Diversification Effect of Standard and Optimized Carry Trades*

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Abstract

Standard carry trades, which consist of purchasing high- and selling low-yield currencies, provide an economic diversification effect. However, the diversification effect is not robust, and is not borne out by much statistical evidence. We introduce optimized carry trades, which incorporate risk components in the currency selection process. These optimized carry trades provide a diversification effect and robustly enhance the risk-return profile of an underlying portfolio, both economically and statistically. Furthermore, optimized carry trades are applicable as a cash overlay strategy to improve the contribution of a cash position and enhance the portfolio return. The positive contribution of the cash overlay with optimized carry trades is larger than with standard carry trades.

Keywords: Diversification Effect, Carry Trade, Portfolio Optimization, Alternative Asset Class
JEL classification: G10, G11

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1 Introduction

The main idea of diversification is to avoid putting all one's eggs in one basket. This means that an investor purchases several assets to reduce unsystematic risk of the corresponding portfolio. According to financial theory, an investor is compensated only for systematic or market risk. The investor therefore aims to reduce unsystematic risk, as it is not rewarded.
Over the past few years, several asset classes have been added to the investment universe of portfolio managers - always with the aim of increasing the diversification of the underlying portfolio, and reducing the unsystematic risk. For example, portfolio managers incorporate real estate (Gordon, Canter, & Webb, 1998) or commodities (Ferri, 2010; Geman & Kharoubi, 2008; Marston, 2011) to diversify their portfolios. Theoretically, diversification evokes a shift in the mean-efficient frontier of the portfolio towards the northwest. A good indication of the diversification potential of a new asset is its correlation to the existing portfolio. Optimally, the correlation is close to zero, with the result that the new asset and the underlying portfolio behave differently, and under normal conditions, independently of one another. This distinct behavior is particularly beneficial during financial slack, when the losses of the portfolio can be balanced by the returns of the new asset. However, Hung, Onayev, and Tu (2008) demonstrate that the diversification effect is time-varying and is linked to a time-varying correlation between assets. Moreover, the more the diversification effect of a certain asset class declines, the more portfolio managers adapt the asset class to their investment universe, with the result that the benefits of diversification decrease over time. Consequently, portfolio managers are in search of new and hitherto undetected assets or asset classes, which offer an additional diversification effect.

Nowadays, a well-diversified portfolio is an international multi-asset class portfolio. The international component imports the unasked-for currency risk, which contributes significantly to the portfolio's return and volatility. Campbell, Serfaty-De Medeiros, and Viceira (2010) design a currency hedging method to significantly reduce the volatility of an international equity or bond investor's portfolio. There seems to be evidence that their hedging approach reduces unsystematic risk. Additionally, Kroencke, Schindler, and Schrimpf (2014) illustrate that different currency investment styles diversify an international portfolio, documented by a significant shift in the mean-efficient frontier. Campbell et al. (2010) and Kroencke et al. (2014) demonstrate that currencies, as a separate asset class, provide some diversification effect. The most common currency strategies are based on the currency momentum, its value, or its interest rate.
The standard carry trade, which consists of purchasing high- and selling low-yield currencies, has been profitable over the past few decades. This positive return is based on the failure of the uncovered interest rate parity and, consequently, a compensation for a certain risk consumption such as crash risk (Brunnermeier, Nagel, & Pedersen, 2008) or peso events (Burn-

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side, Eichenbaum, Kleshchelski, & Rebelo, 2011). Additionally, Jurek (2008) and Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) find that equity risk factors have only a limited explanatory power for standard carry trade returns. Thus, standard carry trades do not compensate for equity risk. Cenedese, Sarno, and Tsiakas (2014) consistently find that standard carry trades have a low correlation to equities. These findings demonstrate that carry trades have a diversification potential for an international equity portfolio. Das, Kadapakkam, and Tse (2013) investigate the diversification effect of standard carry trades in economic terms, and find an enhancement of the risk-return profile for an international portfolio. As a carry trade is a zero-investment strategy, allocating weight on a carry trade is not feasible. Das et al. (2013) therefore suggest backing standard carry trades with U.S. treasury bills, so that a carry trade position consists of a currency strategy, i.e. the carry trade, and a bond investment, i.e. the U.S. treasury bills. However, Levy and Lerman (1988) illustrate that a bond investment provides a diversification effect for U.S. investor. The documented diversification effect might therefore be driven by the increased bond investment. Furthermore, Das et al. (2013) find that the correlation between a standard carry trade and the equity market is approximately 70% during the recent financial crisis[1], with the result that the diversification effect is less prominent.

In this paper we introduce optimized carry trades. The main difference between optimized and standard carry trade is that optimized carry trades incorporate risk components in the currency selection process, while standard carry trades select currencies according to their interest rate. The first optimized carry trade tracks a standard carry trade as closely as possible. Hence, the tracking error between the optimized and the standard carry trade is minimized. The second optimized carry trade minimizes volatility, and therefore adopts a low volatility strategy. This optimized carry trade has a correlation to equity of 30% during volatile time periods[2].

The empirical results, which are adjusted by transaction costs, reveal that both optimized carry trades have an enhanced risk-return profile. This is captured by a larger Sharpe ratio and a reduced 95% Value-at-Risk.

We continue with an examination of the diversification effect of carry trades within an international multi-asset class portfolio. This portfolio consists of the traditional asset classes such as equity, bonds, real estate, and commodities and the non-traditional asset class carry trade. The portfolios' performance, adjusted by transaction and rebalancing costs illustrates that all carry trades provide an enhancement of the risk-return profile. These empirical findings are supported by test statistics, which examine the differences in performance measures and the

[1] By the recent financial crisis we refer to the global financial crisis and define it as having taken place from September 2007 to March 2009. In September 2007, S&P 500 had its peak and in March 2009 its nadir.

[2] We define volatile time as the time period, where the VIX Index is larger than 20%. The threshold 20% is chosen, as the historic average of the VIX Index is close to 20%.

shift of the mean-efficient frontier. The test statistic for mean-efficient frontier is based on the Mean-Variance Spanning (Huberman & Kandel, 1987) and a step-down test (Kan & Zhou, 2008). All test statistics for optimized carry trades are highly significant.

To demonstrate the robustness of our results, we investigate the sub periods of the past 16 years, and the period where the VIX Index is larger than 20%. Over these sub periods, the standard carry trade loses its positive contribution almost entirely. By contrast, optimized carry trades remain a significant enhancement of the risk-return profile and the mean-efficient frontier. In a second robustness analysis, we vary the size of the currency universe. The optimized carry trades in the previous analysis select currencies from the G10 universe. We now vary the currency universe, and order the currencies according to their liquidity. The smallest currency universe captures the four most liquid currencies. An optimized carry trade with these four currencies is already able to provide a significant diversification effect. This analysis reveals that a positive relationship exists between the size of the currency universe and a positive contribution to the portfolio. Overall, the optimized carry trade following a minimal volatility approach provides the largest contribution.

One of the most essential differences between standard and optimized carry trades is the absolute cumulative currency weight. This cumulative weight refers to each carry trade's cumulative exposure in the currency market. It demonstrates that optimized carry trades have a larger exposure in the currency market than standard carry trades. As carry trades are backed by cash, the cash position increases in a linear manner with exposure in the currency market. The cash position rises, and the remaining traditional asset classes receive less weight. Cumulative exposure of optimized carry trades in the currency market has an effect on the portfolio's weighting scheme. To ensure comparability, we norm the absolute cumulative weight, so that standard and optimized carry trades have the same absolute cumulative exposure.

Furthermore, we study carry trades as a potential cash overlay. Here, carry trades are backed by cash, with the result that the cash position provides a higher yield and, hence, an enhancement of the portfolio performance. The analysis reveals that optimized carry trades are able to significantly increase the annual return, while the differences in volatility are not significant. We conduct a robustness analysis for different portfolio compositions and find similar results.

To summarize, optimized carry trades offer a significant and, in particular, larger diversification effect than standard carry trades. This diversification effect is especially observable during time periods with larger volatility.

Our paper is closely related to the recent work showing the diversification effect of currency style investments (Kroencke et al., 2014) and carry trades (Barroso & Santa-Clara, 2015; Das et al., 2013). However, the diversification effect of optimized carry trades is neither economically nor statistically examined.

The rest of the paper is structured in the following way: Section 2 provides brief literature review. Section 3 introduces standard and optimized carry trades, the composition of the benchmark portfolios and measurement of the diversification effect. Section 4 presents the empirical results and the impact of the various carry trades on the benchmark portfolios. Section 5 draws conclusions.

