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Understanding The FX Carry Trade: An Empirical Study

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ABSTRACT

This paper dives in to the profitability of the currency carry trade for the G10 currencies. The paper demonstrates that the British Pound is the provides the highest excess return although mostly driven by an appreciation of the exchange rate whereas The New Zealand Dollar provides the highest interest rate differential and only experience a smaller depreciation of the exchange rate, which makes it the second most profitable strategy. In addition, finds that high interest rate currencies are exposed to crash risk, which points towards the fact that currency investors “go up by the stairs and down by the elevator”.

Besides studying the currency carry trade on a stand-alone basis, the paper examines how the currency carry can provide value to a mean-variance optimizing investor. Here the paper finds that interest rates and currencies generally has low correlation with equities and bonds, making it a valuable asset for diversification. In order to derive to this result, the paper examines nine portfolios keeping three assets fixed and changing each of the currency carry strategies for each of the nine portfolios. The result is that the minimum variance portfolio with the lowest standard deviation is the Australian Dollar whereas the maximum slope portfolio with the highest risk-return trade-off is the Australian Dollar carry maximum slope portfolio. Finally, the tangency portfolio with the highest Sharpe Ratio is the Japanese Yen carry trade tangency portfolio.

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1. Introduction

The currency carry trade has for many decades been an attractive investment strategy for investors. The profitability arises when investors borrow money in a low interest rate currency and deposit the borrowed money in a deposit account in a higher interest country. However, this comes with the risk of depreciation of the investment currency and vice versa. Hence, this paper will study when and which of the G10 currencies that are profitable. In addition, the paper will explore that the high interest rate currencies are tied to crash risk, as it is said that currency carry investors “go up by the stairs but down by the elevator”. Studying these phenomena’s will help better the understanding the profitability of the currency carry trade.

To complement and deepen the understanding of the profitability of the currency carry trade, the paper will strive to develop a better understanding of how the currency carry trade can be valuable in a mean-variance efficient portfolio setting. In order to achieve this understanding, the paper will analyse each of the G10 currency carry trades and how they add value to a mean-variance efficient portfolio. By doing so, the paper tries to connect how macro-economic phenomena’s can be a valuable investment asset to complement a portfolio of traditional assets such as equities and bonds. Both in terms of minimizing the risk of the portfolios but also maximizing the risk-return profile of the portfolios but with and without a risk free assets.

1.1. Literature Review

The aim of this section is to present and review some of the key messages, observations and results from other studies but also theory relevant for this paper. The section is not exhaustive in terms of amount of studies on the topic of currency carry and portfolio theory.

Frenkel and Levich (1975) present some of the earliest work on the driving forces and theories behind exchange rate determination and their profitability. Frenkel and Levich (1975), present a procedure to estimate transaction costs in the foreign exchange markets. Frenkel and Levich (1975), furthermore, demonstrates that allowance for these cost accounts for most of the profit opportunities associated with the covered interest rate parity. In addition, Frenkel and Levich (1975) shows how demand and supply elasticities and lags in executing arbitrage can account for all of the profit opportunities. Frenkel and Levich (1975) demonstrates these results through the German Mark, U.S. Dollar and the British Pound over the period of January 1962 and November 1967.
Frenkel and Levich (1977) continues to study the effects of transaction costs on covered interest

rate arbitrage. Frenkel and Levich (1977) do so by studying if, and to what extent short-term capital movements has been affected by different economic environments generated by different exchange regimes. In order to do so, Frenkel and Levich (1977) divides their sample period in to three stages. The first: tranquil peg spanning from 1962 to 1967, the second being the turbulent peg spanning from 1968 to 1969, as this is the period where the British devaluation took place and gave rise to a turbulent period. Finally, the third period named the managed float from 1973 to 1975 was studied. Several conclusions came out of this study, the first was; the execution of transactions associated with covered interest arbitrage increased dramatically during the managed float period compared to the previous periods. Second, despite large differences in the estimated cost, they played a similar quantitative role in accounting for deviations from the parity during the tranquil peg and the manged float peg (Frenkel and Levich, 1977). The third, concerning the efficacy of arbitrage in eliminating transaction costs and ensuring that the arbitraged assets are comparable - covered interest arbitrage does not seem to entail unexploited opportunities for profit (Frenkel and Levich, 1977).

Levich (2011), demonstrates that in the aftermath of the Lehman Crisis (the financial crisis) of 08, the deviations from the covered interest parity increased sharply compared to a decade ago because currency bid-ask spreads increased, counterparty risks seem more present and risk capital is missing due to scarcity and being too expensive. Baba and Packer (2009) present similar points by studying the derivations from the covered interest rate parity in the currency swap markets around the collapse of the Lehman Brothers for the EUR/USD, CHF/USD and GBP/USD pairs. Baba and Packer (2009), put forward results pointing towards the fact that, while shortages in the currency and money markets had mostly been a dollar liquidity problem for European financial institutions but spilled over and became a global dollar shortage in the aftermath of the Lehman collapse. Furthermore Baba and Packer (2009), highlight that central bank measures was taken in the FX swap markets to counter the shortage and reduction in creditworthiness by initiating swap lines with the European central bank and the Swiss central bank and sharply increased credit lines for non-US banks. Baba and Packer (2009) argues, that the measures taken by central banks provided as a great tool to diminish the level of FX swap market deviation in the period after the Lehman collapse.

Like with the covered interest parity, a lot of literature studying the uncovered interest rate parity exists. One well-known paper presented by Fama (1984) presents evidence suggesting that high interest rate currencies does not depreciate as much as the interest rate difference, hence giving rise to the forward premium puzzle. In fact, Fama (1984) illustrate that the investment currency appreciate a little on average although with a small R^2, which is in sharp contrast to the uncovered interest rate parity that dictates that the investment currency should depreciate with an amount equal to the interest rate differential and vice versa. In addition, in theory the slope coefficient of this regression should be equal to one and the intercept be equal to zero in the regressions.

However, debate exists in the literature on the subject of the uncovered interest rate parity as many choices has to be made for practical reasons when studying the uncovered interest rate parity, where starting and end point of the sample period is said to be one of the most critical areas (Norges Bank Investment Management, 2014). Menkhoff, Sarno, Schmeling and Schrimpf (2012) presents a paper using a large set of 48 currencies (including a euro zone pair before the establishment of the euro in 1999) and a factor model, which does not seem to have any significant influence on the performance of the strategy. However, these results are somewhat in contrast to the findings of Bansal and Dahlquist (2000). Bansal and Dahlquist (2000) shows that using information from 28 developed and emerging countries, the negative correlation between interest rates and depreciation of investment currencies, is primarily confined to high income countries and in particular to countries where the interest rate exceeds the U.S. In addition, Bansal and Dahlquist (2000), show that the forward premium puzzle does not seem to be present in emerging countries and is rather a connection between GNP per capita, average inflation, inflation volatility and country ratings. Many studies related to the uncovered interest rate parity tends to study the profitability of the carry trade or the deviations from the uncovered interest rate parity with short-term interest rates such as one-month or three-month interest rates. However, Chinn and Quayyum (2012) investigates the deviations from the uncovered interest rate parity at both short and long horizon bond maturities. Chinn and Quayyum (2012) finds that the uncovered interest rate parity tends to hold better in the long-term than in the short-term across the Canadian Dollar, Japanese Yen, British Pound, Swiss Franc and U.S. Dollar. In other words, this means that the slope coefficients in the Fama (1984) regressions of the long-term uncovered interest rate parity maturities tend to be non-negative.

Now over the years, other explanations as to why the carry trade are profitable on average has emerged. Besides, the deviations from the uncovered interest rate parity, explanations arising from sources of risk has been presented in the literature. The idea behind, is that the profitability must be driven by some sort of risk, like with so much else. According to Norges Bank Investment Management (2014), risk-based explanations is concerned with estimating a factor model that shows that excess returns are due to certain risk factors and once corrected for, these models leave alphas statistically significant from zero. Now, Lustig, Roussanov and Verdelhan (2011), puts forward a paper, which use a two factor model but this model only contains factors from currency markets. The two factors Lustig, Roussanov and Verdelhan (2011) use to explain the excess returns are the market or dollar factor and the currency factor, which are the average return of exchange rates versus the dollar and the currency factor, which is a portfolio of foreign currencies with high interest rates minus a portfolio of currencies with low interest rates. Hence, developing such model draws inspiration from research put forward by Fama and French (1992) in equity markets and both models seem to explain the cross-section of the assets under examination.

Contrary to keeping currency markets separated is the approach where researchers has been looking at equity and bond markets as possible risk-based explanations to interest rates and exchange rates, in particular the carry strategy. Christiansen, Ranaldo and Söderlind (2011), differentiate themselves by taking another approach by not keeping the currency markets segmented by using bond and equity markets as systemic risk factors to estimate time-varying exposure. These factors depends on proxies for currency-implied volatility (FX volatility and the VIX) and the TED spread as state variables (i.e. the T-bill rate minus Eurodollar rate) in the period from 1995 to 2008 with daily observations (Christiansen, Ranaldo and Söderlind, 2011). Results from carry trade strategies based on the G10 currencies show that risk exposures of the carry trades are to a large extent regime dependent: the beta with the equities is positive in normal times, which is amplified in turbulent times according to Christiansen, Ranaldo and Söderland (2011). Furthermore, the returns are more predictable during turbulent times and display a direct exposure to a volatility factor - the results holds for individual currencies according to Christiansen, Ranaldo and Söderland (2011). Now, Christiansen, Ranaldo and Söderland (2011) also finds that 1/3 of the carry trade performance in times of high volatility is driven by exposure to traditional risk factors such as equity and bond returns whereas 2/3 is driven by exposure to the volatility factor itself.

Other literature in the field of interest rates and exchange rates is work presented by Brunnermeier, Nagel and Pedersen (2009), who tied the excess returns of the carry trade strategy to skewness of the exchange rates as a measure of crash risk. By doing so, Brunnermeier, Nagel and Pedersen (2009) demonstrate that currencies are exposed to crash risk, hence confirming that currency investors “go up by the stairs and down by the elevator”. However, Brunnermeier, Nagel and Pedersen (2009) only study this on the G9 instead of G10 currencies, which excludes the Swedish Krona. The sample period subject for analysis in the paper presented by Brunnermeier, Nagel and Pedersen (2009) are 1986 to 2006 using quarterly and daily data. However, Brunnermeier, Nagel and Pedersen (2009), put forward that a carry trade portfolio are exposed to increases in risk aversion as measured by the VIX index. By applying a one-factor model Brunnermeier, Nagel and Pedersen (2009) finds that periods with increases in the VIX happens at the same time when the carry trade experience loses. Furthermore, Brunnermeier, Nagel and Pedersen (2009) ties the decrease of open futures contracts by speculators to the increases in the VIX for currencies with a positive interest rate differential with the U.S. Dollar indicating liquidity risk as a driving factor. Mancini, Ranaldo and Wrampelmeyer (2013) support these results by arguing that carry trades are exposed to liquidity risk as measured by price impact, return reversal, trading cost and price dispersion. In addition, they find that liquidity spirals might trigger these findings.

Lustig and Verdelhan (2007) put forward a paper that is highly inspired by Yogo's (2006) model in equity markets. The results show that aggregate consumption growth risk help explain why currencies with low interest rate carry do not appreciate as much as the interest rate differential and, likewise why high interest rate carry strategies does not depreciate as much as the interest rate differential. In addition, Lustig and Verdelhan (2007), show that domestic investors earn negative excess returns on low interest rate currency portfolios and positive excess returns on high interest rate currency portfolios. Lustig and Verdelhan (2007), argue that this is true because high interest rate currencies depreciate on average when domestic consumption growth is low and low interest rate currencies appreciate under same conditions, hence they provide as a hedge against domestic consumption growth risk (Lustig and Verdelhan, 2007).

Lastly, in another end of the literature around the term carry, is the work put forward by Kojien, Moskowitz, Pedersen and Vrugt (2018) who takes the term "carry" and expands it to other asset classes. Koijen, Moskowitz, Pedersen and Vrugt (2018), argue that any assets "carry" can be divided in to an ex-ante model-free characteristic, and its expected price appreciation. The assets under examination are equities, fixed income, treasuries, commodities, currencies, credit, call & put options. The sample period vary across the assets under examination, however, the earliest sample period begins in 1973 and ends in 2012. Furthermore, the paper shows that a portfolio of different carry strategies with different assets classes produces better Sharpe Ratios than a currency carry strategy.

Finally, and for the use of this paper, the well-known and famous mean-variance framework presented by Markowitz (1952, 1959). Markowitz (1952, 1959) presents a relatively intuitive framework, under certain assumptions, to help improve investors build efficient portfolios of different risky assets and a risk free asset. This framework help investors' decision-making when selecting assets to hold in their portfolios. Now, the main inputs for this framework are expected return, variance and covariance relationships between the assets, which makes it a time efficient framework to apply. Under the mean-variance framework, the investor is assumed to desire a portfolio with the lowest possible variance given a level of expected return due to risk aversion or maximize the risk-return profile of a portfolio and so the aim is to find an efficient "solution" to these problems. This paper will implement this framework to analyse how the carry trade contribute to a portfolio even though the model has been under some criticism after its development. The introduction is kept short in this section as the model is used in the paper where more details are explained.

1.2. Motivation and Problem Statement

On the basis of the introduction and literature review this section will constitute the motivation behind the research questions. It should be clear to the reader that the field of currency carry trades has been widely studied subject over the past decades. This, drives the motivation to obtain an understanding of the profitability and performance of the currency carry trade and to an extend contribute with inputs where the author finds it relevant or where the author believes the findings of this paper can be a reinforcement to existing literature. At the same time the paper will attempt to discover new results. Furthermore, the author believe that the field of interest rates and currencies provides as an interesting field to study. This is true, as the author wants to explore and develop a further understanding of other assets than equities and bonds to see how they provide opportunities for an investor both on a stand-alone basis but also in portfolio context. In addition, interest rates and exchanges rates are a phenomena of great concern in macro-economics and so the author will try to connect the macro related assets to traditional assets of the financial markets such as equities and bonds (of course bonds and equities are also of concern in macro-economics).

Above considerations gives rise for the author's problem statement and research questions:

"Why is the FX carry trade profitable and how does the G10 currencies add value to a portfolio of risky assets from a historical stand-point?"

The paper will utilize four main research question in order to answer the main problem statement. The four research questions are the following:

Question 1: What are exchange rates and how are they determined?

This question are answered by outlining a general understanding of foreign exchange markets and the main equilibrium conditions that are said to hold in theory but in practice tends not to hold.

Question 2: Why is the FX carry trade profitable and how does crash risk tie to the FX carry trade?

The deviation of from the uncovered interest rate parity and the profitability is studied through the G10 currencies with the U.S. Dollar as base currency. Furthermore, the paper will explain how the cross-section of interest rate differentials are tied to crash risk of exchange rates, which is said to drive some of the profitability.

Question 3: How does the inclusion of the FX carry trade affect a mean-variance efficient portfolio and which portfolio is the most desired?

By changing the framework from financial econometrics to a mean-variance framework, the paper will answer this question by studying how each carry trade adds value to a mean-variance optimized portfolio. The aim is to see, which of the currencies are the most valuable asset to a mean-variance optimizing investor.

Question 4: How many of the portfolios with the FX carry trade outperform the single assets of the portfolio?

Naturally, a mean-variance optimizing investor would desire the portfolio with a carry trade that will outperform the single assets in the portfolio. Hence, this question is answered by comparing the results of each portfolio (a portfolio including the FX carry trade) with the stand-alone assets in the portfolio for both the minimum variance portfolio, the maximum slope portfolio and tangency portfolio.

1.3. Limitations

This paper is focusing solely on interest rates and currencies for the G10 currencies and the S&P500, Russell 2000 index and the Barclays U.S. treasury Total Return Unhedged USD index . By doing so, the paper assumes that transaction costs are non-existing due to the very liquid markets of these assets or at least very low compared to other assets. In addition, the paper does not take any bid-ask spreads in to account. The assumption regarding no transaction costs also translates in to equities and bonds when analysing the carry trade in a mean-variance setting. Naturally, transaction costs are non-preventable in a real world setting.

The paper is solely focusing on financial movements when looking at exchange rates i.e. movements due to interest rate differentials. Now in reality, exchange rates movements can be due to many other reasons but primarily trade between individuals and countries.

Finally, is an empirical paper i.e. using theory to study phenomena's in the financial markets. Hence, the paper is focusing on the historical period between 1999 and 2019 for the G10 currencies and the S&P500 index, the Russell 2000 index, Barclays U.S. treasury Total Return Unhedged USD index and the U.S. Federal Reserve Rate.

1.4. Structure

The aim of this section is to provide an overview of the paper to the reader in order to help the reader understand structure of the paper. After the abstract, literature review, problem statement, limitations and research questions, the paper will unfold as; first, a general foundation behind foreign exchange markets followed by an exploration of theoretical equilibrium conditions in these markets, which provides as main research area. After exploring the equilibrium conditions, the paper will dive in to part one, which is a smaller part of the paper that consists of financial econometrics (crash risk i.e. skewness) trying to explain one reason behind the profitability of the currency carry trade and how the carry trade is profitable. The second and largest part, is concerning the well-known, but somewhat, theoretical framework of the mean-variance portfolio theory in order to analyse how an investor can benefit from including the currency carry trade strategy in a portfolio. After outlining the theory, the paper will describe the data and then apply the theory as outlined. Hence, both part one and two extends to results. Finally, the paper will end by discussing the results, provide critique and then conclude on the results. For a visual presentation, see figure 1 below.

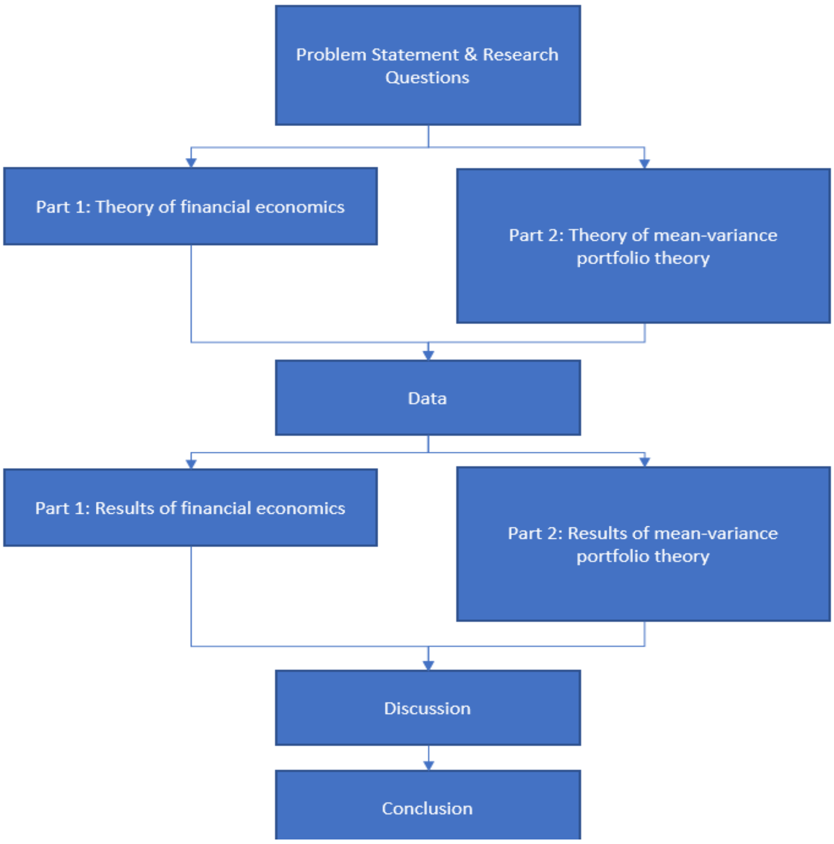

Figure 1. Is a visual representation of how the paper is structured. The size of the individual boxes is approximately appropriate to how much each part constitute in the paper. Source: Author's own creation.

