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Essays on Currency Anomalies

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Julkaisun nimike
Esseitä valuuttamarkkinoiden anomalioista

Tiivistelmä

Tämä väitöskirja tutkii valuuttamarkkinoiden anomalioita. Neljä toisiinsa tiiviisti liittyvää tutkimusta tarkastelee valuuttakurssien tunnusomaisia riskitekijöitä, niiden ominaisuuksia ja tarjoaa riskiin perustuvan selityksen valuuttamarkkinoiden korkoero- ja momentum-ilmiöille. Ensimmäisessä esseessä tutkitaan osakemarkkinoiden likviditeetin vaikutusta näiden ilmiöiden epänormaaleille tuotoille. Toisessa ja kolmannessa esseessä tutkitaan valuuttojen korkoeroilmiön riskiprofiileja ja tarjotaan riskiin pohjautuva selitys epänormaaleille tuotoille. Neljännessä esseessä tutkitaan korkoerostrategian hajautusmahdollisuuksia ja tarkastellaan valuuttojen yhteisriippuvuutta.

Ensimmäisen esseen tutkimustulokset osoittavat, että osakemarkkinoiden likviditeetti selittää momentum-sijoitusstrategian tuottoja valuuttamarkkinoilla, mutta se ei selitä valuuttojen korkoeroon perustuvan sijoitusstrategian tuottoja. Toisen esseen tutkimustulokset osoittavat, että valuuttojen korkoeroilmiötä voidaan selittää valtioiden vakavaraisuuteen liittyvällä riskipreemiolla, joka vaihtelee yli ajan.

Kolmannen esseen empiiriset tulokset osoittavat, että korkoeroon perustuvan sijoitusstrategian tuotot linkittyvät myös maiden poliittiseen riskiin, antaen samalla riskiin pohjautuvan selityksen. Neljännen esseen tutkimustulokset puolestaan osoittavat, että aalloke-korrelaatioita hyödyntävä sijoitusstrategia antaa huomattavia hajautushyötyjä ja löytää hyödynnettäviä malleja valuuttakurssien muutoksissa.

Kollektiivisesti voidaan sanoa, että näiden neljän esseen tutkimustulokset tarjoavat uutta tietoa valuuttakurssianomalioiden ominaisuuksista ja niitä selittävistä riskitekijöistä.

Asiasanat
Korkoerostrategia, momentum-ilmiö valuuttamarkkinoilla, markkinalikviditeetti, vakavaraisuuden riskipreemio, poliittinen riski, hajauttaminen

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Abstract

This thesis investigates various aspects of currency market anomalies. Four interrelated essays examine risk characteristics, explore the attributes, and provide risk-based interpretation of the two currency anomalies, namely currency carry trade and currency momentum. The first essay examines the effect of equity market illiquidity on the excess returns of these anomalies. The second and third essays explore the risk profile of currency carry trades and offer risk-based interpretation of strategy's payoffs. The fourth essay investigates carry trade diversification opportunities and linkages of major carry trade currencies.

The findings of the first essay indicate that equity market illiquidity explains the evolution of currency momentum strategy payoffs, but not carry trade. The results of the second essay show that currency carry trades can be rationalized by the time-varying risk premia originating from the sovereign solvency risk. The third essay finds that carry trade profitability depends on a country's political risk, supporting the risk-based view on forward bias. The fourth essay shows that strategies built on the basis of wavelet correlation have significant diversification benefits and finds exploitable patterns in exchange rate movements.

Collectively, the findings of the four essays provide new evidence on the attributes of currency anomalies, supply a number of original results, and add to the international finance literature.

Keywords
Carry Trades, Currency Momentum, Market Illiquidity, Solvency Risk Premia, Political Risk, Carry Trade Diversification

DEDICATION

This work is dedicated to my Mom.

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Throughout my academic journey, I have grown tremendously in both a professional and personal way, and I owe it all to the amazing people I was fortunate enough to meet on the way. It is truly a special moment in my life and I feel thrilled to finally be able to express my deepest gratitude to people who provided support and opportunities throughout my doctoral studies.

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Vaasa, June 2016

Vitaly Orlov

Contents

This dissertation consists of an introductory chapter and the following four essays:

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Dimic, N., V. Orlov, and V. Piljak (2016). The effect of political risk on currency carry trades. *Finance Research Letters (forthcoming)*.[2]

Orlov, V. and Äijö, J. (2015). Benefits of wavelet-based carry trade diversification. *Research in International Business and Finance*, 34, 17-32.[3]

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1 INTRODUCTION

This doctoral dissertation investigates various aspects of foreign exchange market anomalies in four inter-related essays. The comprehension of exploitable disparities in macroeconomic conditions and positive average historical returns of currency anomalies has been the central topic of the international finance literature over the last three decades. The focus of this dissertation is on two anomalies: currency carry trade and currency momentum. The first essay examines both currency momentum and carry trade, the second and fourth essay investigate only the currency carry trade strategy, and the third essay separately explores individual currency carry trades.

The global currency market is the biggest financial market, and has a trading volume twelve times greater than that of all the world's stock markets (Triennial Central Bank Survey, 2010). Interestingly, only 10% of the volume is associated with the maintenance of international trade while the rest can be partly attributed to speculative activity. The scope and prominence of currency market arbitrage are due to persistent deviations from macroeconomic parity conditions, namely uncovered interest parity, and empirical rejection of the forward rate unbiasedness hypothesis; that is, the forward premium is an apparent biased predictor of a future spot exchange rate change, as manifested in Hansen and Hodrick (1980, 1983) and Fama (1984). These feasible discrepancies in macroeconomic parity conditions give rise to positive average historical currency excess returns and the forward premium puzzle. Seeking an explanation of the forward premium puzzle and currency excess returns is a current and prime topic in international finance.