2 Related literature

Ultimately, all investors aim to maximize their utility, and diversification increases the utility of the underlying portfolio. The positive contribution of diversification is well documented in the literature (see, for example, Grubel (1968), Levy and Sarnat (1970), French and Poterba (1991) or Christoffersen, Errunza, Jacobs, and Langlois (2012)). A diversification effect is directly linked to an enhancement of the risk-return profile of the underlying portfolio. Therefore, a close-to-zero correlation is a first indication that the considered asset, asset class or strategy has the potential to diversify. As correlation is time-dependent (Bollerslev, Engle, & Wooldridge, 1988), the diversification effect of the considered asset varies over time. Moreover, correlation is influenced by the economic market cycle (Baele & Inghelbrecht, 2009; Longin & Solnik, 1995). It is generally observed that correlation between assets increases sharply during times of financial stress. However, diversification is needed to counteract losses, particularly during financial stress. For example, an asset with a weak risk-return profile might have a larger diversification effect than an asset with a distinct Sharpe ratio. Investors therefore find diversification in small caps (Eun, Huang, & Lai, 2008) and real estate (Eichholtz, 1996), for example.

Diversified portfolios of institutional investors consist of equity, bonds, real estate, commodities and other forms of alternative investments. Furthermore, these portfolios are exposed to international assets. Again, the reason for the international expansion of the investment universe is diversification. Solnik (1995) demonstrates that foreign equity investments enhance the risk-return profile. While the purchase of foreign assets provides diversification, it simultaneously imports a certain amount of currency risk. In order to hedge currency risk, Froot (1993) suggests leaving the currency exposure unhedged. Perold and Schulman (1988), on the other side, propose a full hedge. Solnik (1974) reveals that a full hedge is optimal, only if equity and currencies are uncorrelated or their sensitivity is zero. Campbell et al. (2010) conduct a regression analysis and find that the sensitivities for some currencies are significantly different from zero. From a risk management perspective, they argue that a deviation from the full hedge is beneficial for the investor. Currency positions negative to their equity sensitivity significantly reduce the portfolio's volatility, independent of the investor's reference currency. Campbell et al. (2010) document a significant decline in volatility of approximately two percentage points, as their suggested currency exposure is a beneficial alternative to the full hedge. The applied risk-minimizing strategy purchases primarily U.S. dollar, Euro and Swiss franc and sells Australian dollar, New Zealand dollar, Canadian dollar, British pound and Japanese yen. The currencies that are sold, are mainly high-yield currencies. Selling high-yield currencies therefore seem to be contradictory here, as these currencies are traded at a premium. However, high-yield currencies are exposed to rare economic disasters (Farhi & Gabaix, 2015), which is why the strategy suggested by Campbell et al. (2010) aims to reduce the portfolio's sensitivity to extreme events. The investigation undertaken by Campbell et al. (2010) reveals that the currency exposure has a substantial impact on the risk-return profile of the associated portfolio.

Currencies in portfolio management are classified as a non-traditional asset class. Kroencke et al. (2014) study the diversification effect of foreign exchange (FX) style investments such as a currency momentum strategy. They state that FX style investments provide a diversification effect and cause a shift in the efficient frontier. Barroso and Santa-Clara (2015) add currency positions to a value weighted portfolio, and document an improved risk-return profile. However, the absolute cumulative exposure is approximately three times larger than the volume of the underlying portfolio. This means that each dollar invested in equity is opposed by three dollars in the currency market. The overall risk-return profile of the considered value weighted portfolio is therefore affected by currency positions in a number of ways.

Das et al. (2013) argue that standard carry trades have a diversification effect for a portfolio of institutional investors. They implement carry trades by a long-short currency portfolio plus an investment in treasury bills, or by an exchange traded fund (ETF). Levy and Lerman (1988) provide empirical evidence that bond positions have a significant diversification effect on equity portfolios. As carry trades are backed by bonds, including carry trades in a portfolio increases the number of purchased bonds, with the result that fixed income instruments are overweighted. Therefore, the diversification effect of Das et al. (2013) could be driven by three possibilities: First, the overweighting of bonds could cause a diversification, while the carry trade has no contribution. Second, only the standard carry trade itself could diversify a portfolio. Third, both components could enhance the risk-return profile of the underlying portfolio. The diversification effect of Das et al. (2013) could therefore be driven by the carry trade position, by a larger bond position, or by a joint effect of both components.

Nevertheless, carry trades are a speculative strategy, which profits from the violation of interest rate parity. Hence, the demand for foreign currencies is also sourced by speculative reasons, which is expressed in the Siegel paradox. This paradox summarizes a unique feature of the currency market. Exchange rates – foreign over domestic, and domestic over foreign currency result simultaneously in a positive expected return (Siegel, 1972). For example a U.S. investor expects a positive expected return on Japanese yen over U.S. dollar, while a Japanese investor perceives, at the same time, a positive expected return on U.S. dollar over Japanese yen. This puzzle of a simultaneous positive expected return leads to a symmetric currency demand of investors independent of the reference currency. Furthermore, Siegel (1972) states that the expected anticipated spot rate at time $t + 1$ is larger than the forward rate with maturity at time $t + 1$, with the result that foreign currency positions are profitable.

The Siegel paradox, as well as the associated violation of the interest rate parity forms the forward premium puzzle (Engel, 1996; Fama, 1984) and the basis for carry trades. If the uncovered interest rate parity were to hold, then the expected profit of carry trades would be zero. However, empirical evidence reveals that carry trades have an annual return of approximately 1.5%, with a standard deviation of 5% (Burnside, Eichenbaum, & Rebelo, 2011; Clarida, Davis, & Pedersen, 2009; Wagner, 2012). Brunnermeier et al. (2008) state that the positive return compensates for currency crashes, which is quantified by a negative skewness. Moreover, carry trades are exposed to peso events (Burnside, Eichenbaum, Kleshchelski, & Rebelo, 2011)[3]. The peso problem refers to catastrophic events. For example, high-yield currencies have the ability to "*go up by stairs and down by the elevator*" (Brunnermeier et al., 2008, p.4). As the carry trade strategy purchases high-yield currencies, a sharpe and sudden depreciation of these currencies leads into losses of carry trades. Such a depreciation typically occurs in times of financial stress. Menkhoff, Sarno, Schmeling, and Schrimpf (2012) therefore find a negative relationship between high-yield currencies and innovations in global FX volatility. Consequently, this leads to small returns in times of unexpected high volatility. In order to explain the returns of carry trades, Burnside, Eichenbaum, and Rebelo (2011) investigate the traditional risk factors for carry trades. One of their main conclusions is that traditional risk factors, such as equity market return are not able to explain a significant proportion of carry trade returns. Christiansen, Ranaldo, and Söderlind (2011) examine the time-varying systematic risk consumption of carry trades. They document a mean reverting behavior of carry trades during regimes of high FX volatility. Carry trades therefore provide smaller returns, during periods of greater volatility.

Overall, it is at least true to say that the positive returns of carry trades compensates for currency crashes, peso events, global FX volatility and systematic risk.

3 Carry Trades and Global Portfolio

We define a carry trade as a zero investment strategy in the FX market. Therefore, we assume that the cumulative sum of all currency weights is equal to zero only at settlement date.

[3] A peso event is a low probability event, which does not occur in the observation period.

3.1 Standard and optimized carry trades in a multi-asset class portfolio

A standard carry trade employs an equal weighting scheme. Funding and investment currencies are selected according to their implied interest rates, and high- and low-yield currencies are therefore purchased and sold, respectively. The aim is to capture the interest rate differential of the chosen currencies.

A standard carry trade with one funding and one investment currency is constructed as follows: Let us suppose that, the investor's universe encompasses n currencies. Let $F_{t,t+1}^{low}$ ($F_{t,t+1}^{high}$) be the one-period forward rate between t and $t+1$ with the lowest (highest) implied interest rate. S_t^{low} (S_t^{high}) is the corresponding spot exchange rate at time t. The return of the funding (investment) leg at $t+1$ equals

$$r_{t+1}^{fund} = 1 - \frac{F_{t,t+1}^{low}}{S_{t+1}^{low}} \qquad \left(r_{t+1}^{inv} = \frac{F_{t,t+1}^{high}}{S_{t+1}^{high}} - 1 \right). \tag{1}$$

Following Bakshi and Panayotov (2013), the return of this standard carry trade is defined as

$$r_{t+1}^{(1)} = \frac{r_{t+1}^{fund} + r_{t+1}^{inv}}{2}, \tag{2}$$

i.e. the funding leg of the carry trade exclusively finances the investment leg of the carry trade. The described carry trade refers to $r_{t+1}^{(1)}$ and is called standard carry trade No.1, as one funding and one investment leg are involved. Under this construction, funding and investment leg always occur in pairs. More generally, $\mathcal{N}$ currency pairs, i.e. $\mathcal{N}$ funding and $\mathcal{N}$ investment legs, set up the standard carry trade No. $\mathcal{N}$. The return of standard carry trade No. $\mathcal{N}$ equals:

$$\bar{r}_{t+1}^{(\mathcal{N})} = \frac{1}{\mathcal{N}} \sum_{i=1}^{\mathcal{N}} r_{t+1}^{(i)} \text{ and } r_{t+1}^{(i)} = \frac{r_{t+1}^{fund_i} + r_{t+1}^{inv_i}}{2}, \tag{3}$$

where $r_{t+1}^{fund_i}$ ($r_{t+1}^{inv_i}$) is the return of the funding (investment) leg with the i^{th} lowest (highest) implied yield at the end of month t. Standard carry trades have a symmetric weighting scheme, as the weight given to each currency and the number of funding and investment currencies are identical. The currency selection process of standard carry trades disregards any risk component or other currency characteristics.

