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Carry Trade Returns and Segmented Risk Pricing

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Abstract The returns to carry trades are controversially discussed. There seems to be no unifying risk-based explanation of currency returns and stock returns, while the countries' interest rate differential plays a leading part in the carry-trade performance. Therefore, this paper addresses carry-trade returns from a risk-pricing perspective and examines if these returns can be connected to cross-country differences in risk pricing in the interest-rate market compared to the stock market. Data from Thomson Reuters Datastream and Federal Reserve Economic Data covering Australia, Japan, New Zealand, Switzerland and the United States were analyzed based on GMM estimation. The results indicate significant and persistent cross-country differences in risk aversion in the interest-rate market compared to the implied risk aversion in the stock market. This may offer opportunities for risk arbitrage and, therefore, a risk pricing-related explanation of carry-trade returns.

Keywords Carry Trade · Currency Returns · Foreign Exchange · Risk Aversion · Stochastic Discount Factor

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Introduction

Carry trade strategies show a persistent outperformance compared to a passive benchmark strategy, even on a risk-adjusted basis, and appear to be unrelated to traditional risk factors (Burnside, 2011a; Byrne et al., 2018). Here, investors construct a zero-investment portfolio where they borrow funds in low interest rate currencies and invest

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in high interest rate currencies. At the end of the investment period, investors are exposed to exchange rate risk when converting the funds for local consumption.

If the foreign interest rate (investment currency) is higher than the domestic interest rate (funding currency), the forward exchange rate is quoted at a premium.[1] Thus, when considering pure exchange rate risk, the high interest rate currency is expected to depreciate in order to prevent favorable trading opportunities. However, one can observe that investment currencies do not depreciate at the amount of the interest rate differential (Lustig & Verdelhan, 2007). Because of this, exchange rates become partly predictable (Della Corte et al., 2009) and an uncovered speculation strategy in the future spot exchange rate might be profitable. As this empirical observation is persistent over time, it has attracted considerable research interest.

The literature controversially discusses the returns to carry trades as a risk premium for the uncovered exchange rate risk when considering risk-averse investors. Lustig and Verdelhan (2007, 2011) explained the cross section of currency returns by the consumption-based asset pricing model. Zviadadze (2017) provided evidence of multiple sources of consumption risk of currency returns. In contrast, Burnside (2011a, 2011b) showed that traditional risk factors, i.e., consumption risk, fail to explain carry-trade returns. He concluded that so far, there exists no unifying risk-based explanation of currency returns and stock returns. Menkhoff et al. (2012) related carry-trade returns to less traditional risk factors such as global foreign exchange volatility, while Christiansen et al. (2011) used an asset pricing model dependent on foreign exchange volatility regimes. Based on their results, currency returns are negatively correlated with global foreign exchange volatility and stock market risk of high interest rate currencies increases in regimes of high foreign exchange volatility.

This asymmetric correlation with stock market risk points to a stream of literature that relates carry-trade returns to crash risk and peso events. Brunnermeier et al. (2008) showed that the returns of high interest rate currencies are negatively skewed and exposed to crash risk, which is related to funding illiquidity. Dobrynskaya (2014) and Lettau et al. (2014) explained the cross section of carry-trade returns with an asset pricing model accounting for stock market downside risk. In contrast, Byrne et al. (2018) showed that a common (carry-trade) risk factor produces smaller pricing errors compared to foreign exchange volatility and stock market downside risk. They concluded that carry trade portfolios are exposed to risk characteristics not captured by stock market downside risk and, thus, currency and stock markets are not completely integrated. Burnside (2011a) ruled out crash risk as currency crashes are not systematically correlated with distress in the stock market. Burnside et al. (2011) argued that there is a small probability of peso events, while the stochastic discount factor (SDF) in these states must be sufficiently large in order to justify carry-trade returns.

Bhansali (2007) identified a relationship between carry-trade returns and implied volatility. He proposed that different risk pricing between the foreign exchange market and the options markets could lead to potential arbitrage opportunities. Clarida et al. (2009) replicated carry trades by foreign exchange option strategies and

[1] In this paper, spot and forward exchange rates are quoted indirectly as foreign currency units per one unit of domestic currency.

substantiated his findings. Jurek (2014) hedged crash risk with foreign exchange options and showed that crash-hedged carry trades still offer a great portion of unexplained excess returns. He concluded that carry-trade returns are not due to peso problems.

Lustig et al. (2011) explained carry-trade returns by different loadings of each country's SDF on a common global risk factor, which can be identified by the slope factor of currency returns sorted by their interest rates. Based on these findings, Verdelhan (2018) added a characteristics-based explanation by cross-country differences of preference parameters. With heterogeneous risk aversions of domestic and foreign investors, Verdelhan (2010) built a model that reproduces the uncovered interest rate parity puzzle, which forms the basis for currency returns. On an aggregate basis, Ornelas (2019) found predictive power of the volatility risk premium (risk aversion sentiment) over future currency returns. A similar conclusion was drawn by Demirer et al. (2020), who used a time-varying risk aversion index.

This paper addresses carry-trade returns from a risk pricing perspective and contributes to the literature of proposed differences in risk pricing and heterogeneous risk aversion by an empirical analysis. It builds on the conclusion drawn by Burnside (2011a) that there appears to be no unifying risk-based explanation of currency returns and stock returns, and it extends the findings of Bhansali (2007) by quantifying his reasoning of different risk pricing. This paper adds to Verdelhan (2018) by estimating cross-country differences of preference parameters in terms of risk aversion as well as to Ornelas (2019) and Demirer et al. (2020) by disaggregating the relationship between risk aversion and carry-trade profitability at the country level. It also adds to Zviadadze (2017) by estimating preference parameters.