The purpose of this dissertation is to investigate risk characteristics, explore the attributes, and provide a risk-based interpretation of the two most prominent currency anomalies in the international finance literature, namely currency carry trade and currency momentum: the two currency anomalies rooted in the existence of the forward premium puzzle. Currency carry trade strategy is implemented by borrowing in a low interest rate currency and subsequently investing in a high interest rate currency. Currency momentum is a long-minus-short strategy based on lagged currency excess returns. The explanation of the profitability of these two anomalies is a topical and important research subject, as indicated by the many recent studies in the international finance literature (see, e.g., Lustig, Roussanov, and Verdelhan, 2011; Menkhoff, Sarno, Schmeling, and Schrimpf, 2012a; Lettau, Maggiori, and Weber, 2014; Daniel, Hodrick and Lu, 2016; Ready, Roussanov, and Ward, 2016 and others). This dissertation builds upon much of the recent evidence as well as classic contributions and, through its four essays, significantly expands the existing literature and reveals novel evidence on different aspects of the forward premium puzzle and the foreign exchange market anomalies.

The remainder of the introductory chapter is organized as follows. Section 2 describes the contribution of each essay and also the dissertation as a whole. Section 3 provides a brief description of the theoretical background of the four essays of this dissertation and is followed by the summaries of essays provided in Section 4.

2 CONTRIBUTION OF THE DISSERTATION

The four essays that comprise this dissertation provide new evidence on the foreign exchange market anomalies and add to the current topics of the international finance literature. However, each of the essays approaches the topic from a slightly different perspective. The first essay explores how equity market conditions contribute to the observed returns of the currency momentum and carry trade strategies, while it does not aim to provide a complete explanation for the anomalies. In contrast, the second and the third essay approach the topic from the angle of risk-based interpretation and shed light on the possible origins of heterogeneities in the cross section of currency returns. The fourth essay deviates from the subjects of predecessors to investigate linkages among common carry trade currencies, while addressing the topic from a practical perspective. The common ground for all of the four essays is in the examination of various aspects of currency anomalies.

This dissertation as a whole makes a number of contributions to the finance literature, while each of the four essays adds to various specific streams of the international finance and macroeconomic literature related to the return predictability of currency anomalies, cross-market segmentation of predictability, inter-market linkages, currency market liquidity, risk-based explanations of the forward premium puzzle, currency risk premia, international portfolio diversification, and the financial crisis. Accordingly, this dissertation through its interconnected constituent essays unites those contemporary international finance topics and sheds light on each of them. Collectively, the inferences from the four essays of this dissertation help advance understanding of the attributes of currency anomalies, identify a number of original results, and substantially add to the international finance literature. A more detailed description of the contribution of each essay is provided below.

The first essay of this dissertation contributes to a number of strands of literature in several important ways. First, the essay extends the strand of literature on return predictability of currency anomalies, by exposing the predictive role of equity market illiquidity in explaining the inter-temporal variations in currency momentum returns. Further, the essay addresses the critique that the literature on predictability is segmented across markets. Despite its importance, there is little evidence available on the cross-market links between currency anomalies on the one hand and stock market conditions on the other. Hence, the first essay contributes toward filling this gap. Second, the findings of the essay provide additional support for the theoretical framework that links market liquidity and funding liquidity. Third, the essay contributes to the strand of literature on recent trends in market anomalies by providing evidence on the two most prominent currency market anomalies payoff realizations and their interaction with equity market conditions over the most recent decade. Finally, this study provides additional support to the prior literature that documents the linkage between equity and foreign exchange markets.

The second essay makes several contributions to the international finance literature. First, the empirical findings of this essay lend additional support to the risk-based view of the forward premium puzzle, manifested in studies such as those of Hansen and Hodrick (1980), Fama (1984). This essay shows that the apparent slump in UIP can be interpreted as a compensation for risk. Second, this essay extends the findings of prior literature searching for an appropriate time-varying currency risk premium that rationalizes returns to the carry trade strategy. The essay identifies a new source of risk premia and shows that currency carry trades can be comprehended as a compensation for sovereign solvency risk. In addition, it introduces a new, solvency-based, risk factor and shows that its covariance with returns accounts for almost all of the variation in the cross-section of carry trade returns. Third, relying on fundamental measures of the financial competence of the economy, the second essay adds to the prior literature on a country's creditworthiness as an explanation of currency carry trades, while addressing the critique of applying market measures to assess sovereign financial solvency.

The third essay, in a similar way to the second paper, contributes to the strand of literature searching for an appropriate source of risk to explain the existence of the forward premium puzzle. The third essay takes a step along this path and contributes to the international finance literature by showing that carry trade returns are high/low in countries with high/low values of the composite political risk measure. The evidence in the third essay suggests that individual carry trades are heterogeneously exposed to political risk that, potentially, makes it more difficult for economic agents to predict future spot exchange rates of politically distressed countries, reinforcing the forward premium bias. In addition, the third essay adds to the literature on emerging market finance in showing that the political risk effect originates in emerging economies, while it is not evident in developed countries.

The fourth and final essay makes several contributions to the relevant segments of international finance literature. First, the essay adds to the literature on international portfolio diversification and inter-market linkages in the foreign exchange market by extending the analysis of carry trade diversification opportunities and examining the temporal structure of correlations among the most common carry trade currencies. Second, the fourth essay employs a wavelet technique in assessing correlation structure in the currency market and thus enriches the growing literature on the linkages between currencies. In addition, the essay provides new evidence on the inter-market linkages around the dates of the global financial crisis. The third element of contribution of the essay is reflected in its investigation of carry trade excess returns on five different time scales. Therefore, the study aims to extend the existing literature that employs static correlation and a single investment horizon approach in portfolio construction.

3 THEORETICAL FUNDAMENTALS

This section briefly presents the theoretical background and the analytical framework underpinning this dissertation and each of the four essays therein. First, Section 3.1 provides an overview of the evidence on macroeconomic parity conditions and the forward premium puzzle, which are common fundamentals for all four essays. Next, the following subsections set out the literature background of each constituent essay with the appropriate arrangements based on the corresponding foreign exchange market anomaly.