By contrast, optimized carry trades are constructed based on an optimized weighting scheme. The first optimized carry trade tracks a benchmark carry trade as closely as possible, with the constraint of a minimal interest rate delta. Suppose, r_B is the return of the benchmark carry trade. Then, the optimization is formulated as

$$\begin{aligned}\omega^* = argmin_\omega\Big(\sigma^2(\omega r - r_B)\Big) &\text{ such that} \\ i'_{foreign}\omega &\geq i_{target} \\ \mathbb{1}_{1\times n}\omega &= 0,\end{aligned} \tag{4}$$

where $\sigma^2(\cdot)$ refers to the corresponding standard deviation, r is the currency return defined in Equation (1). $i_{foreign}$ is a $n \times 1$ vector of foreign implied interest rates and i_{target} equals the mean of the maximal interest rate delta[4] at optimization time, i.e.

$$i_{target} = \frac{\max\left(i_{foreign}\right) - \min\left(i_{foreign}\right)}{2}. \tag{5}$$

The second optimization constraint $\mathbb{1}_{1\times n}\omega = 0$ ensures that the cumulative currency weights equal zero, so that the optimized carry trade is a zero-investment strategy, like the standard carry trades. As the returns of investment and funding legs deviate only by their sign (Equation (1)), a positive (negative) weight of ω^* is associated with an investment (a funding) leg. This carry trade is called the Tracking Error (TE) carry trade.

The second proposed optimized carry trade minimizes the volatility of the currency positions, and the optimization is formulated as

$$\begin{aligned}\omega^* = argmin_\omega\Big(\omega'\Sigma\omega\Big) &\text{ such that} \\ i'_{foreign}\omega &\geq i_{target} \\ \mathbb{1}_{1\times n}\omega &= 0,\end{aligned} \tag{6}$$

where Σ is the covariance matrix of the investment leg returns. This carry trade is called the Minimal Volatility (MinVol) carry trade.
It is important to mention that both optimization approaches are based on historical observations, and the covariance matrix and the tracking error are therefore estimated on a historical window of length ws. $i_{foreign}$ and i_{target} are observed at time t. Hence, we apply the optimizations in an out-of-sample setting. This means that at time t we consider only historical observations which are available at time t. The estimates for ω^* are applied for the time period between t and $t+1$.

We now turn to the integration of carry trades into a multi-asset class portfolio. As carry trades follow a zero-investment strategy, their net investment is zero. Thus, we assume an

[4] We use the mean as the standard carry trades allocate 50% to the funding and investment sources. This is illustrated in Equation (2).

investment in cash equal to the absolute exposure of the carry trade[5]. The carry trade is therefore backed by an investment in a risk-free asset. The return of a carry trade and a simultaneous investment in a risk-free asset equals:

$$r_{CT} = \omega_{CT}\Big(\frac{F}{S} - 1\Big) + \mathbb{1}_{1\times n}|\omega_{CT}|r_f, \tag{7}$$

where ω_{CT} denotes the weights given to each currency of the associated carry trade, and $|\omega_{CT}|$ is the absolute value of ω_{CT}. r_f equals the risk-free rate of Fama and French (1993).

Lastly, each trading action causes either transaction or rebalancing costs. Transaction costs occur for carry trades. We define the transaction costs of currency i at time t as

$$TC_{i,t} = \frac{F^{ask} - F^{bid}}{F^{ask} + F^{bid}}. \tag{8}$$

The transaction costs are half of the bid-ask spread, and are expressed in percentage. This calculation overestimates the transaction costs, as the effective costs are smaller than half of the bid-ask spread (Mancini, Ranaldo, & Wrampelmeyer, 2013). Furthermore, this calculation assumes that the investor buys (sells) the currency forward contract at the ask (bid) quote and settles the contract at the next month's mid-quote.
Rebalancing costs occur for trading actions of traditional asset classes. Each trading action costs 50 basis points (bps) relative to its reallocated volume.

3.2 Economical and statistical evaluation

The diversification effect is measured both economically and statistically. The economic diversification effect is quantified by the first four moments of the portfolio return, measures for tail risk, and the risk-adjusted return. The statistical significance is investigated by the Mean-Variance Spanning test (De Roon, Nijman, & Werker, 2001; Huberman & Kandel, 1987) and a step-down test (Kan & Zhou, 2008).

The Mean-Variance Spanning test examines whether J additional assets can evoke a shift in the mean-efficient frontier of K benchmark assets. The test assumes frictionless markets and runs the following OLS regression:

$$r_t = \alpha + \beta R_t + \varepsilon_t, \tag{9}$$

where r_t refers to the return of the additional asset class and R_t denotes the yield of the

[5]It would be also possible to implement carry trades in a portfolio via margins. As margins leverage the return by the inverse of the applied margin, the risk-return profile of carry trades is shifted linearly. This would lead to the same empirical conclusion.

traditional asset classes, respectively. $\alpha \in \mathbb{R}^J$ is a constant vector. ε denotes a J-dimensional random variable with $\mathbb{E}[\varepsilon_t] = 0$. The slope coefficient β equals a $J \times K$ matrix. Furthermore, it is assumed that the usual assumptions with respect to OLS regressions are applied, and that the returns are independent and identically distributed.

The Mean-Variance Spanning test has the null hypothesis that the K benchmark assets have the same span as the combination of the $J + K$ additional and benchmark assets together. The null hypothesis is equivalent to

$$\alpha = 0 \text{ and } \psi = \mathbb{1}_{J\times 1} - \beta \cdot \mathbb{1}_{K\times 1} = 0_{J\times 1}. \tag{10}$$

$\mathbb{1}_{J\times 1}, (\mathbb{1}_{K\times 1})$ equals a J (K)-dimensional unit vector. To test this null hypothesis, we run a correlated Huberman and Kandel (1987) F-test, which examines the joint null hypothesis.

Our empirical analysis is based on an international multi-asset class portfolio. Therefore, the investment universe encompasses eight traditional asset classes, i.e. domestic equity, domestic small caps, international (developed markets) equity, emerging market equity, real estate, commodities, cash and fixed income. Carry trades are added to the investor's universe, as a non-traditional asset class. The K benchmark assets are the eight assets representative of the traditional asset classes. Carry trades are considered as an additional asset class, with the result that J equals one.

The step-down test investigates the improvement of the tangency and minimum-variance portfolio separately, and divides the joint hypothesis into two examinations. First, the enhancement of the tangency portfolio is tested, i.e. it is examined whether $\alpha = 0$. Second, based on the statistical test result of the tangency portfolio, the improvement of the minimum-variance portfolio is discussed. This means that $\mathbb{1}_{N\times 1} - \beta \cdot \mathbb{1}_{K\times 1} = 0_{N\times 1}$ given $\alpha = 0$ is examined.

The correlated F- and step-down test assume usual conditions, which are frequently violated in empirical data. In order to deal with absence of homoscedasticity, we run two asymptotic Wald tests under conditional heteroscedasticity.

4 Empirical results

The collected data consist of monthly time series from January 1985 until December 2016. They are provided by Barclays and Reuters, and are available on ThomsonReuters Datastream. The prices are closing, end of month, and quoted in U.S. dollar, as it is assumed we are dealing with a U.S. investor. The currency universe for all carry trades is Australian dollar (AUD), British pound (GBP), Canadian dollar (CAD), Euro (EUR), Japanese yen (JPY), New Zealand dollar (NZD), Norwegian krone (NOK), Swedish krona (SEK), and Swiss franc (CHF). The time series of the Euro before 2000 equals a synthetic Euro exchange rate, which is calculated by the method suggested by the Bank of England (2015). The traditional asset classes consist of domestic equity (represented by the MSCI USA), international equity (MSCI EAFE), emerging market equity (MSCI EM), commodities (S&P GSCI Commodity), REITS (FTSE/Nareit All REITs), government bonds (Barclays U.S. Government Index) and corporate bonds (Barclays Aaa U.S. Corporate Index).

Table 1 reflects the summary statistic of traditional asset classes (Panel A), carry trades (Panel B), and their correlations (Panel C) from January 1988 to December 2016. The shorter observation period is due to the fact that optimized carry trades require historical observations to estimate the necessary parameters. The estimation window to determine the optimal weighting scheme is therefore 36 months[6].

