ERASMUS UNIVERSITY ROTTERDAM
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A crisis-robust carry trade strategy developed using the VIX

Author: T.H. Egbers
Student number: 305981
Thesis supervisor: dr. L.A.P. Swinkels
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ABSTRACT

This thesis tested whether a carry trade strategy can be made crisis-robust using the VIX. The crisis-robust carry trade strategy uses three in-sample estimated crisis definitions to determine an out-of-sample crisis period. During the estimated crisis periods this thesis tested four different alternative strategies including a PPP-based strategy and a momentum strategy. Furthermore, this thesis developed equally-weighted portfolios without filters, equally-weighted portfolio including filters and IRD/ΔPPP/momentum-weighted portfolios, which consisted of 21 major currency pairs. The performance of in total 36 developed crisis-robust carry trade strategies are examined in this thesis. The crisis-robust portfolios generally outperformed the carry trade strategy, the PPP-based strategy and a naïve 50/50 combination of the carry trade strategy and the PPP-based strategy based on risk-adjusted performance measures. This thesis concluded that an equally-weighted CT-PPP portfolio including filters using the ΔVIX crisis definition meets the traits of a crisis-robust carry trade strategy. A Mean-Variance analysis showed that the CT-PPP portfolio including filters using the ΔVIX crisis definition is expected to be economically significant for an investor.

Keywords: market timing strategy, exchange rates, carry trade strategy, uncovered interest parity, purchasing power parity, VIX.

1 Introduction

In April 2010 the Bank for International Settlements described the remarkable growth of the foreign exchange market in one of its quarterly reviews. It reported that on an average day the turnover of the foreign exchange market is close to four trillion US Dollars. The daily turnover of the foreign exchange market exceeds for example the Gross Domestic Product of Germany for a whole year[1]. According to the Bank for International Settlements the large turnover is to some extent due to increased trading activity by pension funds, hedge funds, mutual funds and other financial institutions[2]. Galati et al. (2007) examined the tremendous growth of the foreign exchange market since 2004 and concluded that: "strategies such as the carry trade, which use leverage to exploit interest rate differentials and exchange rate trends in an environment of low market volatility, have been profitable over the past years." For that reason currencies with high interest rates, like the Australian Dollar and the New Zealand Dollar showed especially strong growth over these years. However, the carry trade strategy is negatively affected by global financial crises. An increase in stock market volatility and risk aversion of investors is often associated with large losses incurred by the carry trade strategy. An example of an abrupt unwinding carry trade is a large appreciation of the Japanese Yen against the US Dollar in October 1998. And more recently on 16 August 2008 the Japanese Yen appreciated over 7.5% on one trading day against the Australian Dollar after a constant depreciation in the preceding months.

This thesis could potentially provide for a solution to a so far unresolved problem for the traditional carry trade strategy. The carry trade strategy has proven both its statistical and economical relevance during 'calm' periods, but the carry trade strategy provided unsatisfying results during turbulent times. With the development of the carry trade strategy and subsequently the acknowledgment of its poor performance during crisis periods, academic papers have so far failed to solve one remaining issue in finishing a strong performing currency trading strategy: "develop a crisis-robust carry trade strategy". First an appropriate measure is needed to anticipate the large losses of the carry trade strategy. Brunnermeier et al. (2008) suggested the CBOE VIX ("**VIX**"), because an increase in the level of the VIX is empirically related to future carry trade losses. The VIX is an implied volatility index for the S&P 500, which is often used as a measure for the market's expectation of stock market volatility for the next 30 days.

[1] Statistics on the Gross Domestic Product of Germany are extracted from the website of the International Monetary Fund. Weblink: http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/weoselgr.aspx.

[2] Argument is stated in the BIS Quarterly Review of April 2010.

Another crucial element of this thesis is the alternative strategy, which is used in periods when the carry trade strategy is expected to fail. The alternative strategy is required to provide for strong (risk-adjusted) performance during periods of increased volatility. If this thesis succeeds in anticipating large abrupt unwinding carry trades and finding a strong performing alternative strategy, then the crisis-robust carry trade strategy is applicable to the foreign exchange market. Brière & Drut (2009) developed a crisis-robust carry trade strategy, which applied the carry trade strategy during non-crisis periods and a PPP-based strategy during crisis periods. Although Brière & Drut (2009) developed a carry trade strategy which generated strong risk-adjusted performance, the paper provided for certain limitations as well. The crisis periods were estimated backward looking and the recent financial crisis is excluded from the sample period. This thesis is considered innovative for the following reasons:

(i) A crisis-robust carry trade strategy is tested during a sample period which includes the recent financial crisis.

(ii) This thesis provides for a crisis-robust carry trade strategy based on the VIX where an in-sample crisis definition determines an out-of-sample crisis period.

(iii) This thesis examines whether an interest rate differential-weighted portfolio, a ΔPPP-weighted portfolio and a momentum-weighted portfolio of currency pairs outperforms an equally-weighted portfolio of the currency pairs.

The principal research question this thesis aims to answer is:

Is it possible to develop a crisis-robust carry trade strategy using the VIX?

The main hypotheses of the research are the following:

H_0: The crisis-robust carry trade strategy does not generate statistically and economically significant strong risk-adjusted performance.

H_a: The crisis-robust carry trade strategy generates statistically and economically significant strong risk-adjusted performance.

The remaining part of the thesis is structured as follows: chapter 2 discusses the theoretical framework of this thesis and summarizes the relevant previous literature. The data and methodology used for the analysis are described in chapter 3 and chapter 4. Subsequently chapter 5 summarizes the results of the empirical analysis. Lastly the conclusions of the thesis are drawn in chapter 6.

2 Theory and previous literature

This chapter first describes the theoretical framework for this thesis. Subsequently a summary of the results of academic papers on trading strategies for the foreign exchange market is made. Lastly this chapter sets out crisis definitions applied in academic papers.

2.1 Theoretical framework

In an efficient foreign exchange market all available information should be incorporated in the price of an exchange rate. As a result thereof traders should generally not be able to earn significant excess risk-adjusted returns by exploiting inefficiencies in the foreign exchange market. There has been an ongoing debate about the efficiency or inefficiency in the foreign exchange market with respect to the Interest Rate Parity ("**IRP**") and the Purchasing Power Parity ("**PPP**"). The IRP states that a trader cannot profit from borrowing or lending currency at a domestic or foreign interest rate. According to the IRP, the difference in the domestic and foreign interest rate ("**interest rate differential**") is compensated by either the forward exchange rate or the expected future exchange rate. If the IRP holds, an investor should be indifferent to lend or borrow a domestic or foreign currency. The IRP can be divided into the Covered Interest Parity ("**CIP**") and the Uncovered Interest Parity ("**UIP**").

2.1.1 Covered Interest Parity

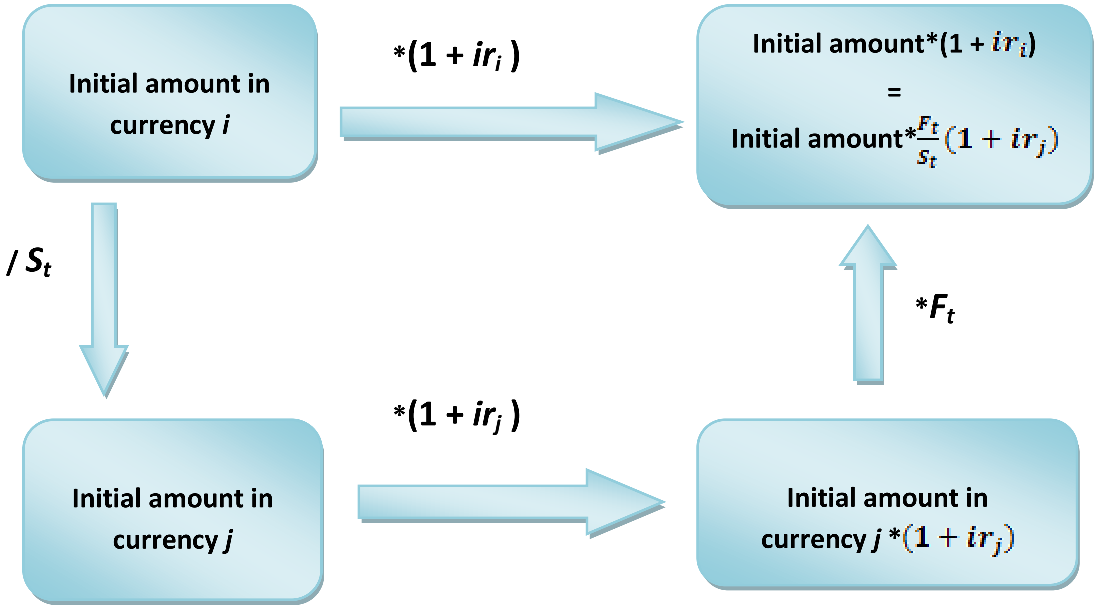
The CIP describes a situation where an interest rate differential is offset by the forward exchange rate of the respective currencies. The return on an initial amount borrowed at the domestic interest rate is equal to the return if the initial amount is borrowed at the interest rate in a foreign currency. If the foreign interest rate is higher than the domestic interest rate, then the interest rate differential is compensated by a lower forward exchange rate. Mathematically the covered interest parity is represented by the following formula:

$$\left(1 + ir_{i,t}\right) = \frac{F_{ij,t}}{S_{ij,t}}\left(1 + ir_{j,t}\right) \qquad (1)$$

Where $ir_{i,t}$ is the interest rate in the domestic currency, $ir_{j,t}$ is the interest rate in the foreign currency, $S_{ij,t}$ is the spot exchange rate and $F_{ij,t}$ is the forward exchange rate at time *t*.

Graphically the CIP is represented as below:

Figure 1: Graphical representation of the covered interest parity.



There are numerous academic papers which described and tested the validity of the CIP condition. Frenkel & Levich (1975) showed that deviations from the CIP have occurred. However deviations from the CIP condition do not provide for arbitrage opportunities in the foreign exchange market after accounting for transaction costs. In general Frenkel & Levich (1975) concluded that the CIP held for the period from January 1962 up to November 1967. A similar conclusion is drawn by Taylor (1986) which found data that supported the CIP. Taylor (1986) tested whether a profit could be made by borrowing in one currency and lending US dollars. The results indicated that out of 144 data points only one arbitrage opportunity occurred.

Summarizing the academic papers on the CIP it can be concluded that deviations from the CIP arise. Trading strategies that try to exploit the CIP are, however, not expected to earn significant excess risk-adjusted returns.

2.1.2 Uncovered Interest Parity

The UIP describes a situation where the difference in interest rates for two countries on time *t* is offset by a change in the exchange rate on time *t + 1*. The return on an initial amount lent at a domestic interest rate is equal to the return if the initial amount is lent at the interest rate in a foreign currency. If the initial amount is lent at a higher interest rate, then the interest rate differential is compensated by a depreciation of the future exchange rate. If the UIP holds then the investor would be indifferent in choosing between the domestic or foreign interest rate.

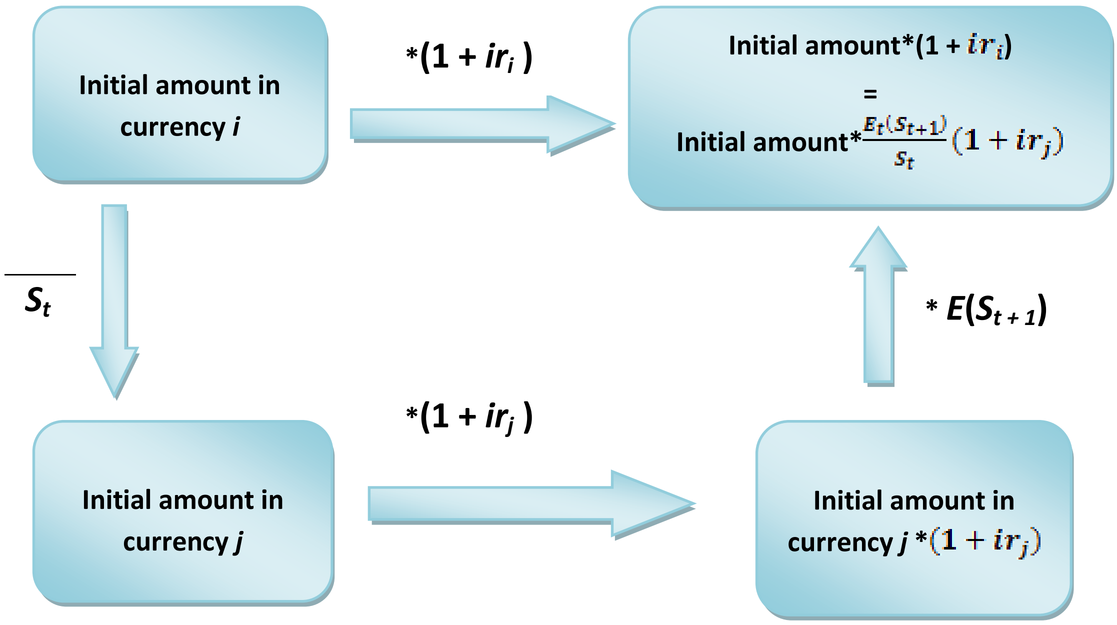
Mathematically the UIP is represented as below:

$$(1 + ir_i) = \frac{E_t(S_{t+1})}{S_t}(1 + ir_j) \qquad (2)$$

Where $E_t(S_{t+1})$ is the expected spot exchange rate at time *t + 1*.

Graphically the UIP is represented as below:

Figure 2: Graphical representation of the uncovered interest parity.



The UIP is not as empirically verified as the CIP. In contrast to the expectations of the UIP, where a depreciation of the future exchange rate is expected to compensate a positive interest rate differential, the exact opposite is observed by Flood & Rose (1994) and Jurek (2007). This phenomenon, typically referred to as the "forward discount puzzle", allows for profitable trading strategies on the foreign exchange market. The literature on deviations from the UIP is predominant, but there are papers in favor of the UIP. Flood & Rose (2002) examined the influence of financial crises on the UIP. The paper found results indicating that the predictions of the UIP show more validity during crisis periods. The paper reported that high interest rate currencies depreciate during a crisis-strewn period, which is more in line with the predictions of the UIP. The depreciation, however, was in general not large enough to compensate the entire interest rate differential.

Profitable carry trade strategies are possible if the interest rate is not fully compensated by a depreciation of the underlying currency pair.

When both the CIP and the UIP hold, then the forward rate of an exchange rate at time *t* is the unbiased estimator for the future spot exchange rate at time *t + 1*. It is formulated as below:

$$E_t[S_{i,t+1}] = F_{i,t} \tag{3}$$

2.1.3 Purchasing Power Parity

The PPP is a widely supported theory. The basic idea of the PPP is extracted from the 'law of one price'. The law of one price states that a good is equally expensive in each country when converted to a common currency. The most prominent example of the economic law is the Big Mac Index, which provides a close examination of exchange rate valuation. The PPP applies the law of one price to a basket of goods. Using the PPP a value for the exchange rate is determined based on the change in two countries relative price levels. A distinction is made between the relative PPP and the absolute PPP. The absolute PPP involves an equilibrium exchange rate which is an exact representation of the law of one price. A change in prices is offset by a change in the exchange rate. Mathematically the absolute PPP is represented as below:

$$P_t = P_t^* S_t \tag{4}$$

Where P_t is the price of a basket of goods in a domestic currency, P_t^* is the price of the basket of goods in a foreign currency and S_t is the spot exchange rate at time *t*.

The relative PPP states that the relative change in prices for the countries result in adjustments for the underlying currency pair. The relative PPP is formulated as below:

$$\frac{P_t^* S_t}{P_t} = \frac{P_{t-1}^* S_{t-1}}{P_{t-1}} \tag{5}$$

There is an ongoing debate on the subject whether the relative PPP and the absolute PPP hold in the foreign exchange market. The absolute PPP generally provided for poor results, while the relative PPP showed more correct predictions. The predictions based on the relative PPP showed disappointing results in the short run, but the predictions improved on the long run. Abuaf & Jorion (2012), among other papers[3], stated that exchange rates showed considerable deviations from the

[3] Two important papers that tested predictions on exchange rates using the PPP are Meese & Rogoff (1983) and Cheung et al. (2005).

relative PPP for short time horizons, while mean reversion[4] occurred for longer time horizons. The strongest predictions are observed for time horizons over twelve months. Zurbruegg & Allsopp (2004) examined the impact of currency crises on the validity of the long-run PPP relationship. They concluded that the results were not consistent for the entire sample, but in general the exchange rates converged towards a PPP-estimated value during crisis periods. These results indicate that a PPP-based strategy, where a trader invests according to the forecasted value of the exchange rate, can be successful especially during crisis periods.

If we summarize the relevant academic papers for the theoretical framework of this thesis, it appears that in general the UIP hypothesis is rejected, while the CIP showed more valid results. For that reason significant excess risk-adjusted returns are possibly generated by exploiting the failure of the UIP. The relative PPP can provide for an alternative strategy during periods when the UIP holds, because the relative PPP typically provided strong predictions during crisis periods.