3.1 Interest rate parity conditions and the forward premium puzzle

Over recent decades, the foreign exchange market efficiency debate has taken place in the framework of forward exchange rate predictive ability; that is, under an assumption of the currency market being efficient, a forward rate must reflect the market expectations of the level of the future spot exchange rate which will prevail at the time the forward contract matures:

$$E_t\left((S_{t+T}) \mid \Omega_t\right) = F_{t,T}\,, \tag{1}$$

where rational expectations of the future spot exchange rate given the set of information Ω at time t equate to the forward rate F_t perceived by the market at time t as an accurate predictor of future spot rate (at time T).

There are two macroeconomic conditions that theorize the forward-spot rate relationship, namely covered and uncovered interest parities. Covered interest parity postulates that the domestic interest rate is higher or lower relative to the foreign interest rate by an amount that is equal to the forward discount or premium. In practice, empirical tests document that the forward premium is indeed closely linked to the interest rate differential and no long-lived profitable arbitrage opportunities exist if transaction costs are accounted for, lending support to the covered interest parity condition (see, e.g., Frenkel and Levich 1975, 1977; Taylor 1987; Akram, Rime and Sarno, 2008; Baba and Packer, 2009).

In contrast to covered interest parity, uncovered interest parity presumes no-arbitrage condition with no forward hedging against exposure to exchange rate risk. Thus, provided that uncovered interest parity holds, high interest rate currency depreciation offsets the interest rate differential (forward premium) and returns to currency speculation are zero. In practice this would mean that the slope coefficient of the Fama (1984) regression of exchange rate change on the prior interest rate differential is equal to unity:

$$S_T - S_t = \alpha + \beta(F_{t,T} - S_t) + \varepsilon_T , \quad (2)$$

where $S_T - S_t$ is the spot exchange rate change, $F_{t,T} - S_t$ is the log forward discount, that under covered interest parity is approximately equal to the cross-country interest rate differential at time t, and ε_T is a random disturbance term.

According to the theoretical prediction of the uncovered interest parity condition, the slope coefficient in (2) is equal to one. However, empirical results of such a test of the unbiasedness hypothesis indicate that β is not only far from unity, but also on average far lower than zero (Fama, 1984; Froot and Thaler, 1990; Engel, 1995). This implies negative covariance between the risk premium and an expected depreciation. Hence, theoretical predictions of parity conditions are violated in the data, such that on average low interest rate currencies depreciate relative to the high interest rate currencies. The forward premium is consistently shown to be a biased predictor of a future spot exchange rate change over the last three decades (Lewis, 2011). These exploitable disparities in macroeconomic conditions stipulate positive average historical returns on currency speculations and the existence of a forward premium puzzle, that remains a primary and unresolved topic of international finance literature.

3.2 Currency anomalies

3.2.1 Currency carry trade and explanations of excess returns

The carry trade strategy is executed by borrowing in currencies with low interest rates and investing in currencies with high interest rates. The exercise of the carry trade strategy is firmly related to the forecasting shortcomings of forward rates, which was previously referred to as the forward premium anomaly. Specifically, forward premia, contrary to the unbiasedness hypothesis, fall short in predicting future spot exchange rate appreciation. If forward rates were unbiased, the carry trade returns would be indistinguishable from zero. The explanation of positive historical carry trade payoffs has become a cornerstone of understanding the forward premium puzzle. Historically, foreign exchange market arbitrage is a long standing issue of international finance stretching back as far as the pre-gold standard study of Keynes (1923). Nevertheless, literature on the forward premium puzzle emerged in the early 1980's and has often identified four major ways to interpret the existence of carry trade returns and the empirical rejection of the forward unbiasedness hypothesis.

The first stream of literature strives to provide a risk-based explanation for the puzzle through defining carry trade returns as a compensation for an appropriate risk. Building on the classic contribution of Hansen and Hodrick (1980), Fama (1984) brings the discussion to the efficient markets framework and illustrates the apparent failure of UIP across various currencies and time periods, which manifests in negative estimates of the slope parameter of the so-called Fama-regression (2). Importantly, the residual component of that regression is interpreted as the time-varying currency risk premium that rationalizes returns to the carry trade strategy.

Alternatively, the existence of that residual component is taken as evidence of market inefficiency, constituting the second interpretation. Pioneered by Bilson (1981), the interpretation shows that the nature of forward premium bias is broadly coherent with the behavioral finance perspectives found in Froot and Thaler (1990). Burnside, Han, Hirshleifer, and Wang (2011) argue that the forward premium puzzle can be explained by investor overconfidence causing an overreaction to macro information and discrepancies in forward and spot rate responses.

The third class of explanations focuses on errors in market expectations due to the potential for "peso problems", a term first introduced by Krasker (1980) to describe how uncertainty about a future shift in regimes results in biased measures of market expectations and, hence, a skewed distribution of forecast errors. In addition, Kaminsky (1993), Evans (1996), and Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) examine peso problems, measurement errors, and rare disasters, and infer that forward rates are biased. Furthermore, Lewis (2011) shows that potentially rare disasters may bias slope estimates of the Fama-regression. Building on evidence of peso problems, Lewis (1989) demonstrates that learning effects can account for as much as half of the magnitude of forward premium bias.

In addition, several studies focus on the interpretation of the puzzle from the microstructure point of view, constituting the fourth class of explanations. Evans and Lyons (2002) adopting the microstructure approach, find evidence of order flow related determinants of exchange rates. Lyons (2001) proposes limits to the speculation hypothesis and demonstrates that order flow information may reveal additional insights into the forward premium puzzle.