Domestic and international equity have annual excess returns of 7.76% and 3.53% with a standard deviation of 14.33% and 17.06%, and a Sharpe ratio of 0.54 and 0.21, respectively. Government bonds are low volatility assets, with a standard deviation of 4.23% and a Sharpe ratio of 0.68, respectively[7].

Consistent with Bakshi and Panayotov (2013), standard carry trades have an annual return of between 2.20% and 2.57%, and the risk-adjusted return is in the range of 0.38 to 0.52. A diversification effect within standard carry trades is observable as the volatility and tail risk decline, while the Sharpe ratio rises as the number of currencies involved increases. Furthermore, all standard carry trades feature a negative skewness, which is an indicator of crash risk (Brunnermeier et al., 2008). The crash risk also reduces as the number of currency pairs involved increases, as the standard carry trades No.1 and No.3 have a skewness of -1.20 and -0.58, respectively. This crash risk has been compared to "*picking up pennies in front of a truck* (Burnside, Eichenbaum, & Rebelo, 2008, p.586)", as standard carry trades provide positive returns over a long period, but market turbulence could result in catastrophic losses.

An examination of optimized carry trades (Table 1, Panel B) in an out-of-sample setting reveals that TE carry trade has a Sharpe ratio of 0.54, which is similar to its tracked carry trade[8]. However, a remarkable differences exist in the higher moments. TE carry trade has a skewness of -1.61. This means that, in economic terms, this optimized carry trade has a greater crash risk than its tracked carry trade. This therefore reflects a larger tail risk when measured by the Value-at-Risk 95%. The MinVol carry trade has a Sharpe ratio of 0.67, which is the highest figure among all carry trades examined.

Panel C of Table 1 depicts the correlation matrix between traditional asset classes and carry trades. Standard and TE carry trades have a correlation with domestic and international

[6]In the subsequent analysis we assume an estimation window of 36 months to calculate the optimal weighting scheme. In a robustness analysis we vary the length of the estimation window.

[7]The summary statistics for the remaining traditional asset classes are presented in the internet appendix.

[8]The optimization approach of TE carry trade requires a benchmark carry trade to track. We select standard carry trade No.3 as the tracked carry trade We exchange the tracked carry trade in one of our robustness analyses.

equity of approximately 30%. MinVol carry trade is maximally correlated at 8%.
The correlation matrix and the summary statistics strongly indicate a potential diversification effect of carry trades. As the MinVol carry trade captures the smallest relation to traditional asset classes, a larger diversification potential seems to exist. Furthermore, MinVol carry trade is correlated to other carry trades by only ≈65%. This indicates that a deviating weighting scheme from the standard carry trade causes a substantially different behavior.

4.1 Diversification effect over the entire sample period

The benchmark portfolio is equally invested in all traditional asset classes, such that each component has a weight of 1/8. Adding a carry trade as a non-traditional asset class to the benchmark portfolio, each portfolio component has an initial weight of 1/9.

Panel A of Table 2 illustrates the portfolio performances and their significance tests of the benchmark portfolio, with and without carry trades, over the entire sample period. All summary statistics are adjusted by transaction and rebalancing costs.
Over the entire sample period from January 1988 to December 2016, the benchmark portfolio has an annual volatility of 8.56%, with a Sharpe ratio of 0.52 and a certainty equivalent of 6.15%. The monthly Value-at-Risk 95% equals -3.24%. We select standard carry trade No.3 as representative of the standard carry trades[9]. The benchmark portfolio, including standard carry trade No.3, has a volatility of 7.81% and a Sharpe ratio of 0.53. The portfolio's risk-return profile is therefore slightly improved. The difference in volatility with respect to the benchmark portfolio is significant. Simultaneously, the return is reduced significantly by 31bps to 4.10%. The Value-at-Risk 95% is improved, and equals -2.86%. The Jensen-α is not significantly different from zero, and therefore the improvement doe not result in a significantly positive risk-free return. These empirical findings are in line with Das et al. (2013). Statistically, the investigation reveals that standard carry trades are not able to increase the risk-return profile of an equally weighted portfolio. The main contribution of a standard carry trade is to reduce volatility. However, the diminished standard deviation is driven by the increased cash position required to back a carry trade, and the smaller volatility of a standard carry trade, which is below the portfolio's overall standard deviation. Therefore, the first result is that standard carry trades have a small contribution to make for an equally-weighted investor.
In contrast to standard carry trades, the TE carry trade is able to increase the excess return to 4.81%, while reducing the volatility to 7.46%. Consequently, the Sharpe ratio hikes to 0.65. The differences in both Sharpe ratio and volatility are significant. The Jensen-α equals 1.03% and is significant. Consistent with this, the certainty equivalent increases to 6.96%, which

[9] In a robustness analysis we demonstrate the influence of other standard carry trades on the benchmark portfolio.

is 81bps higher than the certainty equivalent of the benchmark portfolio. Hence, a dynamic weighting scheme results in a significant enhancement of the underlying portfolio.
Adding a MinVol carry trade to the benchmark portfolio has an even stronger effect than the TE carry trade. The benchmark portfolio with MinVol carry trade provides an annual return of 4.90%, a standard deviation of 7.19%, and a Sharpe ratio of 0.69. All differences find statistical evidence. Furthermore, the Jensen-α is 1.26%, and significant.
This investigation reveals that optimized carry trades are able to enhance risk-return profile significantly.

Panel A of Table 2 also provides the test statistics of the Mean-Variance spanning and step-down tests. Both tests examine the impact of carry trades on the mean-efficient frontier. Generally speaking a diversification is achieved if there is a significant shift in the mean-efficient frontier towards northwest. Such a shift can be brought about by an improvement in the minimum-variance or tangency portfolio. The correlated Huberman and Kandel (1987) F-Test examines a general improvement of the mean-efficient frontier. All examined carry trades are able to reject the null hypothesis, and each carry trade therefore has a significant impact on the mean-efficient frontier. The Mean-Variance spanning test under conditional heteroscedasticity provides similar results. We find significant results for the step-down test in the case of all carry trades examined, and are therefore able to document a significant improvement in the minimum-variance and tangency portfolio.
This statistical examination reveals that carry trades cause a significant shift in the entire mean-efficient frontier, and have an effect on the minimum-variance and tangency portfolio. All examined carry trades therefore enhance the risk-return profile of the benchmark portfolio. Moreover, in contrast to standard carry trades, optimized carry trades do not significantly reduce the annual return. However, Mean-Variance spanning and step-down tests examine the binary impact of the carry trade concerned on the benchmark portfolio. These test statistics therefore do not indicate the extent of influence on the mean-efficient frontier.

4.2 Diversification effect during sub periods

Figure 1 illustrates the time-varying correlation between domestic equity and carry trades. The displayed correlations fluctuate strongly, with the result that the diversification effect seems to be time-varying. The correlation coefficients are calculated on a 24 month rolling window. An inspection of the plot reveals that standard, TE, and MinVol carry trades have a diverse time-varying correlation. This time-varying correlation allows three potential conclusions. First, TE and standard carry trades have a similar time-varying behavior. This observation is to be expected, due to construction of the TE carry trade. Second, MinVol carry trades display a diverse behavior, particularly between 2007 and 2013, which is the period of the recent financial crisis and the European debt crisis. Here, MinVol carry trades reduce their correlation to domestic equity, while standard and TE carry trades increase their correlation to domestic equity. This is particularly noticeable during the recent financial crisis. It indicates a potential diversification effect of MinVol carry trades under financial stress, and a reduced exposure to rare economic disasters (Farhi & Gabaix, 2015). Third, all carry trades have a similar correlation from 1992 to 1995 and from 2003 to 2007. In these periods volatility is reduced. MinVol carry trades therefore have a similar correlation during low volatility periods, but display considerable differences during high volatile periods. The correlation analysis suggests that the MinVol carry trades provide a larger diversification potential compared to the other examined carry trades.

We now split our overall sample period into two equal parts. Panel B of Table 2 reports the portfolio performance and the corresponding test statistics for January 2001 to December 2016, i.e. the second half of the sample. The time period between 2001 and 2016 is of considerable economic interest, as several crises took place, for example the dot-com bubble and the recent financial and European debt crisis. Furthermore, it also covers the unconventional measures taken by central banks, which influenced and reduced the difference in interest rates between economic areas. Consequently, as the interest rates between currencies converge on one another, the interest rate delta of standard carry trades narrows, with the result that that one of carry trades' main return component decreases.