The analysis differs from Verdelhan (2010), who applied a consumption-based asset pricing model with external habit preferences, and from research estimating time-varying implied risk aversion in the stock market (i.a., Rosenberg & Engle, 2002), as both consumption-based risk aversion and implied risk aversion across countries and time are examined, while relating potential differences to currency returns. If markets are complete, there should be a common SDF that prices states of nature, which, accordingly, should not be systematically different between financial market segments. Then, the change in exchange rates equals the ratio of the countries' SDFs. With incomplete markets as in real life (Cochrane, 2005), i.e., not all states of nature can be spanned, the SDF is not unique (Backus et al., 2001). Thus, differences in risk pricing of financial market segments could lead to (significantly) different return-risk tradeoffs, i.e., risk arbitrage.

A data set over the period from January 2008 to March 2017 was analyzed which uses the U.S. dollar (USD) as the numeraire currency, the Japanese yen (JPY) and the Swiss franc (CHF) as funding currencies, and the Australian dollar (AUD) and the New Zealand dollar (NZD) as investment currencies. The countries' interest rate differential plays a leading part in the carry-trade performance (Lustig et al., 2011) and a direct relationship between SDF and interest rate exists (Cochrane, 2005). Thus, the central asset pricing model was used to analyze the consumption-based risk pricing in the corresponding interest rate market. With regard to the findings of Bhansali (2007) and in combination with Burnside's (2011a) conclusion, this is compared to a market-implied measure of risk pricing using implied and realized volatility of the countries' stock market indices.

Based on a generalized method of moments (GMM) estimation, significant and persistent cross-country differences of risk aversion were found in the interest rate market compared to the implied risk aversion in the stock market. This may offer opportunities for risk arbitrage and, therefore, a risk pricing-related explanation of carry-trade returns. However, this would also imply that there is no unifying SDF. Consequently, the interest rate market and the stock market appear to be segmented in risk pricing for the countries of carry-trade currencies.

Carry Trade Returns

The forward exchange rate $F_{t,t+1}$ represents the price at point in time t for a currency exchange taking place at point in time t+1. The price is determined by market participants, while the value follows from the law of one price. If one abstracts from transaction costs and default risk, the foreign currency (FC) investment $r^{FC}_{t,t+1}$ converted back at a predetermined forward exchange rate at the end of the investment period t+1 should yield the same payoff as the domestic currency (DC) investment $r^{DC}_{t,t+1}$. Thus, the forward exchange rate is a function of the interest rate differential between FC and DC, as well as the current spot exchange rate S_t, depicted in Eq. (1) with discrete compounding:

$$F_{t,t+1} = S_t \cdot \frac{\left(1 + r^{FC}_{t,t+1}\right)}{\left(1 + r^{DC}_{t,t+1}\right)}. \tag{1}$$

If the foreign interest rate exceeds the domestic interest rate, the forward exchange rate is quoted at a premium. Therefore, when considering pure exchange rate risk, the foreign currency is expected to depreciate in order to prevent favorable trading opportunities. However, it is persistently observed that high interest rate currencies do not depreciate at the amount of the interest rate differential (Lustig & Verdelhan, 2007).

This empirical observation is known as the forward rate bias or forward premium puzzle. If persistent, it produces predictable returns (Della Corte et al., 2009) which can be exploited in trading strategies such as the carry trade. Note that this is a zero-investment strategy, which means that small excess returns on an after-cost basis can also provide trading incentives. If one assumes that the covered interest rate parity from Eq. (1) holds, the carry-trade strategy can be implemented by taking positions in the forward exchange rate. The respective trading strategy reads as follows:

$$r^{CT}_{t,t+1} = \begin{cases} \frac{F^b_{t,t+1}}{S^a_{t+1}} - 1 \text{ if } F^b_{t,t+1} > S^a_t, \\ \frac{S^b_{t+1}}{F^a_{t,t+1}} - 1 \text{ if } F^a_{t,t+1} < S^b_t, \\ 0 \quad \text{otherwise,} \end{cases} \tag{2}$$

where $r_{t,t+1}^{CT}$ denotes the carry-trade excess return. If the forward exchange rate quotes at a premium (discount), one sells (buys) the foreign currency forward, speculating on a lower (higher) future spot exchange rate. In practice, this strategy is based on bid (b) and ask (a) rates, while taking costs into account. Thus, when the forward premium or discount quotes within the cost band, no transaction is executed.

To gain a better understanding of the return-risk tradeoff for different interest rate differentials, i.e., forward premia, the return characteristics of individual carry-trade currencies were analyzed using spot exchange rates and one-month bid and ask-forward exchange rates with a daily frequency. The trading strategy, based on Eq. (2), was computed with a monthly frequency to circumvent overlapping time periods. Additionally, the interest rate differential of each currency pair was compared, which is based on the countries' deposit rates. Data were retrieved from Thomson Reuters Datastream (2017)[2] and cover the period from January 2008 to March 2017. To preclude extensive default risk and inflation risk, only currencies of developed countries were considered. For two common funding currencies, the JPY and the CHF were used. For two common investment currencies, the AUD and the NZD were used. All currencies are based on the USD as the domestic currency. In order to investigate gains from portfolio diversification, a carry-trade portfolio was constructed covering all four currency pairs with weight w, where the ex-post Sharpe ratio is maximized:

$$\max_{w} \frac{w'\,E}{w'\,\Sigma w} \text{s.t. } w'\,1 = 1. \tag{3}$$

The mean E and the covariance matrix Σ are based on the corresponding carry-trade excess returns. As an alternative, a zero-investment benchmark strategy was used, represented by an investment in the S&P500 index, which is funded by the average deposit rate of the considered countries. The descriptive statistics for the individual carry-trade strategies, the carry-trade portfolio, and the benchmark strategy are depicted in Table 1.