2.2 Carry trade strategy

An investor is possibly able to profit from the failure of the UIP by means of currency trading strategies. Galati et al. (2007) stated that the carry trade strategy is based on the failure of the UIP. The carry trade strategy borrows at a low interest rate currency and lends at a higher interest rate currency at the same time. The underlying exchange rate of the currencies is expected to depreciate to the exact point where the interest rate differential is compensated, if the UIP holds[5]. The previous sections, however, claimed that the UIP is generally not empirically verified by academic papers. The carry trade strategy is profitable when a positive interest rate differential is not fully offset by a depreciation of the exchange rate. Darvas (2009) showed that the carry trade strategy is significantly profitable for most of 11 major exchange rates from 1976 up to 2008. Darvas (2009) also showed that the strong performance of the carry trade strategy is persistent over the entire sample period. Furthermore Darvas (2009) concluded that the failure of the UIP is exploitable for close to all currency pairs even after accounting for transaction costs.

Additional to Darvas (2009), Dunis & Miao (2007) developed the carry trade strategy for nine major currency pairs between January 1999 and March 2005 and found that a simple carry trade strategy performs well in terms of annualized returns, risk-adjusted returns and maximum potential loss. Dunis & Miao (2007) claimed that the interest rate differential between two currencies is not

[4] Mean reversion refers to the phenomenon that deviation in prices or returns move back towards an average.
[5] Definition of the carry trade strategy extracted from Galati et al. (2007).

fully compensated by a depreciation or appreciation of the underlying exchange rate. Furthermore Dunis & Miao (2007) concluded that the carry trade strategy generated poor performance in times when the market volatility is high[6].

Another important feature of the carry trade strategy is emphasized by the paper of Burnside et al. (2008). Burnside et al. (2008) emphasized the diversification opportunities[7] among different currency pairs. The paper developed an equally-weighted portfolio of 23 currency pairs. The equally-weighted portfolio showed a large decrease in the volatility which resulted in an increase in the Sharpe ratios of the portfolio. Brière & Drut (2009) created, next to an equally-weighted portfolio of all currency pairs, two portfolios consisting of either high or low interest rate differential currency pairs. Brière & Drut (2009) observed larger deviations from the UIP for portfolios with high interest rate differential currency pairs. But similar to Dunis & Miao (2007), Brière & Drut (2009) reported a strong impact of financial crises on the carry trade strategy. The high interest rate differential currency pairs generated lower Sharpe ratios during crisis periods[8], but Brière & Drut (2009) found statistically significant higher Sharpe ratios during non-crisis periods.

Looking at the results of academic papers on the carry trade strategy it can be concluded that in general the UIP hypothesis is not supported. Deviations from the UIP can be exploited by borrowing at a low interest rate currency and lending at a higher interest rate currency. Additionally, the performance of a portfolio consisting of multiple currency pairs is expected to generate stronger performance due to the diversification benefits. Lastly the influence of financial crises appeared to have an impact on the returns of carry trades. The impact of global financial crises on the carry trade strategy is examined in the next section.

2.3 Carry trade strategy during financial crises

The influence of financial crises on the performance of the carry trade strategy is frequently examined in academic papers. This is because the performance of the carry trade strategy is negatively affected by financial crises. Section 2.1 of this thesis mentioned the increased validity of the UIP during financial crises, which is related to a decrease in returns for the carry trade strategy. Brunnermeier et al. (2008) for instance observed strong performing carry trade portfolios in general,

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[6] The performance of the carry trade during periods of increased volatility is further examined in section 2.3.

[7] Diversification opportunities refer to the possible risk reduction in terms of volatility when a trader constructs a portfolio of different currency carry trades.

[8] A crisis period in the paper of Brière & Drut (2009) is defined as periods where the level of the VIX is one standard deviation above its average from January 1990 up to December 2008.

but indicated that the return distributions of carry trades are negatively skewed. A negative skewness for the return distribution indicates an asymmetric distribution where a relative large proportion of the returns are slightly above the average and a relative small proportion of returns are well below the average. Brunnermeier et al. (2008) formulated it as follows: “exchange rates go up by the stairs and down by the elevator”. The paper concluded that the considerable losses are due to abrupt unwinding of carry trades during currency crashes. A similar conclusion is drawn by Menkoff et al. (2012a) who claimed that high interest rate currencies are negatively related to a volatility proxy[9]. The volatility proxy produced by Menkoff et al. (2012a) captured over 90% of the excess returns in five carry trade portfolios between November 1983 and August 2009. The strong relation between the volatility and carry trade returns can be used in order to cut the considerable losses of a carry trade during periods of abrupt unwinding carry trades. To my knowledge Brière & Drut (2009) is the first paper that produced a crisis-robust carry trade strategy, which used the relationship of increased volatility and carry trade losses. Brière & Drut (2009) developed a market timing strategy based on the carry trade strategy, but used the absolute PPP during periods of increased volatility. The periods of increased volatility were identified as periods where the VIX was one standard deviation above the historical average over the period from January 1990 up to December 2008. The performance of the market timing strategy generated substantially stronger risk-adjusted performance compared to a normal carry trade strategy. The market timing strategy developed by Brière & Drut (2009), however, is not yet applicable to the foreign exchange market. The crisis periods are defined backward looking, while a market timing strategy is required to estimate the crisis periods on the actual moment of investing. The strong risk-adjusted performance of the crisis-robust carry trade strategy developed by Brière & Drut (2009) is, for that reason, not realistic from the perspective of an investor.

2.4 Purchasing Power Parity-based strategy

This thesis will try to provide for an alternative investment strategy that can be used during periods of increased risk aversion or volatility. An alternative strategy during periods of increased volatility is useful for developing a crisis-robust carry trade strategy. The relative PPP can be of help in developing a crisis-robust carry trade strategy due to its mean reverting nature in periods defined as crisis periods. The PPP as a trading strategy is not as widely used and proven as the carry trade

[9] The volatility proxy is an average of the absolute daily return for the exchange rates in the sample.

strategy. Bilson (1984) is, to my knowledge, the first academic paper that described a trading strategy based on the PPP. It provided a new approach to determine the value of exchange rates based on the PPP and found strong results in terms of profits and variance. Balassa (1964) claimed that the absolute PPP and the relative PPP determination of an exchange rate can assist in assessing whether an exchange rate is overvalued or undervalued. Bilson (1984) invests according to an expected mean reversion towards the PPP-estimated value for the exchange rate.

Brière & Drut (2009) separated the performance of PPP-based strategies in crisis periods and non-crisis periods. They found results indicating that an absolute PPP-based strategy would generate stronger performance during crisis periods. Furthermore Brière & Drut (2009) found that an alternating strategy between the carry trade strategy in non-crisis periods and a PPP-based strategy during crisis periods generated statistically significant larger Sharpe-ratios compared to both strategies individually. For that reason a PPP-based strategy is potentially an appropriate alternative strategy during periods with increased volatility.

2.5 Momentum strategy

Next to the fundamentalist trading strategies mentioned above, there are technical trading strategies possible as well. Burnside et al. (2011) claimed improved profitability by combining a carry trade strategy and a momentum strategy. Burnside et al. (2011) observed a significant increase for the Sharpe ratio of an equally-weighted combination of the carry trade strategy and a momentum strategy compared to the individual currency trading strategies. Furthermore Burnside et al. (2011) stated that a momentum strategy was particularly profitable during major financial crises, while the carry trade strategy generated poor risk-adjusted performance during these periods. Muga & Santamaría (2007) found evidence for a momentum effect in stock returns during the Spanish stock market crash of 1997. A momentum strategy could potentially provide for positive returns during periods when the carry trade strategy is expected to fail. This thesis uses, for that reason, a momentum strategy as an alternative strategy when the next period is identified as a crisis period.

2.6 Crisis definitions

The crisis-robust carry trade strategy developed in this thesis deals with different strategies during crisis periods or non-crisis periods. In order to determine which strategy an investor should follow, there are methods needed to identify the crisis periods. The investment strategy in this thesis involves a monthly rebalancing strategy, thus a crisis definition is needed that anticipates a next month's crisis period. A crisis period is usually associated with increased stock market volatility in the foreign exchange market. An implied volatility index is a forward looking volatility measure that could potentially anticipate an increase in the stock market volatility of the next month. Siriopoulos & Fassas (2009) reviewed 12 different implied volatility indices and found that the VIX is best in terms of predicting future equity volatility. Using a regression Siriopoulos & Fassas (2009) determined that close to 70% of the realized volatility is explained by the predicted implied volatility of the underlying equity index in the period from January 2004 up to December 2008. The implied volatility indices are possibly valuable to market timing strategies which need to anticipate periods of increased stock market volatility. Copeland & Copeland (1999) used the VIX to develop a market timing strategy. The paper invested long in value (growth) firms and large-capitalization stocks (small-cap stocks) when the level of the VIX exceeded a certain critical value above (below) its 75-day moving average. This simple trading rule resulted in significant excess risk-adjusted returns for both strategies. Similar conclusions can be drawn from Brière and Drut (2009) where a market timing strategy between the carry trade strategy and a PPP-based strategy is robust to crises.

Summarizing academic papers on crisis identifiers it appears that the VIX outperforms other implied volatility indices in terms of predictions on future stock market volatility. Although the implied volatility indices do not necessarily predict the realized volatility accurate, the VIX is possibly useful for developing a crisis-robust carry trade strategy.

2.7 Transaction costs in the foreign exchange market

This thesis aims to determine the profitability of the different strategies in a realistic manner. For that reason the transaction cost are taken into account as well. The transaction costs in the foreign exchange market are usually approximated based on the approach suggested by Frenkel & Levich (1977). Frenkel & Levich (1977) shows that the transaction costs are proportional to the value of the transaction. Typically a relative amount of the transaction is used, which varies among different papers. Due to the high liquidity of the foreign exchange market rather low transaction costs are used by academic papers which test the profitability of currency trading strategies. Levich & Thomas (1993) and Osler & Chang (1995) use a constant of 0.05% per round trip transaction. They show that the transaction costs in turbulent periods increase due a widening of the bid-ask spread, but on average a constant of 0.05% is realistic. For that reason this thesis includes a constant of

0.05% per round trip transaction as an approximation of the average transaction costs over the entire sample period.

2.8 Expected return for the carry trade strategy using the CAPM

An interesting aspect of carry trade strategy is the expected return in a CAPM setting. Burnside et al. (2011) examined the expected profitability of the carry trade strategy. They found a statistical significant beta of 0.029 for monthly data on the carry trade strategy from an US based investor from 1976 up to December 2010. The beta of an asset *i* is the sensitivity for the returns of asset *i* compared to the market returns. The beta of an equally-weighted carry trade strategy is calculated as below:

$$\beta_i = \frac{covar(R_i, R_m)}{var(R_i)} \tag{6}$$

Where $covar(R_i, R_m)$ is the covariance between the returns of the equally-weighted carry trade strategy and the MSCI World Index and $var(Ri)$ is the variance of the equally-weighted carry trade strategy.

This thesis found a beta of 0.39 for an equally-weighted portfolio of the carry trade strategy. Burnside et al. (2011) found a smaller beta, because they estimated the beta for a carry trade strategy of a single exchange rate. If the beta for an equally-weighted portfolio of the carry trade strategy is calculated, the variance of the asset is expected to decrease due to diversification benefits. The decreased variance and possibly a higher covariance result in a beta of 0.39 for an equally-weighted portfolio of the carry trade strategy. Using the beta an expected return for the carry trade strategy is calculated based on the CAPM. The CAPM applicable to an equally weighted zero-investment portfolio[10] is represented by the following formula:

$$E[R_i] = \beta_i E[R_m] \tag{7}$$

Where $E[R_i]$ is the expected return for an equally-weighted carry trade strategy on 21 currency pairs and $E[R_m]$ is the expected return on the market portfolio, which is based on historical returns.

The expected return on the MSCI World Index from March 1993 up to February 2012 is 0.39%. For that reason the expected return for an equally-weighted carry trade strategy of the 21 currency pairs in the sample is equal to **0.15% per month**.

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[10] A zero-investment portfolio is a portfolio where the cumulative investment in all assets is equal to zero.

3 Data

This chapter sets out the definitions for the variables of the data used in this thesis. Additionally, the descriptive statistics on the main variables are summarized and discussed in this chapter.

3.1 Data definitions

This thesis focuses on the monthly performance of the trading strategies from 28 February 1993 up to 29 February 2012 ("**sample period**"). The sample period results in 228 monthly returns or 19 annualized returns. When using Datastream, the monthly nominal exchange rates and 1-month interbank rates are downloaded at the closing rate on the last trading day of the month. The monthly nominal exchange rates are downloaded for the following seven countries: Australia, Canada, Germany[11], Japan, Switzerland, United Kingdom and the United States. The seven currencies of the respective countries are the Australian Dollar ("**AUD**"), the Canadian Dollar ("**CAD**"), the Swiss Franc ("**CHF**"), the Euro ("**EUR**")[12], the Japanese Yen ("**JPY**"), the Great Britain Pound ("**GBP**") and the US Dollar ("**USD**"), which resulted in 21 underlying currency pairs. These currency pairs are included in the dataset because they represent the most liquid currencies[13]. Furthermore, this thesis uses data on the different proxies for risk free rates, again extracted from Datastream at the closing rate on the last trading day of each month. Additionally the VIX level, the MSCI World Index, the S&P 500 and the Barclays US aggregate Bond index are downloaded from Datastream at the closing rate on the last trading day of each month, again from 28 February 1993 up to 29 February 2012. The codes used to extract the data from Datastream are all set out in Appendix A. Monthly data on Consumer Price Indices ("**CPI**") of the seven countries[14] included in the data are downloaded from the website of OECD statistics[15] for the period January 1993 up to January 2012. The next section describes the descriptive statistics on the data used in this thesis.

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[11] Germany is chosen as a proxy for Europe for the 1-month interbank rate instead of the Euribor, because the full data for Europe is not available. The R^2 of the 1-month interbank rate of Europe and Germany for the available period is 0.97, hence the German 1-month interbank suits as a proxy for the 1-month Euribor rate.

[12] Data for the Euro from January 1993 up to 1 January 2002 is based on a synthetic Euro.

[13] Currency pairs among these countries far most chosen for academic papers on liquid currencies.

[14] There is only quarterly data for the Consumer Price Index in Australia. The quarterly data is converted into monthly data using the frequency conversion option ('Linear-match last') in Eviews 7.

[15] Weblink: http://stats.oecd.org/.

3.2 Descriptive statistics

Next the descriptive statistics on the main variables in this thesis are stated. From the descriptive statistics it is possible to extract expectations about probable outcomes for this thesis. **Table 1** shows large differences in the 1-month interbank rates between the different countries. The average 1-month interbank rate differs from 0.05% for Japan up to 0.45% for Australia. Looking at the monthly 1-month interbank difference an average return of 0.4% per month is generated by exclusively borrow the currency in Japan and lend the currency in Australia during the entire sample period.

Table 1: Descriptive Statistics on the 1-month interbank rates for the period from March 1993 up to February 2012.

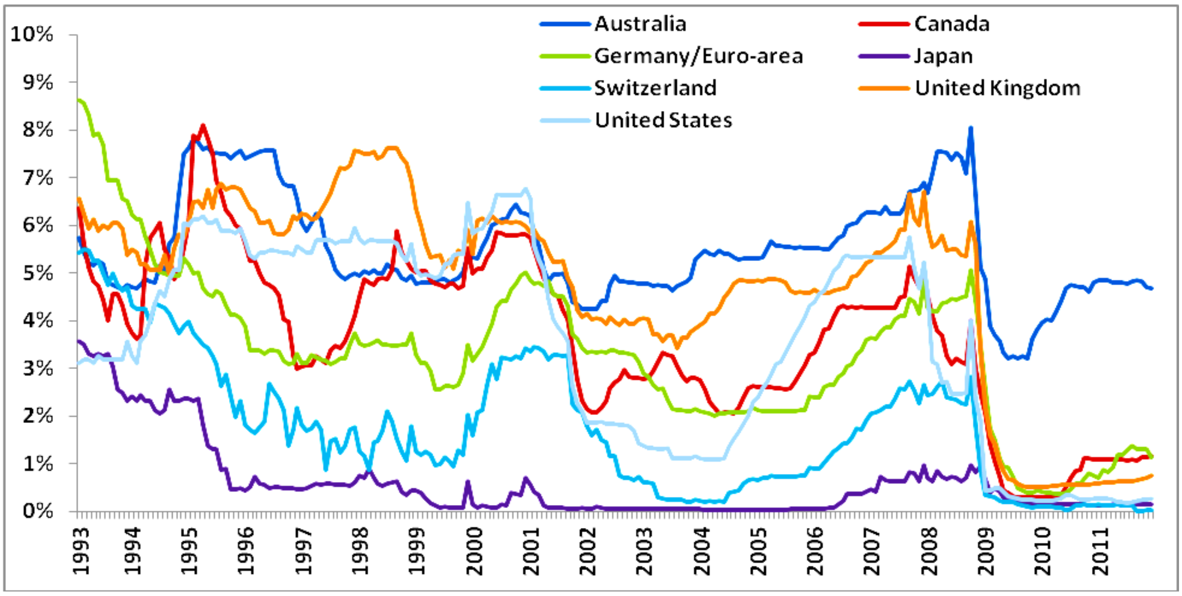
	Australia	Canada	Europe	Japan	Switzerland	UK	US
Ann. Average	5.48%	3.65%	3.29%	0.59%	1.74%	4.73%	3.57%
Monthly average	0.45%	0.30%	0.27%	0.05%	0.14%	0.38%	0.29%
Std. dev.	1.07%	1.74%	1.64%	0.81%	1.40%	2%	2.12%
Minimum	3.21%	0.30%	0.37%	0.04%	0%	0.50%	0.19%
Maximum	8.06%	8.11%	8.63%	3.56%	5.50%	7.63%	6.78%
Skewness	0.52	-0.12	0.53	2.09	0.74	-1.02	-0.31
Kurtosis	2.78	2.57	3.83	6.55	2.77	3.10	1.61

Table 1 shows more or less comparable results to the descriptive statistics of Brière & Drut (2009). **Table 1** observes slightly lower averages for the 1-month interbank rates, but this is due to the specific sample period. The sample period of Brière & Drut (2009) is from January 1990 up to December 2008, which excludes the recent financial crisis. The influence of the recent financial crisis on the 1-month interbank rates is observed in **Figure 3**. **Figure 3** shows large variations in the 1-month interbank rates over time, but the 1-month interbank rates are particularly low from approximately January 2009 up to December 2011. This explains the slightly lower averages of the 1-month interbank rates in **Table 1** compared to the descriptive statistics in Brière & Drut (2009). Furthermore **Figure 3** shows that in general the 1-month interest rates declines over time. The interest rates spread from 3% up to 9% at the start of the sample period and gradually decrease starting at the end of the nineties. The financial crises have an impact on the interest rate differentials as well. In 2002 and especially 2009[16] all seven interest rates converged towards the other interest rates except for the Australian 1-month interbank rate. **Figure 3** suggests the

[16] These periods are typically associated with the 'Dot-com crisis' and the 'credit crunch'.

profitability of a carry trade strategy is affected by financial crises due to diminishing interest rate differentials.