The benchmark portfolio in the period between January 2001 and December 2016 has an excess return of 5.05%, a volatility of 9.83%, a Sharpe ratio of 0.51, and a certainty equivalent of 4.44%. Adding a standard carry trade to the benchmark reduces the portfolio's volatility to 9.02%, and the return decreases to 4.51%, with a Sharpe Ratio of 0.50. The certainty equivalent therefore declines to 4.22% and the Jensen-α equals 0.04%. The standard carry trade is not able to enhance the risk-return profile in economic terms, and the positive contribution of the standard carry trades is generated primarily before 2001[10]. Nevertheless, the Mean-Variance spanning test indicates a positive contribution on the mean-efficient frontier. The improvement of the mean-efficient frontier is driven primarily by the minimum-variance portfolio.

We now turn to the empirical results of optimized carry trades. The optimized carry trades stand in stark contrast to the standard carry trades. In each case, adding MinVol or TE carry trade to the benchmark causes an enhancement of the risk-return profile with respect to the benchmark. The improvements find statistical evidence. Four observations need to be mentioned here. First, including one of the optimized carry trades in the benchmark leads to a reduction in annual excess return of approximately 30bps. However, the test statistics for the differences in excess return are insignificant. Second, each optimized carry trade reduces the portfolio's volatility by at least 117bps. This means that adding MinVol (TE) carry trade

[10]The internet appendix contains the portfolio performances between January 1988 and December 2000.

to the benchmark, the portfolio's standard deviation equals 8.26% (8.66%). Third, MinVol (TE) carry trades increase the Sharpe ratio to 0.57 (0.55). Furthermore, MinVol (TE) carry trades have a significant Jensen-α of 0.62% (0.45%). The positive contribution of each optimized carry trade is also noticed at a significant shift of the mean-efficient frontier, caused by an enhancement of the minimum-variance and tangency portfolio. Fourth, MinVol carry trades provide, in economic terms, the largest enhancement of the risk-return profile. The return-loss function equals -79bps[11]. This means that the excess return of the benchmark with MinVol carry trades is 79bps larger than the benchmark under the assumption of same volatility. Hence, the MinVol carry trades have the largest quantity of the return-loss function among the examined carry trades.

We now discuss the portfolio performances during higher financial market stress. Panel C of Table 2 reports the portfolio performance and the corresponding test statistics for the time period when the VIX Index exceeds 20%[12]. The benchmark portfolio posts a loss of -2.53% with a volatility of 10.97%, and a the Sharpe ratio of -0.23. Adding a standard carry trade to the benchmark portfolio causes only minor enhancements. Therefore, in economic terms, a standard carry trade provides a negligible impact − which is also borne out by a insignificant Jensen-α of 0.07%. Again, optimized carry trades have a significant positive influence on the benchmark portfolio. Adding the TE (MinVol) carry trade to the benchmark reduces the loss to -1.30% (-0.99%) and the volatility to 9.56% (9.11%). The corresponding Sharpe ratio increases significantly to -0.14 with the TE carry trade, and to -0.11 with the MinVol carry trade. The Jensen-α equals 0.89% and 1.09 for the TE and MinVol carry trades, respectively. All improvements are significant. Furthermore, the return-loss function of TE (MinVol) carry trades is -89bps (-109bps). Both optimized carry trades enhance the mean-efficient frontier and in particular the minimum-variance and tangency portfolio.

This analysis clearly reveals that all carry trades have a positive impact on the benchmark portfolio and provide a positive diversification effect. However, only optimized carry trades are able to enhance the risk-return profile of the underlying portfolio significantly. This demonstrates that a deviation from the rigid weighting scheme of a standard carry trade adds positive value. Furthermore, it seems that a positive relation exists between the freedom to modify the weighting scheme of a standard carry trade and the diversification effect of the optimized carry trade. This is confirmed, as the TE carry trade has a smaller economic impact on the

[11] The return-loss function is introduced by DeMiguel, Garlappi, and Uppal (2009). It examines the differences in return of a test portfolio and its benchmark under the assumption of the same volatility. The return-loss function equals

$$RL = \frac{\sigma_P}{\sigma_B} \cdot \mu_B - \mu_P, \tag{11}$$

where σ_P (σ_B) and μ_P (μ_B) denotes the volatility and average excess return of the test portfolio (benchmark).

[12] The average of the VIX Index between 1986 and 2016 is approximately 20%. Thus, we set the threshold to 20% to capture the time period with an enlarged stress level.

underlying portfolio than the MinVol carry trade. Over all examined time periods, MinVol carry trades provide the largest economic diversification effect.

4.3 Currency universe, estimation length, and tracked carry trade

In the last two subsections we studied optimized carry trades which employ the entire currency universe of nine foreign currencies. We now vary the composition of the currency universe. This examination reduces the number of available currencies, and discusses the impact between currency universe and the positive contribution of carry trades. We follow the Bank for International Settlements (2016), and rank the currencies according to the market turnover, i.e. Euro, Japanese yen, British pound, Australian dollar, Canadian dollar Swiss franc, Swedish krona, New Zealand dollar and Norwegian krone. This ranking is fixed over the entire sample period, i.e. from January 1986 to December 2016. This order of currencies has a look-ahead bias, as in 1986, for example, there was no obvious reason for a unique European currency. However, one can argue that from today's perspective, this sorting is plausible.

Table 3 illustrates the benchmark portfolio with and without carry trades. As a first step, we restrict the currency universe to the four most liquid currencies, i.e. Euro, Japanese yen, British pound, and Australian dollar. Adding TE or MinVol carry trade to the benchmark portfolio causes a significant enhancement of the risk-return profile. The TE (MinVol) carry trade increases the Sharpe ratio to 0.55 (0.57), and reduces the portfolio volatility to 7.83% (7.68%), respectively. By comparison, the benchmark portfolio has a Sharpe ratio of 0.52 and a volatility of 8.56%. Both improvements find statistical support. However, a positive relation seems to exist between the available currencies and the risk-return enhancement, i.e. the larger the currency universe, the more distinct the enhancement in the risk-return profile. Therefore, the Jensen-α and the return-loss function have a positive relationship with currency universe. The increase in the Sharpe ratio and certainty equivalent is driven by a constantly declining volatility and an almost linear increase in excess return. This observation is consistent with the liquidity premium in currency markets (Engel, 1992). Our empirical examination reveals that the size of the available currency universe has an impact on the diversification effect. Nevertheless, a currency universe of the four most liquid currencies is sufficient to provide a significant diversification effect.

We also investigate a deviating currency universe of standard carry trades. Table 3 illustrates the performance of the benchmark with different standard carry trades. The examination reveals that all standard carry trades create a significant decline in annual return and volatility and increase the Sharpe ratio marginally. The investigation reveals that varying currency universes do not have an impact on the diversification of standard carry trades.

The construction of optimized carry trades requires a certain estimation window. So far, we assume that the estimation window has a fixed length of 36 months. We now examine the impact of the length of the estimation window on the diversification effect. Table 4 reflects the portfolio performance, with different lengths of estimation window of the benchmark portfolio with TE or MinVol carry trade[13]. Panel A (Panel B) assumes a currency universe for optimized carry trades of the four most liquid (all available) currencies. The empirical results demonstrate that a deviating estimation window has a marginal impact as all economic measures only vary on the second digit. The documented diversification effect of TE and MinVol carry trade is therefore robust against a varying length of estimation window. The analysis reveals robust results with respect to various estimation windows and the variation of the currency universe. For the subsequent analyses, we set therefore the length of the estimation window to 36 months and consider the entire currency universe.

4.4 Volume of optimized carry trades

We now turn to the discussion of the volume of carry trades. By our definition of standard carry trades, the absolute cumulative currency weight equals one, as half of a U.S dollar is invested and funded in high- and low-yield currencies, respectively. Figure 2 reflects the time-varying absolute cumulative weight of optimized carry trades. The varying absolute cumulative weight of optimized carry trades is due to construction, as the optimization approach requires only a zero-investment strategy, and makes no assumption about the absolute cumulative weight. The main observation of this plot is that the average absolute cumulative weight for both optimized carry trades is larger than one. TE and MinVol carry trades have an average volume of 1.86 and 1.88, respectively. Therefore, the average demand for forward contracts is \$1.86 and \$1.88. This finding influences the composition of the underlying portfolio, as carry trades are backed by a risk-free asset, and that the volume of the risk-free asset and the absolute exposure of the carry trade are equal. For purposes of illustration, let us examine the following example: The initial portfolio weight of carry trades is 10%. As standard carry trades have an absolute cumulative weight constant to one, these carry trades have a constant portfolio weight of 10%. Optimized carry trades have a larger volume, and are represented by an average portfolio weight of 18.6% or 18.8%, respectively. With respect to the initial portfolio weighting, carry trades are overweighted, while the traditional asset classes are underweighted. Each traditional asset class has an average weight of approximately 9%. Such an active underweighting causes trading actions, which go along with rebalancing costs. The associated costs are already incorporated in the previous analyses, and the positive economic contribution is already adjusted by the trading activity. We therefore norm the exposure of each optimized carry trade, so that the demand for forward contracts equals one. Consequently, the portfolio weights are constant with normed optimized carry trades.