The table reports the annualized mean return, volatility, skewness, and maximum drawdown (Max DD) of the individual carry-trade strategies, the carry-trade portfolio, and the benchmark strategy. To measure downside risk, the square root of the annualized lower partial moment (LPM) is reported. This was computed with a target of zero as the carry trade is a zero-investment strategy, while the order amounts to two, comparable to downside volatility. Thus, risk-adjusted performance is measured by the Sharpe ratio and Sortino ratio. The success rate indicates the probability of a positive return. Additionally, Table 1 reports the absolute average interest rate differential (Int. Diff.), the portfolio weight of Eq. (3), and the correlation coefficients of respective returns to the global foreign exchange (FX) volatility based on Menkhoff et al. (2012) and to the S&P500 returns.

[2] Due to the availability of time series data for implied volatility indices in the stock market, the size of the sample is limited in time and currencies covered.

Table 1 Carry Trade Returns: Descriptive Statistics

	USDJPY	USDCHF	USDAUD	USDNZD	Portfolio	Benchmark
Mean	-1.18	0.85	3.05	3.83	4.01	4.89
Volatility	8.98	10.52	14.64	15.02	9.75	15.75
Skewness	0.36	0.06	-0.42	-0.12	-0.02	-0.77
Max DD	6.87	11.94	15.83	12.75	11.64	17.36
$\sqrt{\text{LPM}_{2,0}}$	6.33	7.32	10.33	10.17	6.16	11.48
Sharpe ratio	-0.13	0.08	0.21	0.25	0.41	0.31
Sortino ratio	-0.19	0.12	0.30	0.38	0.65	0.43
Success rate	33.33	39.64	54.95	52.25	53.15	58.56
Int. Diff	0.46	0.53	3.10	2.91		
w	-55.72	84.20	16.31	55.21		
$\rho\left(r_t, \sigma_t^{\text{FX}}\right)$	-0.29**	0.00	-0.23*	-0.21*	-0.08	-0.43***
$\rho\left(r_t, r_t^{\text{S\&P500}}\right)$	0.16	-0.28**	0.63***	0.65***	0.37***	

Significance levels are *** $p<0.1\%$, ** $p<1\%$, * $p<5\%$. Returns are monthly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017)

Based on the sample, funding currencies exhibit low or even negative mean returns compared to investment currencies with mean returns up to 3.83 percent per annum for USDNZD. This corresponds to higher volatility risk for investment currencies. Similarly, downside risk in terms of lower partial moments is higher for investment currencies. Those currencies appear to be more prone to crash risk with a maximum drawdown of 15.83 percent per month for USDAUD, which is also reflected in a negative skewness. The risk-adjusted performance, in turn, is higher for investment currencies compared to funding currencies, while slightly lower compared to the benchmark. Similar to investment currencies, the benchmark shows high volatility risk and downside risk, with a higher negative skewness of -0.77.

The risk-adjusted performance appears to be positively related to the success rate. Compared to funding currencies, the probability of a positive return based on the trading rule in Eq. (2) is substantially higher for investment currencies, which exhibit large interest rate differentials. USDCHF returns show no correlation to global foreign exchange volatility and a negative correlation to the S&P500 returns, significant at the one percent level, which makes it interesting for portfolio diversification. In contrast, returns of USDJPY and the two investment currencies exhibit a negative correlation to global foreign exchange volatility and a positive correlation to the S&P500 returns, which is highly significant for the two investment currencies.

The carry-trade portfolio shows gains of diversification by reduced risk compared to the benchmark, while the mean return increased up to 4.01 percent per annum. The downside risk could be reduced to 6.16 percent per annum, while returns show only marginal (negative) skewness. Compared to investment currencies, carry-trade portfolio returns exhibit a lower negative correlation to global foreign exchange volatility, which is not significant at the five percent level, and a lower positive correlation to the S&P500 returns. Thus, negative skewness and stock market risk (Dobrynskaya, 2014; Lettau et al., 2014) are more apparent for investment currencies while the carry-trade portfolio could partly diversify this risk.

Online Supplemental Appendix Table 1 quantifies the diversification potential by depicting the correlation coefficients of individual carry-trade returns. USDCHF returns show a strong negative correlation to the two investment currencies' returns, which is highly significant. Therefore, the carry-trade portfolio invests (on average) 84.20 percent in USDCHF and 55.21 percent in USDNZD, funded by USDJPY.

The Sortino ratio is more than 50 percent higher for the carry-trade portfolio compared to the benchmark strategy, because downside risk could be reduced. In addition, carry-trade portfolio returns show only marginal skewness, so the hypothesis of a normal distribution cannot be rejected with significance at the five percent level ($p = 0.07$), illustrated in the upper panel of Fig. 1. However, some crash risk is still obvious, reflected by the maximum drawdown of 11.64 percent per month in January 2015 when the Swiss National Bank suddenly unpegged the Swiss franc from the Euro.

From the lower panel of Fig. 1, it can be inferred that the correlation of carry-trade portfolio returns to the S&P500 index is negative at some time periods. This can be seen during 2011 when the Eurozone debt crisis deepened and the cumulative