2. Theoretical Foundation

Following section will provide a definition of the currency carry trade (FX carry trade) combined with an explanation of the theoretical foundation that allows for the FX carry trade to work in practice. Furthermore, the section will outline one of the main theoretical risk factors that the FX carry trade investor is said to be compensated for when entering the FX carry trade. In addition, this section will explain the tools provided by the mean-variance framework to facilitate a portfolio analysis with the FX carry trade as a complimentary asset to equities and bonds (kept fixed in all the portfolios).

2.1. The Market For Foreign Exchange

Understanding the market for foreign exchange (FX markets) is essential to understanding the currency carry trade, its assumptions and the associated equilibrium conditions.

Money represents purchasing power. Having money in domestic currency gives the investor power to purchase goods, services and/or assets from other participants in the domestic country. In contrast, purchasing goods, services and/or assets in foreign countries requires the investor to have the foreign currency in order to perform transactions. To own foreign currency, the investor has to purchase the foreign country's currency. Hence, the investor has to sell the domestic currency in exchange of the foreign currency (i.e. foreign exchange). By buying foreign currency, the investor now has the opportunity to perform transactions in other countries with whom the investor desire and by that the investor now successfully translated domestic purchasing power to foreign purchasing power (Eun and Resnick, 2014).

As one can imagine, the market for foreign exchange is of great importance and of great size as people needs to do transactions with many different objectives across countries. Hence, generally speaking, the foreign exchange market can be defined as the conversion of purchase power from one currency into another, bank deposits of foreign currency, the extension of credit denominated in foreign currency, foreign trade financing, trading in foreign currency options and futures contracts and currency swaps (Eun and Resnick, 2014). Of course, covering all the topics is too extensive for the scope of this paper, hence the main objective is to describe the mechanics of the currency markets and structure of the foreign exchange market in relation to the spot market and interest rates.

The foreign exchange market can be divided in two: interbank market and retail (Eun and Resnick, 2014). However, this report will only focus on the interbank market as it entails large commercial banks having deposit accounts with one another.

Spot markets and forward foreign exchange markets are over-the-counter (OTC) markets. OTC means that trading does not take place in a central marketplace where buyers and sellers meet physically. In contrast, the foreign exchange market is a linkage of bank currency traders, nonbank dealers, and FX brokers across the world (Eun and Resnick, 2014). The spot market is the immediate purchase or sale of foreign exchange whereas the forward market involves contracting for the future purchase or sale of foreign exchange. In the forward exchange market, the price agreed to in the forward contract may be the same as the spot exchange rate (Eun and Resnick, 2014). Understanding how the spot and forward market works is essential to understanding the uncovered and covered parity conditions in the following sections as the forward exchange rate can be assumed to be an unbiased predictor of the spot exchange rate under certain assumptions (Eun and Resnick, 2014).

2.2. The Covered Interest Rate Parity

Expanding upon the knowledge from previous section, one can now begin studying the driving forces behind exchange rate changes since these are the foundation for the understanding of the profitability of the FX carry trade.

To begin with, one need to explore the first arbitrage condition, namely the covered interest rate parity, that must hold when the international financial/monetary markets are in equilibrium (Eun and Resnick, 2014). Now suppose that an investor has one dollar to invest over a one-year period (Eun and Resnick, 2014). Investing one dollar in the money markets can happen in two ways under the covered interest rate parity (Eun and Resnick, 2014). First, the investor can deposit one dollar in a domestic risk-free deposit account with a maturity value of (assuming the investor is dollar denominated) (Eun and Resnick, 2014):

$$\$1 \cdot (1 + i) \ (\mathbf{1})$$

i is the risk-free domestic risk-free deposit rate. On the other hand, the U.S. investor can invest in the U.K by following three steps (Eun and Resnick, 2014):

1. Exchange one dollar for the equivalent in pounds at the spot exchange rate (s)
2. Invest the amount in pounds at the U.K interest rate with a maturity value of £ $\left(\frac{1}{s}\right) * (1 + i^*)$
3. Sell the maturity value of the U.K investment from step 2. With a forward exchange contract for a dollar amount of \$ $\left[\left(\frac{1}{s}\right)(1 + i^*)\right] F$, where F denotes the agreed forward exchange price.

From above it should be clear that the two strategies should yield the same net proceeds at maturity, as the U.K investment is completely risk free since the exchange rate risk is hedged with a forward contract (Eun and Resnick, 2014). Hence, the arbitrage condition demands that the dollar amounts at maturity (the dollar interest rate) from the two investments are the same (Eun and Resnick, 2014):

$$(1 + i) = \frac{F}{S} * (1 + i^*) \ (\mathbf{2})$$

The above equation can be estimated by:

$$(i^* - i) = \frac{F - S}{S} * (1 + i^*) \cong \frac{F - S}{S} \ (\mathbf{3})$$

Rearranging expression (2), allows us the express the forward price as a function of the spot exchange rate and the domestic (i) and foreign interest rate (i^*) (Eun and Resnick, 2014):

$$F = S\left[\frac{1+i}{1+i^*}\right] \ (\mathbf{4})$$

Hence, according the covered interest parity and expression (4) if the interest rate is higher in the U.S than in the U.K the dollar is at a discount (F>S) and so the dollar is expected to depreciate against the UK pound. This means that the investor would basically be indifferent of where to invest money in the case that the covered interest rate parity holds (Eun and Resnick, 2014).

2.3. The Uncovered Interest Rate Parity

Given the understanding of the covered interest rate parity, one can now begin exploring the uncovered interest rate parity and its implications on exchange rate determination. If one reformulate the covered interest rate parity condition in (2) in terms of the spot exchange rate one get (Eun and Resnick, 2014):

$$S = \left[\frac{1+i^*}{1+i}\right] F \ (\mathbf{5})$$

One see that spot exchange rates depends on relative interest rates given the forward spot exchange rate. A higher U.S. interest rate will lead to a higher U.S. dollar price (i.e. lower exchange rate due stronger dollar) because the higher US interest rate will attract investors and capital to the U.S. On the other hand, a lower interest rate will lead to a lower U.S. dollar price as investors are pulling capital out of the U.S. (Eun and Resnick, 2014)

If the assumption is that the forward exchange rate is the expected future spot exchange rate conditional on all relevant information being available now, one see that (Eun and Resnick, 2014):

$$F = E(S_{t+1}|I_t) \ (\mathbf{6})$$

Where $S_{t+1}$is the future spot rate when the forward contract matures and I_t denotes the set of information currently available. Putting equation 5 and 6 together gives the following relationship (Eun and Resnick, 2014):

$$S = \frac{1+i^*}{1+i} E(S_{t+1}|I) \ (\mathbf{7})$$

When forward exchange rate is replaced with the future spot rate depending an all relevant information being available, one see a few important mechanics. The first important observation is that the spot price now depends on expectations. Expectations can lead to the fact that when investors expect an increase in the spot exchange rate, it tends to increase. Secondly, exchange rate depends on events and news, which investors form expectations on. Hence, investors constantly update their expectations on news or events, which in turn will lead to a continuously update of the current exchange rate (Eun and Resnick, 2014). Accordingly, when the forward exchange rate (F) is replaced with the expected spot exchange rate $E(S_{t+1})$ in equation (3), one can see that:

$$(i - i^*) = \frac{E(S_{t+1}) - S_t}{S_t}(1 + i^*) \cong \frac{E(S_{t+1}) - S}{S} \ (\mathbf{8})$$

Upon some simple rearrangement, one can see that the interest rate differential is approximately equivalent to the expected change in the exchange rate $E(e) = \frac{E(S_{t+1})-S_t}{S_t}$ (Eun and Resnick, 2014) :

$$(i - i^*) \approx E(e) \ (\mathbf{9})$$

Now, this result is central to this paper, as violations of these parity conditions provides as foundation for the FX carry trade, which exploits interest rate differentials. In order execute the carry trade and exploit the interest rate differential, the investor has to buy high interest rate currencies, which is funded by selling low interest rate currencies also known as investment and funding currencies. This means that the investor takes a loan in one country and deposits the capital in a deposit account in a higher interest rate country. In addition, it should now be clear to the reader that the main difference between the two parity conditions, is namely, that the covered interest rate parity involves hedging of the exchange rate risk with a forward contract whereas the uncovered is not hedging the exchange rate risk.

In case the uncovered interest rate parity is violated, one can see that the FX carry trade will be profitable as long as the interest rate differential is positive and greater than the rate of appreciation of the funding currency in the investment period. However, if the circumstances where that interest rate differentials are high such that high levels of capital are flowing in to the money markets, the funding currency may depreciate (Eun and Resnick 2014). This is in sharp contrast to the predictions of the uncovered interest parity (Eun and Resnick 2014). Now, this will lead to three interesting observations, if the rate of depreciation of the funding currency is greater than the funding currency interest rate, it will make the funding cost negative, which effectively will make the FX carry trade more profitable. Of course, if the funding currency appreciates more than interest rate spread, investor would lose money. The second observation, is that the in case the uncovered interest rate parity is violated, the carry trade is clearly not risk free because of the exchange rate risk. Third observation, is that when the funding interest rate is negative and the investment interest rate is positive, it will boost the potential profitability of the carry trade (Eun and Resnick, 2014).

The covered and uncovered interest rate parity gives rise to further questions, which this report aims to study. In particular, as the uncovered interest rate parity give investors opportunity to implement the profitable FX carry trade and so it is interesting to see if the uncovered interest rate parity is violated in practice. As it is assumed that if the interest rate differential is positive, the excess return on the carry trade should be zero as the exchange rate would eliminate the positive gains. In addition, in case the uncovered interest rate parity is violated the carry trade is, in theory, exposed to certain risks. Although many potential risk factors seem obvious such as capital control, others might not. In following sections, this report will strive to study some of the risk factors that are not as clear as capital controls, which might be the driving forces behind the profitability of the FX carry trade.

2.4. Crash Risk

The skewness of a distribution of returns describes how symmetrical the returns are around the distribution mean. When the skewness of returns are different from zero, the return distribution is said to be asymmetric – either positive or negative. As seen from the definition of skewness:

$$skew = \frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{\sigma^2}\right)^3 \quad \mathbf{(10)}$$

Here n describes number of observations, x_i denotes observation i, $\bar{x}$ is the mean of the observations and σ^2 is the standard deviation of the observations (Defusco., R, Mcleavy., D, Pinto., Jerald, Anson., Mark, 2007).

From figure 2 below, one can see the three distributions, which are negative, neutral and positive, respectively. Figure 2 panel C, displays a distribution with positive skewness and so the tail is asymmetric, which leans towards positive values. This distribution will tend to have many small losses and few but high wins. Figure 2 panel A, displays a distribution with negative skewness. This distribution will lead to a negative distribution in which the asymmetric tail leads towards negative values. This distribution will lead towards many small wins and few but high losses. Lastly, in panel B is the gauss or normal distribution, which is evenly distributed around the mean of zero and a symmetric tail to each side.

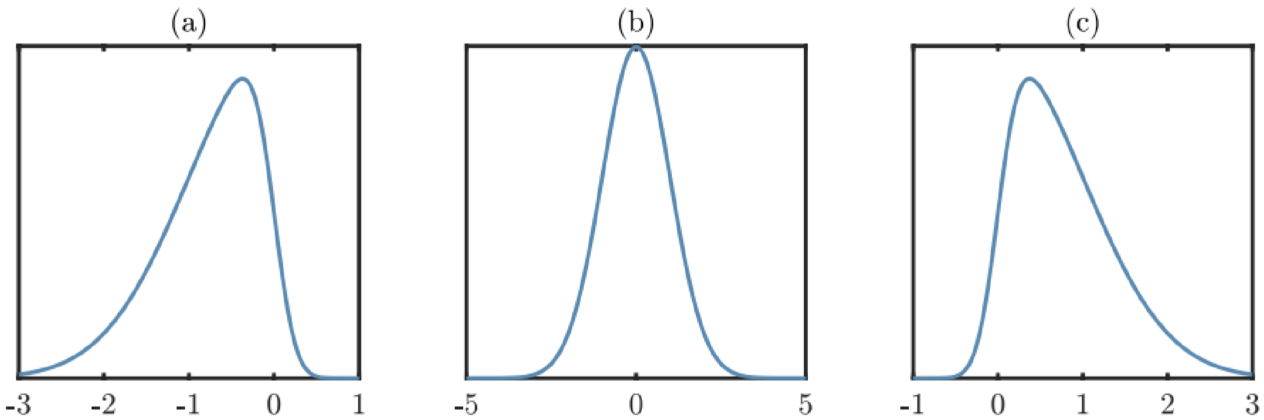

Figure 2. Panel A shows a left skewed distribution, panel B shows a neutral or gauss distribution and panel C shows a right skewed distribution. Source: Authors own creation

Skewness or crash risk is said to be one of the main risks behind the FX carry profitability and are studied by Brunnermeier, Nagel and Pedersen (2009).

2.5. Carry In Portfolio Context

Studying the profitability of the FX carry trade on a stand-alone basis is, of course, highly relevant when an investor is considering this strategy as an investment opportunity. However, on the other side of the coin, the risk-return profile of the investor's overall portfolio is of great concern to the investor. Hence, in order to take a broader approach to the asset class of currencies and interest rates, one has to understand the mechanics of portfolio theory and it is here the mean-variance portfolio theory comes in handy.

The main intuition of portfolio theory is, in short, that the risk of large negative returns is smaller of a portfolio consisting of two assets compared to a "portfolio" consisting of one asset. In case the former ends up materialising and leading to a negative return of the first asset, it is then assumed to be countered with the possibility for the second asset ending up with a positive return (Munk, 2018). Hence, due to this brief introduction of the intuition behind portfolios, the paper will change the framework for studying the carry trade in portfolio context by utilizing the well-known mean-variance framework.

Now, this section aim to study how the FX carry strategy can complement a portfolio of stocks and bonds. The paper will study the performance of a portfolio of stocks, bonds and the FX carry trade in historical perspective. Before such an analysis can take place, one have to define some portfolio statistics in order to build a portfolio for the purposes of analysis.

Overall, the return of a portfolio consisting of many risky assets is defined as (Munk, 2018):

$$r_p = \pi_1 \cdot r_1 + \pi_2 \cdot r_2 \cdots + \pi_N \cdot r_N = \sum_{i=1}^{N} \pi_i r_i \ (\mathbf{11})$$

Where r_i is the rate of return of asset i, π_i is the weight in asset i and N is the number of assets in the portfolio. Notice that the weights of the portfolio must sum to one and that the equation can be restated as the product of two Nx1 vectors, which will be useful later (Munk, 2018). Hence, many different combinations of weights and returns exists depending on the investor's desires for their portfolios.

Now, risk and return in this context and according to much of the finance literature is measured in terms of standard deviation and expected returns. Furthermore, the introduction of matrix definitions of the returns, variance and standard deviations of the returns of a portfolio is necessary. As mentioned, the rate of returns and weights can be expressed as Nx1 vectors and are an arithmetic average of the log returns annualized:

$$\boldsymbol{\mu} = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ \vdots \\ r_N \end{pmatrix} \ (\mathbf{12})$$

And the portfolio weights as:

$$\boldsymbol{\pi} = \begin{pmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \vdots \\ \pi_N \end{pmatrix} \ (\mathbf{13})$$

And the variance-covariance matrix of the rate of returns $\omega = Var(\boldsymbol{r})$ of **r** is defined as N x N matrix (Munk, 2018):

$$\omega = \begin{pmatrix} Var[r_1] & Cov[r_1, r_2] & Cov[r_1, r_3] & \cdots & Cov(r_1, r_N) \\ Cov[r_2, r_1] & Var[r_2] & Cov[r_1, r_3] & \cdots & Cov(r_2, r_N) \\ Cov[r_3, r_1] & Cov[r_3, r_2] & Var[r_3] & \cdots & Cov(r_3, r_N) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Cov[r_N, r_1] & Cov[r_N, r_2] & Cov[r_N, r_3] & \cdots & Var[r_N] \end{pmatrix} \mathbf{(14)}$$

Since $Var(r_i) = Cov(r_i, r_i)$, we can write any element of the matrix as $\omega_{ij} = Cov(r_i, r_j)$ even for $j = i$. And since $Cov(r_i, r_j) = Cov(r_j, r_i)$, the variance-covariance matrix is symmetric in the sense that $\omega^T = \omega$. Now, the variance of the rate of the return of the portfolio is defined as (Munk, 2018):

$$Var[r(\boldsymbol{\pi})] = \boldsymbol{\pi} \cdot (\omega \boldsymbol{\pi}) \; \mathbf{(15)}$$

$\boldsymbol{\pi}$ denotes the vector of portfolio weights and ω is the variance-covariance matrix. Now, that the variance of the rate of the returns of the portfolio is defined, then we can go ahead and define the standard deviation of the portfolio, which is the variance of the rate of return squared (Munk, 2018):

$$\sigma[r(\boldsymbol{\pi})] = \sqrt{\boldsymbol{\pi} \cdot \omega \boldsymbol{\pi}} \; \mathbf{(16)}$$

It is clear that many different portfolio can be obtained from a wide range of combinations of weights in the different assets that the portfolios consists of given an expected return and variance-covariance matrix of the returns. This is the main focus of the mean-variance theory, which looks at the trade-off between risk and return between assets, as investors tend to give up higher expected returns in order to have lower risk. The idea behind portfolio construction is basically, that investors can diversify asset specific risk away, and therefore only be compensated for market risk or systematic risk. However, diversification come with a trade-off as investors may have to give up some expected returns in order to achieve a portfolio with the lowest risk i.e. variance (Munk, 2018). Now in order to analyse this phenomenon, the introduction mean-variance analysis introduced by Markowitz (1952, 1959) is necessary. Mean-variance analysis will later allow an investor to determine portfolios with certain characteristics such as minimum variance over a given time period, maximum ratio between return and risk and the maximum Sharpe ratio of a portfolio.

2.5.1. Mean-Variance analysis

The main assumption behind mean-variance analysis is that the investor only cares about expected return and the variance of the return of the portfolio over a given time period. Naturally, this means that the investor desire the portfolio with the lowest variance given an expected return. For further use, definitions from section 2.5., will be applied. Here $\boldsymbol{\mu}$ is the vector of expected returns, $\boldsymbol{\pi}$ is the vector of portfolio weights, which must sum to one and $\omega = \omega_{ij}$ is the variance-covariance matrix. It is further assumed for the purpose of explaining the theory, that the investor only invests in N risky assets and no risk free asset (Munk, 2018).