Figure 3: The development of the 1-month interbank rates over the period from March 1993 up to February 2012.



On the other hand, section 2.2 previously mentioned that the performance of the carry trade strategy is not solely based on the interest rate differential. The appreciation or depreciation of a currency pair has an impact on the performance of a carry trade strategy as well. The UIP stated that a low interest rate currency is expected to appreciate against a high interest rate currency and vice versa. From that perspective it is interesting to analyze the descriptive statistics on the monthly returns of the currencies quoted against the JPY[17]. The JPY is expected to appreciate on average against all other currencies according to the UIP. Previous academic paper showed that in contrast to the UIP the high interest rate currencies in general tend to appreciate against low interest rate currencies. Although that conclusion is not confirmed by **Table 2**, **Table 2** shows that a simple carry trade strategy for all currencies quoted against the JPY would generate a positive return. The negative returns on the depreciation are compensated by a larger interest rate differential. The largest monthly average return found following a carry trade strategy for the entire period is 0.42%. That return is generated when an investor borrows currency in Japan and lends it in Australia during the entire sample period. The interest rate differential accounts for 0.4% per month, while the appreciation of the AUD generates an additional return of 0.02% per month. When the return

[17] **Figure 3** showed that for a large proportion of the sample period the 1-month interbank rate of Japan is the lowest rate of the sample.

distributions are examined for the JPY against all other currencies it appears they are all negatively skewed. Negative skewness values for the return distibutions are possibly an indication of large abrupt unwinding carry trades as suggested by Brunnermeier et al. (2008). Summarizing **Table 2** it can be concluded that a profitable carry trade strategy is possible for all currencies quoted against the JPY. Furthermore hints of large abrupt unwinding carry trades are observable in **Table 2.**

Table 2: Descriptive statistics on the JPY quoted against the remaining currencies from March 1993 up to February 2012

	AUD	CAD	CHF	EUR	GBP	JPY	USD
Monthly average	0.02%	-0.06%	0.07%	-0.19%	-0.15%	-	-0.17%
St. dev.	3.9%	3.9%	3.5%	2.9%	3%	-	3.3%
Minimum	-23.5%	-18.2%	-13.3%	-13.7%	-13%	-	-16.6%
Maximum	10.6%	11.5%	9.4%	8.5%	7%	-	10.2%
Skewness	-1.16	-0.82	-0.75	-0.55	-0.88	-	-0.48
Kurtosis	8.59	5.79	4.94	5.12	5.14	-	5.88
IRD	0.4%	0.25%	0.09%	0.22%	0.33%	-	0.24%

Lastly the correlations for the returns on the currency pairs are stated in **Table 3**. Burnside et al. (2008) showed that a diversified portfolio of multiple carry trade strategies provides significant risk reduction. This thesis develops portfolios consisting of 21 currency pairs, which are expected to generate significant diversification benefits. **Table 3** states low correlations among a large proportion of the currency pairs in the sample. Low correlations indicate large diversification opportunities. Some of the currency pairs show rather high correlations. In particular the following currencies observed high correlations:

(i) The CAD and the USD.

(ii) The CHF, the GBP and the EUR.

The high correlation is due to the high amount of mutual trading among these countries. For that reason the correlations of currency pairs quoted against these currencies are relatively high. **Table 3** observed high correlations for the returns of the CAD/AUD and the USD/AUD (0.75), the EUR/USD and the EUR/CAD (0.64) and the CAD/CHF and the USD/CHF (0.7).

Summarizing the descriptive statistics it can be concluded that profitable carry trade strategies on average are possible. However the interest rate differentials are affected by global financial crises. The correlation matrix indicates strong diversification benefits for a large proportion of the currency pairs. The descriptive statistics provided to some extent expectations about the results, but definitive conclusions will be drawn based on the results, which will be presented in chapter 5.

Table 3: Correlation matrix for the returns of the 21 currency pairs from March 1993 up to February 2012.

	AUD/ CHF	CAD/ AUD	CAD/ CHF	CAD/ JPY	CAD/ USD	EUR/ AUD	EUR/ CAD	EUR/ CHF	EUR/ JPY	EUR/ USD	GBP/ AUD	GBP/ CAD	GBP/ CHF	GBP/ EUR	GBP/ JPY	GBP/ USD	JPY/ AUD	JPY/ CHF	USD/ AUD	USD/ CHF	USD/ JPY
AUD/CHF	1																				
CAD/AUD	-0.36	1																			
CAD/CHF	0.66	0.42	1																		
CAD/JPY	0.43	0.12	0.51	1																	
CAD/USD	0.45	-0.07	0.39	0.58	1																
EUR/AUD	-0.82	0.46	-0.47	-0.33	-0.45	1															
EUR/CAD	-0.46	-0.48	-0.85	-0.42	-0.36	0.55	1														
EUR/CHF	0.47	-0.01	0.48	0.27	0.17	0.00	0.03	1													
EUR/JPY	0.07	-0.26	-0.16	0.69	0.33	0.08	0.35	0.29	1												
EUR/USD	-0.08	-0.50	-0.48	0.08	0.47	0.15	0.64	0.15	0.60	1											
GBP/AUD	-0.62	0.62	-0.14	-0.24	-0.46	0.71	0.10	-0.09	-0.17	-0.27	1										
GBP/CAD	-0.34	-0.27	-0.60	-0.35	-0.47	0.42	0.67	-0.05	0.15	0.25	0.54	1									
GBP/CHF	0.48	0.25	0.66	0.29	0.05	-0.20	-0.43	0.57	-0.05	-0.36	0.34	0.18	1								
GBP/EUR	0.02	-0.03	0.02	0.06	-0.09	-0.04	-0.02	0.00	0.06	-0.12	-0.03	-0.05	-0.03	1							
GBP/JPY	0.08	-0.02	0.08	-0.01	0.07	-0.06	-0.07	0.08	-0.04	0.01	0.04	0.00	0.12	0.33	1						
GBP/USD	0.09	-0.34	-0.22	0.22	0.51	-0.02	0.32	0.11	0.49	0.72	0.06	0.51	0.21	-0.14	0.06	1					
JPY/AUD	-0.05	0.01	-0.06	-0.06	-0.18	0.02	0.06	-0.07	-0.03	-0.12	-0.07	-0.04	-0.15	0.05	-0.71	-0.21	1				
JPY/CHF	-0.10	-0.01	-0.11	0.07	-0.11	0.01	0.04	-0.18	0.10	-0.07	-0.07	-0.02	-0.18	0.25	-0.69	-0.11	0.66	1			
USD/AUD	-0.55	0.75	0.03	-0.30	-0.71	0.63	-0.11	-0.13	-0.42	-0.67	0.75	0.12	0.14	0.05	-0.04	-0.58	0.09	0.05	1		
USD/CHF	0.31	0.47	0.70	0.07	-0.36	-0.14	-0.59	0.37	-0.41	-0.85	0.22	-0.26	0.64	0.09	0.05	-0.62	0.05	-0.05	0.57	1	
USD/JPY	0.16	0.17	0.27	0.77	-0.06	-0.06	-0.21	0.19	0.62	-0.25	0.06	-0.06	0.29	0.17	-0.04	-0.12	0.05	0.17	0.16	0.34	1

4 Methodology

This chapter contains the various methodologies used to develop the carry trade strategy, the PPP-based strategy and a momentum strategy. Additionally, the measures to identify crisis periods are summarized. Furthermore this chapter sets out the methodology to develop and evaluate crisis-robust carry trade strategies. Lastly the required methodology to execute a Mean-Variance analysis is set out in this chapter.

4.1 Trading strategies

Chapter two described the trading strategies applied in previous literature. This thesis uses the carry trade strategy, the relative PPP-based strategy and a momentum strategy. The investment decisions for the strategies are described below:

(i) Carry trade strategy

The investment decision for the carry trade strategy is based on the difference in interest rates between two countries of a currency pair. An investor borrows currency at the low interest rate and lends the currency at the highest interest rate. Hence an investor invests long (1) in a currency pair if the domestic interest rate is higher than the foreign interest rate. The investment decision is formulated as below:

$$ID^{CT}_{E_{ij},t} = \begin{cases} 1 & if\ ir_{i,t} < ir_{j,t} \\ -1 & if\ ir_{i,t} > ir_{j,t} \\ 0 & if\ ir_{i,t} = ir_{j,t} \end{cases} \qquad (8)$$

Where $ID^{CT}_{E_{ij},t}$ is the investment decision and $i_{x,t}$ is the 1-month interbank rate in country *x* on time *t*.

Bhansali (2007) applied an IRD-filter to the currency pairs in a portfolio in order to benefit from the largest interest rate differentials. This thesis develops a carry trade strategy with a minimum interest rate differential of *c* per month. Various critical values for *c* are tested in order to verify the robustness of an IRD-filter. The investment decision for the carry trade strategy including an IRD-filter is determined as below:

$$ID^{CT}_{E_{ij},t} = \begin{cases} 1 & if\ \left(ir_{i,t} - ir_{j,t}\right) \geq c \\ -1 & if\ \left(ir_{i,t} - ir_{j,t}\right) \leq -c \\ 0 & otherwise \end{cases} \qquad \text{with } c = 0.05\%, 0.1\%, \ldots, 0.25\% \qquad (9)$$

(ii) PPP-based strategy

The PPP-based strategy is an alternative strategy to the carry trade strategy. The PPP-based strategy applied in this thesis follows the relative version of the theory. The relative PPP states changes in relative price indices between countries is translated to the underlying exchange rate. Mathematically the relative PPP is represented as below:

$$\frac{P_t^* S_t}{P_t} = \frac{P_{t-1}^* S_{t-1}}{P_{t-1}} \tag{10}$$

Where P_t is the price of a basket of goods in the domestic currency, P_t^* is the price of the basket of goods in the foreign currency and S_t is the exchange rate at time *t*. The right side of the equation is equal to the left side of the equation, except all elements are at time *t - 1*.

The data on consumer price indices of the previous month is not available at the actual moment of investing. This thesis aims to calculate the returns of the strategies in a realistic manner. Hence the PPP-estimated value for the exchange rate is calculated as below:

$$PPP_{E_{ij},t} = S_t = {\frac{P_{t-2}^* S_{t-1}}{P_{t-2}}} \Big/ {\frac{P_{t-1}^*}{P_{t-1}}} \tag{11}$$

Where $PPP_{Eij,t}$ is the PPP-estimated value for a currency pair.

The out-of-sample PPP-estimated value for the currency pair is compared to the actual value for the currency pair. The investment decision for the PPP-based strategy is based on the undervaluation or overvaluation of the currency pair. An investor invests long (short) if the value of the currency pair is below (above) the PPP-estimated value for the currency pair. The investment decision is formulated as below:

$$ID_{E_{ij,t}}^{PPP} = \begin{cases} 1 & if\ E_{ij,t} < PPP_{E_{ij},t} \\ -1 & if\ E_{ij,t} > PPP_{E_{ij},t} \\ 0 & if\ E_{ij,t} = PPP_{E_{ij},t} \end{cases} \tag{12}$$

Similar to the carry trade strategy a filter is applied to the PPP-based strategy. For the PPP-based strategy a portfolio is developed consisting of currency pairs with a minimum difference between the PPP-estimated value and the actual value for a currency pair (“**ΔPPP**”). The investment decision for the PPP-based strategy including a ΔPPP-filter is formulated as below:

$$ID_{E_{ij,t}}^{PPP} = \begin{cases} 1 & if\ \Delta PPP \geq d \\ -1 & if\ \Delta PPP \leq -d \\ 0 & otherwise \end{cases} \qquad \text{with } d = 0.5\%, 1\%, \ldots, 2{,}5\% \tag{13}$$

(iii) Momentum strategy

Additionally a momentum strategy is tested in this thesis as well. A winners-minus-losers portfolio (**"WML"**) is used, as suggested by Jegadeesh & Titman (1993). The investment decision of a WML portfolio is based on the profitability of the carry trade strategy for the previous month. First it is needed to define the last month winners and losers for each month. The returns for the carry trade strategy are ranked from the lowest generated return up to the highest generated return. The last month returns are defined as below:

$$R^{CT}_{X,t} = \left[R^{CT}_{X_1,t}, R^{CT}_{X_2,t}, \ldots, R^{CT}_{X_{21},t}\right] \qquad \text{with } R^{CT}_{X_1,t} \leq R^{CT}_{X_2,t} \leq \cdots \leq R^{CT}_{X_{21},t} \qquad (14)$$

Where $R^{CT}_{X_1,t}$ is the lowest generated return and $R^{CT}_{X_{21},t}$ is the highest generated return in month *t*.

The WML portfolio buys the past winners and the past losers. Various amounts of winners and losers from two up to four are used to prevent arbitrary choices. The investment decision is formulated as below:

$$ID^{WML}_{E_{ij},t} = \begin{cases} 1 & if\ R^{WML}_{E_{ij},t-1} \geq R^{CT}_{X_{21-e},t} \\ -1 & if\ R^{WML}_{E_{ij},t-1} \leq R^{CT}_{X_e,t} \\ 0 & otherwise \end{cases} \qquad \text{with } e = 2, 3, 4 \qquad (15)$$

The return of the three trading strategies consists of the interest rate differential and a depreciation or appreciation of an exchange rate. The monthly return of the trading strategies is calculated as below:

$$R^{x}_{E_{ij},t} = ID^{x}_{E_{ij},t}\left(\left(ir_{i,t} - ir_{j,t}\right) + \ln\left(E_{ij,t+1}/E_{ij,t}\right)\right) \qquad \text{with } x = CT, PPP, WML \qquad (16)$$

Where $R^{x}_{E_{ij},t}$ is the return for the trading strategy in month *t*.

4.2 Crisis indicators

An important element of this thesis is the identification of crisis periods. Using the crisis indicator an investor can develop a market timing strategy. The VIX is used as a risk aversion measure to identify the crisis periods. If the VIX exceeds a certain critical value ("**CV**"), then the next period is identified as a crisis period. This thesis will use different methods to develop the critical values. Various critical values are tested for the three methods applied in this thesis. Appendix B shows little sensitivity in returns and standard deviation of a crisis-robust portfolio to different critical values. Based on appendix B a critical value is determined for each method. The choice of another critical value is suited for this thesis as well, because Appendix B showed little sensitivity. The critical values can be divided into three methods:

*(i) Absolute value for the VIX ("**AV**")*

The first critical value is a naïve absolute value for the VIX. The level of the VIX represents a forecasted value for the volatility for equity for the next 30-day period. In that sense a higher level of the VIX indicates a higher expected volatility for the next month. The critical value is formulated as below:

$$CV_t^{AV} = 25 \tag{17}$$

Where CV_t is the critical value.

*(ii) Sudden changes in the level of the VIX ("**ΔVIX**")*

The second critical value is based on sudden changes in the level of the VIX. A similar model is described in the paper by Copeland & Copeland (1999). It identifies a crisis period if the change in the VIX of the previous month exceeds a specific value. The critical value applied in this thesis is formulated as below:

$$CV_t^{\Delta VIX} = 20\% \tag{18}$$

*(iii) In-sample moving average and standard deviation of the VIX ("**MA**")*

The last critical value uses the in-sample moving average and standard deviation of the VIX. This method of crisis identification is based on the methodology used in Brière & Drut (2009). The difference compared to Brière & Drut (2009) is that the method described below defines a crisis period at the actual moment of investing. The in-sample moving average of the VIX and standard deviation of the VIX determine an out-of-sample crisis period. The MA critical value is calculated as below:

$$CV_t^{MA} = \left(\frac{1}{12} \sum_{i=1}^{12} VIX_{t-i} \right) + 1.5 * \sigma_t \tag{19}$$

Where VIX_t is the level of the VIX at time t and σ_t is the in-sample standard deviation of the VIX at time t.

