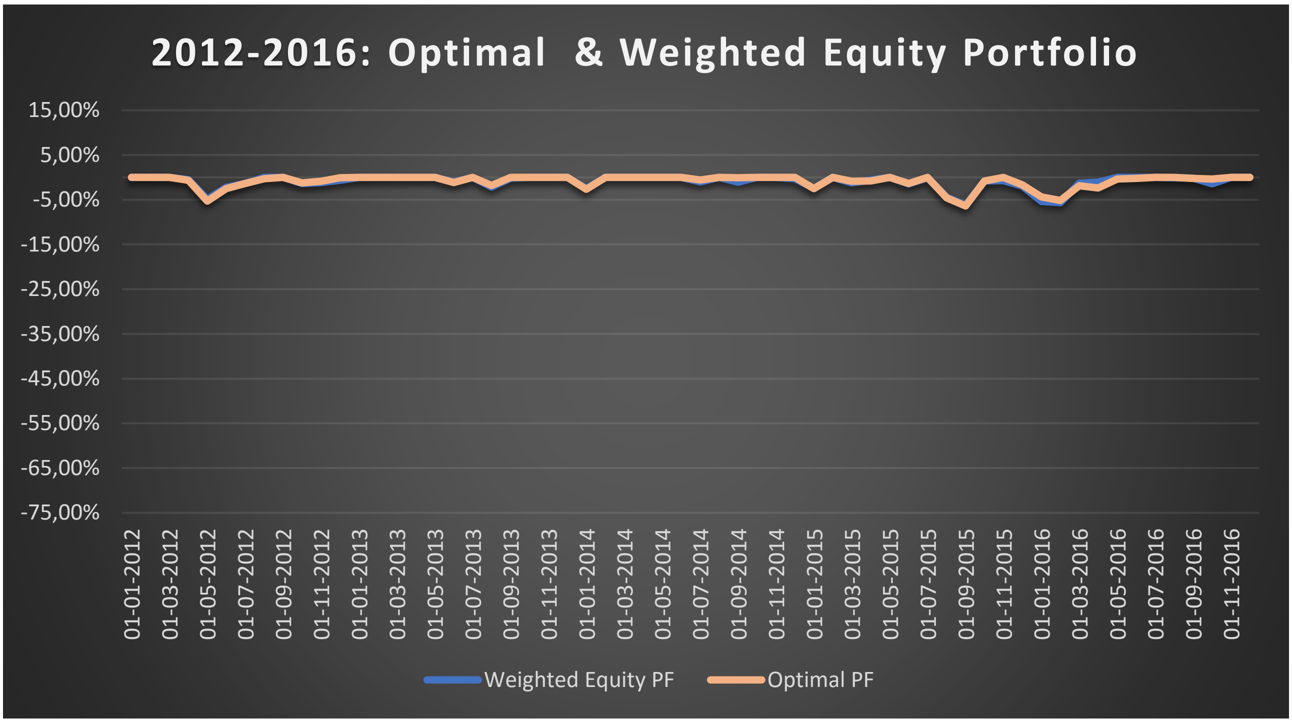
Excel Notebook Name: "Challenging the Assumptions"

Sheet Name	Calculation Description
Transaction Costs	Transaction costs calculations
Daily Return Calculations	Daily return series of USD/EUR
Return and Downside	Cumulative return and drawdown calculations, graphs, and statistics for USD/EUR with daily frequency.

Appendix 2: Sub-period drawdown models: Optimal portfolio & Weighted Equity Portfolio






2012-2016: Optimal & Weighted Equity Portfolio
15,00%
5,00%
-5,00%
-15,00%
-25,00%
-35,00%
-45,00%
-55,00%
-65,00%
-75,00%
01-01-2012
01-03-2012
01-05-2012
01-07-2012
01-09-2012
01-11-2012
01-01-2013
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01-07-2016
01-09-2016
01-11-2016
Weighted Equity PF
Optimal PF