The second essay is most closely related to the risk-based explanations of carry trade excess returns, which attempts to explain the forward premium puzzle through the identification of a convenient time-varying risk premia. The inability of conventional risk factors to indisputably reconcile the puzzle as evident in Burnside, Eichenbaum, and Rebelo (2011), has spurred a number of original currency-specific interpretations. Lustig, Roussanov, and Verdelhan (2011) adopt a Fama and French (1993) style approach to forward-sorted currencies and find heterogeneity in exposures to common risks across portfolios, related to rational risk premia. In a similar vein, Menkhoff, Sarno, Schmeling, and Schrimpf (2012a) demonstrate that global currency market volatility shocks exert a compelling pricing power in the cross-section of carry trade returns. Rafferty (2012) indicates that global foreign exchange market skewness is also a valid risk factor. Mancini, Ranaldo, and Wrampelmeyer (2013) and Karnaukh, Ranaldo, and Söderlind (2015) reveal the substantial role of currency market liquidity in explaining the carry trade strategy payoffs. Hassan (2013) and Martin (2013) adopt theoretical models to argue that the spread between two countries' currency returns is related to the size of the countries. Jylhä and Souminen (2011) show that hedge fund capital flows affect interest rates and exchange rates, in turn affecting carry trade profitability, in a manner consistent with the risk-based explanation. Ready, Roussanov, and Ward (2015) in the model of equilibrium show that heterogeneity in excess returns between high and low interest rate currencies arises from the differences in composition of the trade balance. Bakshi and Ponayotov (2013) document the predictive role of commodities in explaining the time-series of carry trade returns. Lettau, Maggiori, and Weber (2014) argue that investment currencies exhibit large beta loadings conditional on the state of the market, particularly in times of market downturn. Correspondingly, Jurek (2014) shows that returns on a short put position in such currencies explain carry trades. Daniel, Hodrick and Lu (2015), however, find no evidence of downside risk in dollar-neutral carry trades. Ranaldo and Söderlind (2010) find that low interest rate currencies serve as a hedge against market turmoil, appreciating when the aggregate risk is high. Mueller, Stathopoulos, and Vedolin (2015) find a counter cyclicality in cross-sectional correlation dispersion between high and low carry trade currencies which is consistent with the rational risk premia interpretation. Finally, Koijen, Pedersen, Moskowitz, and Vrugt (2012) provide a comprehensive overview of carry trade strategy in different markets and reviews of research within the area. However, none of the above papers investigated the existence of risk premia in the foreign exchange market, as the second essay of the current dissertation does.

Despite the abundance of research searching for rational risk premia, only a few studies have attempted to explain forward bias as a risk premium originating from political risk. Bachman (1992) shows that political regime changes between 1973 and 1985 in the major developed countries could affect forward bias. Bernhard and Leblang (2002) argue that democratic processes (in eight industrial countries between 1974 and 1995) distorted forward rate forecasting ability, and thereby contributed to resolving the forward premium puzzle. Capitalizing on previous evidence, the current research adopts a large set of carry trades (48 currencies over the period 1985–2013) and investigates a comprehensive set of political risk components with the goal of comprehending the determinants of carry trade returns and, therefore, forward bias. The third essay takes a step on this path by examining the effect of political risk on individual currency carry trades.

Finally, several studies investigate the investment properties of currency carry trades and show that diversification across several currencies leads to carry trade risk reduction. Burnside Eichenbaum, Kleshchelski, and Rebelo (2006) show that the Sharpe ratio generated by an equally weighted portfolio of carry trade strategies is positive and statistically different from zero. Continuing their research Burnside, Eichenbaum, and Rebelo (2008) find that diversification among currencies boosts the Sharpe ratio. An equally weighted carry trade portfolio appears to provide a higher Sharpe ratio and other benefits of diversification in comparison to individual carry trade strategies and stock market benchmark. Inter alia, Burnside, Eichenbaum, and Rebelo (2011) and Bakshi and Panayotov (2013) show that returns are better for portfolios of currencies and that diversification leads to a higher Sharpe ratio and reduction in volatility, implying that diversification across currencies is the key factor in portfolio feature adjustment. The fourth essay of this dissertation is related to this strand of literature and investigates linkages between major carry trade currencies along with carry trade diversification opportunities.

3.2.2 Currency momentum and market liquidity

Similar to the carry trade strategy, currency momentum is the prominent foreign exchange market anomaly, which yields significant returns of around one percent per month, due to exploitable disparities in macroeconomic parity conditions (Menkhoff, Sarno, Schmeling, and Schrimpf, 2012b). Currency momentum strategy is executed by taking a long position in currencies with high excess returns in the preceding month(s) and a short position in currencies with low past excess returns. Similar to stock momentum, past winners tend to record positive excess returns while past losers exhibit negative return continuation, resulting in a profitable long-short investment strategy.

Contrary to the literature on currency carry trades, there is little research on momentum strategy in the foreign exchange market. Asness, Moskowitz, and Pedersen (2013) document the existence of positive returns on momentum strategy in the cross section of currencies. Burnside, Eichenbaum, and Rebelo (2011) find that neither traditional risk factors nor currency-specific risk factors are able to explain returns on currency momentum strategy. Menkhoff, Sarno, Schmeling, and Schrimpf (2012b) find that currency momentum returns do not exhibit any interactions with standard proxies for currency market illiquidity, currency market volatility, or business cycles. In addition, currency momentum is found to be uncorrelated with carry trade, which creates a hurdle providing a common explanation for the two currency strategies.

The first essay bridges the evidence on currency momentum with the literature on equity momentum and market state conditions. Avramov, Cheng, and Hameed (2015), examining equity market states interactions with stock momentum, show that market illiquidity is able to explain variation in stock market momentum payoffs. Cooper, Gutierrez, and Hameed (2004) show that past performance of the market index also predicts equity momentum payoffs. Wang and Xu (2010) point out that equity momentum returns are lower following periods of high market volatility. Pastor and Stambaugh (2003) find that equity illiquidity explains payoff realizations of stock momentum and guide future research to explore how the equity illiquidity affects other markets and various pricing anomalies therein. The first essay follows this guidance and examines the predictive role of equity market illiquidity and other equity market states in explaining the variations in currency momentum payoffs.