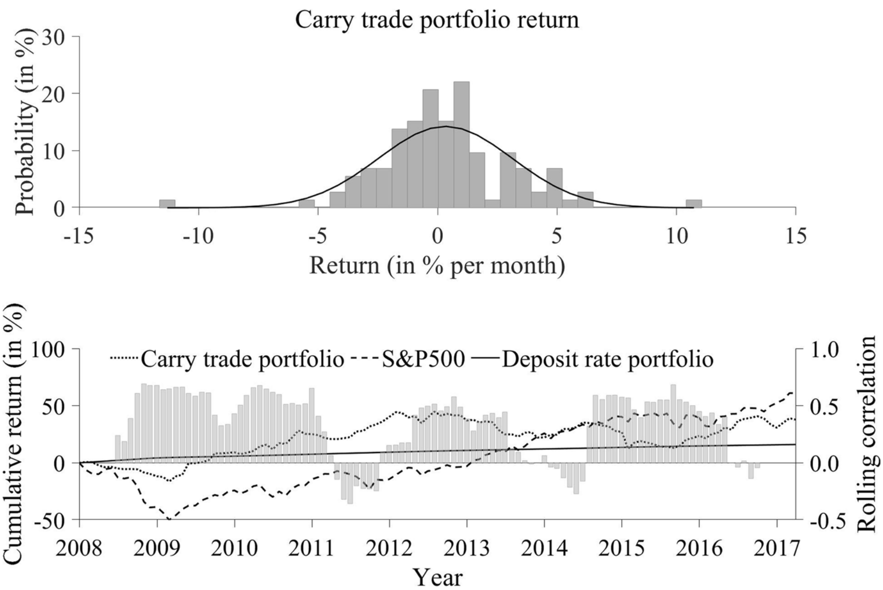

Fig. 1 Returns to the carry trade portfolio and benchmark. The upper panel of this figure illustrates the probability distribution of the carry-trade portfolio return and its normal approximation. The lower panel shows the cumulative returns of the carry-trade portfolio and the benchmark, divided into the S&P500 and the risk-free alternative as an equally weighted portfolio of the sample countries' deposit rates. Additionally, the figure shows the rolling correlation between carry-trade portfolio returns and S&P500 returns with a time window of 13 months. Returns are monthly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017)

return of the carry-trade portfolio increased, while the cumulative S&P500 return plunged to -22.95 percent in September 2011. This is consistent with the findings of Burnside et al. (2011) and Menkhoff et al. (2012), where carry-trade portfolio returns appear to be unrelated to traditional risk factors. It also supports the conclusion drawn by Byrne et al. (2018) that, based on the larger pricing error of stock market downside risk as compared to a common (carry trade) risk factor, currency and stock markets are not completely integrated, which will be quantified in the next two sections.

Risk Pricing in the Interest Rate Market

Based on the results of the prior section, there appears to be a compensation for higher levels of exchange rate risk among carry-trade currencies. Compared with the benchmark strategy however, the risk-adjusted performance of the carry-trade portfolio is considerably higher. This is primarily due to the diversification gains of funding currencies in terms of the USDCHF. Besides the future spot exchange rate, carry-trade returns depend on the forward exchange rate, which is a function of the interest rate differential between foreign and domestic currency.

Therefore, interest rates were examined for individual countries of carry-trade currencies focusing on risk pricing in the interest rate market. More precisely, the countries' risk aversion was analyzed using the central asset pricing model, in which the price equals the expected discounted payoff. Risk corrections are generated by the correlation of an asset's stochastic payoff or return, with a common SDF. The most basic asset pricing equation comes from the first-order condition of optimal consumption and portfolio formation, where the SDF is represented by the marginal rate of intertemporal substitution of consumption, formulated for returns as follows (Cochrane, 2005):

$$1 = E_t\left[m_{t+1} \cdot R^i_{t+1}\right] = E_t\left[\beta \cdot \frac{u'\left(c_{t+1}\right)}{u'\left(c_t\right)} \cdot R^i_{t+1}\right], \tag{4}$$

and as $R^f_t = \frac{1}{E_t\left(m_{t+1}\right)}$:

$$E_t\left(R^i_{t+1}\right) - R^f = -R^f_t \cdot \mathrm{cov}\left(\beta \cdot \frac{\mathrm{u}'(c_{t+1})}{\mathrm{u}'(c_t)}, R^i_{t+1}\right). \tag{5}$$

The SDF or pricing kernel m_{t+1} evaluates every state of R^i_{t+1} by a value function, which must be specified by an appropriate asset pricing model. The SDF is identified by the consumption-based asset pricing model, where the value function consists of a time discount β and a risk discount $\frac{u'\left(c_{t+1}\right)}{u'\left(c_t\right)}$. The risk discount must be formalized by a representative investor's risk preference in terms of a utility function. Thus, assets which are negatively correlated with marginal utility, i.e., they yield low returns in unfavorable consumption states where marginal utility is high, are risky as they make the consumption stream more volatile and, therefore, must compensate the investor with a risk premium.

Following Cochrane (2005), an analytical solution for the risk-free interest rate under uncertainty in discrete time was used by assuming log-normal consumption growth and risk-averse investors with a power utility function. These investors prefer a steady stream of consumption over time and across states of nature, while the aversion to risk and intertemporal substitution can be expressed by the curvature of the power utility function. Following this, from the consumption-based asset pricing model in Eq. (4) one can derive the risk-free interest rate r_t^f under uncertainty as follows:

$$r_t^f = \delta + \gamma \cdot E_t\left(\Delta \ln\ c_{t+1}\right) - \frac{\gamma^2}{2} \cdot \sigma_t^2\left(\Delta \ln\ c_{t+1}\right), \tag{6}$$

where δ represents the time discount $\beta = e^{-\delta}$ and γ denotes the risk aversion from the curvature of the power utility function: $u_t = \frac{1}{1-\gamma} \cdot c_t^{1-\gamma}$. This approach was used since no assumption about complete markets must be made and the direct relationship between the risk-free interest rate and risk aversion establishes a straightforward estimation in discrete time. The low variance of consumption growth limits the explanatory power of asset returns, which motivated adjustments as, e.g., habit formation (Campbell & Cochrane, 1999). However, as the aim of this study is to test for differences in risk aversion across countries and interest rates are not too noisy, the classical consumption-based asset pricing model was applied. This is accompanied by test statistics as suggested by Kleibergen and Zhan (2020).