[13]The differences between the results in Table 2 and 4 are caused by different observation periods.

4.5 Carry trades as cash overlay

The normed optimized and standard carry trades differ only in the relative weighting of currencies, as the absolute cumulative currency weight of each carry trade equals one. Originally, we introduce carry trades as a non-traditional asset class. The assumption is that cash is a risk-free asset, and captures the risk-free rate. As one asset of our equally weighted portfolio is cash, we consider this cash position to back carry trades. Therefore, carry trades now act as a cash overlay to increase the return contribution of cash.

Table 5 reflects the portfolio performances for carry trades as cash overlay. Panel A illustrates the performance of an equally weighted portfolio. Using a standard carry trade as cash overlay increases the excess return significantly by 21 bps to 4.62%. The cash overlay leads to a rise in volatility, but the difference is not significant. Consequently, the additional risk is compensated by an increase in Sharpe ratio and certainty equivalent, which is equal to 0.53 and 6.28%, respectively. Consistent with this, the cash overlay has a Jensen-α of 0.10%. However, the Jensen-α and the increase in Sharpe ratio are not significant, and the cash overlay with a standard carry trade is of an economic nature only, and finds no statistical evidence. Das et al. (2013) also investigate the diversification effect of standard carry trades, and it seems that their documented diversification effect is economic in nature, and does not enhance the risk-return profile statistically.

We now turn to the discussion of TE and MinVol carry trades as cash overlay. Both optimized carry trades provide a similar contribution in economic terms. TE and MinVo carry trades significantly increase the excess return to 4.58%, and the Sharpe ratio to 0.53. However, the TE carry trade as a cash overlay causes an insignificant Jensen-α of 0.10%, while the Jensen-α with the MinVol carry trade is significant and equals 0.15% Additionally, the return-loss function for the MinVol carry trade is 12bps, which is the highest figure among all cash overlays.

So far, we always assume an equally weighted benchmark. However, Coval and Moskowitz (1999) document that investors prefer to purchase domestic assets, so that their portfolios have a home bias. Panel B of Table 5 therefore indicates the portfolio performance of an international portfolios with a home bias. We assume the following portfolio composition for this investor: Domestic equity 35%, domestic government and domestic corporate bonds 30%, cash 15% and the remaining traditional asset classes – i.e. real estate, commodities, international and developed equity – 5%. The benchmark portfolio has an excess return of 4.60%, a volatility of 7.39%, and a Sharpe ratio of 0.62. Using a standard carry trade as cash overlay increases the annual return significantly to 4.85%. Volatility and Sharpe ratio increase to 7.65% and 0.64, respectively.

The TE and MinVol carry trades, as a cash overlay have a similar economic contribution. The MinVol (TE) carry trade increases the excess return significantly to 4.80% (4.81%). However, only the cash overlay with the MinVol carry trade increases the Sharpe ratio significantly to 0.65 and displays a significant Jensen-α of 0.17%.

As a robustness test we also examine an investor who is invested only in his domestic market. First, we consider a 20-80 investor, whose portfolio consists of 20% domestic equity and 80% fixed income investments. We split the fixed income position into 60% in government bonds and 20% in cash. Second, an 80-20 investor is assumed, i.e. 80% domestic equity and 20% fixed income. The fixed income is divided into 15% government bonds and 5% cash. The portfolio performances are illustrated in Table 5. Both examinations reveal that all carry trades are able to improve the benchmark portfolio though cash overlay. However, only the MinVol carry trade can enhance the risk-return profile significantly.

Overall, this investigation reveals that MinVol carry trades are able to robustly enhance the risk-return profile of the underlying benchmark through cash overlay. This improvement is observed at a significant higher annual return, a significant higher Sharpe ratio and a significantly positive Jensen-α. Comparing the contribution with other carry trades as cash overlay, the MinVol carry trades clearly outperform the others. MinVol carry trades therefore provide a significant and a large contribution to all simulated investment preferences.

5 Conclusion

Investors seek alternative asset classes to enhance the risk-return profile of their portfolio and to realize a larger diversification. This paper investigates the diversification effect of standard and optimized carry trades. The first suggested optimized carry trade strategy aims to minimize the tracking error of a standard carry trade, while the second carry trade strategy minimizes volatility.

We consider carry trades as a new asset class, and add these strategies to our investment universe. We demonstrate that carry trades enhance the risk-return profile of the underlying portfolio, and that this improvement is driven primarily by a reduction in portfolio volatility. Over the entire sample period, the past 16 years, and during periods with greater volatility, optimized carry trades provide a sound diversification effect. This observation is based on the significant improvement of the mean-efficient frontier, a significant positive Jensen-α, a significant increase in Sharpe ratio, and a significant decline in volatility. By contrast, standard carry trades only offer a significant reduction of volatility and annual return over the entire sample period. Standard carry trades are not able to enhance the risk-return profile significantly. The analysis reveals that optimized carry trades are able to capture a significant diversification effect. MinVol carry trades, in particular, provide a diversification effect during

all examined time periods, and specially during periods with exceedingly high volatility.
We continue with an analysis of the currency universe and design optimized carry trades, where currencies are pre-selected according to their corresponding market turnover. The smallest evaluated optimized carry trade contains the four most liquid currencies. These carry trades display a robust contribution under varying currency universes. Moreover, we find a positive relationship between cardinality of currency universe and the diversification effect, i.e. the larger the currency universe, the more distinct the enhancement of the risk-return profile.
We continue with an analysis of the absolute cumulative exposure of optimized carry trades. There, we find that the absolute exposure of optimized carry trades is larger and more time-varying than the exposure of standard carry trades. This time-varying exposure of optimized carry trades has an impact on the remaining portfolio weights, as carry trades require an investment in a risk-free asset. The larger the investment in the risk-free asset, the less capital is left to purchase traditional asset classes. Therefore, the time-varying exposure of optimized carry trades leads to an adjustment of the overall portfolio composition, so that the portfolio weights fluctuate over time. The initial portfolio weights therefore form the realized weights. Thus, we norm the optimized carry trades so that their absolute cumulative exposure is equal to one, and the carry trades do not lead to a rebalancing of other assets. Furthermore, we employ carry trades as a cash overlay strategy. The idea of overlaying a cash position with a carry trade is to increase the return of the cash position. In economic terms, all carry trades employed as cash overlay enhance the risk-return profile of the underlying portfolio. This improvement is driven by an enlargement of the annual return, which is significant for all examined carry trades. Simultaneously, the portfolio's volatility increases marginally. This observation is examined for different portfolio strategies. However, only the contribution of the MinVol carry trade is supported by statistical evidence. Furthermore, this carry trade provides the largest enhancement measured by the Jensen-α and Sharpe ratio.

Our study reveals that the MinVol carry trade has several positive characteristics. First, over all examined periods, the MinVol carry trade has the ability to provide diversification. Second, the MinVol carry trade is applicable as a cash overlay, and provides a positive return contribution. Third, it is less correlated to traditional asset classes over the entire sample period and especially during periods with greater volatility. This diversification effect is larger than that of effect with standard and TE carry trades.

Our findings are helpful for portfolio and asset managers. The MinVol carry trade causes a lower portfolio volatility over the whole sample period for all underlying investment philosophies. During periods of higher volatility, when diversification is especially required, this carry trade demonstrates a significant reduction in losses. On the other hand, the MinVol carry trade can be adopted as a cash overlay strategy. There, the MinVol carry trade significantly increases the contribution of the cash position. Overall, the MinVol carry trade captures a diversification effect, displays an enhancement of the associated risk-return profile for all examined asset allocation, and is applicable as a cash overlay. Such a multiple application is unique among the examined carry trades.

Table 1: Descriptive Statistics

The table reports the descriptive statistics for traditional asset classes (Panel A) and carry trades (Panel B). Panel C depicts the correlation between traditional asset classes and carry trades. The sample period is between January 1988 and December 2016. The excess return (ex ret) and the volatility (vol) are expressed in percent and are annualized. skew stands for skewness. kurt refers to kurtosis. SR is the annualized Sharpe ratio. VaR95% stands for the Value-at-Risk 95% and is expressed in percent on a monthly basis. Standard No.1, No.2 and No.3 refer to a standard carry trade with one, two and three currency pairs, respectively. TE and MinVol CT stand for the tracking error and minimum volatility carry trade, respectively. DEq, IEq and GovB refer to domestic equity, international equity and government bond index, respectively.