Second, the first essay is closely related to the two literature strands on foreign exchange market liquidity, and on cross-market linkages between equity and foreign exchange markets. Perhaps, due to issues of data availability, research on foreign exchange market illiquidity has emerged only recently. Early research approached FX illiquidity using the bid-ask spreads component of transaction costs (Bollershev and Melvin, 1994; Bessembinder, 1994). Evans and Lyons (2002), Breedon and Vitale (2010), Breedon and Ranaldo (2012), and Banti, Phylaktis and Sarno (2012) approach FX illiquidity from the market microstructure perspective and argue that order flow can explain a substantial part of exchange rate variations. Mancini, Ranaldo, and Wrampelmeyer (2013) show that liquidity risk explains carry trade returns, and also report the presence of a liquidity risk premium around the time of the 2008 financial crisis. Karnaukh, Ranaldo and Söderling (2015) develop a systematic FX illiquidity measure and advance the understanding of both supply-side and demand-side determinants of variations in currency illiquidity by analyzing a large set of currencies over a long period. Brunnermeier, Nagel, and Pedersen (2008) argue that FX liquidity, driven by supply-side factors attributed to funding illiquidity, is associated with risk premia in foreign exchange.

In addition, a number of studies provide evidence of cross-market linkages between equity and foreign exchange markets. Brandt, Cochrane, and Santa-Clara (2006) empirically combine stock markets, risk-free assets and exchange rates in their international risk sharing estimations. Pavlova and Rigobon (2007) highlight the examples of independence across stock, bond, and foreign exchange markets. Kamara, Lou, and Sadka (2008) suggest that equity market conditions affect institutional investors' trading patterns, which in turn results in commonality across markets. Menkhoff, Sarno, Schmeling, and Schrimpf (2012a) provide evidence that the condition of the forex market, the state of global FX volatility, affects other asset markets, and also prices a cross section of equity momentum and corporate bonds. Filipe and Suominen (2014) show that equity market states in Japan affect currency markets and currency trading, and also expose various channels through which the Japanese stock market conditions significantly affect the lending ability banks, the funding risk of yen carry traders, and the carry trade anomaly itself. However, none of the above papers empirically investigates the role of equity market illiquidity in the foreign exchange market, something the first essay of this dissertation does.

4 SUMMARY OF THE ESSAYS

This dissertation comprises the four essays described below. The individual contribution of each co-author of essays is as follows:

Essay 1: The essay is single-authored by Vitaly Orlov.

Essay 2: The essay is single-authored by Vitaly Orlov.

Essay 3: The main author of the essay is Vitaly Orlov, who is responsible for the research idea, research design, data collection, empirical analysis, and writing the essay. The role of Mr. Dimic and Dr. Piljak lay in giving valuable comments and suggestions for developing and improving the paper.

Essay 4: The main author of the essay is Vitaly Orlov, who is responsible for the research idea, research design, data collection, empirical analysis, and, partially, writing the essay. Professor Äijö contributed with valuable comments and suggestions, shared responsibility for writing the essay, and supervised the process of publishing the paper.

4.1 Currency momentum, carry trade, and market illiquidity

The first essay of the dissertation investigates the role of equity market illiquidity in explaining the inter-temporal variations in returns of currency momentum and carry trade strategies. In addition to equity market illiquidity, the essay also examines the predictive role of other market state, namely market volatility and market downturn. In addition, this study concurrently investigates the effects of foreign exchange market illiquidity and equity market illiquidity. Finally, the essay provides evidence on currency market anomalies payoff realizations and interaction with equity market conditions over the most recent decade, one of relatively liquid markets.

International finance literature has devoted considerable attention to currency market anomalies, however, there is a little evidence on the issue of liquidity in the foreign exchange market. At the same time, equity market liquidity, along with its relationship with various anomalies in the equity and other financial markets has been extensively studied. Equity market illiquidity is found to explain payoff realizations of various pricing anomalies in the stock market (see, e.g., Pastor and Stambaugh, 2003; Acharya and Pedersen, 2005; and Avramov, Cheng, and Hameed, 2015), the government and corporate bond markets (see, e.g., Fleming and Remolona, 1999; and Bongaerts, de Jong, and Driessen, 2012), and empirically helps to explain returns on commodities and on hedge funds (see Amihud, Mendelson, and Pedersen, 2005). Pastor and Staumbagh (2003) find that equity illiquidity explains payoff realizations of stock momentum and recommend future research explores how the equity illiquidity affects other markets and various pricing anomalies therein. However, despite its importance, there is little evidence available on the cross-market links between currency anomalies on the one hand and stock market conditions on the other. Therefore, the aim of this paper is to fill this gap and to provide new evidence for the predictive role of equity market illiquidity in explaining the variations in currency anomalies.

The data sample examined in this study consists of 48 currencies and stretches back to 1976. Following recent studies (e.g., Burnside, Eichenbaum, and Rebelo, 2011; and Menkhoff, Sarno, Schmeling, and Schrimpf, 2012b), we extend the dataset back to 1976 by complementing Barclays data quoted against the U.S. dollar (data become available from October 1983) with historical Reuters data quoted against the British Pound (available from January 1976), subsequently converting these additional quotes against the U.S. dollar. Doing so opens up a larger cross-section of currencies and longer time series essential for the analysis.

Taken together the empirical findings of this paper support the notion that equity market conditions affect speculative strategies in the foreign exchange market. The results of this paper indicate that dollar-based currency momentum profitability depends on the level of aggregate equity market illiquidity. Returns on currency momentum are low (high) following months of high (low) equity market illiquidity. In other words, aggregate equity market illiquidity explains the evolution of currency momentum payoffs, but the equity illiquidity effect is found to be fairly inconspicuous in currency carry trade returns. Moreover, the economic impact of the illiquidity effect is substantial, as one standard deviation increase in equity market illiquidity reduces profit by 0.303% per month, which approximates in value to one-third of average monthly profits. The effect of equity market illiquidity dominates other measures of equity market conditions. In addition, the results indicate the reversal in predictability patterns in the most recent decade due to structural and technological changes. Finally, the predictive effect of equity market illiquidity on currency momentum returns is robust to the alternative equity illiquidity specification and persists after controlling for aggregate foreign exchange market liquidity, and also sustains a number of robustness checks. In light of the findings, this paper significantly expands the existing literature by revealing novel evidence on the effect of equity market illiquidity on the currency market.