The expected return, variance and standard deviation of the portfolio is denoted by (Munk, 2018):

$$\mu(\boldsymbol{\pi}) = \boldsymbol{\mu} \cdot \boldsymbol{\pi} = \sum_{i=1}^{N} \mu_i \pi_i \ (\mathbf{17})$$

$$\sigma^2(\boldsymbol{\pi}) = \boldsymbol{\pi} \cdot \omega\boldsymbol{\pi} = \sum_{i=1}^{N} \sum_{j=1}^{N} \pi_i \pi_j \omega_{ij} \ (\mathbf{18})$$

$$\sigma(\boldsymbol{\pi}) = \sqrt{\boldsymbol{\pi} \cdot \omega\boldsymbol{\pi}} = \left(\sum_{i=1}^{N} \sum_{j=i}^{N} \pi_i \pi_j \omega_{ij} \right)^{1/2} \quad (\mathbf{19})$$

Next, the paper will utilize some auxiliary constants introduced by Munk (2018) as the scope of the paper is not to derive the mathematics and proofs behind all the definitions and models used in this paper. However, the auxiliary constants are a solution to the quadratic minimization problem, which aims to find mean-variance efficient portfolios with expected return $\bar{\mu}$ under the mean variance theory. The quadratic minimization problem, looks as follows (Munk, 2018):

$$min\ \boldsymbol{\pi} \cdot \omega\boldsymbol{\pi} \ (\mathbf{20})$$

$$s.t. \boldsymbol{\pi} \cdot \boldsymbol{\mu} = \bar{\mu} \ (\mathbf{21})$$

$$\boldsymbol{\pi} \cdot \mathbf{1} = 1 \ (\mathbf{22})$$

As mentioned, in order to solve the minimization problem, one can use the following auxiliary constants.

$$A = \boldsymbol{\mu} \cdot \omega^{-1}\boldsymbol{\mu} \ (\mathbf{23})$$

$$B = \mathbf{1} \cdot \omega^{-1}\boldsymbol{\mu} \ (\mathbf{24})$$

$$C = \mathbf{1} \cdot \omega^{-1}\mathbf{1} \ (\mathbf{25})$$

$$D = AC - B^2 \ (\mathbf{26})$$

Where A, C and D are positive and B can be both positive and negative and that B is different from zero (Munk, 2018). Now in order to get the mean-variance efficient portfolios with expected return $\bar{\mu}$, variance of the returns and the standard deviation one apply the following (Munk, 2018):

$$(1)\ \boldsymbol{\pi}(\bar{\mu}) = \frac{C\bar{\mu} - B}{D}\omega^{-1}\boldsymbol{\mu} + \frac{A - B\bar{\mu}}{D}\omega^{-1}\mathbf{1}\ (\mathbf{27})$$

$$(2)\ \sigma^2(\bar{\mu}) = \boldsymbol{\pi}(\bar{\mu}) \cdot \omega\boldsymbol{\pi}(\bar{\mu}) = \frac{C\bar{\mu}^2 - 2B\bar{\mu} + A}{D}\ (\mathbf{28})$$

$$(3)\ \sigma(\bar{\mu}) = \sqrt{\frac{C\bar{\mu}^2 - 2B\bar{\mu} + A}{D}}\ (\mathbf{29})$$

Hence, the portfolio of all the assets with the lowest variance is the minimum variance portfolio given a level of expected return. However, it is more interesting to find a solution to this problem where there is no constraint on the expected return and here the auxiliary constants also provide as tool to solve this problem.

2.5.2. Minimum Variance Portfolio

The minimum variance portfolio is the portfolio that has the lowest variance across all portfolios. It is not just the portfolio with the minimum variance for a given expected return and so the restriction on expected return, definition 21, in the quadratic minimization problem is removed. The auxiliary constants also come in handy to find the minimum variance portfolio weights, expected return, variance and standard deviation, hence the following definitions is used (Munk, 2018):

$$\boldsymbol{\pi}_{min} = \frac{1}{C} \cdot \omega^{-1} \cdot \mathbf{1}\ (\mathbf{30})$$

$$\mu_{min} = \frac{B}{C}\ (\mathbf{31})$$

$$\sigma_{min}^2 = \frac{1}{C}\ (\mathbf{32})$$

$$\sigma = \frac{1}{\sqrt{C}}\ (\mathbf{33})$$

In addition if r_{min} denotes the return on the minimum variance portfolio and r denotes the return on any risky asset or portfolio of risky assets then (Munk, 2018):

$$Cov(r, r_{min}) = Var(r_{min})\ \mathbf{(34)}$$

As will be illustrated later, the minimum variance portfolio is on the efficient frontier. In addition, it is worth noticing that the asset with lowest standard deviation will tend to be assigned a larger weight in this portfolio. However, the correlation (covariance) structure between the assets also play an important role for the portfolio weights. An asset with relatively high standard deviation between the assets could have a high weight in the portfolio if the correlation structure with the other assets are low. Hence, a high standard deviation asset with low correlation with other low standard deviation assets can be used for diversifying idiosyncratic risk away (Munk, 2018).

2.5.3. Maximum Slope Portfolio

From section 2.5.1., and 2.5.2., it is now apparent that the investor can construct many different portfolios consisting of many assets. One can also see that some portfolios are "more" efficient than others in terms of lower variance. So far, section 2.5.1., has illustrated how to minimize the variance of different portfolios given an expected return where the portfolio with the lowest variance i.e. standard deviation, is the minimum variance portfolio. However, as shown in section 2.5.2., if one remove the restriction on the expected return then the investor can construct a portfolio that is even "more" efficient as it is the portfolio with the lowest variance of all the efficient portfolios.
Before diving into the characteristics of the efficient frontier according to the mean-variance theory, one has to define the characteristics of the maximum slope portfolio. A portfolio with higher expected return is possible given that the investor take on more risk. Hence, this portfolio is called the maximum slope portfolio since the investor maximize the slope μ/σ or risk-return relationship, as it is the slope that connect any point on the efficient frontier from origin. In order to do, one can exploit the fact that the maximum slope portfolio is located on the mean-variance frontier such that the variance and expected return satisfy equation (28) (Munk, 2018).

$$max = \frac{\bar{\mu}}{\frac{\sqrt{(C\bar{\mu}^2 - 2B\bar{\mu} + A)}}{D}} = \frac{\bar{\mu}\sqrt{D}}{\sqrt{C\bar{\mu}^2 - 2B\bar{\mu} + A}}\ \mathbf{(35)}$$

The result from the maximization problem yields the following results for the maximum slope portfolio weights, expected return, variance and standard deviation:

$$\boldsymbol{\pi}_{max} = \frac{1}{\mathbf{1} \cdot \omega^{-1}\boldsymbol{\mu}}\omega^{-1}\boldsymbol{\mu} = \frac{\mathbf{1}}{B}\omega^{-1}\boldsymbol{\mu}\ \mathbf{(36)}$$

$$\mu_{max} = \frac{A}{B} \ \mathbf{(37)}$$

$$\sigma_{max}^2 = \frac{A}{B^2} \ \mathbf{(38)}$$

$$\sigma_{max} = \frac{\sqrt{A}}{|B|} \ \mathbf{(39)}$$

It seems most intuitive that the maximum slope portfolio corresponds to the upward sloping part of the efficient frontier. However, this is only true when the expected return on the minimum variance portfolio is positive, which is when B > 0. If B < 0 and then the maximum slope portfolio will end up at the down-ward part of the efficient frontier. Essentially, this is somewhat a weird situation as it would mean that this portfolio is the portfolio with the most negative slope of all the efficient portfolios (Munk, 2018).

2.5.4. The Efficient Frontier

This section will explore and describe the properties of the efficient frontier as it aims to connect section 2.5.2, 2.5.3 and 2.5.5. The possibility for a visual representation of the efficient portfolios that the mean-variance framework provides is a great tool to help decision making for the investor and get deeper understanding of the portfolios. The mean-variance frontier can be formed in two ways: first way is to consider a range of many values of expected returns and then compute the standard deviations from equation 29 in combination with the auxiliary constants. The second way of determining the mean-variance frontier is to determine the minimum variance and the maximum slope portfolio weights, their expected returns and standard deviations given the definitions from section 2.5.2 and 2.5.3 (Munk, 2018). Then one can generate the frontier by considering many different combinations of the two portfolios and then compute the expected return and standard deviation for the combinations (Munk, 2018). This paper will use the latter of the two approaches and construct the expected return of the frontier portfolios as:

$$\mu(\pi) = w\mu_{min} + (1 - w)\mu_{max} \ \mathbf{(40)}$$

Where μ_{min} and w is the expected return and weight on the minimum variance portfolio and μ_{max} and (1-w) is the expected return and weight on the maximum slope portfolio.

In order to work out the standard deviation and variance of the combined portfolio, the approach require to have the covariance between the minimum variance and the maximum slope portfolio.

Fortunately, this turns out to be the variance of the minimum variance portfolio if r_{min} is the return on the minimum variance portfolio and r is the return on the maximum slope portfolio from equation 34 (Munk 2018):

$$Cov(r, r_{min}) = Var[r_{min}]$$

Which says that the covariance between an asset or portfolio of assets is equal to the variance of the minimum variance portfolio. This is highly useful for the computation of the variance of the combined portfolio as the covariance between the maximum slope portfolio and the variance of the minimum variance portfolio is equal to the variance of the minimum variance portfolio:

$$\sigma^2(w) = w^2\sigma_{min}^2 + (1-w)^2\sigma_{slope}^2 + 2w(1-w)\sigma_{min}^2 = w(2-w)\sigma_{min}^2 + (1-w)^2\sigma_{slope}^2 \ \mathbf{(41)}$$

And the standard deviation:

$$\sigma(w) = \sqrt{\sigma^2(w)} \ \mathbf{(42)}$$

If investors can form portfolios of only N risky assets it means that a mean variance optimizing investor chooses a combination of two special portfolios. The first is the minimum variance portfolio and the second is the maximum slope portfolio and in combination these portfolios as mentioned form the mean-variance frontier of risky assets. Furthermore, any other combination of the portfolios generate the rest of the frontier. A visual representation based on this methodology will be provided in section 4.3.5 but also explained in section 4.3.3.

2.5.5. The Tangency Portfolio

Besides analysing a portfolio of only risky assets, it is also interesting to analyse a portfolio of both a risk free asset and risky assets (Munk, 2018). As this paper will demonstrate later, a risk free asset will in a diagram with expected return on the vertical axis and standard deviation on the horizontal axis, correspond to a point of $(0, rf)$ (Munk, 2018). The introduction of a risk free asset, allows the investors to combine a risk free asset with a portfolio of risky assets (Munk, 2018). Hence, the risk-return combinations that is available from a combination of the risk free asset and the risky assets form a straight slope between the point $(0, rf)$ and (σ, μ) (Munk, 2018). Instead of this slope μ/σ in section 2.5.3., of only analysing the portfolios without the risk free asset, the slope is now the

Sharpe Ratio $\frac{\mu - rf}{\sigma}$. However, if the weight on the risky assets or portfolio is negative, which is the case when $\mu_{min} < rf$ then the slope will be negative Sharpe Ratio.

Like with the maximum slope portfolio, the investor wants a combination of a mean-variance efficient portfolio that is tangent with the mean-variance efficient frontier and the risk free asset i.e. the name tangency portfolio. Hence, this portfolio should have the highest Sharpe Ratio and should be located at the most north-west point on the efficient frontier among all the portfolios (Munk, 2018).

There are primarily two points that are interesting under this approach. The first being, where the auxiliary constant B is greater than C multiplied by the risk free rate $B > Crf$ i.e. then the risk free rate is smaller than the expected return on the minimum variance portfolio (Munk, 2018). In this case the tangency portfolio is on the efficient frontier or upward sloping part of the mean-variance frontier of risky assets. Now, the highest slope is referred to as the capital allocation line (frontier of all assets) and is essentially the combination of the tangency portfolio of risky assets and the risk free asset (long positions) (Munk, 2018). Now, points north east on the capital allocation line to the tangency portfolio of risky assets corresponds to a short position in the risk free and a leveraged position in the tangency portfolio of risky assets (Munk, 2018).
The second scenario is when the auxiliary constant B is smaller than C multiplied by the risk free rate, as $B < Crf$. Here the risk free rate is greater than the expected return of the minimum variance portfolio. The result is that the tangency portfolio is on the down-ward sloping branch of the mean-variance frontier, or the "inefficient" part of the mean-variance frontier (Munk, 2018). In order to obtain the highest Sharpe Ratio, the investor would have to combine a short position in the tangency portfolio with a long position in the risk free asset (Munk, 2018). However, even though this combination is said to be mean-variance efficient, it is still on the down-ward sloping part of the mean-variance frontier or "inefficient" frontier. As the expected return is lower than the minimum variance portfolio's expected return and has higher standard deviation, the investor would, in theory not want to hold this portfolio compared to the minimum variance portfolio even though it is mean-variance efficient (Munk, 2018).

However, a third option does exists when the auxiliary constant B is equal to C multiplied by the risk free rate as, $B = Crf$. The reason why this scenario is not as interesting as the two previous is because of the fact that no tangency portfolio exists and the mean-variance efficient portfolios has 100 pct., in the risk free asset and a position in a specific zero investment portfolio of risky assets

(Munk, 2018). Hence, this scenario is very unlikely to exists and so no further emphasis will be put on it.

The following notations denote how the tangency portfolio weights are calculated together with its expected return, variance and standard deviation (Munk, 2018).

The weights of the tangency portfolio are:

$$\boldsymbol{\pi}_{tan} = \frac{1}{B - Crf}\omega^{-1}(\boldsymbol{\mu} - rf\mathbf{1})\ (\mathbf{43})$$

Where the expected return, variance and standard deviation are denoted by:

$$\mu_{tan} = \frac{A - Brf}{B - Crf}\ (\mathbf{44})$$

$$\sigma_{tan}^2 = \frac{A - 2Brf + Crf^2}{(B - Crf)^2}\ (\mathbf{45})$$

$$\sigma_{tan} = \frac{\sqrt{A - 2Brf + Crf^2}}{|B - Crf|}\ (\mathbf{46})$$

3. Data

Part one of the paper concerning section 2.2, 2.3, 2.4, 4.1, 4.2 will use quarterly interbank deposit interest rates and exchange rates from the following countries (G10 currencies): Australia (AUD), New Zealand (NZD), United States (USD), Sweden (SEK), Canada (SEK), Switzerland (CHF), European Union (EUR), Japan (JPY), Norway (NOK), England (GBP). The currencies are given in terms of how much it takes of the foreign currency to purchase one USD. In addition to quarterly data, this part will use daily exchange rate to calculate average within quarterly skewness. The sample period is between January 1999 to January 2019.

Part two of this paper concerning section 2.5, 2.5.1, 2.5.2, 2.5.3, 2.5.4, 2.5.5, 4.3, 4.3.1, 4.3.2, 4.3.3, 4.3.4. and 4.3.5 that is examining the effects of the carry trade in portfolio context use monthly exchange rates and interest rates for the G10 currencies. In addition, monthly prices of the S&P500, which is a value-weighted index of large cap equities, the Russell 2000 is a value-weighted index of small cap equities and Barclays U.S. treasury Total Return Unhedged USD index, which is a proxy for a bond portfolio. Finally, the U.S. Federal reserve rate is used as the risk free asset, which is also based on monthly prices. The sample period is January 1999 and January 2019.

4. Results

This section will provide the results that is derived on the basis on the theoretical foundation from section 2 and from section 3 relating to data.

4.1. The Uncovered Interest Rate Parity

The motivation behind the carry trade strategy stems from a deviation of the uncovered interest rate parity. In order to, confirm that there is an empirical basis for the carry trade strategy, the paper will perform the following simple regression analysis, which is similar to the one of Fama's paper from 1984 and section 2.3:

$$\Delta s_{t+1} = \alpha + \beta(i_t^* - i_t) + \epsilon \ \mathbf{(47)}$$

Where Δs_{t+1} is the log change of the spot exchange rate from period t to period $t+1$, stated as $\log(s_{t+1}) - \log(s_t)$ (Brunnermeier et al., 2009). Like with the spot exchange rate, the interest rate differential is the log difference between the two countries, where the base country is the U.S. or domestic interest rate (i) and the foreign interest rate (i^*), which can be stated as $\log(i^*) - \log(i)$ (Brunnermeier et al., 2009). Epsilon is the error-term. Now, if the uncovered interest rate parity holds, we would expect the slope to be one and the intercept zero.

Panel A	AUD	CAD	JPY	NZD	NOK	CHF	GBP	EUR	SEK
intercept	-0.0100	-0.0019	-0.0030	-0.0066	0.0039	-0.0148	-0.0040	0.0030	0.0009
slope	2.3921	-0.4089	-0.4747	1.6814	-0.9109	-2.6991	1.2115	2.5993	-2.6638
R^2	0.0272	0.0004	0.0016	0.0127	0.0051	0.0357	0.0069	0.0317	0.0420

Table 1. Displays the results from the OLS regression for the nine carry trades with the U.S. Dollar as funding currency. The figure displays the intercept, slope and R squared from equation 47. See appendix A for regression output. Source: author's own creation.

Five out of nine currencies yields a negative slope coefficient where the British Pound is the only currency that is close to one. However, none of the currencies are significant at 5 pct., significance level and so the interest rate differential are not fully offset by a change in exchange rates. In addition, all of the regressions shows a low R^2 and so the regression model does not do a particular good job in explaining the exchange rate movements. Hence, this shows that high interest rate currencies does not depreciate as much as the interest rate differential and that low interest rate currencies does not appreciate as much as the interest rate differential versus the U.S. Dollar.

Now that the foundation for the uncovered interest rate parity has been investigated, one can move on to study and analyse the characteristics of the carry trades. Before continuing, some additional introduction of relevant terms has to be put forward. Using the notions for the interest rates and the change in the exchanges rates from above, the excess return on the carry trade can be defined as (Brunnermeier et al., 2009):

$$z_{t+1} = (i_t^{*} - i_t) - s_{t+1} \quad \mathbf{(48)}$$

In figure 3, one can see all the nine currency carry trades with the U.S. Dollar as the funding currency. From figure 3 panel A, one can see the carry trade strategy with the Australian Dollar as the investment interest rate, which shows that the strategy has mostly been positive, especially from 2001 to 2004 where the U.S. interest rate increased significantly and the Australian interest rate was lagging but increased as well from around 2006 to mid 2008. Following the financial crisis, the interest rate differential increased again due to very low U.S. interest rates until 2018 where the U.S. interest rate has become higher than the Australian interest rate. That being said, it is evident that this carry trade has for the most part been profitable from a pure interest rate stand-point. From figure 3 panel B, one can see that the Canadian interest rate and U.S. interest rate has been close to each other with no significant difference like the Australian interest rate and U.S. interest rate. In fact, the U.S. interest rate was higher than the Canadian from 2005 to 2010, where the Canadian interest rate rose above the U.S interest rate. Around 2016 the U.S. was again higher than the Canadian interest rate. Hence, this interest rate differential has been positive in the aftermath of the financial crisis until 2016 from a pure interest rate stand-point. Figure 3 panel C, shows the New Zealand interest rate differential and it is evident that this trade has been mostly positive except in the beginning of the period from 1999 to 2001 where the U.S. interest rate was higher than the New Zealand interest rate, which also applies to the end of the sample period around 2018. Figure 3 panel D, displays the Japanese Yen interest rate differential, which in contrast to the New Zealand interest rate differential, has been mainly negative. Figure 3 panel E, displays the Norwegian krone interest rate differential. It is evident, that this interest rate differential has been mostly positive except for the period 2004 to mid 2007, hence the period leading up to the financial crisis and then from 2017 and on-wards this interest rate differential was not positive. Figure 3 panel F, shows the Swiss Franc interest rate differential and it is evident that this interest rate differential has been mostly negative or close to zero except for a brief moment around 2012. Figure 3 panel G, shows the interest rate differential of the euro, which is more interesting as this interest rate differential fluctuates quite a bit. In the beginning of the sample period until around 2001 the interest rate differential was negative and then became positive until 2005. From 2005 to approximately 2010 it was mostly either negative or close to zero and then became positive again for a short period of time until 2013 and then returned back to negative which continued until the end of the sample period. Figure 3 panel H, displays the British Pound interest rate differential, which was highly positive from mid 2001 to around 2006 and from 2009 to 2016 it was mainly zero or slightly positive, however, from 2016 and to the end of the sample period this interest rate differential pair was negative. The final interest rate differential pair is displayed in figure 3 panel I, which is the Swedish Krona. The Swedish Krona interest rate differential is also fluctuating a lot and when comparing with the euro interest rate differential, it looks like it is fluctuating as much even to the extend where it looks like there is a clear negative relationship. However, by eye-balling the figure, it can be seen that the Swedish Krona has been negative from the beginning of the sample period to approximately mid 2001. From 2001, the interest rate differential was positive to 2005 where it went negative and it was positive from 2010 to 2015 where it went negative.