Below a crisis indicator ("**CI**") is calculated for each month. The crisis indicator indicates a crisis period for the next month if the value is one and a non-crisis period if the value is zero. The CI is based on data available at the actual moment of investing. It is calculated as below:

$$CI_t = \begin{cases} 1 \; if \; VIX_{i,t} \geq CV_{i,t}^{s} \\ 0 \quad otherwise \end{cases} \quad \text{with s = AV, ΔVIX, MA} \tag{20}$$

4.3 Crisis-robust carry trade strategies

Using the crisis definitions a crisis-robust carry trade strategy is developed. The crisis-robust portfolios use the carry trade strategy during non-crisis period and follow an alternative strategy during crisis periods. This thesis tests the following four crisis-robust carry trade strategies:

*(i) Carry trade-no trade ("**CT-0**")*

Section 2.3 concluded that the carry trade strategy incurred large losses during financial crises. Due to the poor performance in such times Dunis & Miao (2007) tested a portfolio where one invests according to the carry trade strategy if CI=0 and no trade is made if the CI=1. The CT-0 aims to benefit from the strong performance during calm periods and aims to cut the large losses during turbulent times. The return for the CT-0 portfolio is formulated as below:

$$R_{E_{ij,t}}^{CT-0} = \begin{cases} R_{E_{ij,t}}^{CT} & if \; CI_t = 0 \\ 0 & if \; CI_t = 1 \end{cases} \tag{21}$$

Where $R_{E_{ij,t}}^{CT-0}$ is the return of the CT-0 crisis-robust carry trade strategy.

(ii) Carry trade-reverse carry trade ("$\boldsymbol{CT\text{-}CT^{1}}$")

Furthermore Dunis & Miao described a portfolio where one invests according to the carry trade strategy during non-crisis periods and opposite to the carry trade strategy in crisis periods. The reverse carry trade strategy borrows at a high interest rate currency and lends at a low interest rate currency. The CT-CT^{-1} invests according to the carry trade strategy if CI is equal to zero and invests according to the reverse carry trade strategy if CI is one. The return of CT-CT^{-1} portfolio is calculated as below:

$$R^{CT-CT^{-1}}_{E_{ij,t}} = \begin{cases} R^{CT}_{E_{ij,t}} & if\ CI_t = 0 \\ -R^{CT}_{E_{ij,t}} & if\ CI_t = 1 \end{cases} \qquad (22)$$

*(iii) Carry trade-PPP-based strategy ("**CT-PPP**")*

Brière & Drut (2009) developed a crisis-robust carry trade strategy, which used the carry trade strategy if a period was defined as a non-crisis period. A PPP-based strategy was applied to periods defined as crisis periods. This thesis tests a similar crisis-robust carry trade strategy, but determines the crisis periods at the actual moment of investing. The return for the CT-PPP portfolio is calculated as below:

$$R^{CRP}_{E_{ij,t}} = \begin{cases} R^{CT}_{E_{ij,t}} & if\ CI_t = 0 \\ R^{PPP}_{E_{ij,t}} & if\ CI_t = 1 \end{cases} \qquad (23)$$

*(iv) Carry trade-Winners-minus-losers ("**CT-WML**")*

Next to the fundamental trading strategies discussed above Burnside et al. (2011) emphasized the benefits of combining the carry trade strategy and a momentum strategy. A momentum strategy is particularly applicable for this thesis, because an investment decision is made each month[18]. The combination of fundamental trading and technical trading follows a carry trade strategy during non-crisis periods and a momentum strategy during crisis periods. The momentum strategy identifies the past best performing currency pairs and aims to gain profits from a continuing trend. The return for the CT-WML portfolio is calculated as below:

$$R^{CRP}_{E_{ij,t}} = \begin{cases} R^{CT}_{E_{ij,t}} & if\ CI_t = 0 \\ R^{WML}_{E_{ij,t}} & if\ CI_t = 1 \end{cases} \qquad (24)$$

[18] In contrast to trading strategies such as the 'Moving Average' and 'Trading range breakout' rules.

4.4 Developed portfolios

The paper of Burnside et al. (2008) found strong risk-adjusted performance for portfolios of currency pairs. Hence this thesis develops different portfolios of the currency pairs. The portfolios can be divided into the following four categories:

*(i) Equally-weighted portfolio ("**EW**")*

Burnside et al. (2008) tested an equally-weighted portfolio consisting of 23 different currency pairs. The equally-weighted portfolio showed strong performance due to diversification benefits. For that reason this thesis developed an equally weighted portfolio as well. This thesis tests an equally-weighted portfolio of all 21 currency pairs and an equally-weighted portfolio including the IRD-filter or ΔPPP-filter as suggested in section 4.1. The return of an equally-weighted crisis-robust carry trade strategy is calculated as below:

$$R_{EW}^{CRP} = \frac{1}{n_t} \sum_{ij \in \Omega_t} R_{E ij,t}^{CRP} \tag{25}$$

Where R_{EW}^{CRP} is the return of a crisis-robust carry trade strategy of an equally-weighted portfolio in month *t*. The sum is taken over all possible exchange rates, this is represented by $ij \in \Omega_t$.

(ii) IRD-weighted portfolio

Brière & Drut (2009) claimed that portfolios consisting of high interest rate differentials showed increased risk-adjusted performance. An IRD-weighted portfolio has not been applied in academic papers before, but following Brière & Drut (2009) one could expect an increase in risk-adjusted performance. The return of an IRD-weighted crisis-robust carry trade portfolio is computed as below:

$$R_{IRDW}^{CRP} = \frac{1}{\sum_{ij \in \Omega_t} |i_i - i_j|} \sum_{ij \in \Omega_t} R_{E ij,t}^{CT} \tag{26}$$

Where R_{IRDW}^{CRP} is the return of a crisis-robust carry trade strategy of an interest rate differential-weighted portfolio in month *t*.

(iii) ΔPPP-weighted portfolio

An IRD-weighted portfolio for the carry trade strategy is expected to generate increased risk-adjusted performance following Brière & Drut (2009). Correspondingly higher returns can be expected when the PPP-estimated value of a currency pair deviates more from the actual value of a currency pair. For that reason this thesis uses a ΔPPP-weighted PPP-based strategy, which has not been tested by academic papers before. The return of a ΔPPP-weighted PPP-based strategy is computed as below:

$$R_{\Delta PPP}^{CRP} = \frac{1}{\sum_{ij \in \Omega_t} |\Delta PPP_{ij,t}|} \sum_{ij \in \Omega_t} R_{E_{ij,t}}^{PPP} * |\Delta PPP_{ij,t}| \tag{27}$$

(iv) Momentum-weighted portfolio

Lastly, a momentum-weighted portfolio of the WML portfolio is tested in this thesis. The WML portfolio identifies past winners and past losers in the sample and aims to benefit from a continuing trend. The best performing currency pairs of last month are expected to outperform the remaining currency pairs and the worst performing currency pairs of last month are expected to underperform the remaining currency pairs. From that perspective, it can be expected that larger weights for the best performing currency pairs in the past could potentially provide for higher returns. This thesis tests, for that reason, a momentum-weighted portfolio of the WML portfolio. The return of a momentum-weighted momentum strategy is formulated as below:

$$R_{Momentum}^{CRP} = \frac{1}{\sum_{n=21-\varepsilon}^{21} R_{X,t-1}^{CT}} \sum_{\varepsilon} R_{E_{ij,t}}^{W} \, R_{X,t-1}^{CT} - \frac{1}{\sum_{n=1}^{\varepsilon} R_{X,t-1}^{CT}} \sum_{21-\varepsilon} R_{E_{ij,t}}^{L} \; R_{X,t-1}^{CT} \tag{28}$$

Where $R_{E_{ij,t}}^{W}$ is the return of the past winners at time *t* and $R_{E_{ij,t}}^{L}$ is the return of the past winners at time *t*.

4.5 Performance evaluation

Chapter 6 draws conclusions whether the developed portfolios are considered crisis-robust. The crisis-robust portfolios are evaluated on different performance measures. The performance of the developed portfolios is evaluated on the following four different performance measures:

(i) Sharpe ratio

The Sharpe ratio was first introduced in 1966 by the paper of Sharpe (1966). The Sharpe ratio is a performance measure which reflects the excess return of the portfolio over a risk free rate and takes into account the amount of risk of a portfolio. The Sharpe ratio is calculated as below:

$$SR_{portfolio} = \frac{R_p}{\sigma_p} \tag{29}$$

Where $SR_{portfolio}$ is the Sharpe ratio of a portfolio, R_p is the return of the portfolio and σ_p is the standard deviation of the returns.

The Sharpe ratio can be tested for its significance according to the test statistic developed by Jobson & Korkie (1981) and adjusted by Memmel (2003). The hypotheses to test whether a Sharpe ratio is significantly different from zero are:

H_0: $SR_{portfolio} = 0$

H_a: $SR_{portfolio} \neq 0$

(ii) Modified Sharpe ratio

Previous literature indicated that the carry trade strategy as well as the PPP-based strategy showed non-normal return distributions. For that reason the modified Sharpe ratio ("**MSR**") is included as well. The MSR, as suggested by Gregeriou & Gueyie (2003), is based on the Sharpe ratio. However, the MSR has the added value that the skewness and kurtosis values of the return distribution are taken into account as well. The results of Gregeriou & Gueyie (2003) showed that return distributions with fat tails generally underestimate the risk. The modified Sharpe ratio is calculated as below:

$$MSR_p = \frac{R_p}{VaR_{modified}} \tag{30}$$

Where MSR_p is the modified Sharpe ratio and $VaR_{modified}$ is the modified Value at Risk.

The modified Value at Risk adjusts the normal standard deviation for the skewness and kurtosis of the return distribution. The modified Value at Risk is calculated as below:

$$VaR_{modified} = R_p - \left(z_c + \frac{1}{6}(z_c^2 - 1)S + \frac{1}{24}(z_c^3 - 3z_c)K - \frac{1}{36}(2z_c^3 - 5z_c)S^2\right)\sigma_p \tag{31}$$

Where z_c is the critical z-score at a certain confidence level, S and K are the skewness and excess kurtosis for the returns of the portfolio and σ_p is the standard deviation for the returns of the portfolio.

A test statistic to test whether a modified Sharpe ratio is statistically significant has not been developed yet, in contrast to the Sharpe ratio. For that reason the modified Sharpe ratios in this thesis are not tested for their statistical significance.

(iii) Modigliani-Modigliani risk-adjusted performance

Modigliani-Modigliani risk adjusted performance ("**M²**") is an alternative risk measure to measure the performance of a portfolio. In contrast to the (modified) Sharpe ratio, the M^2 expresses the risk-adjusted performance in a percentage, which makes it easy to interpret. Additionally the M^2 solves the problem of negative Sharpe ratios, because it is expressed in a percentage. For that reason the economical interpretation of the M^2 performance measure is more valuable compared to a Sharpe ratio. The M^2 is calculated as below:

$$M^2 = R_p * \frac{\sigma_m}{\sigma_p} \tag{32}$$

*(iv) Success rate of the market timing strategy ("**Success**")*

In order to evaluate the forecasting skills of the crisis definitions the success rate of the market timing is added to the performance measures. Merton (1981) provided both a parametric test and a non-parametric test to evaluate the forecasted market timing ability. The nonparametric test developed by Henriksson & Merton (1984) does not require any assumptions about the return distributions or a specific model for the asset selection. For that reason the nonparametric test is applied to the crisis definitions of this thesis. The crisis definition has predictive power if they anticipate an underperformance of the carry trade strategy. The probabilities for the success rates are defined below:

$$p_{1,t} = P\left[CI_t^x = 0 \middle| R_t^{CRP} \leq R_t^{CT}\right] \quad \text{and} \quad 1 - p_{1,t} = P\left[CI_t^x = 1 \middle| R_t^{CRP} \leq R_t^{CT}\right] \tag{33}$$

$$p_{2,t} = P\left[CI_t^x = 1 \middle| R_t^{CRP} > R_t^{CT}\right] \quad \text{and} \quad 1 - p_{2,t} = P\left[CI_t^x = 0 \middle| R_t^{CRP} > R_t^{CT}\right] \tag{34}$$

Where $p_{1,t}$ is the probability of a correct forecasted outperformance of the carry trade strategy and $p_{2,t}$ is the probability of a correct forecasted underperformance of the carry trade strategy.

If the crisis definitions anticipate an underperformance and an outperformance of the carry trade strategy perfect, then $p_{1,t}$ = $p_{2,t}$ = 1. Simultaneously it follows that if the crisis definitions always predict the wrong strategy, then $p_{1,t}$ = $p_{2,t}$ = 0. To verify whether the crisis definitions possess statistical significant forecasting skills the following hypotheses are tested:

H_0: $p_{1,t} + p_{2,t} = 1$

H_a: $p_{1,t} + p_{2,t} \neq 1$

If $p_{1,t}$ + $p_{2,t}$ is statistically significant larger than one, then the crisis indicators possess significant forecasting skills. The opposite applies if $p_{1,t}$ + $p_{2,t}$ is statistically significant below one. The non-parametric test is based on Bayes' Theorem of conditional probability and follows a hypergeometric distribution. The non-parametric test of market timing is formulated as below:

$$P[n_1 = x|N_1, N_2, m] = \frac{\binom{N_1}{x}\binom{N_2}{m-x}}{\binom{N}{m}} \quad (35)$$

Where N is the total amount of observations, N_1 is the amount of observations where $R_t^{CRP} \leq 0$, N_2 is the amount of observations where $R_t^{CRP} > 0$, x is the amount of correct forecasts given that $R_t^{CRP} \leq R_t^{CT}$ and m is the amount of forecasted crisis periods by the crisis indicators.

The distribution is accurately approximated by the Normal distribution. The mean and variance are calculated as below:

$$E(n_1) = \frac{nN_1}{N} \quad \text{and} \quad \sigma^2(n_1) = \frac{n_1 N_1 (N - N_1)}{N^2(N-1)} \quad (36)$$

The mean and variance allow for the development of critical value where the null hypothesis is rejected. Section 5.5 uses the success rate to evaluate to forecasting skills of the crisis definitions.

4.6 Mean-Variance analysis

The Modern Portfolio Theory ("**MPT**") developed by Markowitz is a theory which maximizes the expected return of a portfolio at a certain quantity of risk. The return of a crisis-robust carry trade strategy with optimal weights according to the MPT is computed as below:

$$R_p = \sum_{i=1}^{21} \omega_i^* R_i \quad (37)$$

Where ω^* are the optimal weights for the portfolio and R_i is the expected return for currency pair *i*.

The optimal portfolio weights are calculated using the MPT. This thesis uses the MPT to maximize the expected Sharpe ratio. The optimal weights are calculated as below:

$$\omega^* = \frac{e'V^{-1}e\bar{R}_p - \bar{r}'V^{-1}e}{\bar{r}'V^{-1}\bar{r}e'V^{-1}e - (\bar{r}'V^{-1}e)^2}V^{-1}\bar{r} + \frac{\bar{r}'V^{-1}\bar{r} - \bar{r}'V^{-1}e\bar{R}_p}{\bar{r}'V^{-1}\bar{r}e'V^{-1}e - (\bar{r}'V^{-1}e)^2} \quad (38)$$

Where R_p is the required return of the portfolio, V is the variance-covariance matrix and r is the average return for the currency pairs.

Next the economic significance of the crisis-robust portfolios is tested by means of Mean-Variance spanning tests. An investor optimizes its investment portfolio solely based on mean and variance, which are estimated by the following formulas:

$$\hat{\mu} = \frac{1}{T}\sum_{t=1}^{T} R_t \quad \text{and} \quad \hat{V} = \frac{1}{T}\sum_{t=1}^{T}(R_t - \hat{\mu})(R_t - \hat{\mu})' \quad (39)$$

Where $\hat{\mu}$ is an estimator for the return and $\hat{V}$ is the estimated variance-covariance matrix.

According to the spanning tests developed by Huberman and Kandel (1987) and adjusted by Kan and Zhou (2003) an investor can benefit from investing in the new asset if the diversification benefits are significant. The Mean-Variance spanning test used for this thesis tests whether a set of K assets spans a larger set of K+1 assets. The following hypotheses are tested:

H_0: The K benchmark assets span the larger set of K+1 assets

H_a: The K benchmark assets do not span the larger set of K+1 assets

The likelihood ratio test as suggested by Huberman & Kandel (1987) is used. The likelihood ratio test compares the unconstrained maximum likelihood estimator with the constrained maximum likelihood estimator of the null hypothesis. Asymptotically the Likelihood ratio test statistic is stated as follows:

$$LR = -T\ln(U) \sim \chi_2^2 \quad (40)$$

The sample contains 228 observations, hence an exact distribution for a finite sample is favorable. Huberman & Kandel (1987) stated an exact distribution for a finite sample, but according to Kan & Zhou (2003) it is not valid when only one asset is added to the investment portfolio. In this thesis one new asset is added to the investment portfolio, which has the following exact distribution:

$$\left(\left(\frac{1}{U}\right) - 1\right)\left(\frac{(T-K-1)}{2}\right) \sim F_{2,T-K-1} \quad (41)$$

Where U is the likelihood ratio test, which is equal to:

$$U = \left(\frac{\widehat{c_1}}{\hat{c}}\right)\left(\frac{\sqrt{1 + \widehat{d_1}/\widehat{c_1}}}{\sqrt{1 + \hat{d}/\hat{c}}}\right) \tag{42}$$

Where $\left(\frac{\widehat{c_1}}{\hat{c}}\right)$ and $\left(\frac{\sqrt{1+\widehat{d_1}/\widehat{c_1}}}{\sqrt{1+\hat{d}/\hat{c}}}\right)$ should be close to one if the benchmark assets span the larger set.