4.2 Solvency risk premia and the carry trades

The second essay examines the risk-return characteristics of the currency carry trade strategy and rationalizes the strategy returns as a compensation for common risk. There is abundant evidence suggesting the existence of common determinants of inter-temporal variations in carry trade returns, which lends support to a rationalization of strategy returns as a compensation for common risk. This implies that there are persistent differences in global risk exposures across countries and this heterogeneity is the source of carry trade profitability. The second essay sheds light on a possible origin of such heterogeneity and offers a new risk-based explanation for currency risk premia wherein currency carry trades can be rationalized by the time-varying risk premia originating from the sovereign solvency risk. Hinging on classic asset pricing procedures the second essay introduces a new, solvency-based risk factor and shows that its covariance with returns accounts for almost all cross-sectional variation across portfolios.

The main avenue for research perceives carry trade returns as a compensation for a common risk. Accordingly, currencies are prone to deliver low/high carry trade returns in bad/good times due to persistent heterogeneity in risk exposures between investment and funding currencies. Several recent studies suggest a number of possible explanations for observed patterns of heterogeneous risk exposures (see, e.g., Lustig, Roussanov, and Verdelhan, 2011; Menkhoff, Sarno, Schmeling, and Schrimpf, 2012a; Lettau, Maggiori, and Weber, 2013). Overall, the cumulative evidence points to time-varying risk premia as the pervasive source of the carry trade returns and to the forward premium puzzle not being without costs. The purpose of the paper is to contribute toward the identification of an appropriate risk premia that explains the carry trade profitability.

Importantly, this essay abstracts from the market measures of country's creditworthiness and relies on fundamentals. Several recent studies identify the marginal value of sovereign CDS spreads in interpreting the forward premium puzzle around the financial crisis as being broadly consistent with the crash risk explanations (see, e.g., Hui and Chung, 2011; Coudert and Mignon, 2013; Huang and MacDonald, 2014). Along with that, there is also evidence that market-based measures (CDS spreads) do not offer a true prediction of financial distress, if they contain country-specific information at all and that sovereign CDS spreads are plagued by time-varying systemic risk, global risk premia and other global and regional economic forces, while exhibiting almost no evidence of sovereign-specific credit risk premia (see, e.g., Mauro, Sussman, and Yafeh, 2002; Pan and Singleton, 2008; Longstaff, Pan, Pedersen, and Singleton, 2011; and Ang and Longstaff, 2013). Capitalizing on that evidence, this study considers the fundamental measures of the financial competence of the economy. Therefore, in this essay the sovereign solvency risk depends upon a country's ability to repay an outstanding external debt.

In addition, the second essay proposes a new risk-adjusted version of uncovered interest parity. Bridging the macroeconomic concepts of the debt-elastic interest rate and risk premium associated with lending to the economy, the paper derives the uncovered interest parity condition that is disturbed by country-specific risk premia given by the increasing convex function of the debt service capacity of the economy. Therefore, time-varying solvency risk premia offset the disparity between actual and expected exchange rate, establishing equilibrium. This provides a simple and intuitive risk-based view on exchange rate determination by a risk premium varying in the solvency of the economy.

The empirical findings of the second essay indicate that solvency risk retains substantial power to explain the cross-section of carry trade returns. This paper introduces a new, solvency-based, risk factor and shows that its covariance with returns accounts for almost all of the variation in the cross-section of carry trade returns. The empirical approach builds on the classic APT way of explaining the cross-section of carry trade returns and identifies persistent heterogeneity in loadings on a common component across countries' pricing kernels, relying on much of the recent literature (Lustig, Roussanov, and Verdelhan, 2011; and Ready, Roussanov, and Ward, 2015). The results indicate that the solvency sorted and forward discount sorted portfolios are exposed to a risk of a common origin that spurs the heterogeneity in average excess returns. In line with that finding, the heterogeneous risk exposures of currencies reveal that low carry trade currencies serve as a hedge against solvency risk, while high carry trade currencies depreciate, exposing investors to more risk and requiring a higher risk premium. The IMS factor (returns on zero-cost indebted-minus-solvent economies strategy) explains the substantial part of the cross-sectional variation in carry trade portfolios, exhibiting monotonically increasing factor loadings and significant prices of risk, consistent with risk premia explanation. Moreover, the factor is empirically powerful in various model specifications and sample splits, prices different test assets, stands out in competition with other currency-specific risk factors, robust against an alternative funding currency (the Japanese Yen) and alternative solvency measure specifications, and passes several other robustness checks, pointing to the solvency risk factor being a persuasive tool for pricing the cross-section of carry returns.

4.3 The effect of political risk on currency carry trade

The third essay explores the risk profile of individual currency carry trades and investigates whether currency carry trade profitability depends on a country's political risk characteristics. In doing so, the essay considers a comprehensive set of political risk components together with a large set of individual carry trades and aims to elicit the determinants of carry trade returns and, therefore, of forward bias.

Although the risk-based explanations of carry trade profitability is a renowned topic in the international finance literature, very few studies consider a country's political risk characteristics in attempting to explain currency carry trades (see, e.g., Bachman, 1992; and Bernhard and Leblang, 2002). This essay aims to contribute to filling this gap.

The studied sample comprises currency data and political risk measure in the form of annual rating scores for 48 countries. The sample period spans 01/1985 to 12/2013. Data on the political risk measure and its components is acquired from the International Country Risk Guide of the Political Risk Services Group. In addition, the components of political risk are organized into four subgroups as in Bekaert, Harvey, Lundblad, and Siegel (2014), those subgroups being: quality of institutions, conflicts external/internal, democratic tendencies, and government actions.

The findings of the third essay indicate that political risk may contribute to the existence of the forward premium puzzle. Scrutinizing a comprehensive currency universe, composite political risk and the set of political risk components, this study shows that individual carry trade profitability depends on a country's political risk. In particular, carry trade returns are high (low) when political risk is high (low). In addition, the results indicate that the political risk effect originates in emerging economies, while it is not evident in developed countries. Similarly, Erb Harvey, and Viskanta (1996) and Dimic, Orlov, and Piljak (2015), also document the increasing importance of political risk for the financial markets of emerging economies. Further, the paper documents how only the competence of government actions as a stand-alone component of political risk endures the adjustment for common risk factors. Finally, political risk is priced only in the subsample of high interest rate differential countries. To sum up, evidence suggests that individual carry trades are heterogeneously exposed to political risk and currency carry trade profitability depends on a country's political risk characteristics, thus providing new support for the risk-based view on the forward premium puzzle.