It is assumed that consumption is exogenous while the parameters of Eq. (6), $b(\delta, \gamma)$, were estimated via the GMM of Hansen (1982) for the countries of the data set. The country's deposit rate serves as a proxy for the risk-free interest rate. Assuming a linear dependency of the investor's impatience δ on maturity, quantified as maturity premium (MP), a moment condition is derived for the one-month and three-month deposit rates. To allow for overidentifying restrictions, these moment conditions were augmented with lagged instruments in terms of the one-month and three-month deposit rates. This results in the following four moment conditions:

$$u_t(b) = \begin{bmatrix} r_t^{1M} - \left(\delta + \gamma \cdot E_t\left(\Delta \ln c_{t+1}\right) - \frac{\gamma^2}{2} \cdot \sigma_t^2\left(\Delta \ln c_{t+1}\right)\right) \\ r_t^{3M} - \left(\delta \cdot \left(1 + E_t(\mathrm{MP})\right) + \gamma \cdot E_t\left(\Delta \ln c_{t+1}\right) - \frac{\gamma^2}{2} \cdot \sigma_t^2\left(\Delta \ln c_{t+1}\right)\right) \\ \left[r_t^{1M} - \left(\delta + \gamma \cdot E_t\left(\Delta \ln c_{t+1}\right) - \frac{\gamma^2}{2} \cdot \sigma_t^2\left(\Delta \ln c_{t+1}\right)\right)\right] \cdot r_{t-1}^{1M} \\ \left[r_t^{3M} - \left(\delta \cdot \left(1 + E_t(\mathrm{MP})\right) + \gamma \cdot E_t\left(\Delta \ln c_{t+1}\right) - \frac{\gamma^2}{2} \cdot \sigma_t^2\left(\Delta \ln c_{t+1}\right)\right)\right] \cdot r_{t-1}^{3M} \end{bmatrix}. \tag{7}$$

The GMM estimation uses quarterly data of private final consumption expenditure retrieved from Federal Reserve Economic Data (2019), and quarterly averages of the daily one-month and three-month deposit rates from Thomson Reuters Datastream (2017), both covering the period from January 2008 to March 2017. As consumption data are on a quarterly frequency, the preceding four quarters were used to build the expectation and variance of logarithmic consumption growth. The expected value of MP was based on the average difference between the three-month and one-month deposit rates of the preceding four quarters. Table 2 illustrates the estimated variables and parameters.

The table reports the mean of the one-month and three-month deposit rates, as well as their average difference (MP) and correlation for the sample countries. In addition, it also reports the annualized mean of consumption growth, the consumption growth volatility, and the annualized average inflation rate, calculated on the basis of the consumer price index retrieved from Federal Reserve Economic Data (2019). The GMM estimation uses the identity matrix as a weighting matrix and the following as starting values: the mean of the one-month deposit rate for δ and a uniform risk aversion γ of one. To correct for heteroskedasticity and autocorrelation of error terms, Newey and West (1987) standard errors were computed with bandwidth q based on the Bayesian information criterion (BIC) of a VAR(q) model fitting. Due to cross correlation of moment conditions, the covariance matrix is nearly singular, which leads to an unstable efficient weighting matrix. Thus, only robust fixed weighting estimates were computed while correcting their standard errors. Additionally, a time series of parameter values was determined by applying the GMM optimization conditional on a quarterly information set. The average parameters are shown in the lower panel.

From the data set, it can be inferred that the correlation in the short-term interest rate structure is high while the maturity premium appears not to differ substantially

Table 2 Risk Pricing in the Interest Rate Market: Descriptive Statistics and GMM estimation

	Japan	Switzerland	Australia	New Zealand	United States
Descriptive Statistics					
$E\left(r_t^{1M}\right)$	0.14	0.08	3.70	3.51	0.60
$E\left(r_t^{3M}\right)$	0.24	0.20	3.82	3.62	0.80
$E\left(\mathrm{MP}_t\right)$	0.10	0.13	0.12	0.11	0.20
$\rho\left(r_t^{1M}, r_t^{3M}\right)$	0.98	0.99	1.00	1.00	0.97
$E\left(\Delta\ln c_{t+1}\right)$	0.51	1.60	2.45	2.82	1.76
$\sigma\left(\Delta\ln c_{t+1}\right)$	2.38	0.61	0.82	1.69	0.94
$E\left(\pi_t\right)$	0.30	-0.02	2.23	1.76	1.50
GMM: Identity Matrix					
δ	0.10	0.07	2.01***	1.83*	0.42
γ	0.25	0.04	0.69***	0.63*	0.17
q	0	2	1	3	4
TJ_T	15.12	25.50	1.15	2.79	46.46
Conditional Optimization					
$E\left(\delta_t\right)$	0.13	0.07	2.11	2.35	0.55
$E\left(\gamma_t\right)$	-0.04	0.08	0.68	0.57	0.10

Significance levels are *** $p<0.1\%$, ** $p<1\%$, * $p<5\%$. Data are quarterly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017) and Federal Reserve Economic Data (2019) across countries, except for the United States. On average, the deposit rate for countries of carry-trade investment currencies is higher than the deposit rate for countries of carry-trade funding currencies. To explain the observed interest rates with the given consumption growth moments based on Eq. (6), the risk aversion must differ substantially across countries.

For countries of carry-trade funding currencies, the risk aversion is low, e.g., 0.04 for Switzerland. This compares with a substantially higher and highly significant coefficient of 0.69 for Australia. In view of the large interest rate differential between investment currencies and funding currencies, not only the risk aversion, but also the time discount appear to differ substantially across countries. This may stem from the inflation differential between these countries. The average inflation appears to be in the range of the investor's impatience, except for the United States. The conditional optimization supports these findings, as once again the (average) risk aversion differs substantially across countries, found to be highly significant based on a Kruskal–Wallis test ($p = 1.91e\text{-}18$).