5 Results

The next chapter describes the results of the analyses which are relevant for this thesis. The chapter starts with a descriptive statistics on the carry trade strategy, the PPP-based strategy and a momentum strategy. Subsequently the impact of financial crises on the carry trade strategy and the PPP-based strategy is examined. Additionally, the performance of the crisis-robust carry trade strategies is summarized and ultimately a Mean-Variance analysis is executed.

5.1 Carry trade strategy

Chapter 1 and 2 extensively discussed the performance of previous academic papers on the carry trade strategy. The carry trade strategy generally produced significantly positive risk-adjusted performance, but it was affected by financial crises. This chapter develops a carry trade strategy for 21 currency pairs and portfolios consisting of the 21 currency pairs. This thesis verifies the results of previous literature on the carry trade strategy, but applied to a crisis-strewn sample period.

Table 4 provides for rather strong results on the carry trade strategy for the 21 currency pairs during the sample period. The annualized returns are positive for 18 of the 21 exchange rates. The strongest performance in terms of annualized returns is 8.44%, which is generated by the USD/AUD currency pair. The weakest performance is observed for CAD/JPY currency pair, it has an average annualized return of -0.94%. The annualized returns suggest strong performing carry trade strategies, but this is marginally confirmed by the risk-adjusted performance of the carry trade strategy. The Sharpe ratios are considered statistically significant larger than zero for five currency pairs[19]. A negative Sharpe ratio is uncomfortable to interpret, because a high standard deviation improves a negative Sharpe ratio. This is contrast to normal risk-return preferences, hence negative Sharpe ratio are not tested for its significance. One other issue regarding the Sharpe ratio is the normality assumption for the return distributions. In order to test whether the return distributions of the carry trade strategy are normally distributed, the skewness and kurtosis are included in **Table 4**. Based on Brunnermeier et al. (2008), Burnside et al. (2011) and Brière & Drut (2009) a negative skewness and excess kurtosis are expected for the return distributions of the carry trade strategy. These expectations are for a large part supported by the results in **Table 4**. The skewness values vary from -1.21 for the EUR/CHF currency pair up to 0.27 for the GBP/EUR currency pair, but appear negative in general. This is in line with the results of Brière & Drut (2009), which emphasized the

[19] The Sharpe ratios are tested whether they are significantly different from zero according to the test statistic suggested by Jobson & Korkie (1981) and adjusted by Memmel (2003).

higher extreme risks of the carry trade strategy due to asymmetric return distributions. The return distributions show excess kurtosis for close to all currency pairs, which indicates fat tails for the return distributions. Using skewness and kurtosis the validity of the normality assumption for the return distributions is tested. The Jarque-Bera value ("**JB-value**") tests the null hypothesis whether the return distributions of the carry trade strategy are normally distributed. Normality is rejected for 16 currency pairs and all portfolios of the currency pairs. The modified Sharpe ratio does not require the normality assumption and takes skewness and kurtosis into account as well. The sample showed excess kurtosis for nearly all currency pairs and portfolios. Hence a decline in the positive MSR's opposite to the Sharpe ratios is observed for a large part of the sample, because Sharpe ratios are overestimated when the return distributions have fat tails. Unfortunately, the modified Sharpe ratio does not solve the problem of the misinterpretation of negative ratios. For that reason the M^2 measure is included in **Table 4** as well. The M^2 measure indicates low risk-adjusted performance for the carry trade strategy, in line with the results encountered by the (modified) Sharpe ratios. The best performance in terms of the M^2 measure is generated by the USD/AUD currency pair, which is estimated at 0.71% per month.

The developed portfolios showed improved results compared to the carry trade strategy of the individual currency pairs. The equally-weighted portfolio showed in particular low volatility, while the IRD-weighted portfolio outperformed the individual currency pairs both in terms of return and volatility. The strong performance of both portfolios resulted in statistically significant positive Sharpe ratios, which indicate significantly positive risk-adjusted performance. Overall the strongest performance is observed for the equally-weighted portfolios including an IRD-filter[20]. When an IRD-filter of 0.05% is applied the annualized return increases by 1.29% compared to the equally-weighted portfolio of all currency pairs up to 3.71% per year. The increase in returns is a plausible result of cutting the less profitable carry trade strategies, but it is associated with an increase in the volatility of the returns as well. The volatility of an equally-weighted portfolio including an IRD-filter increases gradually with the size of the IRD-filter. The increase in returns and the size of the filter show a different relation. Applying an IRD-filter of 0.05% increases the annualized return significantly, but most of the profits in returns are gained using an IRD-filter of 0.1%. The annualized returns for the IRD-filters from 0.1% up to 0.25% are constant around 5.5%. The volatility of the portfolio increases when a larger IRD-filter is applied, but it generates an equal return. For that reason an IRD-filter of 0.1% or 0.15% captures the benefits of increased returns and limits the increase in volatility. Both portfolios generated a Sharpe ratio of 0.2, which is the largest Sharpe

[20] The equally weighted portfolio including an IRD-filter develops a portfolio consisting of currency pairs where the interest rate differential between the domestic and foreign interest rate exceeds a certain value.

ratio observed for the sample. The risk reduction in terms of volatility for the portfolios is a probable result of diversification benefits as mentioned by Burnside et al. (2008). The return distributions of all portfolios showed negative skewness and excess kurtosis, hence rejected the normality assumption. The MSR's decreased as a result of excess kurtosis for the return distributions. The results in **Table 4** favor an IRD-weighted portfolio over an equally-weighted portfolio in terms of annualized return, (modified) Sharpe ratio and the M^2 measure. The risk-adjusted performance of an equally-weighted portfolio including an IRD-filter of 0.1% or 0.15% and the IRD-weighted portfolio is comparable. The equally-weighted portfolio including an IRD-filter of 0.15% is used throughout the thesis. The IRD-filter of 0.15% provided for strong results, although the choice of an IRD-filter of 0.1% or 0.2% is appropriate as well.

Table 4: Descriptive statistics on the carry trade strategy

		Ann. Mean	Mean	St. dev.	Skew.	Excess Kurt.	JB-value	SR	MSR	M^2	# Trans.
EW		2,42%	0,19%	1,37%	-1,20	5,25	301.8***	0,14**	0,05	0,53%	0.05
EW incl.	**0.05%**	3.71%	0.29%	1.69%	-0.79	3.12	110***	0.17**	0.07	0.37%	0.02
filter	**0.10%**	5.20%	0.40%	1.99%	-0.64	4	159***	0.2***	0.08	0.51%	0.02
	0.15%	5.66%	0.44%	2.15%	-0.79	3.6	138.9***	0.2***	0.08	0.52%	0.01
	0.20%	5.60%	0.43%	2.34%	-0.73	2.99	100.1***	0.18***	0.07	0.43%	0.01
	0.25%	5.65%	0.44%	2.57%	-0.87	3.18	117.9***	0.17**	0.07	0.38%	0.01
IRDW		4,56%	0,36%	1,98%	-0,94	3,83	164.7***	0,18***	0,07	0,71%	0.06
AUD/CHF		5,52%	0,42%	3,59%	-0,44	0,46	8.9**	0,12*	0,05	0,42%	0.04
CAD/AUD		2,57%	0,21%	2,74%	-0,07	0,17	0.3	0,08	0,04	0,23%	0.11
CAD/CHF		1,84%	0,16%	3,47%	-0,33	0,04	4.2	0,05	0,02	0,09%	0.03
CAD/JPY		-0,94%	-0,06%	3,93%	-0,82	2,88	99.1***	-0,02	-0,01	-0,19%	0.01
CAD/USD		1,52%	0,10%	2,32%	-0,54	2,79	80.5***	0,04	0,02	0,08%	0.13
EUR/AUD		3,81%	0,31%	3,16%	-0,12	-0,41	2.3	0,10	0,05	0,33%	0.04
EUR/CAD		1,91%	0,16%	2,97%	0,03	-0,10	0.2	0,05	0,03	0,13%	0.12
EUR/CHF		-0,64%	-0,05%	1,76%	-1,21	6,12	392.1***	-0,03	-0,01	-0,25%	0.01
EUR/JPY		0,52%	0,03%	2,89%	-0,53	2,13	50.8***	0,01	0,00	-0,07%	0.01
EUR/USD		4,47%	0,37%	2,94%	-0,17	0,72	5.4*	0,13**	0,06	0,46%	0.04
GBP/AUD		5,93%	0,49%	3,18%	0,24	0,82	7.9**	0,16**	0,08	0,59%	0.09
GBP/CAD		0,66%	0,05%	2,58%	-0,05	0,22	0.4	0,02	0,01	-0,02%	0.07
GBP/CHF		0,79%	0,05%	2,73%	-0,49	3,14	96.9***	0,02	0,01	-0,03%	0.01
GBP/EUR		1,25%	0,10%	1,73%	0,27	2,26	47.9***	0,06	0,03	0,14%	0.05
GBP/JPY		4,39%	0,36%	3,49%	0,08	0,38	1.4	0,10	0,05	0,36%	0.01
GBP/USD		0,89%	0,06%	2,52%	-0,33	2,46	57.8***	0,02	0,01	-0,02%	0.11
JPY/AUD		5,45%	0,42%	3,89%	-1,15	5,60	331.4***	0,11*	0,04	0,38%	0.01
JPY/CHF		0,73%	0,07%	3,53%	-0,13	1,90	32.6***	0,02	0,01	-0,02%	0.05
USD/AUD		8,44%	0,66%	3,63%	-0,60	2,10	52.7***	0,18***	0,08	0,71%	0.04
USD/CHF		-0,28%	-0,02%	3,37%	-0,03	1,62	23.1***	-0,01	0,00	-0,14%	0.04
USD/JPY		2,18%	0,19%	3,29%	-0,51	2,82	80.7***	0,06	0,02	0,15%	0.04

Notes: The Sharpe ratios are tested at 1% and 5% significance '*' indicates a statistically significant positive Sharpe ratio at 5% significance and '' at 1% significance.**

The transaction costs are taken into account as well, although the transaction costs hardly influence the (risk-adjusted) performance of the carry trade strategy. The average amount of transactions per month ("**# Trans.**") is relatively small. Hence, the average transaction costs for an equally-weighted portfolio are estimated at 0.05 * 0.05% = 0.0025% per month, which influences none of the (risk-adjusted) performance measures. The estimated transaction costs of the IRD-weighted portfolio increase due to a monthly rebalanced portfolio, but the transaction costs remain too small to diminish the risk-adjusted performance.

The developed portfolios showed in particular strong performance in **Table 4**, hence deserve a close examination. **Figure 4** provides the 1-year rolling performance of the developed portfolios. Previous literature documented a negative impact of financial crises on the carry trade strategy. Although it is hard to determine which periods represent the crisis periods, it is visible that the performance of the carry trade declines in turbulent times. Especially the credit crunch from 2007 up to 2009 affected the performance of the carry trade strategy negatively. Additionally, in 1994 a decrease in the performance is observed, which can be linked to the Mexican currency crisis. Furthermore a significant underperformance for the carry trade strategy is observed in the period 1997 up to 1998, which is often related to the Asian currency crisis. The difference in volatility between the developed portfolios stated in **Table 4** is identified by **Figure 4**. The performance of the IRD-weighted portfolio and the equally-weighted portfolio including an IRD-filter of 0.15% showed more deviation throughout the entire sample period compared to the equally weighted portfolio without an IRD-filter. The IRD-weighted portfolio and the equally-weighted portfolio including an IRD-filter of 0.15% show large similarities over time as expected from **Table 4**.

Figure 4: The 1-year rolling performance of the carry trade strategy for three portfolios.

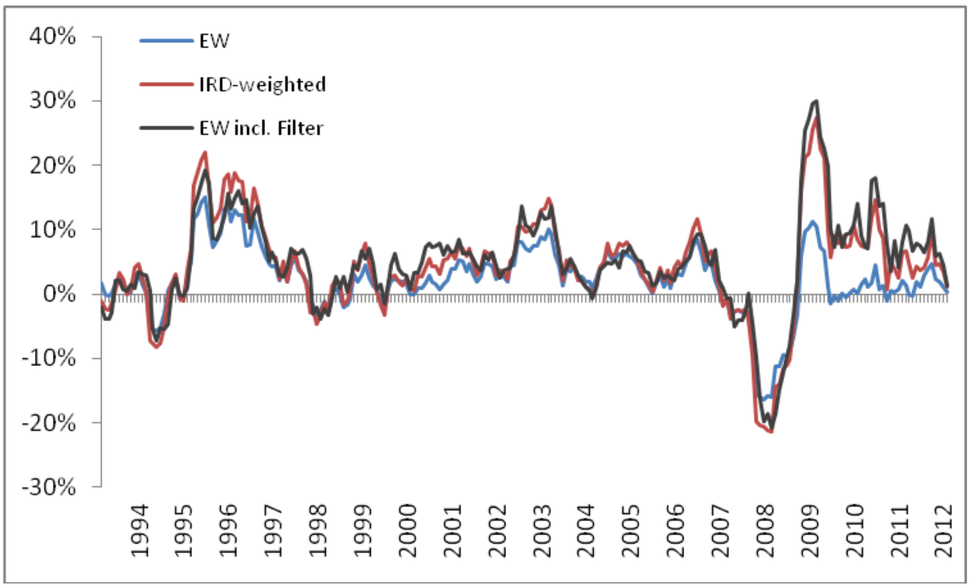
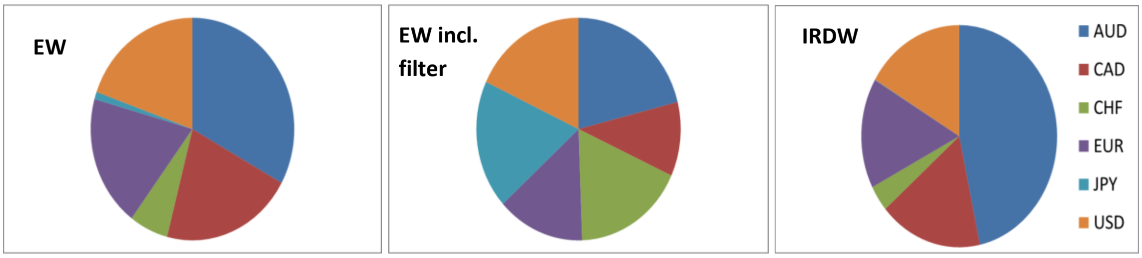


Figure 5 summarizes the currency distribution for the three portfolios. The currency distribution show large variation between the different portfolios. The equally-weighted portfolio including an IRD-filter is well diversified among the different currencies. It has a more or less equal distribution among all currencies. The IRD-weighted portfolio and the equally-weighted portfolio are more concentrated. The JPY is barely traded due to the low interbank rates for a large proportion of the sample period, while the opposite applies to the AUD[21]. **Figure 5** favors an equally-weighted portfolio including an IRD-filter of 0.15% over an IRD-weighted portfolio, because the portfolio is better diversified. For that reason it is less exposed to currency specific abrupt unwinding carry trades.

Figure 5: Average currency distribution of the portfolios over the entire sample period.



	AUD	CAD	CHF	EUR	JPY	USD
EW	33%	21,0%	6,2%	19,1%	1,1%	19,6%
EW incl. filter	21,1%	10,8%	17,6%	13,8%	18,7%	18%
IRDW	46,6%	17%	3,8%	16,1%	0,1%	16,5%

Summarizing the results on the carry trade strategy the following conclusions are drawn:

(i) The carry trade strategy generated statistical significant positive risk-adjusted performance for several individual currency pairs, but improved risk-adjusted performance is observed for portfolios of the currency pairs.

(ii) The 1-year rolling performance of the portfolios is negatively affected by financial crises.

(iii) The IRD-weighted portfolio and the equally-weighted portfolio including an IRD-filter of 0.15% outperformed an equally-weighted portfolio based on risk-adjusted performance measures.

(iv) The equally-weighted portfolio including an IRD-filter of 0.15% is well diversified over all currencies. This is in contrast to the remaining portfolios, which are underexposed to the JPY and overexposed to the AUD.

[21] The development of the 1-month interbank rates over time is observed in **Figure 3**.

5.2 PPP-based strategy

An alternative strategy during crisis periods suggested by previous literature is the PPP-based strategy. Its mean reverting nature can possibly provide for positive returns in times when the carry trade strategy is expected to fail. The PPP-based strategy is, similar to the carry trade strategy, developed for 21 currency pairs and portfolios consisting of the 21 currency pairs.

Table 5 shows the performance of the PPP-based strategy for the sample. The highest annualized returns are generated for the EUR/JPY and the JPY/AUD currency pairs with values over 7%. However, these high returns appear exceptions when the rest of the sample is observed. 14 of the 21 currency pairs earned a negative return on average. The Sharpe ratios are statistically significant positive for the EUR/JPY, the GBP/EUR and the JPY/AUD currency pair. The three significantly positive Sharpe ratios indicate strong risk-adjusted performance, but the PPP-based strategy is generally outperformed by the carry trade strategy. These results are in line with Brière & Drut (2009), which reported a significant underperformance of the PPP-based strategy compared to the carry trade strategy. Brière & Drut (2009), however, observed a positive Sharpe ratio for the equally-weighted portfolio of the PPP-based strategy. These results are partly supported by **Table 5**. **Table 5** shows positive Sharpe ratios for all portfolios, but not statistically significant different from zero. In contrast to Brière & Drut (2009), this thesis uses in-sample data to determine an out-of-sample investment decision. This choice possibly diminishes the returns of the PPP-based strategy, but it improves the validity of the results for a crisis-robust carry trade strategy in this thesis.