Figure 3 shows that the New Zealand interest rate differential is the interest rate differential that is positive most consistently and that the Japanese Yen is the most negative carry trade. In addition, it should be clear to the reader that a negative interest rate from the funding currency is favourable as it means that the investor receives cash flow instead of having to pay and so it boosts the returns coming from the interest rate differential.

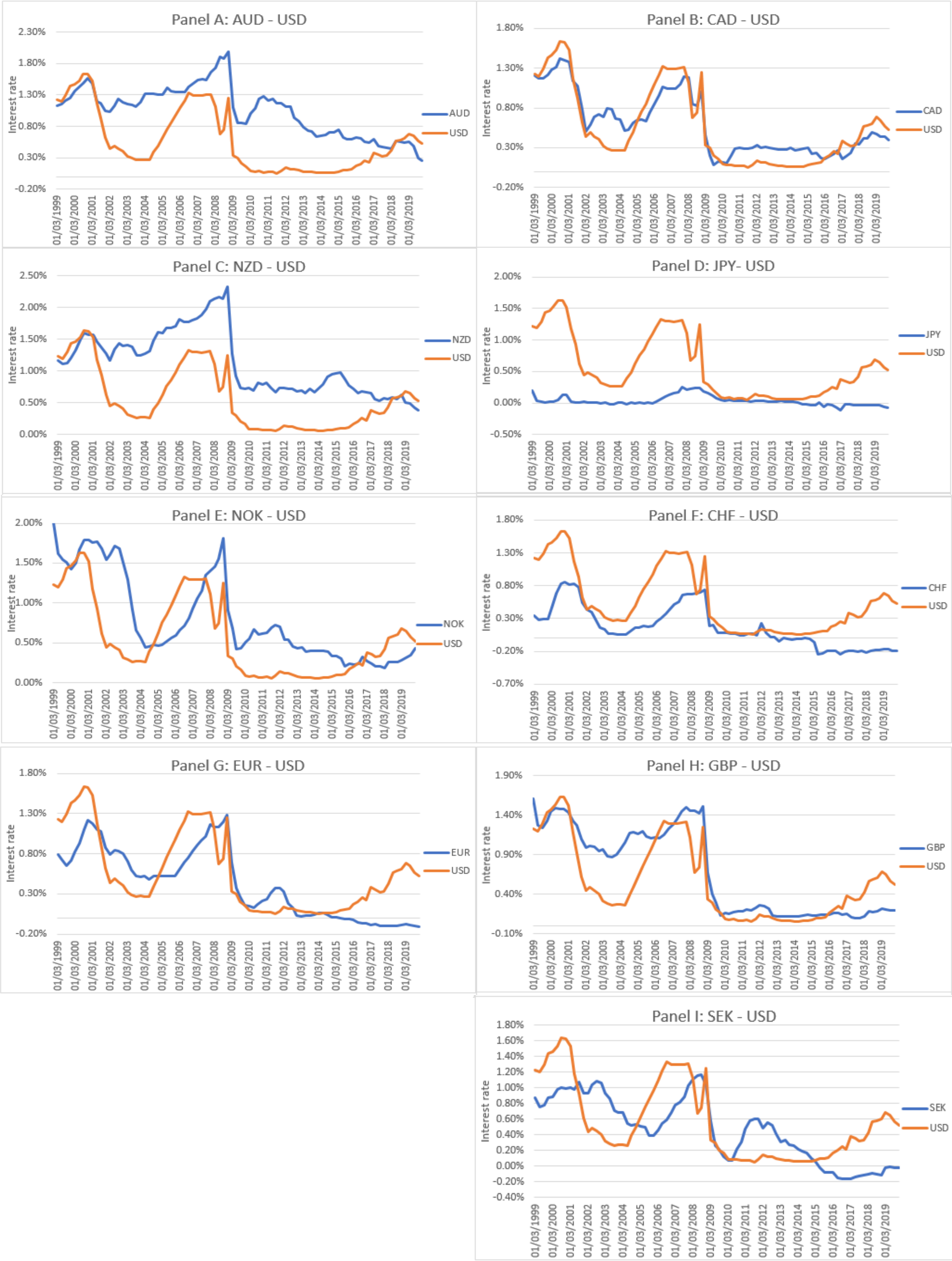

Figure 3. Shows the log interest rate differential on quarterly basis between each of G10 currency and the U.S. interest rate. Source: author's own creation.

In addition to the break-down of the graph for each of the interest rate differentials over the sample period, this section will also dive in to a few descriptive statistics of the currencies and interest rate differentials. Only average change in exchange rate, excess return of the carry trade and interest rate differential will be commented on from table 2 panel A, as average skewness is commented on in section 4.2, below and average interest rate is intuitively derived by commenting on the interet rate differential.

Panel A	AUD	CAD	JPY	NZD	NOK	CHF	GBP	EUR	SEK
s_t	0.002	-0.002	-0.001	0.003	0.002	-0.004	-0.003	-0.001	0.002
z_t	0.003	0.002	-0.005	0.003	0.000	0.000	0.004	-0.001	-0.003
i*-i	0.005	0.000	-0.005	0.006	0.002	-0.004	0.001	-0.001	-0.001
i*	0.010	0.006	0.000	0.011	0.008	0.002	0.007	0.004	0.005
Skewness	-0.163	-0.012	0.053	-0.126	-0.105	0.141	0.020	0.023	-0.021

Table 2. Displays the mean of the change in log exchange rate (s_t), the mean log excess return, which is equal to equation 48 (z_{t+1}), the mean log interest rate differential ($i^* - i$), the mean log foreign interest rate (i^*) and the mean within quarterly skewness (Skewness) for each of the currency trade.

From table 2 panel A, one can see the average change in exchange rates for the Australian Dollar, which does not depreciate as much as the interest rate differential. The average interest rate differential with the U.S. Dollar is 0.005 and the exchange rate only depreciates 0.002 leaving an excess return of 0.003 for the investor over the sample period. Table 2, show the average interest rate differential of the Canadian Dollar carry trade is 0.000 but the exchange rate appreciate leading to an excess return of 0.002. the third currency in table 2, is the Japanese Yen with an average interest rate differential of negative 0.005 and the exchange rate appreciate 0.001 leading to an excess return of negative of 0.005 (rounding). Fourth currency in table 2, is the New Zealand Dollar and it is the currency with the highest average interest rate differential of 0.006, this currency depreciated with 0.003, which leads to an excess return of 0.003 for the investor. The fifth currency in table 2 is the Norwegian Krone, which had an average interest rate differential of 0.002 and a depreciation of 0.002 leading to an excess return of 0.000. The sixth currency carry trade from table 2, is the Swiss Franc carry trade, which has an average interest rate differential of negative 0.004 and appreciates on average with 0.004 providing the investor with an excess return of 0.000. The seventh currency carry trade from table 2, is the British Pound carry trade with an average interest rate differential of 0.001 and appreciates on average with 0.003, leading to an excess return of 0.004. The eight currency carry trade from table 2, is the euro carry trade, which has an average interest rate differential of negative 0.001 and appreciates with 0.001 on average and leads to an average excess return of negative 0.001. The nineth and final currency carry trade from table 2, is the Swedish Krona carry trade, which had an average interest rate differential of negative 0.001 and depreciates on average with 0.002, which leads to an average excess return of negative 0.003 over the sample period.

Now aforementioned analysis provides a somewhat blurred result. If one take a look at the British Pound interest rate, one can see that the interest rate differential is 0.001 and according to the uncovered interest rate parity, one would expect to see a depreciatoin of 0.001. However, the British Pound appreciates with 0.003 making it the most preferable carry strategy of the G10 currencies as the excess return on this strategy is 0.004. This is especially interestring when compared to the New Zealand Dollar interest rate differential that has been consistently positive over the entire sample period, see figure 3 panel C, and therefore has an average interest rate differential of 0.006 but the New Zealand Dollar depreciates with 0.003 leading to an excess return of 0.003. Hence, the exchange rate does not depreciate with nearly as much as it is predicted by the uncovered interest rate parity. However, with this in mind the investor would prefer the British Pound carry trade but it comes with the dependence on the appreciation of the British Pound, which is more risky than chosing the New Zealand dollar or Australian dollar where a higher depreciation of the investment currency is required in order for the trade to not be profitable. On the other side, the carry trade with the largest negative excess return is the Japanese Yen carry trade, which only appreciates with 0.001 and so it provides a negative excess return of 0.005 to the investor over the sample period.

4.2. Crash Risk

This section presents the results relating to the cross-section of FX carry returns. Figure 4, below displays the average within quarterly skewness of daily exchange rates plotted against the average interest rate differential between the U.S. Dollar, as the base currency and investment currency, which is the nine other currencies respectively. Figure 4, shows that the Australian Dollar carry trade has the second highest average interest rate differential of 0.49 pct., and the most negative within quarterly skewness of 16.32 pct. By eye-balling and comparing the results to the paper from Brunnermeier et al. (2009), it seems like the average interest rate differential is 0.11 pct., lower and the average skewness is 0.15 pct., higher in this study. The Canadian Dollar carry trade has fifth highest average interest rate differential or the lowest positive average interest rate differential of 0.03 pct., and fifth most negative average within quarterly skewness of 1.23 pct. In comparison to the paper of Brunnermeier et al (2009), it seems like the interest rate differential is 0.17 pct., lower and the skewness is approximately 13 pct., higher in this study. The third currency of figure 4, is the Japanese Yen carry trade, which has the most negative average interest rate differential of negative

0.52 pct., and the second highest within quarterly skewness of 5.29 pct. In comparison to the study of Brunnermeier et al. (2009), one can see that the average interest differential is approximately 0.2 pct., higher in this study and the skewness is approximately 26 pct., lower in this study. The fourth currency of figure 4, is the New Zealand Dollar carry trade. This carry trade has the highest average interest rate differential of 0.56 pct., and the second most negative within quarterly skewness of negative 12.58 pct. In comparison to Brunnermeier et al. (2009), this currency has an interest rate differential of approximate 0.34 pct., lower in this study and a skewness, which is approximately 0.17 pct., higher in this study. The fifth currency is the Norwegian Krone carry trade, which has an average interest rate differential of 0.23 pct., and third most negative within quarterly skewness of negative 10.46 pct. In comparison to the study of Brunnermeier et al. (2009), this carry trade has an interest rate differential of approximately 0.25 pct., lower in this study and a skewness of approximately 8.6 pct., lower in this study. The sixth currency in figure 4 is the Swiss Franc, which has the second most negative average interest rate differential of negative 0.40 pct., and the highest average within quarterly skewness of 14.14 pct. When comparing the results to the study of Brunnermeier et al. (2009), it is evident that the interest rate differential of the Swiss Franc and the U.S. dollar is almost the same and so are the skewness. The seventh currency in figure 4 is the British Pound, which has an average interest rate differential of 0.11 pct., and an average within quarterly skewness of 1.99 pct. Again, comparing to the Brunnermeier et al. (2009), study one can see that the average interest rate differential is approximately 0.4 pct., lower in this study and the skewness is approximately 11 pct., higher in this study. The eight currency in figure 4 is the euro carry trade. This carry trade has an average interest rate differential of negative 0.14 pct., and an average within quarterly skewness of 2.34 pct. When comparing to the study by Brunnermeier et al. (2009), one can see that the euro carry trade almost did not change in terms of average interest rate differential whereas the average skewness is approximately 10 pct., lower in this study. The ninth and last currency is the Swedish Krona carry trade, which has an average interest rate differential of negative 0.10 pct., and an average within quarterly skewness of 2.05 pct.

Now, the pattern might not be too ground-breaking, as Brunnermeier et al. (2009), has found a similar pattern. The results do distinguish themselves from the study of Brunnermeier et al. (2009), as this study includes the Swedish Krona but the inclusion of the Swedish Krona does not change the trend, hence putting a question mark behind the study of Brunnermeier et al. (2009) as to why this currency is excluded from their study. In addition, it is worth noticing that the currencies with the lowest average interest rate differential has the highest average skewness, hence currencies that are unfavourable in terms of investment currencies, displays higher positive skewness compared to favourable investment currencies, which displays higher negative skewness.

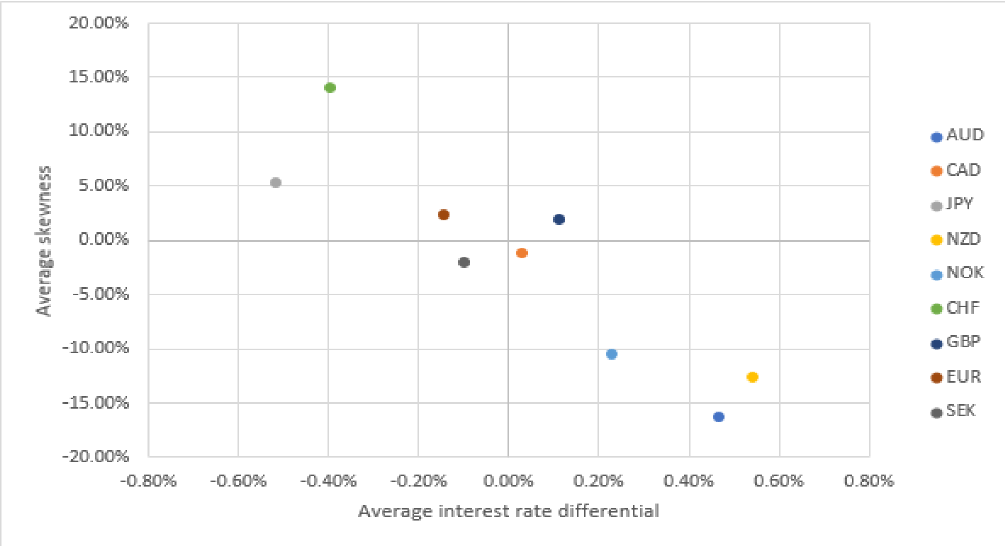

Figure 4. Displays the cross sectional relationship between log within quarterly average skewness of daily exchange rates on the vertical axis and the log quarterly average interest rate differential with the U.S. Dollar for the G10 currencies. Source: authors own creation.

From figure 4 above, it is possible to see that the average interest rate differential and average within quarterly skewness follows a negative pattern. Hence, in order to clarify if such a relationship exists, a cross-sectional regression is performed with the skewness as the dependent variable and the mean interest rate as independent variable. The results of the regression can be seen in appendix B. The variance in the average interest rate differential is able to explain 80.28 pct., of the variance in the skewness, which is considered a high R^2. In addition, the slope coefficient is negative 23.99 and is significant at a five percent significance level. Hence, this confirms that the average interest rate differential of the G9 currencies with USD as the base currency does explain some of the quarterly average skewness and that the when average interest rate differential increases, the skewness drops.

4.3. Mean-Variance Analysis

The following sections will present the results derived from applying the theory outlined in section 2.5 and respective sub-sections.

4.3.1. Expected Returns and Standard Deviations For The Individual Assets

Table 3 below presents annualized expected returns, standard deviations, currency excess returns and Sharpe ratios for all the assets, which is subject for analysis over the sample period. However, it is only the S&P500, the bond index and the Russell 2000 (traditional assets) that are permanent assets in the portfolios whereas each currency carry will vary. From table 3, panel A below, one can see that the annualized risk free rate is 1.90 pct. In addition, the annualized expected return of the S&P500 is 6.51 pct., with an annualized standard deviation of 14.57 pct., which translates in to a 4.61 pct., return in excess of the risk free rate (excess return) leading to an annualized Sharpe Ratio of 31.65 pct. Furthermore, the bond index provides a lower annualized expected return compared to the S&P500 and Russell 2000 of 4.19 pct., with an equivalently lower annualized standard deviation of 4.32 pct., which translates in to a 2.29 pct., excess return and a Sharpe Ratio of 53.01 pct. The last fixed asset of the three permanent assets is the Russell 2000 that provide the highest annualized expected return of 6.54 pct., and the highest annualized standard deviation of 19.48 pct., which translates in to a 4.64 pct., excess return and a Sharpe Ratio of 23.82 pct. Hence, it is the bond index that provides the highest Sharpe Ratio among the three permanent assets followed by the S&P500 and then the Russell 2000. But, it is the Russell 2000 that provides the highest expected returns followed by the S&P500 and the bond index. The low expected returns and volatility of the bond index and high expected returns and volatility of the equity indices are in line with expectations.

Panel A	Expected Return	Standard Deviation	Excess return	Sharpe ratio
SP500	6.51%	14.57%	4.61%	31.65%
Bond index	4.19%	4.32%	2.29%	53.01%
Russell 2000	6.54%	19.48%	4.64%	23.82%
AUD z_t	1.28%	12.30%	-0.62%	-5.02%
CAD z_t	0.94%	8.89%	-0.96%	-10.76%
JPY z_t	-1.83%	9.54%	-3.73%	-39.12%
NZD z_t	1.10%	12.91%	-0.80%	-6.18%
NOK z_t	0.23%	11.05%	-1.67%	-15.12%
CHF z_t	0.13%	10.22%	-1.77%	-17.28%
GBP z_t	1.55%	8.61%	-0.35%	-4.03%
EUR z_t	-0.30%	9.80%	-2.20%	-22.41%
SEK z_t	-1.04%	11.20%	-2.94%	-26.21%
Risk free rate	1.90%			

Table 3. Annualized log expected returns, log standard deviations, carry excess returns and Sharpe ratios for all assets from January 1999 to January 2019. Source: created by the author.

Besides the three previous described assets, are the annualized expected returns for each of the FX carry trades are provided in table 3. As this section strive to study how an investor would benefit from having a portfolio which includes both traditional assets with interest rates and currencies, it makes sense to analyse how the individual FX carry trade would impact the performance of a portfolio of traditional assets. Although an investor most likely would desire a high interest rate carry strategy such as the Australian Dollar or New Zealand Dollar carry trade compared to a low interest rate carry such as the Japanese Yen, Swedish Krona or euro carry trade. It does not matter too much under the mean-variance framework as the low interest rate carry strategy can provide as a great tool for diversification. In addition, as demonstrated later, when introducing a risk free asset, the excess return of the carry strategy per unit of standard deviation (Sharpe Ratio) is more in focus.