The development of risk aversion over time is shown in Fig. 2. During the global financial crisis in 2008, the risk aversion is high for Switzerland associated with an overall high level of volatility. This corresponds with a decreasing cumulative carry-trade portfolio return in Fig. 1. From 2009 onwards, the cross-country difference between risk aversion of carry-trade investment and funding currencies widens. This increases the cumulative carry-trade portfolio return with temporary declines during time periods of volatile risk aversion.

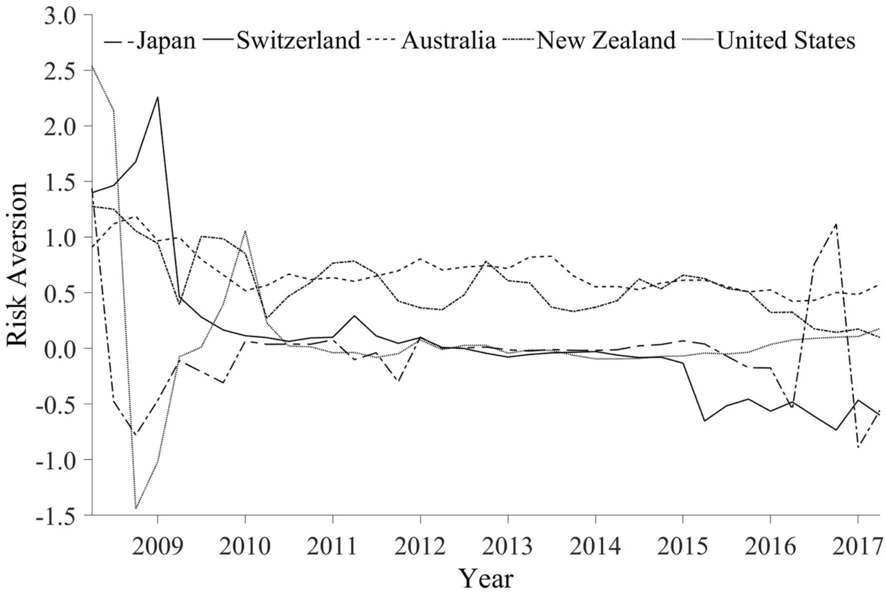

Fig. 2 Risk aversion over time. This figure shows the development over time of risk aversion parameters from the conditional optimization in the interest rate market for the sample countries. Data are quarterly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017) and Federal Reserve Economic Data (2019)

Due to negative expectations of consumption growth in connection with positive interest rates, the sensitivity (risk aversion) turns negative at some time periods. This is particularly evident for countries of carry-trade funding currencies and the United States during time periods of market turbulences. In the short run, expectations may become negative and as investors seem not to save infinitely, the parameter of risk aversion changes the sign.

With respect to the consumption-based asset pricing model in Eq. (5) and from the viewpoint of a U.S. investor, as the USD acts as the reference currency, quarterly averages of monthly carry-trade returns are related to U.S. consumption growth. As can be seen in Online Supplemental Appendix Table 2, the corresponding correlation coefficient is negative for countries of carry-trade funding currencies and positive for countries of carry-trade investment currencies. Although not significant at the five percent level, the coefficients may indicate the direction of influence. Consequently, carry-trade investment currencies exhibit more U.S. consumption risk as they have a higher sensitivity towards currency devaluation, reflected in the correlation of spot exchange rate changes to U.S. consumption growth.

This seems to be compensated by higher carry-trade returns. Carry-trade funding currencies, in turn, yield positive returns when U.S. consumption growth is negative, as they devalue to a lower extent, providing of a hedge against U.S. consumption risk where investors have to pay with low or even negative returns. This is consistent with the findings of Lustig and Verdelhan (2007) and motivates the diversification gains of the carry-trade portfolio in the prior section. Additionally, the correlation of the sample countries' consumption growth to U.S. consumption growth is higher for countries of investment currencies compared to funding currencies, which may point to the fact that risk sharing diverges for these countries (Sarkissian, 2003).

However, as crash-hedged carry trades still offer a high portion of unexplained excess returns (Jurek, 2014), not only different risk sensitivity $\rho\left(r_t^{\mathrm{CT}}, \Delta \ln c_{t+1}^{\mathrm{U.S.}}\right)$ (Lustig & Verdelhan, 2007), but also differences in risk aversion γ across countries and between different financial market segments seem to shed some light on the carry-trade performance. A different risk aversion in the interest rate market compared to the implied risk aversion could induce favorable prices in the options markets, which can then be exploited by replicating carry trades by foreign exchange option strategies (Clarida et al., 2009). Bhansali (2007) used the true option cost, defined as one minus the ratio of the interest rate differential to the option's implied volatility, as a measure of carry-trade attractiveness. Thus, the implied risk aversion across countries was examined in the following.

Risk Pricing in the Stock Market

The countries' interest rate differential (besides the current spot exchange rate) determines the forward exchange rate. Thus, diverting risk aversion between foreign and domestic currency may lead to a forward bias which can be exploited by the carry-trade strategy. In the central asset pricing model of Eq. (4), the SDF evaluates states of nature independently of the financial market segment. If markets were complete, there should be one (unifying) SDF for the interest rate market and stock market.