Panel A: Traditional Asset Classes

	ex ret	vol	skew	kurt	SR	VaR95%
DEq	7.76	14.33	−0.56	4.18	0.54	−6.51
IEq	3.53	17.06	−0.38	3.97	0.21	−8.24
GovB	2.84	4.23	−0.08	3.61	0.68	−1.42

Panel B: Carry Trades

	ex ret	vol	skew	kurt	SR	VaR95%
Standard No.1	2.57	6.82	−1.20	6.51	0.38	−3.12
Standard No.2	2.52	5.10	−0.79	4.97	0.49	−2.56
Standard No.3	2.20	4.19	−0.58	4.67	0.52	−2.08
TE CT	3.06	5.66	−1.61	11.34	0.54	−2.63
MinVol CT	3.39	5.03	−1.18	7.09	0.67	−2.25

Panel C: Correlation between Asset Classes

	DEq	IEq	Govb	Standard No. 1	Standard No. 2	Standard No. 3	TE CT	MinVol CT
DEq	1.00	0.69	0.00	0.19	0.34	0.33	0.27	0.11
IEq		1.00	−0.02	0.08	0.21	0.22	0.22	0.09
GovB			1.00	−0.08	−0.10	−0.11	−0.10	−0.03
Standard No.1				1.00	0.84	0.78	0.73	0.62
Standard No.2					1.00	0.93	0.81	0.65
Standard No.3						1.00	0.79	0.61
TE CT							1.00	0.83
MinVol CT								1.00

Table 2: Portfolio Performance

The table reports the portfolio performance adjusted by rebalancing and transaction costs for an equally weighted and international diversified portfolio. Panel A depicts the sample period between January 1988 and December 2016. Panel B illustrates the sample period between January 2001 and December 2016. Panel C refers to the subsample of the entire period, when the VIX index is larger than 20%.
The first seven columns depict performance measures. The excess return (ex ret) and the volatility (vol) are annualized and expressed in percent. skew stands for skewness. kurt refers to kurtosis. SR corresponds to the annualized Sharpe ratio. VaR95% stands for the Value-at-Risk 95% and is expressed in percent on a monthly basis. CE is the certainty equivalent considering a power utility function with a γ equal to 5. α refers to the Jensen-α with respect to the benchmark, where the standard errors are adjusted by White (1980). RL stands for the return-loss function of DeMiguel et al. (2009). CE, α and RL are annualized and expressed in percent.
The last five columns depicts the differences between the sole benchmark and the benchmark with carry trades. The column p-Value refers to the Mean-Variance Spanning test under normality conditions. p_1 and p_2-Value are the results of the step-down test, where p_1 is associated to the tangency and p_2 to the minimum-variance test statistic. p_{W_e}- and p_{W_a}-Value refer to p-Values of an asymptotic Mean-Variance spanning test under conditional heteroscedasticity.
The row title Benchmark stands for the benchmark portfolio. Standard No.3, TE CT or MinVol CT correspond to the benchmark portfolio including the standard carry trade No.3, tracking error and minimum volatility carry trade, respectively. *, ** and *** next to excess return, volatility and Sharpe ratio refer the 1%, 5% and 10% significant level of corresponding test-statistics with respect to the benchmark portfolio.

	ex ret	vol	SR	VaR 95%	CE	α	RL	MV under Normality p-Value	p_1-Value	p_2-Value	Asymptotic MV p_{W_e}-Value	p_{W_a}-Value
Panel A: January 1988 - December 2016												
Benchmark	4.41	8.56	0.52	-3.24	6.15							
Standard No.3	4.10**	7.81**	0.53	-2.86	6.09	0.08	-0.34	0.00	0.00	0.00	0.00	0.00
TE CT	4.81	7.46***	0.65***	-2.70	6.96	1.03***	-1.36	0.00	0.00	0.00	0.00	0.00
MinVol CT	4.90*	7.19***	0.69***	-2.67	7.16	1.26***	-1.69	0.00	0.00	0.00	0.00	0.00
Panel B: January 2001 - December 2016												
Benchmark	5.05	9.83	0.51	-3.82	4.44							
Standard No.3	4.51**	9.02	0.50	-3.50	4.22	0.04	-0.14	0.00	0.04	0.00	0.00	0.00
TE CT	4.72	8.66**	0.55**	-3.34	4.58	0.45*	-0.58	0.00	0.01	0.00	0.00	0.00
MinVol CT	4.68	8.26***	0.57**	-3.34	4.71	0.62**	-0.79	0.00	0.00	0.00	0.00	0.00
Panel C: VIX > 20%												
Benchmark	−2.53	10.97	−0.23	-5.58	−1.73							
Standard No.3	−2.24	10.03	−0.22	-5.08	−1.02	0.07	-0.36	0.00	0.00	0.00	0.00	0.00
TE CT	−1.30**	9.56**	−0.14***	-4.67	0.12	0.89***	-1.34	0.00	0.00	0.00	0.00	0.00
MinVol CT	−0.99**	9.11**	−0.11***	-4.47	0.61	1.09***	-1.68	0.00	0.00	0.00	0.00	0.00

Table 3: Currency Universe

The table reports the portfolio performance adjusted by rebalancing and transaction costs for an equally weighted and international diversified portfolio. The excess return (ex ret) and the volatility (vol) are annualized and expressed in percent. SR corresponds to the annualized Sharpe ratio. VaR95% stands for the Value-at-Risk 95% and is expressed in percent on a monthly basis. CE is the certainty equivalent considering a power utility function with a γ equal to 5. α refers to the Jensen-α with respect to the benchmark, where the standard errors are adjusted by White (1980). RL stands for the return-loss function of DeMiguel et al. (2009). CE, α and RL are annualized and expressed in percent.
The row title Benchmark stands for to the benchmark portfolio. Standard No.1, No.2, and No.3 stand for the benchmark portfolio with the standard carry trade No.1, No.2, and No.3, respectively. TE and MinVol CT correspond to the benchmark portfolio with a tracking error and minimum volatility carry trade, respectively. The suffix CCY followed by a number refers to the quantity of involved currencies sorted after their liquidity. The sample period is between January 1988 and December 2016. *, ** and *** next to excess return, volatility and Sharpe ratio illustrates the 1%, 5% and 10% significant level of corresponding test-statistics with respect to the benchmark portfolio.

	ex ret	vol	SR	VaR 95%	CE	α	RL
Benchmark	4.41	8.56	0.52	-3.24	6.15		
Standard No.1	4.14*	7.82**	0.53	-2.86	6.13	0.13	-0.37
Standard No.2	4.13**	7.86*	0.53	-2.84	6.11	0.09	-0.33
Standard No.3	4.10**	7.81**	0.53	-2.86	6.09	0.08	-0.34
TE CT CCY4	4.31	7.83**	0.55**	-2.83	6.31	0.30*	-0.54
TE CT CCY5	4.38	7.75**	0.56**	-2.83	6.40	0.41**	-0.67
TE CT CCY6	4.69	7.63**	0.62***	-2.74	6.77	0.80***	-1.08
TE CT CCY7	4.77	7.55***	0.63***	-2.70	6.89	0.94***	-1.23
TE CT CCY8	4.72	7.52***	0.63***	-2.69	6.86	0.91***	-1.22
TE CT CCY9	4.81	7.46***	0.65***	-2.70	6.96	1.03***	-1.36
MinVol CT CCY4	4.34	7.68**	0.57**	-2.84	6.40	0.41**	-0.70
MinVol CT CCY5	4.39	7.58**	0.58***	-2.75	6.48	0.52***	-0.83
MinVol CT CCY6	4.74	7.45***	0.64***	-2.72	6.89	0.95***	-1.30
MinVol CT CCY7	5.03**	7.32***	0.69***	-2.67	7.25	1.33***	-1.70
MinVol CT CCY8	4.84	7.27***	0.67***	-2.66	7.07	1.15***	-1.55
MinVol CT CCY9	4.90*	7.19***	0.69***	-2.67	7.16	1.26***	-1.69

Figure 1: Correlation

This plot depicts the 24-month rolling variance of the domestic equity (DEq) and the correlation between domestic equity and standard carry trade No.3 (Standard No.3), minimum volatility (MinVol CT) and tracking error (TE CT) carry trade, respectively. The grew area denotes the time period of the recent financial crisis between September 2007 and March 2009.