From table 3 above, one can see that the excess return on the carry trade with the Australian Dollar has an annualized expected return of 1.28 pct., with an annualized standard deviation of 12.30 pct., which translates in to an excess return of negative 0.62 pct., and the second highest Sharpe Ratio of negative 5.02 pct. The Canadian Dollar carry trade has an annualized expected return of 0.94 pct., and a standard deviation of 8.89 pct., which translates in to a negative excess return of 0.96 pct., and a negative Sharpe Ratio of 10.76 pct. The Japanese Yen carry trade has an annualized expected return of negative 1.83 pct., and a standard deviation of 9.54 pct., which translates in to a negative excess return of 3.73 pct., and a the most negative Sharpe Ratio of 39.12 pct. The New Zealand Dollar carry trade would provide an annualized expected return of 1.10 pct., with a standard deviation of 12.91 pct., which translates in to a negative excess return of 0.80 pct., and a negative Sharpe Ratio of 6.18 pct., in fact, the New Zealand Dollar carry trade is the carry trade with the third highest Sharpe Ratio. The Norwegian Krone provides an annualized expected return of 0.23 pct., with a standard deviation of 11.05 pct., which translates in to an excess return of negative 1.67 pct., and a negative Sharpe Ratio of 15.12 pct. The Swiss Franc would provide the investor with an annualized expected return of 0.13 pct., and a standard deviation of 10.22 pct., which translates in to a negative excess return of 1.77 pct., and a negative Sharpe Ratio of 17.28 pct. The British Pound carry trade would have provided the investor with an annualized expected return of 1.55 pct., and a standard deviation of 8.61 pct., which translates in to a negative excess return of 0.35 pct., and a negative Sharpe Ratio of 4.03 pct. The euro carry trade would have provided an annualized expected return of negative 0.30 pct., and a standard deviation of 9.80 pct., which translates in to a negative excess return of 2.20 pct., and a negative Sharpe Ratio of 22.41 pct. The Swedish Krona would have provided the investor with an annualized expected return of negative 1.04 pct., and a standard deviation of 11.20 pct., which translates in to a negative excess return of 2.94 pct., and a negative Sharpe Ratio of 26.21 pct.

It is evident between the carry strategies; the British Pound provides the highest annualized expected return of 1.55 pct., followed by the Australian Dollar of 1.28 pct., whereas the Japanese Yen provides the lowest annualized expected return of negative 1.83 pct., followed by the Swedish Krona of negative 1.04 pct. In terms of standard deviation, the New Zealand Dollar carry trade has the highest standard deviation of 12.91 pct., followed by Australian Dollar carry trade of 12.30 pct., whereas the British Pound provides the lowest standard deviation of 8.61 pct., followed by the Canadian Dollar carry trade of 8.89 pct. Finally, the British Pound provides the highest Sharpe Ratio of negative 4.03 pct., followed by the Australian Dollar, which provides a Sharpe Ratio of negative 5.02 pct. In contrast, the Japanese Yen provides the lowest Sharpe Ratio of negative 39.12 pct., followed by the Swedish Krona carry of negative 26.21 pct. Lastly, it is evident from table 3 that all the currency carry trades has a negative excess return and Sharpe Ratio.

4.3.2. Variance - Covariance Matrix

An understanding of the covariance structure between the assets in a portfolio is important when analysing the weights of each asset of the portfolio. The relationship between expected returns and standard deviations is not the only driving force behind the composition of a portfolio although it might give an indication of desired assets to hold in a mean-variance efficient portfolio. Looking at table 4, one can see the covariance relationship of each carry trade strategy with the traditional assets. To begin with, the one can see from table 4, that the covariance relationship between the S&P500, the bond index and the Russell 2000 are the same across all the displayed portfolios. The covariance of the S&P500 with the bond index is negative 0.002, which is said to be in the lower area whereas the covariance between the S&P5000 and the Russell 2000 is 0.024, which is said to be high. Now the covariance between the bond index and the Russell 2000 are negative 0.003, which is said to be in the lower area as well. However, it is worth mentioning that negative covariance can be valuable in a portfolio setting given the fact, that if one asset goes up the other asset go down and so it works like an insurance.

In addition to the traditional assets table 4 panel A, displays the covariance relationship between the traditional assets and the excess return on the Australian Dollar carry trade. It is evident that the Australian Dollar has a covariance with the S&P500 of negative 0.010, a covariance with the bond index of 0.000 and a covariance with the Russell 2000 of negative 0.012. Although mostly negative or zero, the magnitude are relative high in comparison to some of the currencies in the other portfolios, such as the Japanese Yen. The second portfolio in table 4 panel B, contains the covariance between the Swiss Franc carry trade and the S&P500 of 0.002, a covariance with the bond index of 0.001 and a covariance with the Russell 2000 of 0.003. Now, the magnitude of these covariance's are in the lower end in comparison to the other currencies and in particular the Australian Dollar carry trade while all are positive. Table 4 panel C, displays covariance relationships of the third portfolio containing the Canadian Dollar carry trade. The covariance between the Canadian Dollar and the S&P500, the bond index and the Russell 2000 are 0.007, 0.000 and 0.009 respectively, which is in the modest end of the scale while being zero or positive. The covariance relationships of the fourth portfolio containing the British Pound carry trade is displayed in table 4 panel D. The covariance between the British Pound carry trade and the S&P500, the bond index and the Russell 2000 are negative 0.004, 0.000 and negative 0.004, which is somewhere in between low and modest or zero in terms of magnitude although negative or zero. Table 4 panel E, displays the covariance relationship of the assets in the fifth portfolio containing the Japanese Yen carry trade. The covariance between the Japanese Yen carry trade and the S&500, the bond index and the Russell 2000 are negative 0.001, positive 0.002 and negative 0.003., respectively, which is in the low end although mostly negative except for the covariance between the carry and the bond index of 0.002. In fact, this is the highest covariance between a carry trade and the bond index across all the portfolios. Table 4 panel F, displays the covariance relationship of the sixth portfolio containing the euro carry trade. As can be seen, the covariance between the euro carry trade and the S&P500, the bond index and the Russell 2000 are negative 0.004, 0.001, 0.005, which is in the modest end although being negative. Table 4 panel G, displays the seventh portfolio containing the New Zealand Dollar carry trade. The covariance between the New Zealand Dollar carry trade and the S&P500, the bond index and the Russell 2000 are negative 0.009, 0.000 and negative 0.011, which are in the high end in terms of magnitude although mostly negative or zero. Table 4 panel H, displays the covariance relationships in the eighth portfolio containing the Swedish Krona carry trade. The covariance between the Swedish Krone carry trade and the S&P500, the bond index and the Russell 2000 are 0.007, 0.000 and 0.008, which is in the modest to high end. The ninth and final portfolio containing the Norwegian Krone are displayed in table 4 panel I. The covariance between the Norwegian Krone and the S&P500, the bond index and the Russell 2000 are 0.006, 0.000 and 0.007, respectively, which is modest although positive or zero.

From table 4, it is evident that the carry trade with the highest positive covariance are the Canadian Dollar carry trade even though only four out of nine portfolios are pure positive in the covariance relationships. In the other end, the highest negative carry trade are Australian Dollar carry trade. In addition, it is evident from all the nine portfolios that the bond index is the asset that has the lowest covariance with any of the assets, followed by the S&P500 and then the Russell 2000.

Panel A	SP500	Bond index	Russell 2000	AUD z_t
SP500	0.021	-0.002	0.024	-0.010
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	-0.012
AUD z_t	-0.010	0.000	-0.012	0.015

Panel B	SP500	Bond index	Russell 2000	CHF z_t
SP500	0.021	-0.002	0.024	0.002
Bond index	-0.002	0.002	-0.003	0.001
Russell 2000	0.024	-0.003	0.038	0.003
CHF z_t	0.002	0.001	0.003	0.010

Panel C	SP500	Bond index	Russell 2000	CAD z_t
SP500	0.021	-0.002	0.024	0.007
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	0.009
CAD z_t	0.007	0.000	0.009	0.008

Panel D	SP500	Bond index	Russell 2000	GBP z_t
SP500	0.021	-0.002	0.024	-0.004
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	-0.004
GBP z_t	-0.004	0.000	-0.004	0.007

Panel E	SP500	Bond index	Russell 2000	JPY z_t
SP500	0.021	-0.002	0.024	-0.001
Bond index	-0.002	0.002	-0.003	0.002
Russell 2000	0.024	-0.003	0.038	-0.003
JPY z_t	-0.001	0.002	-0.003	0.009

Panel F	SP500	Bond index	Russell 2000	EUR z_t
SP500	0.021	-0.002	0.024	-0.004
Bond index	-0.002	0.002	-0.003	-0.001
Russell 2000	0.024	-0.003	0.038	-0.005
EUR z_t	-0.004	-0.001	-0.005	0.010

Panel G	SP500	Bond index	Russell 2000	NZD z_t
SP500	0.021	-0.002	0.024	-0.009
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	-0.011
NZD z_t	-0.009	0.000	-0.011	0.017

Panel H	SP500	Bond index	Russell 2000	SEK z_t
SP500	0.021	-0.002	0.024	0.007
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	0.008
SEK z_t	0.007	0.000	0.008	0.013

Panel I	SP500	Bond index	Russell 2000	NOK z_t
SP500	0.021	-0.002	0.024	0.006
Bond index	-0.002	0.002	-0.003	0.000
Russell 2000	0.024	-0.003	0.038	0.007
NOK z_t	0.006	0.000	0.007	0.012

Table 4. Each panel shows the variance-covariance relationships of all assets across nine different currency portfolios. Source: author's own creation

4.3.3. Minimum Variance Portfolio For The Individual Currencies

Now that the expected returns, standard deviations and the variance-covariance relationships for all the individual assets have been estimated, one can now continue with the estimation of the portfolio weights, expected returns, variances and standard deviations of the nine minimum variance portfolios. The minimum variance portfolio is interesting to estimate because it is the portfolio combination of all the risky assets with the lowest variance. In other words, it can be argued that it is the "least" efficient portfolio as it separates the efficient and "inefficient frontier", which can be seen in the visual representation in figure 5. Figure 5, has a panel for each of the portfolios and so the reader are encouraged to have a look at the figure for each of the portfolios. Not only does figure 5 contain the minimum variance portfolio but also the maximum slope and tangency portfolio. Now, the reader should be aware that the part of the mean-variance frontier labelled "inefficient frontier" is a reference to section 2.5.4., where it is explained that an investor would always be able to find a more efficient portfolio on the other end on the mean-variance frontier called the "efficient frontier".

Table 5 below displays all the nine minimum variance portfolios where panel A is the minimum variance portfolio with the Australian Dollar carry trade that provides an expected return of 4.09 pct., and a standard deviation of 2.88 pct. The portfolio consists of 14.10 pct., in the S&P500, 64.94 pct., in the bond index, 3.48 pct., in the Russell 2000 and 17.48 pct., in the Australian Dollar carry. It is interesting how the Australian Dollar carry has a higher weight than the Russell 2000 given that the Russell 2000 has a higher expected return of 6.54 pct., compared to the Australian Dollar carry trade of 1.28 pct. However, the Russell 2000 has higher standard deviation of 19.48 pct., compared to the Australian Dollar of 12.30 pct. While this in itself argues for a higher weight to the Australian Dollar carry trade, it still underlines the actual trade-off in practice as the investor have to give up some expected return to get a lower portfolio variance. In addition, one can see that the S&P500 has a lower weight in the minimum variance portfolio, as the S&P500 has an expected return of 6.51 pct., and a standard deviation of 14.57 pct., compared to the Australian Dollar carry trade. Again, this illustrates the risk return trade-off. Even when comparing the S&P500 weight to the bond index weight, it is even clearer that the high weight in the bond index is partly explained by the lowest standard deviation and third highest expected return. However, expected returns and standard deviations does not give the full explanation and the investor therefore have to consider the covariance structure of the assets. Table 4 panel A, allows the investor to better understand the portfolio weights as covariance also plays an important role. The high weight in the Australian Dollar carry stems from the zero covariance with the bond index and to some degree the high negative covariance with the S&P500 and the Russell 2000. This makes it valuable to the minimum variance portfolio in terms of diversification attributes although it has the third highest standard deviation and lowest expected return

Table 5 panel B, shows the minimum variance portfolio with the New Zealand Dollar carry trade. With this portfolio, the investor would expect a return of 4.10 pct., and a standard deviation of 2.98 pct., which is slightly higher than the Australian Dollar minimum variance portfolio. This minimum variance portfolio has the following weights of 13.62 pct., in the S&P500, 67.62 pct., in the bond index, 3.23 pct., in the Russell 2000 and a weight in the New Zealand Dollar of 15.53 pct. The New Zealand Dollar carry trade provides an expected return of 1.10 pct., a standard deviation of 12.91 pct., which makes it the currency with the third highest expected return and the currency with highest standard deviation, however, still the second lowest standard deviation asset of the assets in this portfolio. As before, the investor has to look at the covariance in table 4 panel G. Here it is clear that the high weight, although lower than the Australian Dollar, is due to a covariance of zero with the bond index and covariance with the S&P500 and Russell 2000 that is slightly closer to zero than the Australian Dollar but still in the higher end.

Table 5 panel C, displays the third minimum variance portfolio with the British Pound carry trade. This portfolio provides an expected return of 4.05 pct., and a standard deviation of 3.23 pct., based on the following portfolio weights 11.52 pct., 68.30 pct., 2.46 pct., and 17.71 pct., in the S&P500, the bond index, the Russell 2000 and the British Pound, respectively. The British Pound has a weight slightly higher than the Australian Dollar and the New Zealand Dollar. However, this might be due to the fact that the British Pound carry trade is in fact the carry trade with the highest expected return and lowest standard deviation of 1.55 pct., and 8.61 pct., respectively. The most eye catching is that the portfolio weight is only 0.2 pct., higher that the Australian Dollar even though the standard deviation of the British Pound carry is 3.69 pct., lower while providing higher expected returns of 0.27 pct. As with the previous currencies, the British Pound is also the asset with the second lowest standard deviation in this portfolio. From table 4 panel D, the covariance of zero with the bond index is naturally highly valuable, but, in combination with the low to modest negative covariance with the S&P500 and Russell 2000 makes the weight reasonable.

The minimum variance portfolio with the fourth carry strategy presented in table 5 panel D is the Canadian Dollar. This minimum variance portfolio yields an expected return of 4.05 pct., and a standard deviation of 3.53 pct. The minimum variance portfolio weights in the S&P500, the bond index, the Russell 2000 and the Canadian Dollar carry trade are 8.63 pct., 79.43 pct., 0.80 pct., and 11.14 pct., respectively. However, with a relatively low but still positive expected return of 0.94 pct., and the second lowest standard deviation of 8.89 pct., the Canadian Dollar carry trade is assigned a lower weight in the minimum variance portfolio compared to previous strategies although still high. From table 4 panel C, one can see that the covariance with the bond index is zero and points towards a high weight in combination with the favourable low standard deviation and relatively high expected return. However, the Canadian Dollar carry trade also have a modest positive covariance with the S&P500 and Russell 2000, which points towards a lower weight.

Table 5 panel E, displays the fifth minimum variance portfolio with the Norwegian Krone. This portfolio has an expected return of 4.31 pct., and a standard deviation of 3.60 pct. Now these results are from the portfolio weights of 10.60 pct., 83.24 pct., 1.90 pct., and 4.26 pct., in the S&P500, the bond index, the Russell 2000 and the Norwegian Krone carry trade respectively. Now the Norwegian Krone has expected return of 0.23 pct., with a standard deviation of 11.05 pct., which weigh negatively in a minimum variance portfolio context. This strategy provides almost no expected returns and at the same time provides a high standard deviation or risk compared to the other currencies (e.g. GBP of 8.61 pct.), however, still the second lowest standard deviation in this portfolio. Now looking at table 4 panel I one can see that the Norwegian Krone carry has a covariance with the bond index of zero, which points towards a higher weight. However, the modest covariance with the S&P500 and Russell 2000 in combination with high standard deviation and relatively low expected return argues for a lower weight.

Table 5 Panel F, shows the sixth minimum variance portfolio with the euro carry strategy. Now this minimum variance portfolio provides an expected return of 3.66 pct., with a standard deviation of 2.93 pct. These figures are based on the portfolio weights of 11.05 pct., 67.35 pct., 2.63 pct., and 18.96 pct., in the S&P500, the bond index, the Russell 2000 and the euro carry trade. Given that the euro carry trade provides an expected return of negative 0.30 pct., and a standard deviation of 9.8 pct., it is interesting that it has the highest weight compared to all the previous currencies. However, it is the only carry trade strategy that provides a negative covariance with the S&P500, the bond index and the Russell 2000 of -0.004, -0.001, -0.005. Hence, it might provide a negative expected return and relatively low standard deviation but it does also provide as an pure “insurance” as it covariates negatively with the other assets, and, so that might drive the portfolio weight up. This points towards, that the investor is willing to accept a negative load on the expected return as this portfolio still has a high weight in an asset that has a negative expected return in order to get the benefits of low standard deviation. This willingness stems from the fact that the investor gains some diversification benefits, which emphasise the fact that the euro provides as an asset that is useful for diversification purposes. Also worth noticing, is the fact that this minimum variance portfolio has the second lowest standard deviation of all the carry strategies, only outperformed by the Australian Dollar.

Table 5 panel G, displays the seventh minimum variance portfolio with the Japanese Yen as investment currency for the carry trade. This minimum variance portfolio provides an expected return of 4.36 pct., with a standard deviation of 3.62 pct. These results are based on the following portfolio weights of 11.23 pct., 83.61 pct., 2.59 pct., 2.56 pct., in the S&P500, the bond index, the Russell 2000 and the Japanese Yen carry trade, respectively. Interestingly, the Japanese Yen carry trade provides the largest negative expected return of 1.83 pct., and the third lowest standard deviation of 9.54 pct. Looking at table 4 panel E, one can see the covariance structure of the Japanese Yen carry trade. Worth noticing, is that the Japanese Yen carry trade has the highest covariance with the bond index of all the currencies, which points towards a lower weight although the magnitude of the two other covariance relationships are low but negative. Combining this observation with the high negative expected returns points towards a low portfolio weight despite a low standard deviation and so the portfolio weight of 2.56 pct., seems reasonable despite two negative covariances. Furthermore, this minimum variance portfolio provides the third highest expected return but with the same standard deviation as the Swedish Krona minimum variance portfolio.