Accordingly, based on Burnside's (2011a) conclusion, the results of risk pricing derived from the interest rate market were compared to the stock market. With regard to the relationship of carry trade and implied volatility of Bhansali (2007), risk pricing in the stock market was examined by estimating risk aversion from implied and realized volatility. Via GMM, the volatility risk premium λ was estimated for the sample countries using implied volatility (IV^*) and realized volatility (RV) of the corresponding market portfolios. The estimation was based on the following moment conditions of Bollerslev et al. (2011):

$$u_t(b) = \begin{bmatrix} RV_{t+\Delta,t+2\cdot\Delta} - \alpha_\Delta \cdot RV_{t,t+\Delta} - \beta_\Delta \\ \left(RV_{t+\Delta,t+2\cdot\Delta} - \alpha_\Delta \cdot RV_{t,t+\Delta} - \beta_\Delta\right) \cdot RV_{t-\Delta,t} \\ RV_{t,t+\Delta} - A_\Delta \cdot IV^*_{t,t+\Delta} - B_\Delta \\ \left(RV_{t,t+\Delta} - A_\Delta \cdot IV^*_{t,t+\Delta} - B_\Delta\right) \cdot RV_{t-\Delta,t} \end{bmatrix}, \tag{8}$$

with $\alpha_\Delta = e^{-\kappa\cdot\Delta}$, $\beta_\Delta = \theta \cdot \left(1 - e^{-\kappa\cdot\Delta}\right)$, $A_\Delta = \frac{\left(1-e^{-\kappa\cdot\Delta}\right)}{\kappa} \cdot \frac{\kappa+\lambda}{\left(1-e^{-(\kappa+\lambda)\cdot\Delta}\right)}$, and $B_\Delta = \theta \cdot \left[\Delta - \left(1 - e^{-\kappa\cdot\Delta}\right)/\kappa\right] - A_\Delta \cdot \frac{\kappa\cdot\theta}{(\kappa+\lambda)} \cdot \left[\Delta - \left(1 - e^{-(\kappa+\lambda)\cdot\Delta}\right)/(\kappa+\lambda)\right]$. Then, $\gamma = \frac{\lambda}{\rho\cdot\sigma}$ where ρ denotes the correlation between the market portfolio and its historical volatility σ (RV).

This approach was used since it is subjected to an asset-pricing methodology, with the same utility function as for the estimation in the interest rate market, in contrast to measures of the volatility risk premium as the difference of IV^* and RV (Ornelas, 2019). In market turmoil (when $RV > IV^*$), risk aversion may become negative. Thus, Rombouts et al. (2020) used an adapted approach of the variance risk premium. However, as this analysis' objective is on cross-country differences with a focus on the general behavior of risk aversion, the method of Bollerslev et al. (2011), based on the central asset pricing model, was applied by accompanying test statistics.

The market portfolios were approximated by the respective market indices. The indices are: NIKKEI 225 for Japan, SMI for Switzerland, S&P ASX 200 for Australia, and DJIA for the United States. There is no implied volatility index for New Zealand's S&P NZX 50, so that its risk pricing in the stock market is not covered. The GMM estimation of parameters uses daily data of index prices and their corresponding one-month implied volatility index retrieved from Thomson Reuters Datastream (2017), both covering the period from January 2008 to March 2017. To circumvent overlapping time periods, the estimation was run on a monthly frequency. Table 3 illustrates the estimated variables and parameters.

The table reports the mean of the one-month IV^* and RV of the market indices. The RV was computed by continuously compounded daily returns of 30 trading days (Δ), consistent with the holding period of the one-month IV^*s. To control for potential outliers, the average of the end of month IV^* and RV was used with a time window of three trading days. In addition, the table reports the correlation coefficients

Table 3 Risk Pricing in the Stock Market: Descriptive Statistics and GMM

	Japan	Switzerland	Australia	United States
Descriptive Statistics				
$E(\text{IV}_t^*)$	26.83	19.47	20.27	19.35
$E(\text{RV}_t)$	23.01	16.45	16.29	16.20
$\rho(r_t^{\text{I}}, \text{RV}_t)$	-0.54***	-0.57***	-0.55***	-0.50***
$\rho(r_t^{\text{I}}, \Delta \ln c_{t+1}^{\text{U.S.}})$	0.22	0.26	0.27	0.33*
GMM: Identity Matrix				
λ	0.59***	0.85**	1.21***	1.64**
q	2	2	2	2
TJ_T	3.27	4.60	17.79	6.23
γ	0.05	0.09	0.13	0.20
GMM: Efficient Matrix				
λ	0.52***	0.86***	1.47***	2.04***
TJ_T	1.79	0.84	9.13	2.85
γ	0.04	0.09	0.16	0.25
Conditional Optimization				
$E(\lambda_t)$	0.77	1.03	1.33	1.02
$E(\gamma_t)$	0.06	0.11	0.15	0.13

Significance levels are *** p < 0.1 %, ** p < 1 %, * p < 5 %. Data are monthly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017) and Federal Reserve Economic Data (2019)

of index (I) returns to RV and to U.S. consumption growth. The first-stage GMM estimation used the identity matrix as a weighting matrix and the following as starting values: 1/30 for κ, the mean of RV for θ, and a uniform risk price λ of zero. To correct for heteroskedasticity and autocorrelation of error terms, Newey and West (1987) standard errors were computed with bandwidth q based on the BIC criteria of a VAR(q) model fitting. The second-stage GMM estimation used the efficient matrix as a weighting matrix. To conserve space, only the GMM results for the volatility risk premium are reported. Additionally, a time series of parameter values was determined by applying the GMM optimization conditional on a monthly information set. Then, quarterly averages were used to compare the results to those of the prior section. The average parameters are shown in the lower panel.

The mean of IV* and RV appears to be similar across countries, except for Japan where the level of volatilities is generally higher. Based on the first-stage GMM, the volatility risk premium λ is higher for Australia and the United States, compared to the premium of the two countries of carry-trade funding currencies. This difference is also visible when computing the risk aversion γ. With the efficient weighting matrix, the difference increases slightly with lower standard errors so that all risk premia are highly significant, while the test of overidentifying restriction at the five percent level is rejected only for Australia.