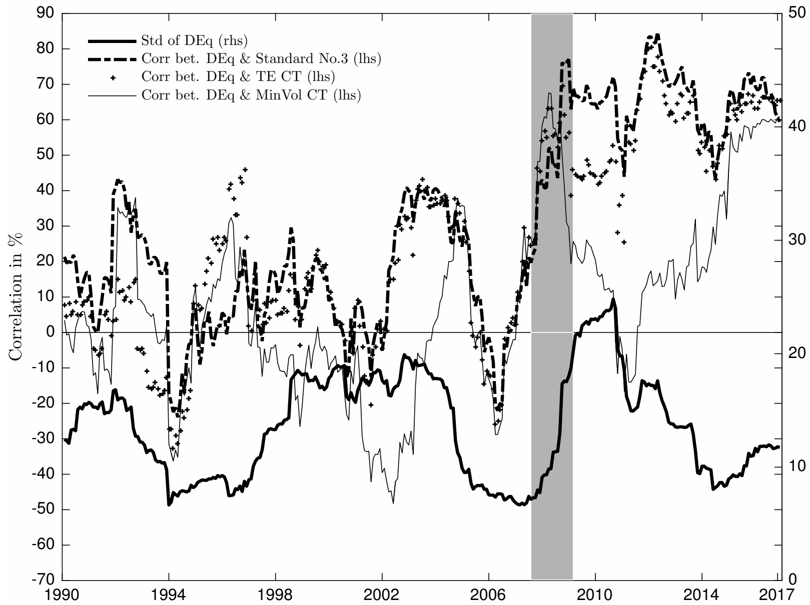


Table 4: Rolling Window Deviation

The table displays the portfolio performance adjusted by rebalancing and transaction cost adjusted for benchmark portfolio with carry trades. The benchmark portfolio consists of equally weighted and international diversified portfolio. Panel A depicts optimized carry trades with a currency universe of the four most liquid currencies, i.e. Euro, Japanese Yen, British pound and Australian dollar. Panel B is based on a currency universe consisting of the G10 currencies. The sample period is between January 1989 and December 2016.

The excess return (ex ret) and the volatility (vol) are annualized and expressed in percent. skew stands for skewness. kurt refers to kurtosis. SR corresponds to the annualized Sharpe ratio. VaR95% stands for the Value-at-Risk 95% and is expressed in percent on a monthly basis. CE is the certainty equivalent considering a power utility function with a γ equal to 5. α refers to the Jensen-α with respect to the benchmark, where the standard errors are adjusted by White (1980). RL stands for the return-loss function of DeMiguel et al. (2009). CE, α and RL are annualized and expressed in percent.

TE CT or MinVol CT refer to the benchmark portfolio including the tracking error and minimum volatility carry trade, respectively. The suffix RW followed by a number corresponds the length of the considered rolling window in months. *, ** and *** next to annual return, volatility and Sharpe ratio indicate 1%, 5% and 10% significant level of corresponding test-statistics with respect to the benchmark portfolio.

Panel A: Four most liquid currencies	ex ret	vol	SR	VaR 95%	CE	α	RL
TE CT RW24	4.22	7.94*	0.53*	-2.86	6.05	0.26	-0.48
TE CT RW30	4.22	7.93**	0.53*	-2.86	6.05	0.26	-0.49
TE CT RW36	4.23	7.94*	0.53*	-2.84	6.06	0.27*	-0.50
TE CT RW42	4.24	7.94*	0.53*	-2.84	6.07	0.28*	-0.51
TE CT RW48	4.25	7.93**	0.54*	-2.84	6.08	0.29*	-0.52
MinVol CT RW24	4.29	7.77**	0.55**	-2.88	6.19	0.41**	-0.69
MinVol CT RW30	4.27	7.78**	0.55**	-2.86	6.16	0.39**	-0.67
MinVol CT RW36	4.27	7.79**	0.55**	-2.85	6.16	0.38**	-0.66
MinVol CT RW42	4.28	7.78**	0.55**	-2.84	6.17	0.40**	-0.68
MinVol CT RW48	4.31	7.78**	0.55**	-2.84	6.20	0.43**	-0.71

Panel B: All available currencies							
TE CT RW24	4.87*	7.55***	0.65***	-2.75	6.87	1.15***	-1.46
TE CT RW30	4.73	7.56***	0.63***	-2.73	6.72	1.00***	-1.31
TE CT RW36	4.69	7.56***	0.62***	-2.70	6.68	0.96***	-1.27
TE CT RW42	4.68	7.58***	0.62***	-2.68	6.65	0.93***	-1.24
TE CT RW48	4.66	7.57***	0.62***	-2.66	6.64	0.92***	-1.23
MinVol CT RW24	4.72	7.27***	0.65***	-2.69	6.81	1.12***	-1.55
MinVol CT RW30	4.70	7.28***	0.65***	-2.69	6.79	1.10***	-1.52
MinVol CT RW36	4.76	7.29***	0.66***	-2.67	6.86	1.16***	-1.58
MinVol CT RW42	4.83*	7.31***	0.66***	-2.64	6.92	1.22***	-1.63
MinVol CT RW48	4.86*	7.31***	0.67***	-2.60	6.94	1.25***	-1.65

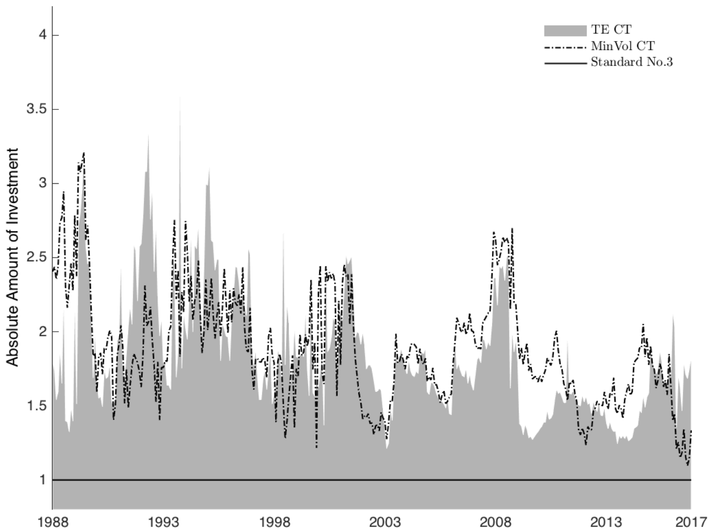
Table 5: Cash Overlay

The table reports the portfolio performance adjusted by rebalancing and transaction costs for different investors. Panel A simulates an equally weighted and international diversified portfolio. Panel B refers to an international portfolio with a home bias. Panel C (Panel D) depicts the portfolio performance for an investor, which is 20% (80%) invested in domestic bonds and 80% (20%) in domestic equity. These portfolios are benchmark portfolios and denote the row name benchmark. Standard No.3, TE CT or MinVol CT correspond to the benchmark portfolio including the standard carry trade No.3, tracking error and minimum volatility carry trade, respectively.
The excess return (ex ret) and the volatility (vol) are annualized and expressed in percent. skew stands for skewness. kurt refers to kurtosis. SR corresponds to the annualized Sharpe ratio. VaR95% stands for the Value-at-Risk 95% and is expressed in percent on a monthly basis. CE is the certainty equivalent considering a power utility function with a γ equal to 5. α refers to the Jensen-α with respect to the benchmark, where the standard errors are adjusted by White (1980). RL stands for the return-loss function of DeMiguel et al. (2009). CE, α and RL are annualized and expressed in percent.
*, ** and *** next to excess return, volatility and Sharpe ratio refer to the 1%, 5% and 10% significant level of corresponding test-statistics with respect to the benchmark portfolio, respectively. The sample period is between January 1988 and December 2016.

Panel A: International portfolio							
	ex ret	vol	SR	VaR 95%	CE	α	RL
Benchmark	4.41	8.56	0.52	-3.24	6.15		
Standard No.3	4.62**	8.78	0.53	-3.24	6.28	0.10	−0.01
TE CT	4.58***	8.69	0.53*	-3.26	6.27	0.10	−0.05
MinVol CT	4.58***	8.61	0.53***	-3.23	6.31	0.15**	−0.12
Panel B: Home biased & international diversified portfolio							
Benchmark	4.60	7.39	0.62	-3.07	6.79		
Standard No.3	4.85**	7.64	0.64	-3.07	6.97	0.10	0.02
TE CT	4.81**	7.55	0.64	-2.96	6.95	0.11	−0.04
MinVol CT	4.80***	7.45	0.65***	-3.01	6.99	0.17**	−0.14
Panel C: 20-80 Investor							
Benchmark	3.19	3.78	0.86	-1.19	6.18		
Standard No.3	3.52**	4.03	0.89	-1.33	6.48	0.18	0.10
TE CT	3.46**	3.91	0.90	-1.23	6.44	0.19	−0.03
MinVol CT	3.45***	3.85	0.92**	-1.26	6.45	0.24**	−0.14
Panel D: 80-20 Investor							
Benchmark	6.58	11.46	0.57	-5.13	7.21		
Standard No.3	6.66**	11.53	0.58	-5.11	7.27	0.05	−0.03
Standard No.3	6.66**	11.53	0.58	-5.11	7.27	0.05	−0.03
TE CT	6.65***	11.51	0.58*	-5.12	7.27	0.04	−0.03
MinVol CT	6.65***	11.47	0.58***	-5.10	7.28	0.06**	−0.06

Figure 2: Development Absolute Amount of Investment

This figure plots the development of the absolute amount of investment for different carry trades. Standard No.3, TE CT and MinVol CT refer standard carry trade No.3, tracking error and minimum volatility carry trade, respectively.



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