The eighth minimum variance portfolio is the minimum variance portfolio with the Swiss Franc, which is displayed in table 5 panel H. This portfolio provides an expected return of 4.40 pct., and a standard deviation of 3.61 pct. Now the portfolio weights in the S&P500, the bond index the Russell 2000 and the Swiss Franc carry trade are 11.52 pct., 83.94 pct., 2.03 pct., and 2.52 pct., respectively. Looking at table 4 panel B, one can see that the Swiss Franc covariance with the S&P500, the bond index and the Russell 2000 are 0.002, 0.001, 0.003, which are all positive but low. As with previous currencies, the covariance between the assets does not provide the full picture, and, one can see that the Swiss Franc provide an expected return of 0.13 pct., with a standard deviation of 10.22 pct. Now, the low weight in the Swiss Franc carry trade is mainly due to the high standard deviation and to some degree the covariance relationships as it is the only currency with positive covariance with all the fixed assets. However, the covariances are in the lower end and so would be expected to be favourable even though they are positive. Of course, the low expected return also contributes, as the investor would not desire a high exposure to an asset with high standard deviation and low expected return compared to the other assets in the portfolio like the bond index that has higher expected return and lower standard deviation but almost the same covariance structure (besides negative sign)

Table 5 panel I displays the ninth and last minimum variance portfolio with the Swedish Krona carry trade. This minimum variance portfolio has an expected return of 4.47 pct., and a standard deviation of 3.62 pct. The portfolio weights in the S&P500, the bond index, the Russell 2000 and the Swedish Krona carry trade are 11.46 pct., 85.59 pct., 2.21 pct., and 0.74 pct., respectively. As can be seen, the Swedish Krona is the carry trade with the lowest portfolio weight in the minimum variance portfolio of all the carry trade strategies. This finding is somewhat interestingly as the

Swedish Krona provides a negative expected return of 1.04 pct., which is higher than the Japanese Yen but the Swedish Krona provides the third highest standard deviation of 11.20 pct., which is a lot higher than the Japanese Yen standard deviation. This in itself explain some of the portfolio weight as these two features are not desirable for the investor. In addition, from table 4 panel H one can see that the Swedish Krona carry trade has a covariance with the bond index of zero, which is favourable. However, the other covariance with the S&P500 and Russell 2000 are of higher magnitude combined with the low expected return and high standard deviation makes the portfolio weight seems reasonable.

Panel A	Min var
SP500	14.10%
Bond index	64.94%
Russell 2000	3.48%
AUD z_t	17.48%
Sum	100.00%
Expected return	4.09%
Variance	0.08%
STD	2.88%

Panel B	Min var
SP500	13.62%
Bond index	67.62%
Russell 2000	3.23%
NZD z_t	15.53%
Risk free	100.00%
Expected return	4.10%
Variance	0.09%
STD	2.98%

Panel C	Min var
SP500	11.52%
Bond index	68.30%
Russell 2000	2.46%
GBP z_t	17.71%
Risk free	100.00%
Expected return	4.05%
Variance	0.10%
STD	3.23%

Panel D	Min var
SP500	8.63%
Bond index	79.43%
Russell 2000	0.80%
CAD z_t	11.14%
Risk free	100.00%
Expected return	4.05%
Variance	0.12%
STD	3.53%

Panel E	Min var
SP500	10.60%
Bond index	83.24%
Russell 2000	1.90%
NOK z_t	4.26%
Risk free	100.00%
Expected return	4.31%
Variance	0.13%
STD	3.60%

Panel F	Min var
SP500	11.05%
Bond index	67.35%
Russell 2000	2.63%
EUR z_t	18.96%
Risk free	100.00%
Expected return	3.66%
Variance	0.09%
STD	2.93%

Panel G	Min var
SP500	11.23%
Bond index	83.61%
Russell 2000	2.59%
JPY z_t	2.56%
Risk free	100.00%
Expected return	4.36%
Variance	0.13%
STD	3.62%

Panel H	Min var
SP500	11.52%
Bond index	83.94%
Russell 2000	2.03%
CHF z_t	2.52%
Risk free	100.00%
Expected return	4.40%
Variance	0.13%
STD	3.61%

Panel I	Min var
SP500	11.46%
Bond index	85.59%
Russell 2000	2.21%
SEK z_t	0.74%
Risk free	100.00%
Expected return	4.47%
Variance	0.13%
STD	3.62%

Table 5. This table displays the nine minimum variance portfolios with each currency under the mean-variance framework. Source: author's own creation

Now based on above analysis, one can now take a broader look from an investor's perspective and better pin-point the most favourable FX carry trade and its minimum variance portfolio. Of course, the minimum variance portfolio of choice to the individual investor depends on the investors risk appetite or risk aversion. However, taking the perspective from a risk averse investor, this investor would desire the minimum variance portfolio with the Australian Dollar as it, not only, provides the lowest standard deviation on portfolio level but also provides the second highest expected return on stand-alone basis. Now on the opposite side, a less risk averse investor would choose the Swedish

Krona carry trade as it is the minimum variance portfolio with the highest standard deviation and the portfolio with the highest expected return. Now, the main difference besides differences in expected returns and standard deviations on portfolio level, is the difference in weights. The investor who chose the minimum variance portfolio with the Australian Dollar are more exposed to the FX carry trade due to the higher weight compared to the low weight of the Swedish Krona minimum variance portfolio. In addition, on stand-alone basis the Swedish Krona provides a lower negative expected return compared to the Japanese Yen but on portfolio level the two minimum variance portfolios provide same standard deviation but two different expected returns.

Lastly, it is worth noticing that when comparing expected returns from each panel in table 5 and table 3, it is evident that none of the minimum variance portfolios outperformed the S&P500 or the Russell 2000. However, the Norwegian Krone carry minimum variance portfolio, the Japanese Yen minimum variance portfolio, the Swiss Franc minimum variance portfolio and the Swedish Krona minimum variance portfolio outperformed the bond index in the sample period.

4.3.4. Maximum Slope Portfolio For The Individual Currencies

After analysing the minimum variance portfolio, one can now slightly change the framework from wanting the portfolio with the lowest variance to the portfolio where the relationship between expected returns and standard deviations are maximized $\left(\frac{\mu}{\sigma}\right)$ as described in section 2.5.3. Below is the analysis of the maximum slope portfolios.

Table 6 panel A, displays the maximum slope portfolio with the Australian Dollar. This maximum slope portfolio has an expected return of 4.21 pct., and a standard deviation of 2.92 pct., which is 0.12 pct., and 0.04 pct., higher than the Australian Dollar minimum variance portfolio. The weights are 15.90 pct., in the S&P500 index, 66.91 pct., in the bond index, 2.83 pct., in the Russell 2000 index and 14.36 pct., in the Australian Dollar carry trade. Now, the weight in the Australian Dollar carry trade and the Russell 2000 index is 3.12 pct., and 0.66 pct., lower than the minimum variance portfolio whereas the weight in the bond index and S&P500 are higher with 1.98 pct., and 1.8 pct. The weights have shifted slightly, which might be because they both provide higher expected returns than the Australian Dollar despite only the bond index having a lower standard deviation. Hence, this is a result of the covariance of the bond index and the S&P500 being closer to zero, compared to the covariance of the Australian Dollar and Russell 2000 with the other assets as can be seen from table 4 panel A.

Table 6 panel B shows the second maximum slope portfolio with the New Zealand Dollar. This portfolio has an expected return of 4.23 pct., and a standard deviation 3.02 pct. The weights are 15.59 pct., in the S&P500 index, 69.55 pct., in the bond index, 2.56 pct., in the Russell 2000 index and 12.29 pct., in the New Zealand Dollar carry trade. Similarly, to the Australian Dollar, this portfolio has a higher expected return and standard deviation compared to the minimum variance portfolio of 0.11 pct., and 0.11 pct., respectively. In addition, the weights are also different as the Russell 2000 and New Zealand Dollar carry trade weights are lower with 0.57 pct., and 2.79 pct., compared to the minimum variance portfolio, whereas the weights in the S&P500 and bond index are higher with 1.70 pct., and 1.66 pct. Again, this portfolio demonstrates the risk-return trade-off as the investor would have to have more exposure to higher expected return and standard deviation assets, besides the bond index. From table 4 panel G, the bond index is further emphasised as a valuable asset because of its low covariance together with the S&P500 compared to the New Zealand Dollar and Russell 2000.

Table 6 panel C, displays the third maximum slope portfolio with the British Pound carry trade, which has an expected return of 4.31 pct., and a standard deviation of 3.33 pct., which is an increase of 0.26 pct., and 0.10 pct., respectively. This portfolio compared to the two previous portfolios, has the highest drop in the carry weight compared to the minimum variance portfolio. The reduction in the British Pound carry weight and the Russell 2000 are 7.95 pct., and 0.65 pct. Whereas the bond index and S&P500 see an increase of 5.68 pct., and 2.91 pct. It is interesting, that the weight in the British Pound carry trade is so significant as it has some good features in terms of high expected return and low standard deviation. This is especially interesting in combination with the covariance that is closer to zero compared to the Australian Dollar carry trade, which can be seen in table 4 panel A and D.

The fourth maximum slope portfolio is with the Canadian Dollar carry trade presented in table 6 panel D. This maximum slope portfolio has an expected return of 5.07 pct., and a standard deviation of 3.95 pct., which is an increase of 1.02 pct., and 0.42 pct., respectively compared to the minimum variance portfolio. Now the weights in the S&P500, the bond index, Russell 2000 and the Canadian Dollar carry trade are 18.31 pct., 90.36 pct., 3.14 pct., and negative 11.81 pct., respectively. Which corresponds to an increase in the S&P500, bond index and Russell 2000 of 9.68 pct., 10.94 pct., and 2.33 pct., but, even more interesting is the fact that the portfolio weight in the Canadian Dollar carry trade shifts sign from positive to negative and therefore yields a change of 22.95 pct. The negative weight of 11.81 pct., in the Canadian Dollar carry trade, translates in to, that the investor will be short the high interest rate currency (the investment currency), which in this case is the Canadian Dollar but will be long the U.S. interest rate (the funding currency). Furthermore, when taking the positive expected return of 0.94 pct., and standard deviation of 8.89 pct., of the Canadian Dollar carry trade into consideration, makes this finding even more interesting as more loading is put on high expected return assets. Naturally, covariance also plays a role in explaining the weights and since the covariance relationships of the Canadian Dollar carry trade with the other assets are in the modest to high range as seen in table 4 panel C.

Table 6 panel E, displays the maximum slope portfolio with the Norwegian Krone carry strategy. The portfolio has an expected return of 5.01 pct., and a standard deviation of 3.88 pct., which is an increase of 0.7 pct., and 0.3 pct., respectively, from the minimum variance portfolio. Furthermore, the weights of this portfolio are 17.37 pct., in the S&P500, 89.48 pct., in the bond index, 2.38 pct., in the Russell 2000 and negative 9.24 pct., in the Norwegian Krone carry strategy. These weighs corresponds to an increase in the S&P500, the bond index and the Russell 2000 of 6.77 pct., 6.24 pct., and 0.49 pct., respectively. Furthermore, the investor would also see a negative weight in the Norwegian Krone carry strategy, like with the Canadian Dollar. Hence, the change in in portfolio weight of the Norwegian Krone carry strategy corresponds to a change of 13.50 pct. However, the negative weight is more clear in the case of the Norwegian Krone as the expected return is very low of 0.23 pct., and a high standard deviation of 11.05 pct., and the covariance is modest with the other assets. However, the large negative weight is assigned in order to optimize the risk-return trade-off.

Panel F in table 6, displays the sixth maximum slope portfolio with the euro. This portfolio has an expected return of 4.09 pct., and a standard deviation of 3.10 pct. Compared to the minimum variance portfolio, this corresponds to an increase of 0.43 pct., and 0.17 pct., respectively. The increase is based on the following weights in the S&P500, the bond index, the Russell 2000 and the euro carry trade of 13.92 pct., 73.61 pct., 1.96 pct., and 10.50 pct., respectively. This corresponds to an increase of 2.87 pct., in the S&P500, 6.26 pct., in the bond index and a decrease in the Russell 2000 and euro carry trade of 0.67 pct., and 8.46 pct. Now the weight in the euro carry trade is still positive even though the expected return of the euro carry trade is negative of 0.30 pct., but with low standard deviation of 9.80 pct., and modest negative covariance with the other assets still makes it a good asset for diversification purposes. Compared to for example the Canadian Dollar carry trade, which has a negative weight in the maximum slope portfolio while it has a positive expected return and low standard deviation but modest to high positive covariance, makes this finding interesting.

In table 6 panel G, one can see the seventh maximum slope portfolio with the Japanese Yen. This portfolio has an expected return of 5.90 pct., and a standard deviation of 4.21 pct., which corresponds to an increase of 1.55 pct., and 0.59 pct., compared to the minimum variance portfolio. This maximum slope portfolio is based on a weight of 18.88 pct., in the S&P500, 104.07 pct., in the bond index, a negative weight in the Russell 2000 of 1.24 pct., and a negative weight in the Japanese Yen carry trade of 21.71 pct. Which corresponds to an increase in the S&P500 of 7.65 pct., and the bond index of 20.26 pct., whereas the bond Russell 2000 index decreased with 3.83 pct., and the Japanese Yen carry trade has seen a high decrease of 24.27 pct. Furthermore, this maximum slope portfolio is interesting for two reasons. It is the only maximum slope portfolio that has a negative (short position) in more than one asset and it is the only maximum slope portfolio with a weight of more than 100 pct., in one asset. In fact, it is the portfolio of all the maximum slope portfolio that has the highest expected return and highest standard deviation.

Table 6 panel H, shows the eight maximum slope portfolio with the Swiss Franc. This portfolio has an expected return of 5.07 pct., and a standard deviation of 3.88 pct., which is an increase of 0.67 pct., and 0.27 pct., compared to the minimum variance portfolio. This maximum slope portfolio is based on a weight of 15.74 pct., in the S&P500, 92.89 pct., in the bond index, 2.63 pct., in the Russell 2000 and negative 11.26 pct., in the Swiss Franc carry trade. This corresponds to an increase in the S&P500 weight of 4.23 pct., 8.95 pct., in the bond index, 0.63 pct., in the Russell 2000 index and a change from a long position to a short position in the Swiss Franc carry trade of 13.77 pct., compared to the minimum variance portfolio. Again, this portfolio would tell the investor to hold a negative weight in a carry strategy that has an positive expected return, which shows that the carry strategy is used for diversification purposes.

The last and ninth carry trade is displayed in table 6 panel I, which is the maximum slope portfolio with the Swedish Krona. This portfolio has an expected return of 5.65 pct., and a standard deviation of 4.07 pct., and is the portfolio with the second highest expected return but also the second highest standard deviation. Now the portfolio weights are 20.46 pct., in the S&P500, 94.43 pct., in the bond index, 2.79 pct., in the Russell 2000 and negative 17.68 pct., in the Swedish Krone carry trade. This is an increase of 9.00 pct., in the S&P500, 8.84 pct., in the bond index, 0.59 pct., in the Russell 2000 and a decrease of 18.42 pct., in the Swedish Krone carry trade.

Panel A	Max Slope
SP500	15.90%
Bond index	66.91%
Russell 2000	2.83%
AUD z_t	14.36%
Sum	100.00%
Expected return	4.21%
Variance	0.09%
STD	2.92%

Panel B	Max Slope
SP500	15.59%
Bond index	69.55%
Russell 2000	2.56%
NZD z_t	12.29%
Sum	100.00%
Expected return	4.23%
Variance	0.09%
STD	3.02%

Panel C	Max Slope
SP500	14.43%
Bond index	73.99%
Russell 2000	1.82%
GBP z_t	9.76%
Sum	100.00%
Expected return	4.31%
Variance	0.11%
STD	3.33%

Panel D	Max Slope
SP500	18.31%
Bond index	90.36%
Russell 2000	3.14%
CAD z_t	-11.81%
Sum	100.00%
Expected return	5.07%
Variance	0.16%
STD	3.95%

Panel E	Max Slope
SP500	17.37%
Bond index	89.48%
Russell 2000	2.38%
NOK z_t	-9.24%
Sum	100.00%
Expected return	5.01%
Variance	0.15%
STD	3.88%

Panel F	Max Slope
SP500	13.92%
Bond index	73.61%
Russell 2000	1.96%
EUR z_t	10.50%
Sum	100.00%
Expected return	4.09%
Variance	0.10%
STD	3.10%

Panel G	Max Slope
SP500	18.88%
Bond index	104.07%
Russell 2000	-1.24%
JPY z_t	-21.71%
Sum	100.00%
Expected return	5.90%
Variance	0.18%
STD	4.21%

Panel H	Max Slope
SP500	15.74%
Bond index	92.89%
Russell 2000	2.63%
CHF z_t	-11.26%
Sum	100.00%
Expected return	5.07%
Variance	0.15%
STD	3.88%

Panel I	Max Slope
SP500	20.46%
Bond index	94.43%
Russell 2000	2.79%
SEK z_t	-17.68%
Sum	100.00%
Expected return	5.65%
Variance	0.17%
STD	4.07%

Table 6. Each panel show a maximum slope portfolio for each currency and its weights, expected return, variance and standard deviation. Source: author's own creation.

Besides looking at each portfolio and its specific features, the investor would also be interested in knowing what the risk-return are in terms of how much expected return per standard deviation (μ/σ) will each portfolio provide and which portfolio provides the largest change. From table 7, it is clear that if the investor held the Canadian Dollar minimum variance portfolio, the investor would get the lowest expected return to standard deviation on 114.76 pct. On the contrary, if the investor held the Australian Dollar minimum variance portfolio, the investor would have the highest expected return to standard deviation of 141.86 pct. The same is true for the maximum slope portfolio, which is, that the investor would have the highest expected return to standard deviation with the Australian Dollar and the lowest with the Canadian Dollar carry trade. However, the largest change between the minimum variance portfolio and maximum slope portfolio is in fact the Japanese Yen, which is typically a funding currency for the carry trade and where the interest rate consistently has been lower than the U.S. interest rate - the change is 19.79 pct. It is also possible to see the difference in risk-return of the minimum variance portfolios and maximum slope portfolios profile in figure 5.

Lastly, it is worth noticing that none of the nine maximum slope portfolios has outperformed the S&P500 or the Russell 2000 over the sample period when comparing expected returns from table 6 and 3. However, all the maximum slope portfolios outperformed the bond index except for the euro carry maximum slope portfolio.

Panel A	AUD	CAD	JPY	NZD	NOK	CHF	GBP	EUR	SEK
Min var	141.86%	114.76%	120.46%	137.80%	119.85%	121.76%	125.21%	124.63%	123.34%
Max slope	143.88%	128.47%	140.25%	139.97%	129.25%	130.71%	129.20%	131.76%	138.74%
Difference	2.02%	13.71%	19.79%	2.17%	9.41%	8.95%	3.99%	7.13%	15.40%

Table 7. Displays the return-risk profile of nine minimum variance portfolios and maximum slope portfolios for each of the nine currencies. Source: authors own creation.

4.3.5.The Tangency Portfolio For The Individual Currencies

With the introduction of a risk free asset, the investor can now analyse how the risky assets can be combined to the tangency portfolio and then how the mix of weights in the tangency portfolio with the risk free asset can change the risk-return profile of the mean-variance efficient portfolios. In order to do so, the following section will apply the expressions from section 2.5.5. However, this section is subject to some preliminary discussion, as the FX carry trade strategy is an overlay strategy or excess strategy to the base currency. Hence, introducing a risk free asset can give rise to confusion and several practical consideration as to how the weights and Sharpe Ratio should be interpreted. In terms of the Sharpe Ratio, one can think of it as how much more expected return do the investor get than the risk free rate per unit of risk. This allows the reader to think about the weights in the same way as other assets as the carry trade weight represent any other assets weight. For an example the Sharpe Ratio of and equity strategy (a long position) is the unit of return in excess of the risk free rate per standard deviation, and, likewise with the carry trade strategy. However, this approach is slightly in contrast to other areas of the literature. Norways Bank Investment Management (2014) addresses the topic briefly, and, provides for an interesting topic of reflection and analysis as to what benefits does the investor get from including only “the long leg” of one of the G10 carry trades instead of including the exact carry trade strategy.