Concentrating on the average returns of the developed portfolios in **Table 5**, it follows that a ΔPPP-weighted portfolio outperforms an equally-weighted portfolio including or excluding a ΔPPP-filter. The volatility of the ΔPPP-weighted portfolio increases significantly as well. Be that as it may, the risk-adjusted performance measures are in slight favor of the ΔPPP-weighted portfolio. For the PPP-based strategy a filter is applied to the equally-weighted portfolio as well, but a ΔPPP-filter instead of an IRD-filter is applied. Different critical values from 1% up to 4% are tested to estimate the impact of the ΔPPP-filter on the performance of the equally-weighted portfolio. Similar to the IRD-filter for the carry trade strategy it appears that an increase in volatility is associated with a larger filter. However the annualized returns indicate a different view compared to the carry trade strategy. An increase in the average return is observed when a filter of 1% or 2% is applied. The high returns diminish when a ΔPPP-filter of 4% is applied. The risk-adjusted performance of an equally-weighted portfolio including filters from 2% up to 3% show little variation. The ΔPPP-filter improves an equally-weighted portfolio in terms of average returns, but the risk-adjusted performance measures are approximately equal. Furthermore the ΔPPP-filter improves an equally-weighted portfolio for the PPP-based strategy, but not to the same extent as the IRD-filter improved an equally-weighted portfolio for the carry trade strategy. The estimated transaction costs observed for the PPP-based strategy increased compared to the carry trade strategy due to a larger amount of transactions. The average return for the PPP-based strategy for a currency pair is diminished by approximately 0.02% up to 0.03% per month. The equally-weighted portfolio without a filter has an average amount of transaction of 0.51 per month, which diminish the monthly average return by approximately 0.026% per month[22]. The (risk-adjusted) performance of the remaining portfolios is affected as well, although the influence is relatively smaller.

Table 5: Descriptive statistics on the PPP-based strategy.

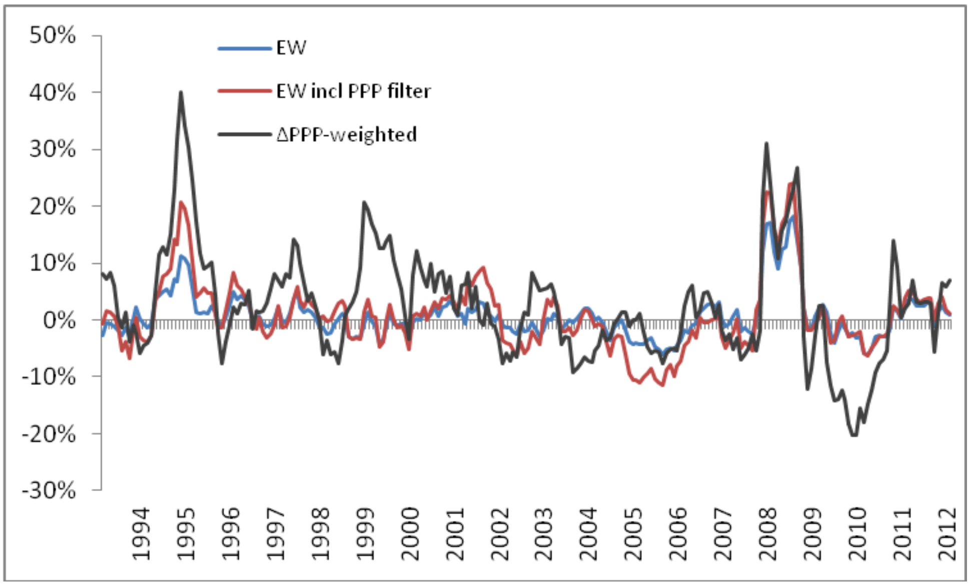
		Ann. mean	Mean	St. dev.	Skew.	Excess kurt.	JB-value	SR	MSR	M2	# Trans.
EW		0.70%	0.06%	1.31%	0.85	3.45	133.8***	0,05	0.03	0.09%	0.51
EW incl.	**1%**	0.84%	0.07%	1.65%	0.68	2.61	78***	0.04	0.02	0.64%	0.51
PPP-filter:	**2%**	1.18%	0.10%	2.14%	0.43	1.21	19.7***	0.05	0.03	0.38%	0.5
	2.5%	1.22%	0.10%	2.22%	0.24	1.05	25.1***	0.05	0.03	0.43%	0.5
	3%	1.31%	0.11%	2.33%	0.46	1.72	34.1***	0.05	0.03	0.47%	0.49
	4%	0.08%	0%	2.78%	0.22	1.06	15.9***	0	0	0.02%	0.5
ΔPPP-weighted		3.03%	0.26%	3.10%	1.15	6.14	390***	0,08	0.05	0.26%	0.5
AUD/CHF		-0.09%	-0.01%	3.62%	0.19	0.24	1.8	0,00	0	-0.13%	0.53
CAD/AUD		-0.76%	-0.04%	2.75%	0.1	0.15	0.5	-0,02	-0.02	-0.19%	0.54
CAD/CHF		-3.78%	-0.30%	3.46%	-0.16	-0.08	1.1	-0,09	-0.09	-0.51%	0.53
CAD/JPY		-0.80%	-0.09%	3.93%	0.3	2.66	66.5***	-0,02	-0.02	-0.22%	0.53
CAD/USD		-0.34%	-0.02%	2.32%	-0.15	2.68	64.8***	-0,01	-0.01	-0.16%	0.52
EUR/AUD		-0.60%	-0.03%	3.18%	-0.06	-0.45	2.2	-0,01	-0.01	-0.17%	0.53
EUR/CAD		-1.19%	-0.07%	2.98%	-0.05	-0.09	0.2	-0,02	-0.02	-0.23%	0.53
EUR/CHF		-1.44%	-0.11%	1.76%	0.07	6.32	360***	-0,06	-0.06	-0.40%	0.56
EUR/JPY		7.09%	0.57%	2.83%	0.45	1.92	40***	0,20***	0.2	0.80%	0.43
EUR/USD		2.80%	0.25%	2.95%	-0.16	0.68	4.8*	0,08	0.08	0.27%	0.5
GBP/AUD		-0.22%	0.00%	3.22%	0.26	0.93	9.9***	0,00	0	-0.11%	0.5
GBP/CAD		-1.80%	-0.14%	2.58%	0.15	0.25	1.3	-0,06	-0.06	-0.37%	0.53
GBP/CHF		2.31%	0.18%	2.73%	0.89	2.89	104.1***	0,07	0.07	0.18%	0.51
GBP/EUR		3.73%	0.31%	1.70%	0.4	2.17	47.5***	0,18***	0.18	0.71%	0.43
GBP/JPY		3.07%	0.23%	3.06%	0.77	1.66	46.1***	0,08	0.08	0.23%	0.49
GBP/USD		0.32%	0.03%	2.52%	0.73	2.4	70.7***	0,01	0.01	-0.07%	0.55
JPY/AUD		8.15%	0.63%	3.86%	0.63	4.83	224.2***	0,16**	0.16	0.63%	0.42
JPY/CHF		-0.83%	-0.05%	3.53%	0.24	1.91	34.2***	-0,02	-0.02	-0.18%	0.57
USD/AUD		-0.15%	0.02%	3.69%	0.39	1.55	26.5***	0,01	0.01	-0.09%	0.51
USD/CHF		-0.82%	-0.04%	3.37%	0.04	1.63	23.3***	-0,01	-0.01	-0.17%	0.5
USD/JPY		-0.34%	-0.01%	3.30%	0.57	2.69	76.3***	0,00	0	-0.13%	0.49

Notes: The Sharpe ratios are tested at 1% and 5% significance '*' indicates a statistically significant positive Sharpe ratio at 5% significance and '' at 1% significance.**

[22] Section 2.7 determined transaction costs at a fixed amount of 0.05% per round trip, thus 0.51*0.05% = 0.026% per month.

The results of **Table 5** are not particularly in favor of using the PPP-based strategy, but the performance of the PPP-based strategy during crisis periods is vital for this thesis. For a close examination of the performance of the PPP-based strategy **Figure 6** is included. **Figure 6** reflects the 1-year rolling performance of the developed portfolios for the PPP-based strategy over the entire sample period. Compared to the carry trade strategy it is visible that the PPP-based strategy generates lower returns on average, while the variation in returns is smaller. The high volatility of the ΔPPP-weighted portfolio stated in **Table 5** is recognized by the large variation of the 1-year rolling performance in **Figure 6**. The PPP-based strategy shows strong performance during periods when the carry trade strategy performed weak. The 1-year rolling performance of the PPP-based strategy is especially stronger during the crisis period from 2007 up to 2009. Moreover the 1-year rolling performance of the PPP-based strategy shows peaks at the end of 1994 and 1999, which are often associated with the Mexican and Asian currency crises.

Figure 6: 1-Year rolling performance of the PPP-based strategy.



5.3 Momentum strategy

Next to the PPP-based strategy, a momentum strategy is used as an alternative strategy as well. Burnside et al. (2011) claimed that a momentum strategy particularly provided strong performance when the carry trade strategy failed. The momentum strategy applied in this thesis is unable to develop a portfolio consisting of one individual currency pair. The momentum strategy determines the past strongest and weakest performing currency pairs and aims to benefit from a continuing trend in those currency pairs. An equally-weighted portfolio and a momentum-weighted portfolio are tested using varying amounts of past winners and losers. **Table 6** summarizes the descriptive statistics on the momentum strategy for the six developed portfolios over the entire sample period.

The momentum strategy provides for larger monthly average returns compared to the carry trade strategy and the PPP-based strategy. However, only one of the six portfolios generated a statistically significant positive Sharpe ratio. The portfolios developed using two past winners and losers generated the largest monthly average, but the portfolios generated the highest standard deviation as well. Both the monthly returns and the standard deviation of the returns decrease when the number of currency pairs increases. For the equally-weighted portfolios the decrease in the monthly average is approximately equal to the decrease in the standard deviation. The risk-adjusted performance for the equally-weighted portfolios is for that reason persistent for the three developed portfolios.

This thesis has a preference for the equally-weighted portfolio over the momentum-weighted portfolios. The consistent risk-adjusted performance results in the preference for the equally–weighted portfolios, although the statistical significant positive Sharpe ratio is observed for a momentum-weighted portfolio. Adding more currency pairs to a portfolio of the momentum strategy increases amount of transactions, but the difference in transaction costs between a WML portfolio consisting of two past winners and losers or three past winners and losers is only 0.14 * 0.05% = 0.007% per month. The differences in average transactions costs between the different portfolios are rather small compared to the average return per month.

Table 6: Descriptive statistics on the momentum strategy from February 1993 up to January 2012.

		Monthly avg.	St. dev.	Skewness	Excess kurt.	SR	MSR	M2	# of trans.
EW	**2**	0.37%	3.64%	-0.39	2.64	0.1	0.04	0.05%	0.34
	3	0.32%	3.37%	-0.53	3.82	0.1	0.04	0.03%	0.48
	4	0.30%	3.14%	-1.05	6.14	0.1	0.03	0.03%	0.61
Momentum-weighted	**2**	0.45%	4.07%	-0.45	4.32	0.11*	0.04	0.09%	0.38
	3	0.33%	4.22%	-1.03	2.96	0.08	0.03	-0.05%	0.49
	4	0.26%	3.98%	-1.15	4.86	0.06	0.02	-1.22%	0.65

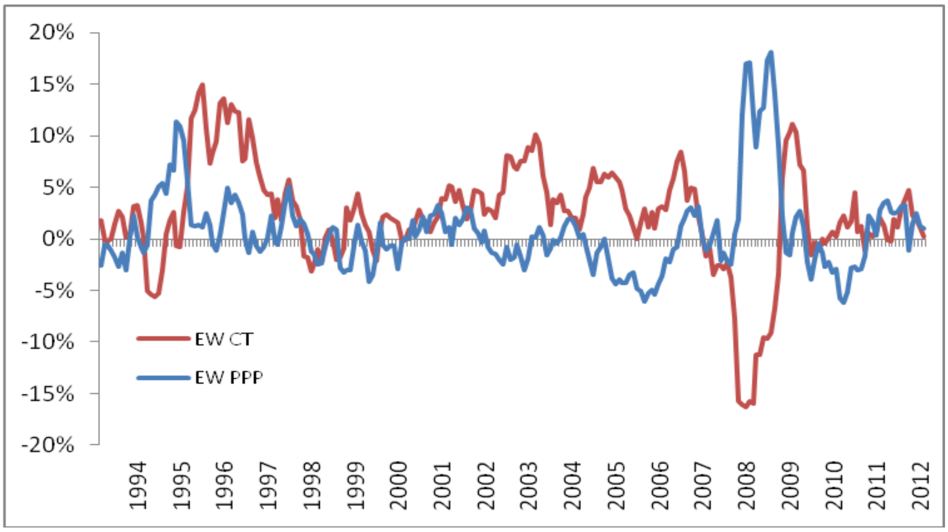
Summarizing the results on the momentum strategy, this thesis favors an equally-weighted portfolio over a momentum-weighted portfolio. Furthermore a WML portfolio is developed using three past winners and three past losers, although the choice for two or four past winners and losers would fit the objectives of this thesis as well.

5.4 Impact of financial crises

Section 5.1 and 5.2 suggested that the PPP-based strategy performed well when the carry trade strategy performed weak. The periods are often related to periods of increased volatility by academic papers. Next the influence of financial crises on the carry trade and PPP-based strategy are examined.

First the 1-year rolling performances of the equally-weighted portfolio of the carry trade strategy and the PPP-based strategy are observed in **Figure 7**. **Figure 7** draws the alternating performance of the carry trade strategy and the PPP-based strategy. A graphical interpretation of the figure indicates that the carry trade strategy offers higher returns for a significantly large proportion of the sample period. The main take-away of **Figure 7** is the outperformance of the PPP-based strategy during the recent financial crisis and the Mexican currency crisis at the end of 1994.

Figure 7: 1-Year rolling performance of the IRD-weighted portfolio of the carry trade strategy and the PPP-based strategy.



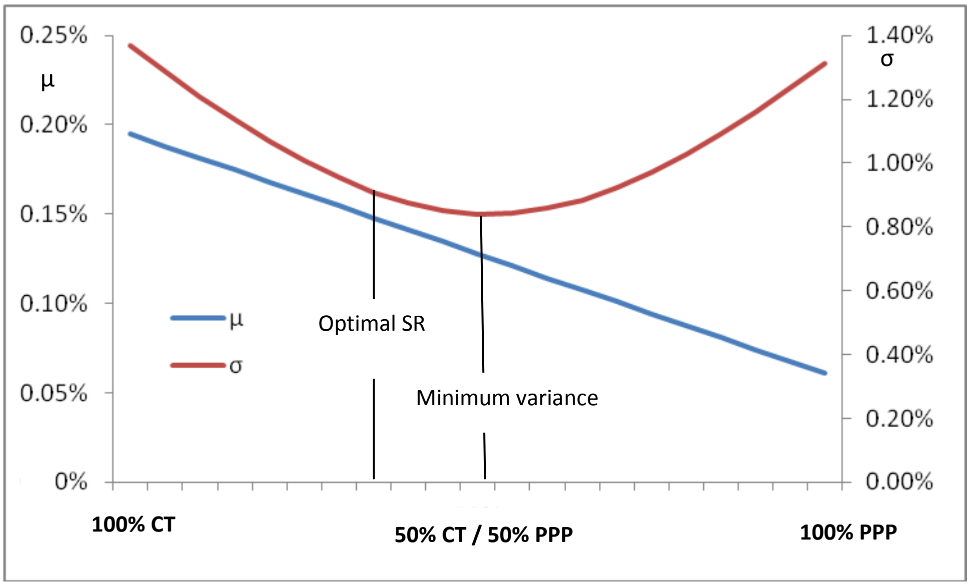
Additionally **Figure 7** suggests that the carry trade strategy and the PPP-based strategy are negatively related. Although the negative relation is not perfect, a negative correlation between the returns of the strategies can be expected. **Table 7** validates the expectations on correlations between the carry trade strategy and the PPP-based strategy. A negative correlation of -0.22 is found for the equally-weighted portfolios. A correlation of -0.22 is not particularly severe, but it is a signal that the alternating strategy might work. A critical element of the suggested alternating strategy is the risk aversion measure, which determines the strategy an investor should apply. Previous literature claimed that the carry trade strategy experienced large losses during periods of increased volatility. For that reason a negative relation is expected for the carry trade strategy and the different risk aversion measures. Simultaneously a positive correlation between the PPP-based strategy and the risk aversion measures is preferable for the market timing strategy. **Table 7** shows negative correlations for the carry trade strategy and the change in the VIX. For that reason a positive change in the VIX of the previous month is associated with a decreasing return for the carry trade strategy. An equal relationship is found for the carry trade strategy returns and the level of the VIX. In contrast to the other risk aversion measures, there is no observable relationship between the moving average of the VIX and the returns of the carry trade strategy. The correlations are close to zero, which indicates no statistical relationship between the variables. The correlations between the risk aversion measures and the returns of the PPP-based strategy show mixed results. The level of the VIX and the returns of the PPP-based strategy provide for the expected relationship with positive values for the correlation close to 0.2. The change in the VIX seems to have no statistical relationship with the returns of the PPP-based strategy, it generated correlations near zero with the returns of the PPP-based strategy. The moving average of the VIX has a small negative correlation with the returns of the PPP-based strategy, but the relationship is hardly significant.