Compared to the results in the interest rate market, the cross-country differences of risk aversion from the conditional optimization are not significant at the five percent level, based on a Kruskal–Wallis test ($p = 0.06$). With respect to the consumption-based asset pricing model in Eq. (5), quarterly index returns are related to U.S. consumption growth. The correlation coefficients are positive, ranging from 0.22 to 0.33. Thus, the differences across countries appear to be smaller when compared to the results of carry-trade returns (Online Supplemental Appendix Table 2), where the correlation coefficients are negative for funding currencies and positive for investment currencies. This also shows that the diversification potential appears to be larger for carry-trade portfolios.

In Fig. 3, the risk aversion is plotted over time. Here, cyclical swings of parameter values seem to be smaller compared to the results in the interest rate market (Fig. 2). In addition, the difference between Australia and the two countries of carry-trade funding currencies narrows after the global financial crisis in 2008 with some minor divergences. This adds to the findings of Bekaert and Hoerova (2016) where U.S. and German risk aversion were positively correlated, as well as Fassas and Papadamou (2018) where on a visual impression the variance risk premium seems not to differ substantially across developed countries.

In contrast, the cross-country differences of risk aversion in the interest rate market appear to be persistent and apparent during the overall time period, which supports the findings of differences in risk pricing between the interest rate market and stock market. Negative risk aversion during periods of market turbulences is evident

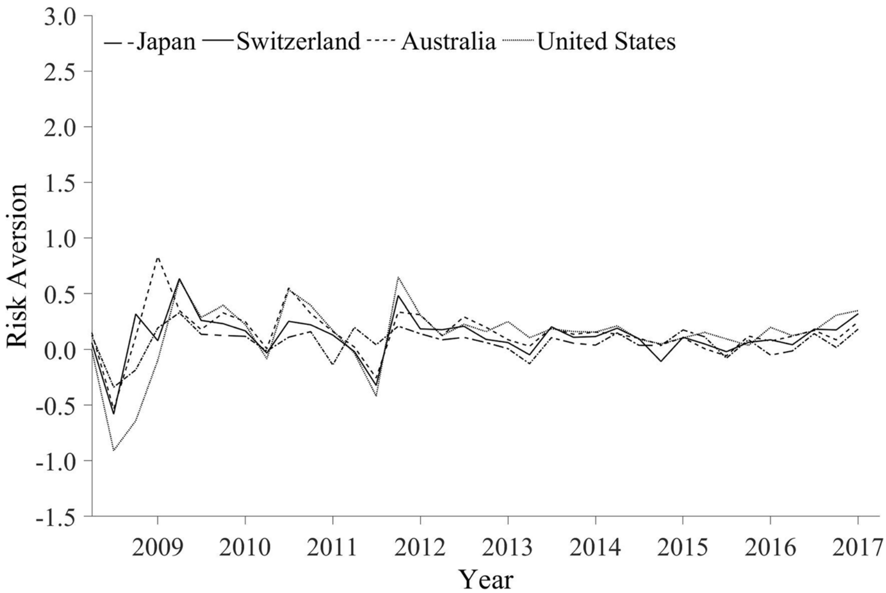

Fig. 3 Risk aversion over time. This figure shows the development over time of risk aversion parameters from the conditional optimization in the stock market for the sample countries. Data are quarterly and the sample period is from January 2008 to March 2017. Source: Own calculation using data from Thomson Reuters Datastream (2017) and Federal Reserve Economic Data (2019)

as, in the short run, realized volatility exceeds implied volatility. Differences in risk pricing between the interest rate market and the stock market would imply that there is no unifying SDF. Thus, (traditional) stock market risk factors may fail to explain carry-trade returns (Burnside, 2011b; Byrne et al., 2018). With real data, one would not assume that risk pricing is equal at every point in time. However, as the cross-country differences in risk aversion in the interest rate market are persistent over time, this would shed some light on the forward rate bias with its risk-adjusted excess returns of carry-trade strategies.

Differences in risk pricing could also explain the relationship between carry-trade returns and implied volatility (Bhansali, 2007) and the excess return of crash-hedged carry trades (Jurek, 2014). If, for example, countries of investment currencies exhibit a lower level of implied risk aversion compared to the risk aversion in the interest rate market, the true option cost of Bhansali (2007) may fall. This presents opportunities for risk arbitrage, which can be exploited by carry trades or foreign exchange option strategies (Clarida et al., 2009). A higher risk aversion for countries of investment currencies (e.g., Australia) in the interest rate market compared to the implied risk aversion can be observed in the sample.

Conclusions

This paper analyzed the return characteristics of individual carry-trade strategies and, thereby, examined risk pricing for the respective countries of carry-trade currencies. The data set spanned January 2008 to March 2017 and covers two common funding currencies and two common investment currencies. Carry-trade investment currencies show higher (downside) risk compared to funding currencies. The risk-adjusted performance of a carry-trade portfolio, however, is considerably higher than a passive benchmark strategy. This is primarily due to diversification gains of funding currencies.

Based on the consumption asset pricing model, the interest rate under uncertainty is related to the first and second moment of consumption growth and, from there, the risk aversion examined. With data of private final consumption expenditure and deposit rates under a GMM estimation, significant and persistent cross-country differences of risk aversion were found. With respect to the SDF as a single risk factor of the central asset pricing model, the implied risk aversion was estimated based on implied and realized volatility in the stock market.

With data for respective market indices under a GMM estimation, the existence of cross-country differences in implied risk aversion could not be confirmed. This may offer opportunities for risk arbitrage and therefore, a risk pricing-related explanation of carry-trade returns. However, this would also imply that there is no unifying SDF and, consequently, the interest rate market and the stock market appear to be segmented in risk pricing for the countries of carry-trade currencies.

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