Table 8 shows the tangency portfolio for all the portfolios with the S&P500, the bond index, the Russell 2000 and the carry strategy which vary between the currencies for each panel. Hence, table 8 panel A shows the tangency portfolio with the Australian Dollar carry trade. This portfolio has an expected return of 4.31 pct., and a standard deviation of 3.02 pct. This is 0.10 pct., expected return and 0.10 pct., standard deviation higher than the maximum slope portfolio, hence, the investor is able to get 0.8 excess expected return per standard deviation ($\frac{\mu_{p-rf}}{\sigma_p}$) by having a risk free asset available i.e. this portfolio has a Sharpe Ratio of 0.8. The weights are 17.46 pct., 68.63 pct., 2.26

pct., 11.65 pct., and 0.00 pct., in the S&P500, the bond index, the Russell 2000, the Australian Dollar carry trade and the risk free asset, respectively. It is evident that the bond index is the asset with the highest weight, then the S&P500, followed by the Australian Dollar carry trade and then the Russell 2000, similarly to the maximum slope portfolio. The reason behind is that the asset with the highest Sharpe Ratio is assigned the highest weight in the tangency portfolio. As one can see from table 3, the bond index has the highest Sharpe Ratio of 53.0 pct., followed by the S&P500 31.6 pct., the Russell 2000 of 23.8 pct., and then finally the Australian Dollar carry trade with a negative Sharpe Ratio of negative 5.02 pct. Now, interestingly is that the Australian Dollar has such a high weight due to its negative Sharpe Ratio - once again the covariance play an important role.

However, as with the minimum variance portfolio and the maximum slope portfolio, the investor cannot rely only on the Sharpe Ratio to rationalise the portfolio weights. The Australian FX carry trade works as an asset that can be used for diversification.

Table 8 panel B, show that the tangency portfolio with the New Zealand Dollar has an expected return of 4.34 pct., and a standard deviation of 3.14 pct. This is 0.11 pct., expected return and 0.11 pct., standard deviation higher than the maximum slope portfolio, hence the investor is able to get 0.78 excess expected return per standard deviation by having a risk free asset available. This tangency portfolio is based a weight in the S&P500 of 17.29 pct., the bond index of 71.22 pct., the Russell 2000 of 1.99 pct., the New Zealand Dollar trade of 9.51 pct., and no weight in the risk free asset, respectively. Like with the Australian Dollar carry trade, the bond index has the highest weight followed by the S&P500, then the New Zealand dollar carry trade, followed by the Russell 2000. As is displayed in table 3, the highest Sharpe Ratio is the same as described in the tangency portfolio of the Australian Dollar carry trade, however, focus is now the Sharpe Ratio of the New Zealand Dollar carry trade, which is negative 6.18 pct. In addition, one can see that the weight in the New Zealand dollar carry trade is now lower than in the maximum slope portfolio and the minimum variance portfolio. As with the maximum slope portfolio, the reason behind is a mix of the negative Sharpe Ratio and a relatively high negative covariance with the other assets.

Table 8 Panel C, displays the third tangency portfolio with the British Pound carry trade. This tangency portfolio has an expected return of 4.54 pct., and a standard deviation of 3.58 pct., which is 0.23 pct., and 0.25 pct., higher than the maximum slope portfolio. Hence, the investor is almost able to get 0.74 excess expected return per standard deviation by including a risk free asset in the portfolio. Now, this tangency portfolio has a weight of 17.01 pct., in the S&P500, 79.01 pct., in the bond index, 1.24 pct., in the Russell 2000, 2.74 pct., in the British Pound carry trade and 0.00 pct., in the risk free asset. Looking at table 3, the Sharpe Ratio of the British Pound is the least negative of the carry trades by negative 4.03 pct. But, the covariance of the British Pound with the other assets are relatively low and so this help explain the weight that is allocated to the British Pound carry trade as it has a negative Sharpe Ratio. In addition, the British Pound carry trade is the currency with the third highest portfolio weight. However, the weight is lower compared to the maximum slope portfolio and the minimum variance portfolio. The weights in the S&P500 and the bond index follow the opposite pattern with increasing weights, which most likely is due to higher expected returns and favourable covariance patterns.

Table 8 Panel D displays the fourth tangency portfolio with the Canadian Dollar carry trade. This portfolio has an expected return of 5.98 pct., and a standard deviation of 4.86 pct., which is 1.20 pct., and 1.05 pct., higher than the maximum slope portfolio. Hence, the investor is able to get 0.84 excess expected return per standard deviation with the risk free asset available from this portfolio. Now, in order to achieve this the investor would have to have a weight of 26.87 pct., in the S&P500, 100.03 pct., in the bond index, 5.20 pct., in the Russell 2000, negative (short position) 32.10 pct., in the Canadian Dollar carry trade and 0.00 pct., in the risk free asset. From table 3, the Sharpe Ratio of the Canadian FX carry trade is negative 10.76 pct., while the covariance structure is modest. Hence, the reason behind the negative weight is most likely that the Canadian Dollar carry trade has a modest covariance compared to the other carry trades but low compared to the fixed assets combined with the fact that the Canadian Dollar carry trade has a relatively high negative Sharpe Ratio. In addition, it is evident that this portfolio takes a larger short position in the Canadian Dollar carry trade and higher long position in all of the other assets compared to the minimum variance portfolio and the maximum slope portfolio.

Table 8 Panel E, displays the fifth tangency portfolio with the Norwegian Krone carry trade. This portfolio has an expected return of 5.57 pct., and a standard deviation of 4.44 pct., which is 0.55 pct., and 0.56 pct., higher than the maximum slope portfolio when the investor has a risk free asset available. This means that the investor is able to get 0.83 of excess return per standard deviation. In order to achieve this, the investor would have to hold a weight of 22.70 pct., in the S&P500, 94.39 pct., in the bond index, 2.77 pct., in the Russell 2000, a negative (short position) weight of 19.86 pct., in the Norwegian Krona carry trade and 0.00 pct., in the risk free asset. From table 3, the Sharpe Ratio of the Norwegian Krone carry trade is negative of 15.12 pct. The large negative weight in the Norwegian Krone is most likely explained by the negative Sharpe Ratio and modest covariance structure as described in previous sections and is further decreased with more than 10 pct., from the maximum slope portfolio. In addition, the weight in other assets are also increased while the bond index is still the asset with the highest weight.

Table 8 Panel F, displays the sixth tangency portfolio with the euro. This portfolio has an expected return of 4.55 pct., and standard deviation of 3.60 pct., which is an increase from the maximum slope portfolio of 0.46 pct., and 0.50 pct., respectively. In addition, this portfolio will provide a Sharpe Ratio or an excess return per standard deviation of 0.74. Now, this portfolio has a weight of 17.02 pct., in the S&P500, 80.38 pct., in the bond index, 1.23 pct., in the Russell 2000, 1.37 pct., in the euro carry trade and 0.00 pct., in the risk free asset. From table 3, it can be seen that the euro carry trade has a Sharpe Ratio of negative 22.41 pct., combined with its modest negative covariance with the other assets helps the investor understand the allocated weight in the tangency portfolio. In contrast to the previous portfolio with the Norwegian krone, the euro carry trade is not the asset with the lowest weight. The asset with the lowest weight is now the Russell 2000, then the euro carry trade, then the S&500 and then the bond index.

Table 8 Panel G, displays the seventh tangency portfolio with the Japanese Yen. This tangency portfolio has an expected return of 7.10 pct., and a standard deviation of 5.26 pct., which is an increase of 1.20 pct., and 1.05 pct., respectively, now that the investor has a the risk free asset available compared to the maximum slope portfolio. It is also worth noticing that this tangency portfolio is the tangency portfolio with the highest expected return and highest standard deviation. The Sharpe Ratio of this tangency portfolio is 0.99, which makes it the tangency portfolio with the highest Sharpe Ratio of all the currency tangency portfolios. In addition, the investor would have to hold a long position in the S&P500 of 24.79 pct., 119.88 pct., in the bond index, a short position of negative 4.21 pct., in the Russell 2000, a short position of negative 40.47 pct., in the Japanese Yen carry trade and no position in the risk free asset. Hence, this tangency portfolio is the only portfolio with a negative weight or short position in the Russell 2000. In addition, it is the only tangency portfolio with a negative weight or short position in both the Russell 2000 and the Japanese Yen carry trade while having an over allocation to the bond index. While interesting in itself, it is also important to have a look at the Sharpe Ratio of the Japanese Yen and its covariance structure. It turns out from table 3, that the Japanese Yen has a high negative Sharpe Ratio of 39.12 pct., which is the most negative Sharpe Ratios among all the currencies combined with its primarily negative and low covariance structure gives rise to a deeper understanding of the weight.

Table 8 panel H, displays the eighth tangency portfolio with the Swiss Franc. This tangency portfolio has an expected return of 5.58 pct., and a standard deviation of 4.38 pct., which is 0.51 pct., higher expected return and 0.50 pct., higher standard deviation compared to the maximum slope portfolio when the investor has a risk free asset available. Holding this portfolio would provide the investor with a Sharpe Ratio of 0.84, which means the investor would earn an excess expected return to the risk free rate per standard deviation of 0.84. Now, in order to construct this portfolio, the investor would have to have a weight of 18.95 pct., in the S&P500, 99.68 pct., in the bond index, 3.08 pct., in the Russell 2000, a negative (short position) weight of 21.71 pct., in the Swiss Franc carry trade and a weight of 0.00 pct., in the risk free rate. Like with tangency portfolio with the Canadian Dollar carry trade, this tangency portfolio see an increase in the S&P500 weights, the bond index, and Russell 2000 compared to the minimum variance portfolio and maximum portfolio while seeing a larger short position in the Swiss Franc carry trade. Part of the reason behind the large short position in the Swiss Franc carry trade is due to the relative high negative Sharpe Ratio of 17.28 from table 3.

Panel A	Tan portfolio
SP500	17.46%
Bond index	68.63%
Russell 2000	2.26%
AUD z_t	11.65%
Risk free	0.00%
Expected return	4.31%
Variance	0.62%
STD	3.02%

Panel B	Tan portfolio
SP500	17.29%
Bond index	71.22%
Russell 2000	1.99%
NZD z_t	9.51%
Risk free	0.00%
Expected return	4.34%
Variance	0.62%
STD	3.14%

Panel C	Tan portfolio
SP500	17.01%
Bond index	79.01%
Russell 2000	1.24%
GBP z_t	2.74%
Risk free	0.00%
Expected return	4.54%
Variance	0.66%
STD	3.58%

Panel D	Tan portfolio
SP500	26.87%
Bond index	100.03%
Russell 2000	5.20%
CAD z_t	-32.10%
Risk free	0.00%
Expected return	5.98%
Variance	0.78%
STD	4.86%

Panel E	Tan portfolio
SP500	22.70%
Bond index	94.39%
Russell 2000	2.77%
NOK z_t	-19.86%
Risk free	0.00%
Expected return	5.57%
Variance	0.69%
STD	4.44%

Panel F	Tan portfolio
SP500	17.02%
Bond index	80.38%
Russell 2000	1.23%
EUR z_t	1.37%
Risk free	0.00%
Expected return	4.55%
Variance	0.77%
STD	3.60%

Panel G	Tan portfolio
SP500	24.79%
Bond index	119.88%
Russell 2000	-4.21%
JPY z_t	-40.47%
Risk free	0.00%
Expected return	7.10%
Variance	0.78%
STD	5.26%

Panel H	Tan portfolio
SP500	18.95%
Bond index	99.68%
Russell 2000	3.08%
CHF z_t	-21.71%
Risk free	0.00%
Expected return	5.58%
Variance	0.67%
STD	4.38%

Panel I	Tan portfolio
SP500	27.11%
Bond index	100.97%
Russell 2000	3.22%
SEK z_t	-31.30%
Risk free	0.00%
Expected return	6.53%
Variance	0.72%
STD	4.86%

Table 8. Displays the nine tangency portfolios for each currency for the sample period. Source: author's own creation

Table 8 Panel I displays, the ninth and final tangency portfolio with the Swedish Krona. This portfolio has an expected return of 6.53 pct., and a standard deviation of 4.86 pct., which is an increase of 0.88 pct., and 0.79 pct., respectively, compared to the maximum slope portfolio. The Sharpe Ratio of this tangency portfolio is 0.95, hence the investor would expect a return in excess of the risk free rate of 0.95 per standard deviation. To achieve this, the investor would have to hold a weight of 27.11 pct., in the S&P500, 100.97 pct., in the bond index, 3.22 pct., in the Russell 2000, a negative (short position) in the Swedish Krona carry trade of 31.30 pct., and a weight of 0.00 pct., in the risk free asset. The portfolio weight in the Swedish Krona carry trade is a result of a negative Sharpe Ratio of 26.21 pct., which can be seen in table 3 and its covariance structure in table 4. Like with the Swiss Franc tangency portfolio, this portfolio see an increase in weights in the S&P500, bond index and Russell 2000 compared with the minimum variance portfolio and maximum slope portfolio while a larger short position in the Swedish Krona carry trade. As with the Japanese Yen tangency portfolio, this portfolio also has an over-allocation in the bond index.

From above it stands clear that a mean-variance optimizing investor would choose the tangency portfolio with the Japanese Yen as it provides the highest Sharpe Ratio compared to the tangency portfolio with the euro that has the lowest Sharpe Ratio. If the tangency portfolios are compared only on expected return and standard deviation, a risk averse investor would desire the tangency portfolio with the Australian Dollar carry trade as it has the lowest standard deviation. In addition, an investor who desire risk would go for the Japanese Yen carry tangency portfolio as it has the highest standard deviation. Furthermore, it is evident when comparing expected returns in table 8 and 3 that only the tangency portfolio with the Japanese Yen that outperformed the Russell 2000 over the sample period and only the Japanese Yen and Swedish Krona outperformed the S&P500. In contrast, all of the tangency portfolios outperformed the bond index over the sample period. This shows, that the Japanese Yen provides the tangency portfolio with both the highest expected return but also the highest standard deviation but comes with a short position in both the Russell 2000 and Japanese Yen carry trade.

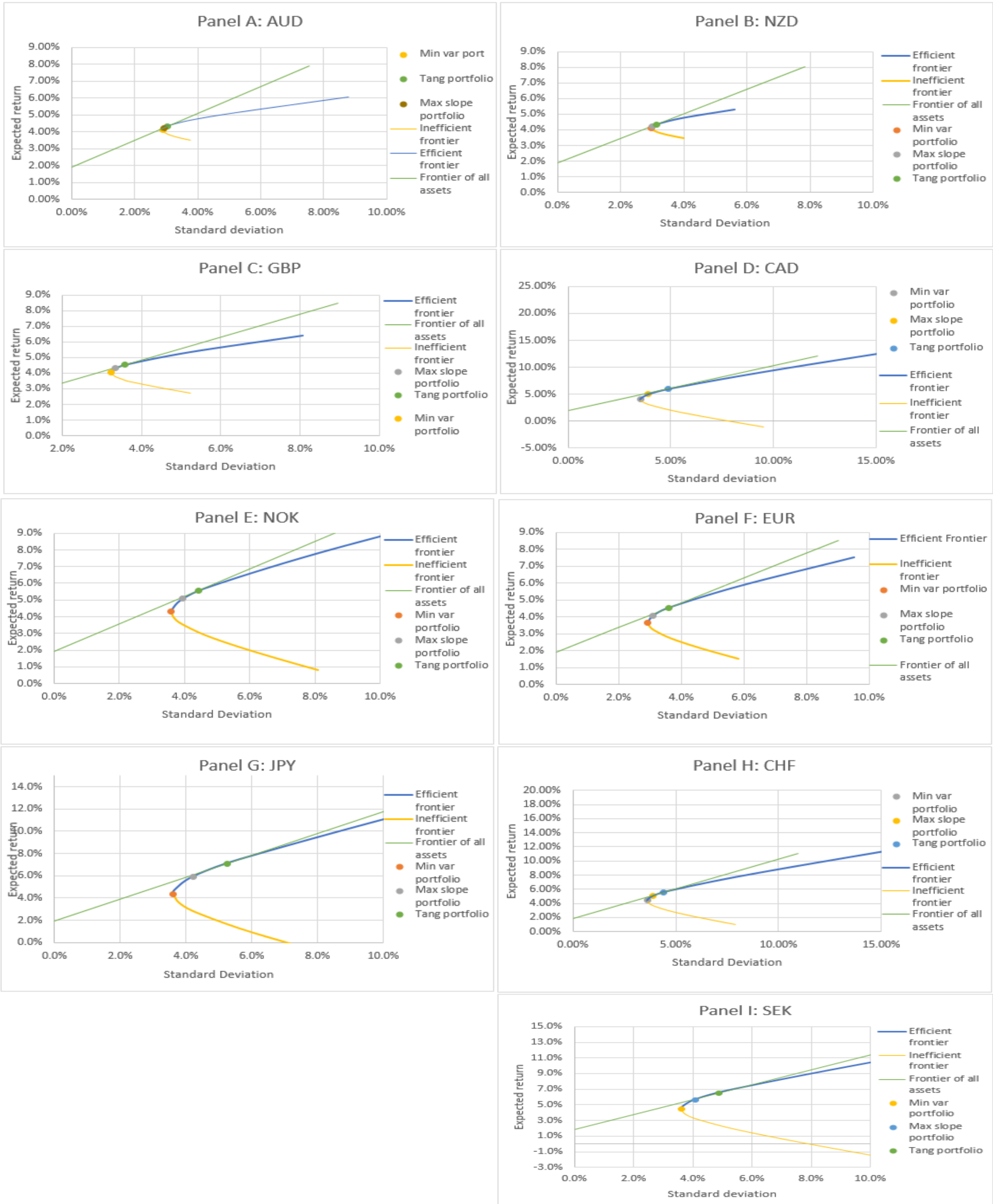

Figure 5. Displays a visual representation of the mean-variance frontier of risky assets divided in to an efficient part and an inefficient part. The visual representation also displays the mean-variance frontier of all assets. In addition, the visual representation also displays all of the three portfolios i.e. minimum variance, maximum slope and tangency portfolios for each currency. To see exact weights see appendix C (The weights are chosen arbitrarily, however, the exact weights for the minimum variance, maximum slope and tangency portfolio are represented).

5. Discussion

The purpose of this section is to discuss the paper's methodologies and results combined with previous studies and other perspectives that could have been relevant to the contribution of understanding the carry trade and its profitability.

In the first part of the paper addressing the validity of the uncovered interest parity and the profitability due to deviations, the paper finds that the results from the regressions are not statistical significant. To address this, the number of observations could be increased to get better estimates, however, the skewness of the exchange rates would still influence the return distributions. In addition, the reason to keep the data sets on a quarterly basis is with the further aim to see how the Swedish Krona would influence the results presented by Brunnermeier et. al (2009). In addition, under this section, the paper find that five out of nine currencies tend to appreciate rather than depreciate with the interest rate differential or depreciate rather than appreciate with the interest rate differential. As mentioned, the British Pound should depreciate with 0.001 according to the uncovered interest rate parity but it turns out to appreciate with 0.003 resulting in the British Pound outperforming a currency like the New Zealand Dollar that consistently has a higher interest rate differential and only depreciate slightly. In addition, this paper assumes that it is only financial capital movements that drives exchange rates i.e. the uncovered interest rate parity. However, in reality citizens and businesses across countries trade with each other and so this also leads to movements in exchange rates. Therefore, further investigation of this can provide for great research in relation to the deviation of the uncovered interest rate parity.