Table 7: Correlation matrix.

			1	2	3	4	5	6	7	8	9
CT	**EW**	**(1)**	1								
	EW incl. filters	**(2)**	0.91	1							
	IRDW	**(3)**	0.95	0.98	1						
PPP	**EW**	**(4)**	-0.22	-0.15	-0.18	1					
	EW incl. filters	**(5)**	-0.18	-0.12	-0.14	0.93	1				
	ΔPPP-weighted	**(6)**	-0.19	-0.17	-0.16	0.67	0.63	1			
	VIX level	**(7)**	-0.26	-0.2	-0.23	0.19	0.16	0.11	1		
	ΔVIX	**(8)**	-0.3	-0.35	-0.33	0.07	0.05	0.07	0.25	1	
	VIX MA	**(9)**	0.03	0.14	0.09	-0.07	-0.04	-0.09	0.36	-0.1	1

The results observed in **Table 7** signal that a profitable market timing strategy, which uses the VIX level or the change in the VIX as a crisis definition, is possible. Moreover, a negative correlation between the carry trade strategy and the PPP-based strategy suggests that a combination of the strategies could potentially provide for high risk-adjusted returns as well. **Figure 8** represents the return and standard deviation for a combined strategy of the carry trade and the PPP-based strategy. **Figure 8** verifies the large possible diversification benefits. The volatility decreases significantly when the strategies are combined. On the other hand **Figure 8** shows that the addition of PPP-based strategy to the portfolio reduces the monthly return as well. The minimum variance portfolio consists for 48.4% of the carry trade strategy and for 51.6% of the PPP-based strategy. The Sharpe ratio of the portfolio is optimal when the combined portfolio consists for 65.6% of the carry trade strategy and for 34.4% of the PPP-based strategy. The optimal Sharpe ratio for the sample period is 0.16, which is statistically significant larger than zero.

Figure 8: Monthly return and standard deviation for a combined portfolio of an equally weighted carry trade strategy and an equally weighted PPP-based strategy.



Next the influence of the crisis definitions on the performance of the strategies is examined. A crisis-robust portfolio is developed by applying a carry trade strategy during non-crisis periods and an alternative strategy during crisis periods. For that reason a strong performance of the carry trade strategy is expected for periods identified as non-crisis periods, while a stronger performance during crisis periods is expected for the PPP-based strategy. The performance of the carry trade strategy and the PPP-based strategy are stated in **Table 8**.

Table 8 shows lower average returns during crisis periods compared to the average returns of the entire sample period for 7 of the 9 portfolios of the carry trade strategy. Solely the absolute value of the VIX provides for results in contrast to the expectations. The return of the carry trade strategy increased when the absolute value measure indicated crisis periods for the IRD-weighted portfolio and the equally-weighted portfolio including an IRD-filter of 0.15%. The remaining crisis definitions provide for rather rewarding results. In particular the change in the VIX crisis definition presents satisfying results. The IRD-weighted carry trade strategy generated a return of -0.71% per month during crisis periods defined by the change in the VIX. A decrease of 1.07% is observed in the average return for a crisis period compared to the average return of the entire sample period.

The results in Table 8 indicate increased profitability for a market timing strategy which alternates between a carry trade strategy and a PPP-based strategy. The highest possible return for such a market timing strategy is generated when an equally weighted portfolio including an IRD-filter for the carry trade strategy during non-crisis periods and a ΔPPP-weighted portfolio of the PPP-based strategy during crisis periods is used. The weighted average return of the market timing strategy would be (89.5%*0.55%) + (10.5%*1.64%) = 0.66% per month.

Table 8: Performance of the carry trade and PPP-based strategies in crisis and non-crisis periods.

			Entire period	Crisis			Non-crisis		
				ΔVIX	AV	MA	ΔVIX	AV	MA
CT	**EW**	**μ**	0.19%	-0.55%	0.13%	-0.25%	0.28%	0.21%	0.28%
		σ	1.37%	2.10%	1.81%	1.92%	1.23%	1.22%	1.22%
	EW incl. IRD-filter	**μ**	0.43%	-0.61%	0.66%	-0.07%	0.55%	0.37%	0.52%
		σ	1.95%	2.86%	2.75%	2.67%	1.78%	1.67%	1.77%
	IRDW	**μ**	0.36%	-0.71%	0.42%	-0.21%	0.48%	0.34%	0.46%
		σ	1.98%	2.88%	2.66%	2.65%	1.81%	1.76%	1.82%
PPP	**EW**	**μ**	0.06%	0.78%	0.36%	0.34%	-0.02%	-0.02%	0.01%
		σ	1.31%	2.06%	1.76%	1.83%	1.18%	1.16%	1.19%
	EW incl. PPP-filter	**μ**	0.08%	0.91%	0.44%	0.38%	-0.02%	-0.02%	0.03%
		σ	1.90%	2.47%	2.36%	2.32%	1.80%	1.75%	1.81%
	ΔPPP-weighted	**μ**	0.26%	1.64%	0.50%	1.03%	0.09%	0.19%	0.11%
		σ	3.10%	5.11%	4.52%	4.51%	2.74%	2.59%	2.74%
50%/50%		**μ**	0.13%	0.11%	0.25%	0.04%	0.13%	0.10%	0.14%
		σ	0.84%	0.97%	0.95%	0.88%	0.83%	0.81%	0.83%
Proportion periods			100%	10,5%	21,5%	15,8%	89,5%	78,5%	84,2%

5.5 Crisis-robust carry trade strategies

Section 5.4 described the profits for an investor by alternating between or combining the carry trade strategy and the PPP-based strategy. Next the profitability for the developed crisis-robust carry trade strategies is examined. **Table 9** summarizes the results on 36 developed crisis-robust portfolios, which are tested for its economical and statistical significance. The crisis-robust portfolios are compared to the carry trade strategy, the PPP-based strategy and a naïve combined strategy consisting for 50% of the carry trade strategy and for 50% of the PPP-based strategy ("**50%/50%**").

Table 9 shows a strong improve in performance for the crisis-robust carry trade strategies compared to the carry trade strategy and the PPP-based strategy. The average returns for 25 of 36 tested portfolios increased during the sample period. The highest annualized return observed is

7.35%, which is generated by the equally-weighted CT-PPP portfolio including filters using the ΔVIX crisis definition. The standard deviation of the tested portfolios showed in general a slight decrease opposite to the carry trade strategy and the PPP-based strategy. The CT-0 portfolio performed particularly well in terms of risk reduction. Compared to the normal carry trade strategy the standard deviation decreased for each crisis definition with a minimal amount of 0.2% per month. The risk reduction is a likely result for the CT-0 strategy, because the strategy aims to benefit from the strong performance of the carry trade strategy during non-crisis periods and cuts the large losses incurred during crisis periods. The risk reduction for the CT-0 portfolio is in line with the results found by Dunis & Miao (2007). The CT-0 crisis-robust carry trade strategy is characterized by its simplicity and low risk, which resulted in high risk-adjusted performance. For that reason the CT-0 crisis-robust carry trade strategy is possibly an attractive addition to a diversified portfolio.

The risk reduction of the tested portfolios is confirmed by the higher moments of the return distributions. The skewness of the return distributions remains negative for a large proportion of the tested portfolios, but the skewness increased for all crisis-robust portfolios. In particular the skewness values for the return distributions of the CT-CT^{-1} and CT-PPP portfolios improved. The return distributions for those portfolios showed positive skewness, hence confirm the impression of risk reduction for the crisis-robust portfolios. A similar conclusion can be drawn from the decrease in kurtosis. The large deviation from the average diminished, although an excess kurtosis is observed for all return distributions. The largest excess kurtosis is observed for the CT-CT^{-1} portfolio. The large excess kurtosis is reasonable, because CT-CT^{-1} portfolio aims to benefit from large abrupt unwinding carry trades. For that reason it is exposed to the large variations experienced by a normal carry trade strategy. A comparison between the CT-CT^{-1} portfolio and the CT-0 portfolio favors the CT-0 portfolio in terms of risk reduction, but favors the CT-CT^{-1} portfolio in terms of annualized returns. Although the tested portfolios showed improved results compared to the carry trade strategy, the naïve 50%/50% portfolio outperforms the tested portfolios in terms of risk reduction. The risk-adjusted performance measures of the tested portfolios indicate generally a positive risk-adjusted performance. The Sharpe ratios are statistically significant positive for 27 of the 36 tested portfolios.

The observed underperformance of the tested portfolios compared to the 50%/50% portfolio is to large extent caused by poor performance of the absolute value crisis definition. If the absolute value crisis definition is ignored, 22 of the 24 tested portfolios showed an increased Sharpe ratio compared to the 50%/50% portfolio. The Sharpe ratios signify statistical significant positive risk-adjusted performance, but the strong risk-adjusted performance diminishes if the skewness and kurtosis are taken into account. The MSR’s decreased compared to the Sharpe ratio due to an excess kurtosis of the return distributions.

Next to the fundamental trading strategies, a combination of the carry trade strategy and a momentum strategy is developed as well. The results in **Table 9** indicate that the combination of a carry trade strategy during non-crisis periods and a momentum strategy during crisis periods showed particularly strong risk-adjusted performance for the equally-weighted portfolio including a momentum-filter. The CT-WML portfolio experienced a large risk reduction, but still underperforms the CT-PPP portfolios based on the risk-adjusted performance measures. The CT-PPP generally outperformed all other tested portfolios. The highest Sharpe ratios, MSR's and M^2 value are found for the equally-weighted CT-PPP portfolio including filters. Based on the results this thesis advises the use of the equally-weighted CT-PPP portfolio including a filter, but the choice for an optimal crisis definition remains.

Evaluating the crisis definitions, it is visible that predictions based on the absolute value of the VIX offered the weakest average returns. The strongest performance in terms of (annualized) returns, (modified) Sharpe ratios and M^2 values is primarily observed for the ΔVIX crisis definition. Based on risk-adjusted performance measures the optimal crisis-robust carry trade strategy is the equally-weighted CT-PPP including filters using the ΔVIX crisis definition. Lastly the success rates of the different portfolios test the market timing ability of the crisis definitions according to the paper of Henriksson & Merton (1984). The crisis definitions showed strong forecasting ability with success rates significantly larger than one for 27 of the 36 tested portfolios. For that reason all crisis definitions appear useful to a market timing strategy to anticipate losses for the carry trade strategy. However, the ΔVIX crisis definition prevails the other crisis definitions in market timing ability for the equally weighted portfolio including the filters. This thesis concludes that an equally-weighted CT-PPP portfolio including filters using the ΔVIX crisis definition ("**CT-PPP***") meets the traits of a crisis-robust carry trade strategy. For that reason this thesis recommends the CT-PPP* portfolio as a crisis-robust carry trade strategy. Section 5.6 tests the economic significance of adding a CT-PPP* portfolio as an asset to a portfolio.

Table 9: Performance of the crisis-robust carry trade strategies.

		CT	PPP	50%/50%	CT-0			CT-CT-1			CTPPP			CT-WML		
					AV	ΔVIX	MA	AV	ΔVIX	MA	AV	ΔVIX	MA	AV	ΔVIX	MA
EW	**Mean**	0.19%	0.06%	0.13%	0.17%	0.25%	0.24%	0.14%	0.31%	0.28%	0.24%	0.34%	0.29%	0.15%	0.24%	0.21%
	St. dev.	1.37%	1.31%	0.84%	1.09%	1.17%	1.13%	1.37%	1.35%	1.35%	1.35%	1.35%	1.33%	1.16%	1.19%	1.17%
	Ann. Return	2.42%	0.70%	1.55%	2.01%	3.07%	2.84%	1.70%	3.75%	3.33%	2.91%	4.03%	3.46%	1.81%	2.93%	2.53%
	Skewness	-1.2	0.85	0.11	-0.52	-0.46	-0.31	0.39	0.37	0.55	0.21	0.15	0.32	-0.44	-0.43	-0.3
	Excess kurt.	5.25	3.45	2.4	3.16	2.49	2.7	4.3	4.52	4.29	3.17	3.35	3.35	1.99	2.13	2
	SR	0.14**	0.05	0.16**	0.15**	0.22***	0.21***	0.1	0.23***	0.20***	0.18***	0.25***	0.22***	0.13*	0.20***	0.18***
	MSR	0.05	0.03	0.07	0.06	0.09	0.08	0.05	0.1	0.09	0.08	0.11	0.1	0.05	0.08	0.07
	M2	0.65%	0.21%	0.69%	0.70%	0.99%	0.95%	0.46%	1.06%	0.93%	0.82%	1.14%	0.99%	0.59%	0.93%	0.81%
	Succes rate	-	-	-	108%	122%***	116%**	108%	122%***	116%**	107%	121%***	110%	115%**	129%***	112%*
	# of transactions	0.05	0.51	0.28	0.04	0.04	0.04	0.08	0.08	0.08	0.13	0.25	0.18	0.08	0.13	0.11
EW incl. filters	**Mean**	0.43%	0.08%	0.26%	0.50%	0.29%	0.44%	0.15%	0.56%	0.45%	0.38%	0.59%	0.50%	0.48%	0.27%	0.41%
	St. dev.	1.95%	1.90%	1.28%	1.69%	1.48%	1.64%	1.99%	1.91%	1.94%	1.83%	1.86%	1.86%	1.71%	1.54%	1.67%
	Ann. Return	5.55%	0.94%	3.17%	6.24%	3.50%	5.54%	1.89%	6.96%	5.63%	4.62%	7.35%	6.23%	6.10%	3.30%	5.23%
	Skewness	-0.78	0.39	0.3	-0.23	-0.53	-0.14	-0.07	0.14	0.22	-0.26	-0.08	0.02	-0.22	-0.48	-0.13
	Excess kurt.	4.35	1.48	2.53	2.98	4	3.41	3.36	3.75	3.47	2.46	2.51	2.38	2.77	3.12	2.94
	SR	0.22***	0.04	0.20***	0.29***	0.19***	0.27***	0.07	0.29***	0.23***	0.21***	0.32***	0.27***	0.28***	0.18***	0.25***
	MSR	0.08	0.02	0.09	0.11	0.07	0.11	0.03	0.12	0.1	0.09	0.13	0.11	0.11	0.07	0.1
	M2	1.01%	0.19%	0.92%	1.34%	0.89%	1.23%	0.34%	1.34%	1.06%	0.96%	1.45%	1.23%	1.29%	0.81%	1.13%
	Succes rate	-	-	-	114%**	130%***	122%***	114%**	130%***	122%***	108%	128%***	119%**	121%***	124%***	117%**
	# of transactions	0.01	0.5	0.26	0.02	0.03	0.02	0.04	0.05	0.05	0.09	0.24	0.17	0.03	0.1	0.07
IRDW/ ΔPPPW	**Mean**	0.36%	0.26%	0.31%	0.27%	0.43%	0.39%	0.18%	0.51%	0.42%	0.39%	0.52%	0.47%	0.23%	0.41%	0.37%
	St. dev.	1.98%	3.10%	1.69%	1.56%	1.72%	1.67%	2.00%	1.95%	1.97%	1.87%	1.93%	1.91%	1.67%	1.78%	1.74%
	Ann. Return	4.56%	3.03%	3.80%	3.21%	5.37%	4.83%	2.20%	6.23%	5.21%	4.63%	6.38%	5.78%	2.83%	5.16%	4.64%
	Skewness	-0.94	1.15	0.09	-0.65	-0.48	-0.4	-0.01	0.01	0.13	0.2	0.15	0.26	-0.58	-0.49	-0.43
	Excess kurt.	3.83	6.14	1.36	3.62	2.65	2.94	3	3.36	3.12	4.54	4.06	4.24	2.36	2.21	2.31
	SR	0.18***	0.08	0.18***	0.17**	0.25***	0.23***	0.09	0.26***	0.22***	0.21***	0.27***	0.25***	0.14**	0.23***	0.21***
	MSR	0.07	0.05	0.08	0.06	0.1	0.09	0.04	0.11	0.09	0.09	0.11	0.1	0.06	0.09	0.08
	M2	0.82%	0.38%	0.83%	0.78%	1.15%	1.06%	0.40%	1.19%	0.98%	0.94%	1.23%	1.13%	0.64%	1.06%	0.97%
	Succes rate	-	-	-	112%*	126%***	121%***	112%*	126%***	121%***	122%***	122%***	121%***	114%**	119%**	122%***
	# of transactions	0.02	0.5	0.26	0.04	0.04	0.04	0.05	0.06	0.06	0.1	0.24	0.18	0.04	0.1	0.08

5.6 Mean-Variance spanning tests

In the following section Mean-Variance spanning tests are executed to test the economic value added of the recommended crisis-robust carry trade strategy. This thesis will conduct spanning tests on three different investment portfolios.