Overall, the evidence points to individual carry trades having different exposures to political risk across market categories and across currencies sorted by forward discounts. However, the economic magnitudes are not high enough to claim that political risk completely explains the forward premium puzzle. Nevertheless, the findings of this paper lend support to the point of view that political science theory can provide insights into financial market anomalies, and suggest that future research should not neglect information on fundamental political processes.

4.4 Benefits of wavelet-based carry trade diversification

The fourth essay of this dissertation investigates currency carry trade diversification opportunities and the links between major carry trade currencies on five different investment horizons, by applying a maximum overlap discrete wavelet transform method. This advantageous technique supports performing scale-to-scale decomposition to assess the temporal and dynamic structure of exchange rate correlations, which provides an opportunity for thorough investigation of the carry trade diversification opportunities and the interdependences of the currencies.

Recent studies indicate that aggregation of currencies in portfolios helps increase the investment properties of currency carry trades, thus, implying that diversification across currencies is an important factor in portfolio construction (see, e.g., Burnside, Eichenbaum, and Rebelo, 2011; and Bakshi and Panayotov, 2013). At the same time, Nekhili, Aslihan, and Gencay (2002) indicate the importance of scale-based analysis in maximizing diversification benefits. In addition, the wavelet analysis of financial time series and maximum overlap discrete transform techniques have been used extensively to study the co-movements dynamics of stock markets (see, e.g., Graham and Nikkinen, 2011; Graham, Kiviaho, and Nikkinen, 2012; and Nikkinen, Piljak, and Äijö, 2012). The fourth essay bridges these strands of the literature to investigate links between major carry trade currencies and explore the diversification properties of carry trades.

The empirical findings reported in the fourth essay indicate that positive and economically significant excess returns are observed on different investment horizons, namely the one-day, one-week, one-month, quarterly, and yearly horizons. In addition, results demonstrate that portfolio composition on the basis of wavelet correlations of returns with dynamic re-balancing leads to Sharpe ratios higher than the simply diversified portfolios and stock market proxy on most of the time scales. These results are more pronounced in the pre-crisis period. Wavelet diversified portfolios have better skewness-return characteristics on a three-month time scale, showing more positive skewness than individual carry trade strategies while posting similar returns. In addition, the wavelet diversification approach seems to perform better on longer time scales (from one-month upward) in a low volatility environment rather than on short horizons in a highly volatile market. Taken together, these findings indicate the importance of the dynamic structure of exchange rate correlations to currency arbitrage strategies. The results of the wavelet correlation analysis suggest that patterns in exchange rate movements exist and interdependencies with portfolio diversification implications may be found and exploited by investors.

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Currency momentum, carry trade, and market illiquidity ☆

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This study empirically examines the effect of equity market illiquidity on the excess returns of currency momentum and carry trade strategies. Results show that equity market illiquidity explains the evolution of currency momentum strategy payoffs, but not carry trade. Returns on currency momentum are low following months of high equity market illiquidity. However, in the recent decade, illiquidity positively predicts the associated payoffs. The findings withstand various robustness checks and are economically significant, approximating in value to one-third of average monthly profits.

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1. Introduction

International finance literature has devoted considerable attention to currency market anomalies over the last three decades. However, only recently advances have been made on the issue of liquidity in the foreign exchange market. At the same time, equity market liquidity, along with its relationship with various anomalies in the equity and other financial markets has been extensively studied.[1] However, despite its importance, there is little evidence available on the cross-market links between currency anomalies on the one hand and stock market conditions on the other.[2] This paper aims for contributing towards filling this gap.

Accordingly, the current research investigates the role of equity market illiquidity and other equity market states in explaining the inter-temporal variations in returns of currency momentum and carry trade strategies. Currency momentum and carry trade strategies have long been known to yield significant excess returns, owing to exploitable disparities in macroeconomic conditions. Recent research reports the time-series dependence of carry trade payoffs on business cycles, stock market volatility, and on liquidity of the foreign exchange market (see Ranaldo and Soderlind, 2010; Christiansen et al., 2011; Menkhoff et al., 2012a; Mancini et al., 2013; Daniel et al., 2015). Other studies suggest that equity market conditions and equity-based funding risk measures may explain a proportion of currency carry trade returns (see Gromb and Vayanos, 2002; Hattori and Shin, 2009; Brunnermeier and Pedersen, 2009; Filipe and Suominen, 2014; Banti and Phylaktis, 2015). At the same time, Menkhoff et al. (2012b) find that currency momentum returns do not exhibit any interactions with standard proxies for currency market illiquidity (further FX illiquidity),

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[1] Equity market illiquidity is found to explain payoff realizations of various pricing anomalies in stock market (see, e.g., Pastor and Stambaugh, 2003; Acharya and Pedersen, 2005; Avramov et al., 2015), government and corporate bond market (see, e.g., Fleming and Remolona, 1999; Bongaerts et al., 2012), and empirically helps to explain returns on commodities and on hedge funds (see Amihud et al., 2005).

[2] A number of studies provide evidence on cross-market linkages between equity and foreign exchange markets. Brandt et al. (2006) empirically combine stock markets, risk-free assets and exchange rates in their international risk sharing calculations. Pavlova and Rigobon (2007) highlight the examples of independence across stock, bond, and foreign exchange markets. Kamara et al. (2008) suggest that equity market conditions affect institutional investors' trading patterns, which in turn results in commonality across markets.

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currency market volatility, or business cycles. Pastor and Stambaugh (2003) find that equity illiquidity explains payoff realizations of stock momentum and guide future research to explore how the equity illiquidity affects other markets and various pricing anomalies therein. This study takes a step on that path and provides new evidence for the predictive role of equity market illiquidity in explaining the variations in currency momentum payoffs.