In the second part of the paper, the paper study how an investor would benefit from including interest rates and currencies in mean-variance efficient portfolios through the inclusion of the carry trade. This is investigated under the classic and well-known mean variance framework, which are subject to multiple uncertainties from a theoretical stand-point. Besides the theoretical uncertainties subject for discussion, one main area requires some attention in relation to the practical applications. The fact that the carry trade is seen to be an excess return strategy, hence, introducing a risk free asset in the mean-variance framework may lead to results that are subject to discussion. Like with the discussion note from Norges Bank Investment Management (2014), they dive in to the subject briefly and only look in to the subject by including only the long leg of the carry trade. Now, since correlation structure of interest rates and currencies generally are quite low with other assets, this approach can lead to an over allocation to the carry strategy in a mean-variance context

(all else kept constant). In addition, this approach is also not a "clear" currency carry strategy as the short leg is excluded. Hence, by including the short leg and a pure currency carry strategy leads to slightly higher correlation with other assets, although not too significant. A result of this, is that the mean-variance analysis with a risk free asset can look forced and skew the results compared to keeping the short leg excluded.
Now, turning to the more theoretical discussion of the applicability of Markowitz (1952, 1959) mean-variance framework, one can see that this model relies on a fixed historical period, like with the first part of this paper, except if rebalancing are available or included in the analysis. Of course, rebalancing of the portfolio weights will change the results, which can be another area for further investigation. In addition to the fixed historical time series, a consequence, is that the estimated values for the expected return, variance and covariance/correlations can be imprecise, which is subject to some critique as the mean-variance framework are sensitive to the expected returns, variance and covariance/correlations. Hence, this has been subject to critique by a few scholars cf., e.g., Chopra & Ziemba (1993) put forward a work addressing the importance of estimating the expected returns, variance and covariance, which depends on the investors risk tolerance. Chopra and Ziemba (1993) explains at higher risk tolerances, errors in means are more important than errors in variances and covariance. Work supporting more precise estimations of the input parameters are presented by Chopra, Hensel & Turner (1993), who argue that a Stein adjustment to the inputs of a mean-variance model perform better than an unadjusted model[1]. However, Markowitz does address the input parameters himself in his original work and encourage the reader to adjust the inputs if the investor believe they are imprecise and so Markowitz argues that some professional judgement can be relevant in combination with statistical methods (Markowitz, 1952). Clearly, adjusting the estimates of the variances and expected returns will change the portfolio construction in the mean-variance framework and depending on which way the investor adjusts the input parameters will determine the allocation of assets.

Another area for discussion is the trade-off between many and few assets. Having too few assets can lead to the exclusion of potential attractive assets. The reason behind, is that the mean-variance framework is a relative easy framework to apply and form decisions from. However, the number of inputs to be estimated increases sharply when increasing the assets. However, this paper counter

[1] Stein adjustment involves the adjustments of the inputs of a country index toward the parameters of a global index. Hence, the weighted average of mean expected returns of an individual country index and a global index is a better estimate of the true estimate of the individual country index (Chopra, Hensel & Turner, 1993).

this by using indices of different types of assets and combine these indices with the currency carry trade that is the main asset subject to analysis. In addition, the use of indices also contributes to overcoming the change of risk-return profile of individual assets. For an example, certain stocks are highly dependent on regulatory constraints and vice versa, which change their risk return profile. Now, the reader might notice that it is only the single carry strategy for each currency that is included in the portfolio in combination with indices of stocks and bonds and wonder why a currency index is excluded. Naturally, the inclusion of such an index could interfere with the results, however, the reason behind the exclusion, is that the paper's aim was to study the value of a single strategy.

A third point worth raising is the fact that the results in the paper are developed under no constraints and so the results include both short and long positions. Naturally, investors can face certain constraints such as only long positions or only short positions or constraints on the portfolio weights in terms of only allowing a certain level on one asset. For example, an investor would desire an exposure to oil and gas but are still cautious and so the investor would not want to hold a high weight due to other expectations than what the pure statistics are pointing towards, hence the investor would constrain the weight in the portfolio that this asset cannot exceed. Naturally, such constraints can change the decision-making of an investor depending on the effects on the mean-variance efficient portfolios and their compositions and therefore also the results of this paper.

6. Conclusion

Exchange rates is the process of when actors in financial markets exchange domestic currency in exchange of foreign currency to make purchases in foreign countries. Now, one of such actors is the financial investors who move capital between countries to exploit interest rate differentials, which in turn leads to price movements of currencies i.e. the exchange rates. This process is formulated as two equilibrium conditions called the covered and uncovered interest rate parity. Violations of the parity conditions leads to trading opportunities where the most famous is called the FX carry trade. Now, the profitability of the carry trade is primarily driven by the deviation of the uncovered interest rate parity but this paper also demonstrates that high interest rate currencies are tied to crash risk and so this is said to be one of the risks that carry traders are compensated for. The paper finds that high interest rate versus the dollar are subject to crash risk and confirms that currency investors go up by the stairs but down by the elevator. These results are based on a cross-sectional regression between skewness of daily exchange rates and interest rate differentials, which yields a high R squared. Furthermore, the paper finds that the British Pound provided the highest excess return due to an exchange rate appreciation on a stand-alone basis followed by the New Zealand dollar which did not depreciate with as much as the interest rate differential.

In the second part of the paper, the framework is changed to a mean-variance framework. Under this framework, the paper finds that none of the minimum variance portfolios outperformed the S&P500 and Russell 2000 in the sample period. However, comparing expected returns on the individual fixed assets and each of the minimum variance portfolios, the paper finds that the Norwegian Krone minimum variance portfolio, the Japanese Yen minimum variance portfolio, the Swiss Franc minimum variance portfolio and the Swedish Krona minimum variance portfolio outperformed the bond index in the sample period. However, the minimum variance portfolio of all the currencies with the lowest standard deviation is in fact the Australian Dollar carry minimum variance portfolio. From a minimum variance perspective, if comparing all the currency minimum variance portfolio, then the Australian Dollar minimum variance portfolio is the most desired regardless of it outperforming the fixed assets.

Instead of analysing which minimum variance portfolio that is most desired from a mean-variance optimizing investor, the paper also analysed the portfolio compositions of the maximum slope portfolio and how the risk-return profile changed compared to the minimum variance portfolio. The paper found that none of the nine maximum slope portfolios outperformed the S&P500 or the Russell 2000, however, all the nine maximum slope portfolios outperformed the bond index. In addition, the maximum slope portfolio with the highest risk return profile $\left(\frac{\mu}{\sigma}\right)$ is the Australian Dollar carry maximum slope portfolio. However, the largest change in risk return profile between the minimum variance portfolio and maximum slope portfolio was with the Japanese Yen carry portfolios, which hold a quite large negative weight in the Japanese Yen carry trade meaning that the investor would be short the investment currency (the Yen) and long the funding currency (the U.S. Dollar). Besides looking at risk-return profile, the maximum slope portfolio with the highest expected return is the Japanese Yen carry maximum slope portfolio but it also comes with the highest standard deviation.

Finally, the paper introduced a risk free asset and analysed the nine tangency portfolios, each containing one carry trade. However, this approach is subject to some debate as to whether or not to include the short leg of the carry trade. This paper analysed the tangency portfolios with the pure carry trade strategy to see how it would add value in a mean-variance efficient portfolio setting even though it can look forced and might skew the results. The paper found that only the Japanese Yen tangency portfolio outperformed the Russell 2000 over the sample period whereas both the Japanese Yen and Swedish Krona outperformed the S&P500 over the sample period. In addition all the tangency portfolios outperformed the bond index. The paper also found that five out of nine tangency portfolios had a negative weight in the carry trade. Finally, the tangency portfolio with the highest expected return was the Japanese Yen carry tangency portfolio but it also had the highest standard deviation. In fact, the Japanese Yen is also the tangency portfolio with the highest Sharpe Ratio, making it the most desired from a mean-variance optimizing investors' perspective.

Finally, the paper found that currencies and interest rates generally has low correlation with the fixed assets in the sample period, which translates in to valuable asset for diversification.

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8. Appendices

Appendix A: Regression output for uncovered interest rate parity regressions for each currency. Data has been prepared in excel but regressed in STATA.

```
. regress AUDCurncy logADDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      2.29
       Model |   .0083515          1   .0083515    Prob > F        =    0.1339
    Residual |  .298805143        82  .003643965   R-squared       =    0.0272
-------------+----------------------------------   Adj R-squared   =    0.0153
       Total |  .307156644        83  .003700682   Root MSE        =    .06037

------------------------------------------------------------------------------
   AUDCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logADDRCCu~y |    2.39211   1.580105     1.51   0.134    -.7512225    5.535442
       _cons |  -.0099657    .010121    -0.98   0.328    -.0300997    .0101683
------------------------------------------------------------------------------
```

Australian Dollar regression output

```
. regress CADCurncy logCDDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      0.03
       Model |  .000055096         1  .000055096   Prob > F        =    0.8569
    Residual |  .138075859        82  .001683852   R-squared       =    0.0004
-------------+----------------------------------   Adj R-squared   =   -0.0118
       Total |  .138130955        83  .001664228   Root MSE        =    .04103

------------------------------------------------------------------------------
   CADCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logCDDRCCu~y |  -.4088787   2.260408    -0.18   0.857    -4.905551    4.087793
       _cons |  -.0018896   .0045282    -0.42   0.678    -.0108977    .0071185
------------------------------------------------------------------------------
```

Canadian Dollar regression output

```
. regress JPYCurncy logJYDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      0.13
       Model |  .000397796         1  .000397796   Prob > F        =    0.7170
    Residual |  .246481921        82  .003005877   R-squared       =    0.0016
-------------+----------------------------------   Adj R-squared   =   -0.0106
       Total |  .246879717        83  .002974454   Root MSE        =    .05483

------------------------------------------------------------------------------
   JPYCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logJYDRCCu~y |   -.474731   1.304977    -0.36   0.717    -3.070747    2.121285
       _cons |  -.0029946    .009028    -0.33   0.741    -.0209541     .014965
------------------------------------------------------------------------------
```

Japanese Yen regression output

```
. regress NZDCurncy logNDDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      1.05
       Model |  .003793179         1  .003793179   Prob > F        =    0.3079
    Residual |  .295503395        82    .0036037   R-squared       =    0.0127
-------------+----------------------------------   Adj R-squared   =    0.0006
       Total |  .299296574        83  .003605983   Root MSE        =    .06003

------------------------------------------------------------------------------
   NZDCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logNDDRCCurncy |   1.681358   1.638826     1.03   0.308    -1.578789    4.941504
       _cons |  -.0065731   .0113007    -0.58   0.562    -.0290537    .0159076
------------------------------------------------------------------------------
```

New Zealand Dollar regression output

```
. regress NOKCurncy logNKDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      0.42
       Model |  .001342379         1  .001342379   Prob > F        =    0.5180
    Residual |     .261149        82  .003184744   R-squared       =    0.0051
-------------+----------------------------------   Adj R-squared   =   -0.0070
       Total |   .26249138        83  .003162547   Root MSE        =    .05643

------------------------------------------------------------------------------
   NOKCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logNKDRCCurncy |  -.9109341   1.403093    -0.65   0.518    -3.702134    1.880266
       _cons |   .0038706    .006933     0.56   0.578    -.0099214    .0176626
------------------------------------------------------------------------------
```

Norwegian Krone regression output

```
. regress CHFCurncy logSFDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      3.04
       Model |  .006582526         1  .006582526   Prob > F        =    0.0850
    Residual |  .177547028        82  .002165208   R-squared       =    0.0357
-------------+----------------------------------   Adj R-squared   =    0.0240
       Total |  .184129554        83  .002218428   Root MSE        =    .04653

------------------------------------------------------------------------------
   CHFCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logSFDRCCurncy |  -2.699132   1.548024    -1.74   0.085    -5.778644    .3803803
       _cons |  -.0148189   .0079297    -1.87   0.065    -.0305935    .0009558
------------------------------------------------------------------------------
```

Swiss Franch regression output

```
. regress GBPCurncy logBPDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      0.57
       Model |  .001190617         1  .001190617   Prob > F        =    0.4530
    Residual |  .171692754        82  .002093814   R-squared       =    0.0069
-------------+----------------------------------   Adj R-squared   =   -0.0052
       Total |  .172883371        83  .002082932   Root MSE        =    .04576

------------------------------------------------------------------------------
   GBPCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logBPDRCCurncy |   1.211482   1.606572     0.75   0.453    -1.984501    4.407466
       _cons |   -.004043    .005311    -0.76   0.449    -.0146083    .0065224
```

British Pound regression output

```
. regress EURCurncy logEUDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      2.68
       Model |  .006660934         1  .006660934   Prob > F        =    0.1052
    Residual |  .203485408        82  .002481529   R-squared       =    0.0317
-------------+----------------------------------   Adj R-squared   =    0.0199
       Total |  .210146341        83  .002531884   Root MSE        =    .04981

------------------------------------------------------------------------------
   EURCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logEUDRCCurncy |   2.599328   1.586548     1.64   0.105    -.5568216    5.755478
       _cons |   .0030009   .0058498     0.51   0.609    -.0086362    .0146381
------------------------------------------------------------------------------
```

Euro regression output

```
. regress SEKCurncy logSKDRCCurncy

      Source |       SS           df       MS      Number of obs   =        84
-------------+----------------------------------   F(1, 82)        =      3.60
       Model |  .010722983         1  .010722983   Prob > F        =    0.0613
    Residual |  .244332927        82   .00297967   R-squared       =    0.0420
-------------+----------------------------------   Adj R-squared   =    0.0304
       Total |   .25505591        83  .003072963   Root MSE        =    .05459

------------------------------------------------------------------------------
   SEKCurncy |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
logSKDRCCurncy |  -2.663823   1.404209    -1.90   0.061    -5.457242    .1295953
       _cons |  -.0008508   .0061086    -0.14   0.890    -.0130027    .0113011
------------------------------------------------------------------------------
```

Swedish Krona regression output

Appendix B: STATA regression results: average quarterly skewness regressed on average interest rate differential.

```
. regress Skewness Averageii

      Source |       SS           df       MS      Number of obs   =         9
-------------+----------------------------------   F(1, 7)         =     28.50
       Model |  .059213069         1  .059213069   Prob > F        =    0.0011
    Residual |  .014541857         7  .002077408   R-squared       =    0.8028
-------------+----------------------------------   Adj R-squared   =    0.7747
       Total |  .073754926         8  .009219366   Root MSE        =    .04558

------------------------------------------------------------------------------
    Skewness |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   Averageii |  -23.99204   4.493857    -5.34   0.001    -34.61832   -13.36576
       _cons |  -.0151958   .0152315    -1.00   0.352    -.0512125     .020821
------------------------------------------------------------------------------
```

Appendix C: Portfolio weights for generation of the mean-variance frontier of risky assets and mean-variance frontier of all assets for each currency.

Risky frontier AUD														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.2	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.2	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	6.08%	5.14%	4.68%	4.32%	4.21%	4.11%	4.09%	4.07%	4.03%	3.97%	3.85%	3.74%	3.62%	3.50%
Standard deviation	8.78%	5.25%	3.78%	3.04%	2.92%	2.88%	2.88%	2.88%	2.89%	2.92%	3.04%	3.23%	3.48%	3.78%

Frontier of all assets AUD						
weight, tangency	0	0.5	1	1.5	2	2.5
weight, riskfree	1	0.5	0	-0.5	-1	-1.5

Risky frontier CAD														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.2	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.2	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	21.46%	13.27%	9.17%	6.09%	5.07%	4.25%	4.05%	3.84%	3.53%	3.02%	2.00%	0.97%	-0.05%	-1.08%
Standard deviation	30.36%	16.35%	9.54%	5.00%	3.95%	3.54%	3.53%	3.54%	3.64%	3.95%	5.00%	6.38%	7.92%	9.54%

Frontier of all assets CAD						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	3.94%	5.98%	8.01%	10.05%	12.09%
Std dev	0.00%	2.43%	4.86%	7.29%	9.72%	12.15%

Risky frontier NOK														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.1	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.1	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	16.26%	10.64%	7.83%	5.72%	5.01%	4.45%	4.31%	4.24%	3.96%	3.61%	2.90%	2.20%	1.50%	0.79%
Standard deviation	24.95%	13.56%	8.10%	4.62%	3.88%	3.61%	3.60%	3.60%	3.67%	3.88%	4.62%	5.65%	6.83%	8.10%

Frontier of all assets NOK						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	3.73%	5.57%	7.40%	9.23%	11.07%
Std dev	0.00%	2.22%	4.44%	6.65%	8.87%	11.09%

Risky frontier EUR														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.1	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.1	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	10.97%	7.53%	5.81%	4.52%	4.09%	3.74%	3.66%	3.61%	3.44%	3.23%	2.80%	2.37%	1.94%	1.51%
Standard deviation	17.35%	9.52%	5.82%	3.56%	3.10%	2.94%	2.93%	2.94%	2.98%	3.10%	3.56%	4.21%	4.98%	5.82%

Frontier of all assets EUR						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	3.22%	4.55%	5.88%	7.20%	8.53%
Std dev	0.00%	1.80%	3.60%	5.41%	7.21%	9.01%

Risky frontier JPY														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.1	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.1	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	30.69%	18.30%	12.10%	7.45%	5.90%	4.67%	4.36%	4.28%	3.58%	2.81%	1.26%	-0.29%	-1.84%	-3.39%
Standard deviation	36.84%	19.74%	11.37%	5.63%	4.21%	3.64%	3.62%	3.62%	3.77%	4.21%	5.63%	7.41%	9.35%	11.37%

Frontier of all assets JPY						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	4.50%	7.10%	9.70%	12.30%	14.91%
Std dev	0.00%	2.63%	5.26%	7.89%	10.52%	13.15%

Risky frontier CHF														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.1	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.1	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	15.80%	10.44%	7.75%	5.74%	5.07%	4.54%	4.40%	4.37%	4.07%	3.73%	3.06%	2.39%	1.72%	1.05%
Standard deviation	24.26%	13.20%	7.93%	4.59%	3.88%	3.63%	3.61%	3.61%	3.68%	3.88%	4.59%	5.57%	6.70%	7.93%

Frontier of all assets CHF						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	3.74%	5.58%	7.42%	9.26%	11.10%
Std dev	0.00%	2.19%	4.38%	6.58%	8.77%	10.96%

Risky frontier SEK														
weight, min-var	-16.0	-8.0	-4.0	-1.0	0.0	0.8	1.0	1.1	1.5	2.0	3.0	4.0	5.0	6.0
weight, max-slope	17.0	9.0	5.0	2.0	1.0	0.2	0.0	-0.1	-0.5	-1.0	-2.0	-3.0	-4.0	-5.0
Expected return	24.62%	15.13%	10.39%	6.84%	5.65%	4.70%	4.47%	4.41%	3.87%	3.28%	2.10%	0.91%	-0.27%	-1.46%
Standard deviation	31.92%	17.18%	10.01%	5.20%	4.07%	3.64%	3.62%	3.62%	3.74%	4.07%	5.20%	6.67%	8.29%	10.01%

Frontier of all assets SEK						
weight, tangency	0.00	0.50	1.00	1.50	2.00	2.50
weight, riskfree	1.00	0.50	0.00	-0.50	-1.00	-1.50
Exp ret	1.90%	4.21%	6.53%	8.84%	11.16%	13.47%
Std dev	0.00%	2.43%	4.86%	7.29%	9.73%	12.16%