First the economic significance is tested for the addition of an equally-weighted CT-PPP portfolio including filters using the ΔVIX crisis defintion to a portfolio consisting of an equally-weighted carry trade strategy and an equally-weighted PPP-based strategy. The CT-PPP* portfolio is chosen based on the best performance described in **Table 9**. Subsequently spanning tests are conducted to test the economic significance of adding the CT-PPP* portfolio to an investment portfolio consisting of equity and bonds from the perspective of an US-based investor. The portfolios are optimized according to the Modern Portfolio Theory. Based on the correlations in **Table 10** diversification benefits are expected when the crisis-robust carry trade strategy is added to the investment portfolio consisting of the carry trade strategy and the PPP-based strategy. The correlation between the CT-PPP portfolio and the equally weighted carry trade strategy is 0.57, while the correlation with the PPP-based strategy is 0.25. For the remaining spanning tests larger diversification benefits are expected due to lower correlations observed in **Table 10**. **Table 10** shows correlations for the CT-PPP* portfolio with equity and bonds close to zero.

Table 10: Correlation matrix.

	Equity	Bonds	CT	PPP	CT-PPP*
Equity	1				
Bonds	-0.14	1			
CT	0.16	-0.03	1		
PPP	-0.09	0.02	-0.22	1	
CT-PPP*	-0.06	-0.03	0.57	0.25	1

The spanning tests applied in this thesis are developed by Huberman & Kandel (1987) and corrected by Khan & Zhou (2008). A Likelihood ratio test is applied to K benchmark assets and adds one new asset, which is the CT-PPP* portfolio. First a Markowitz bullet is formed for the benchmark assets. Subsequently a Markowitz bullet is formed, but the crisis-robust carry trade strategy is included as well. The spanning tests applied in this thesis test the null hypothesis that a first Markowitz bullet consisting of K benchmark assets spans a second Markowitz bullet consisting of K + 1 assets. The hypotheses are formulated as below:

H_0: The K benchmark assets span the larger set of K+1 assets.

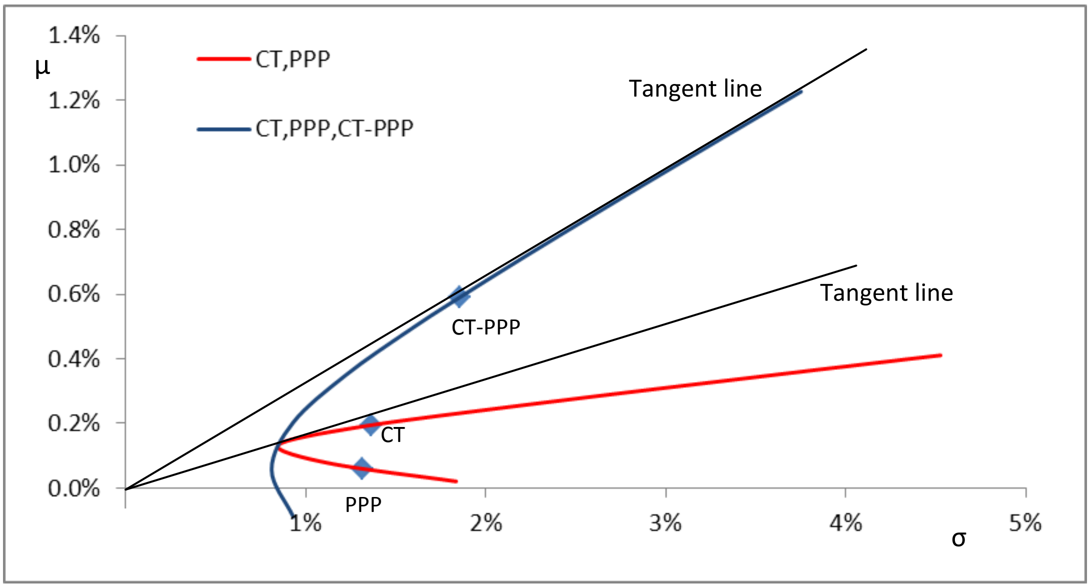
H_a: The K benchmark assets do not span the larger set of K+1 assets.

In case the first Markowitz bullet spans the second Markowitz bullet, then the addition of the crisis-robust carry trade strategy does not improve the investment opportunity set significantly. The hypotheses ar tested using the likelihood ratio test as described by section 4.6. The null hypothesis is rejected if the F-score exceeds a critical value. The relevant critical values for the F-test at a 1% and a 5% significance level are:

$\mathbf{F_{2,225,0.05} = 2.64}$ and $\mathbf{F_{2,225,0.01} = 3.87}$

The first spanning test, tests the economic value added of the CT-PPP* portfolio to an investment portfolio consisting of an equally-weighted carry trade strategy and an equally-weighted PPP-based strategy. The Markowitz bullets for the first spanning test are shown in **Figure 9**.

Figure 9: Markowitz bullets of the first spanning test.

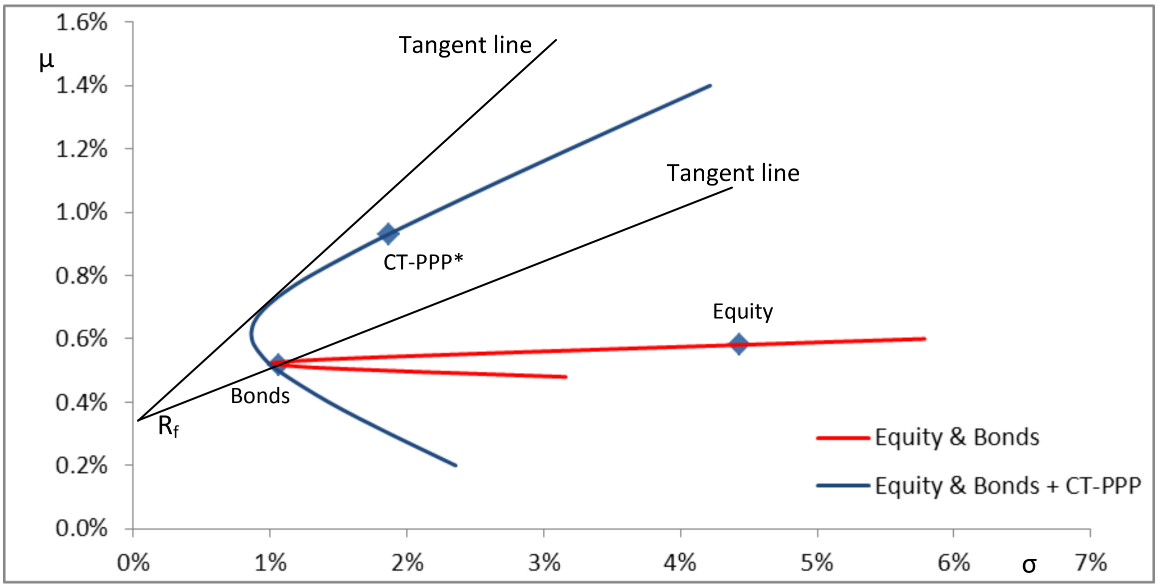


The likelihood ratio test rejects the null hypothesis of spanning. The spanning test generated an F-score of 17.6, which is significant at a 1% significance level. This finding implies that the addition of the crisis-robust carry trade strategy to a portfolio consisting of an equally-weighted carry trade strategy and an equally-weighted PPP-based strategy moves the efficient frontier significantly. An explanation for the rejection is the significant increase in the slope of the tangent line. The shift of the minimum variance portfolio appears smaller when **Figure 7** is examined. The overall shift of the

Markowitz bullet is considered statistically significant. For that reason it can be concluded that an investor is expected to benefit from adding the CT-PPP* portfolio to a portfolio consisting of an equally-weighted carry trade strategy and an equally-weighted PPP-based strategy.

Another interesting aspect is the economic value added of the crisis-robust carry trade strategy to a diversified portfolio for an US-based investor. Next, two different spanning tests are conducted to test the economic value added of a crisis-robust carry trade strategy to a diversified portfolio of an US-based investor. First a diversified portfolio is developed consisting of the S&P 500 and the Barclays US aggregate Bond Index[23]. The difference compared to the first spanning test is that the investment portfolio is not a zero-investment portfolio, hence the tangent line starts at the risk free rate instead of the origin. The risk free rate is represented by the US 3-month Treasury bill. The hypotheses and critical values applied to the first spanning tests are used for the second spanning test as well. The Markowitz bullets for the portfolio consisting of equity and bonds and the portfolio including the CT-PPP* portfolio are represented by **Figure 10**.

Figure 10: Markowitz bullets of the second spanning test.

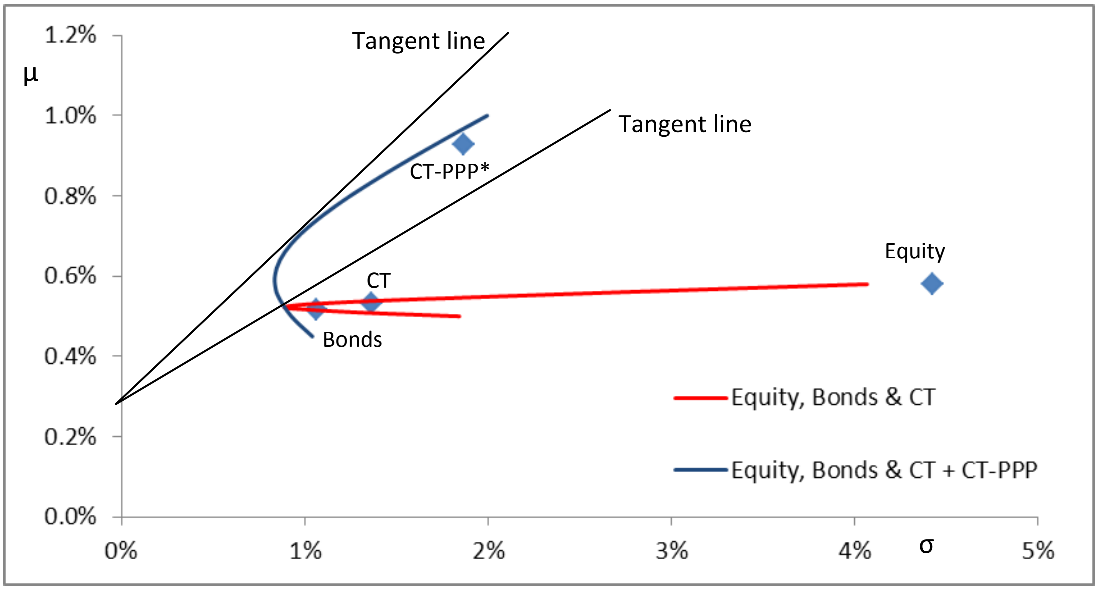


The likelihood ratio test generated an F-score of 41.7, which rejects the null hypothesis of spanning. Thus the addition of the CT-PPP* portfolio as an asset to a portfolio, which consists of equity and bonds shifts the efficient frontier significantly. Both the minimum variance portfolio and the tangency line showed large diversification benefits, which resulted in a strong rejection of the null hypothesis. Economically it means that the addition of the CT-PPP* portfolio is expected to be profitable in terms of risk reduction for a diversified portfolio of an US-based investor.

[23] The S&P 500 serves as a proxy for equity and the Barclays US aggregate Bond Index is used for bonds.

The results of the first two spanning tests indicate large gains in terms of risk reduction due to addition of the crisis-robust carry trade strategy. The last question this thesis answers is whether the crisis-robust is economically significant to a diversified portfolio when the portfolio already includes an equally-weighted portfolio of the carry trade strategy. The Markowitz bullets for the portfolio consisting of equity, bonds and the equally-weighted portfolio of the carry trade strategyand the portfolio including the CT-PPP* portfolio are represented by **Figure 11**.

Figure 11: Markowitz bullets of the third spanning test.



The null hypothesis for the last spanning test is rejected as well. An F-score of 20.7 indicates a significant shift of the efficient frontier. The inclusion of the equally-weighted portfolio of the carry trade strategy to the benchmark assets caused a lower F-score compared to the second spanning test. A part of the diversification benefits of adding the CT-PPP* portfolio are already captured by the equally-weighted portfolio of the carry trade strategy. The spanning test rejects, however, the null hypothesis. Thus the crisis-robust carry trade strategy is considered economically valuable even if the investment portfolio includes an equally-weighted portfolio of the carry trade strategy.

Summarizing the results on the Mean-Variance spanning tests, it can be concluded that the crisis-robust carry trade strategy is economically significant for an investor. The null hypothesis of spanning is rejected for all three investment portfolios indicating a significant shift of the efficient frontier. Both the tangent line and the minimum variance portfolio improved as a result of adding the crisis-robust carry trade strategy.

6 Conclusions

This thesis tested whether a carry trade strategy can be made crisis-robust using the VIX for 21 major currency pairs during the period from 28 February 1993 up to 29 February 2012. The carry trade strategy showed strong risk-adjusted performance for a large proportion of the 21 currency pairs during the sample period, but the performance is negatively affected during crisis periods. The observed risk-adjusted performance of the carry trade strategy during crisis periods and non-crisis periods in this thesis is in line with the results found by Darvas (2009), Burnside et al. (2008), Dunis & Miao (2007) and Brière & Drut (2009). This thesis used three different in-sample estimated crisis definitions to determine out-of-sample crisis periods. During the estimated crisis periods this thesis tested four different alternative strategies including a PPP-based strategy and a momentum strategy. The PPP-based strategy underperformed a carry trade strategy over the entire sample period, but it performed particularly well in periods when the carry trade strategy appeared to fail. Both conclusions are drawn by Brière & Drut (2009) as well. Furthermore, this thesis developed equally-weighted portfolios without filters, equally-weighted portfolios including filters and IRD/ΔPPP/momentum-weighted portfolios of 21 the currency pairs. The risk-adjusted performance showed that diversification benefits for the developed portfolios are present. Large profits in risk reduction and profits are gained when a portfolio of currency pairs is developed. The diversification benefits observed for the developed portfolios in this thesis are previously found by Burnside et al. (2008) and Brière & Drut (2009).

The (risk-adjusted) performance of in total 36 crisis-robust carry trade strategies is examined in this thesis. Based on risk-adjusted performance measures the crisis-robust portfolios generally outperformed the carry trade strategy, a PPP-based strategy and a naïve 50%/50% combination of the carry trade strategy and the PPP-based strategy. This thesis recommends an equally-weighted CT-PPP portfolio including filters using the ΔVIX crisis definition as an investment strategy, because it meets the traits of a crisis-robust carry trade strategy. A Mean-Variance analysis showed that the CT-PPP portfolio including filters using the ΔVIX crisis definition is an economically significant addition to diversified portfolios and a portfolio consisting of the carry trade strategy and a PPP-based strategy. The crisis-robust carry trade strategy is, for that reason, expected to be valuable for investors.

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8 Appendices

A. Datastream codes for the data

Variable	Name	Datastream code	Variable	Specification	Datastream code
Exchange rate	AUD/CHF	CHFAUSP	**1-month interbank rate**	Australia	BBAUD1M
	CAD/AUD	CNAUDSP		Canada	BBCAD1M
	CAD/CHF	CNCHFSP		Germany/euro	BBDEM1M/BBEUR1M
	CAD/JPY	CNJPYSP		Japan	BBJPY1M
	CAD/USD	TEAUDSP		Switzerland	BBCHF1M
	EUR/AUD	TEAUDSP		United Kingdom	BBGBP1M
	EUR/CAD	TECADSP		United States	BBUSD1M
	EUR/CHF	TECHFSP			
	EUR/JPY	JPOCC007			
	EUR/USD	EUDOLLR	**Risk free rate**	Australia	ADBR090
	GBP/AUD	AUGBPSP		Canada	CDN3MTB
	GBP/CAD	TSCADSP		Europe	EIBOR3M
	GBP/CHF	TSCHFSP		Japan	JPINTER3
	GBP/EUR	UKOCC007		GBP	UKGBILL3
	GBP/JPY	UKXYEN		Switzerland	SWLOMBD
	GBP/USD	USBRITP		US	USTBL3M
	JPY/AUD	AUEXCHJP			
	JPY/CHF	JAPAYSF	**Benchmark**	MSCI World Index	MSWRLD$
	USD/AUD	TDAUDSP	**Equity**	S&P 500	S&PCOMP
	USD/CHF	SWISFUS	**Bonds**	Barclays US aggregate	LHAGGBD
	USD/JPY	JAPYNUS	**Implied volatility**	VIX level	CBOEVIX

B. Sensitivity of the average returns of an equally weighted CT-PPP portfolio to different critical values

Absolute Value	**22**	**23**	**24**	**25**	**26**	**27**
μ	0.23%	0.20%	0.21%	0.24%	0.23%	0.24%
σ	1.35%	1.36%	1.37%	1.35%	1.36%	1.35%
Prop. crisis periods	38%	32%	27%	21%	19%	17%
ΔVIX	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
μ	0.21%	0.27%	0.32%	0.34%	0.32%	0.27%
σ	1.29%	1.29%	1.31%	1.35%	1.34%	1.32%
Prop. crisis periods	37%	25%	17%	11%	9%	5%
VIX MA	**1-year**			**3-year**		
	μ + σ	**μ + 1.5σ**	**μ + 2σ**	**μ + σ**	**μ + 1.5σ**	**μ + 2σ**
μ	0.23%	0.29%	0.29%	0.21%	0.24%	0.28%
σ	1.30%	1.33%	1.34%	1.28%	1.29%	1.29%
Prop. crisis periods	24%	16%	11%	26%	19%	11%