The empirical findings of this paper support the notion that equity market conditions affect speculative strategies in the foreign exchange market. We find that dollar-based currency momentum profitability depends on the level of aggregate equity market illiquidity. The full-sample investigation reveals that returns on the momentum long-short strategy are lower following months of high equity market illiquidity, and vice versa, strategy records high profits when the market is liquid. Moreover, the economic impact of the illiquidity effect is substantial, as one standard deviation increase in equity market illiquidity reduces profit by 0.303% per month, which approximates in value to one-third of average monthly profits. In addition, the dominant predictive role of equity market illiquidity stands out after controlling for other dimensions of market conditions.[3] Further, we find that the equity market illiquidity-carry trade relation is not robust, as it is dominated by FX market illiquidity and is attenuated by the introduction of alternative measure of illiquidity and other robustness checks.

The analysis is then extended to high and low illiquidity periods. Findings suggest the substantive ability of equity market illiquidity to predict returns on a currency momentum strategy, but the predictive effect is reversed in the two sample periods. In the period of high illiquidity (1976–2001), months of high (low) equity market illiquidity are followed by low (high) profits on the momentum strategy. Conversely, we find that in the recent decade of low illiquidity (2001–2012) equity market illiquidity positively predicts payoffs of currency momentum, in that returns on the strategies are high (low) following months of high (low) equity market illiquidity. We suggest that the observed divergence in predictability patterns is due to structural and technological changes in the most recent decade, which resulted in lower trading costs, increased market liquidity, a decreased role for funding liquidity, along with an overall increase in the salience of the currency anomalies (see French, 2008; Chordia et al., 2014). These results are only partially confirmed for the carry trade anomaly; that is, the sign of the effect for the carry trade strategy is analogous to its momentum counterpart, but the coefficient estimates only occasionally verge on significance, reflecting the differences between the anomalies.

Additionally, we expand our analysis in a number of directions. First, we show that the equity illiquidity effect on the currency momentum strategy is not subsumed by FX market illiquidity. Second, the main results of the paper hold true when we consider an alternative measure of equity market illiquidity as measured by Corwin and Schultz (2012) and perform sample split tests. Third, we show that results withstand several robustness checks. Specifically, the equity market illiquidity-momentum relationship is evident in portfolio returns with various formation periods and on the level of individual currencies, persists in different sample periods, endures after adjusting for traditional and currency-specific risk factors, transaction cost, currency tradability, and also sustains other robustness checks.

This study contributes to the literature in several important ways. First, we extend the strand of the literature on return predictability of currency anomalies. We provide new evidence on return predictability and add to the findings of studies, such as those of Bacchetta and van Wincoop (2010), Ranaldo and Soderlind (2010), Christiansen et al. (2011) and Menkhoff et al. (2012a), by exposing the predictive role of equity market illiquidity in explaining the inter-temporal variations in currency momentum returns. Further, our findings address Burnside's (2008) critique that literature on predictability is segmented across markets, as Amihud's (2002) illiquidity is also found to explain payoff realizations of equity pricing anomalies. Second, the finding indicating that equity market illiquidity negatively predicts profitability during the high-illiquidity period provides additional support for the theoretical work of Brunnermeier and Pedersen (2009) and Filipe and Suominen (2014) that links market liquidity and funding liquidity. Third, we add to the studies on recent trends in market anomalies (see Chordia et al., 2011; Brogaart et al., 2014; Chordia et al., 2014) by providing evidence on currency market anomalies payoff realizations and interaction with equity market conditions over the most recent decade. Finally, this study provides additional support to the prior literature that documents the linkage between equity and foreign exchange markets (e.g., Hau and Rey, 2006; Korajczyk and Viallet, 1992; Filipe and Suominen, 2014).

The remainder of the paper is organized as follows. In Section 2, we describe the dataset, predictive variables, the portfolio formation process, and provide descriptive statistics. In Section 3, we turn to the relation at the center of the current study and examine the predictive role of equity market illiquidity in portfolio returns. Several robustness checks are reported in Section 4, and Section 5 concludes the paper. This paper is accompanied with the Internet Appendix that provides results of additional robustness checks.

2. Data

2.1. Data sample

The sample consists of end-of-month observations of spot exchange rates, one-month forward exchange rates, and corresponding bid-ask spreads for the period from January 1976 to January 2014. The dataset was obtained from Barclays and Reuters via Datastream and comprises the currencies of the following 48 territories: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, the Euro area, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Iceland, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Ukraine, and United Kingdom. Throughout the studied period, the effective sample size varies greatly due to the availability of data quotes. The total number of end-of-month (not averaged over month) observations is 13,163.

Following recent studies (e.g., Burnside et al., 2011; Menkhoff et al., 2012b), we extend the dataset back to 1976 by complementing Barclays data quoted against the U.S. dollar (data become available from October 1983) with Reuters data quoted against the British Pound (available from January 1976), subsequently converting these additional quotes against the U.S. dollar. Doing this allows us to obtain the larger cross-section of currencies and longer time series essential for further analysis. In addition, in the Internet Appendix, we consider a smaller sample by excluding particular observations when trading was not possible and, even, completely exclude currencies with non-deliverable forward trading in offshore markets.

[3] Alongside the aggregate illiquidity measure, we also consider an aggregate market volatility measure (Wang and Xu, 2010) and a negative market returns measure (Cooper et al., 2004).

2.2. Currency excess returns

In this study we construct currency excess returns in a classic way, adopting the perspective of a U.S. investor, so that the monthly excess return for holding foreign currency *i* is defined as:

$$r^i_{t+1} = i^i_t - i_t - \Delta s^i_{t+1} \approx f^i_t - s^i_{t+1} \quad (1)$$

where i^i_t and i_t stand for the foreign and domestic (U.S.) interest rates in month *t*, respectively, and the interest rate differential is approximately equal to the log forward discount under a covered interest parity condition. f^i_t denotes the log one-month forward rate in units of foreign currency *i* per U.S. dollar in month *t* and s^i is the log spot exchange rate.

In order to account for transactions costs, we compute the log currency excess returns net of bid-ask spreads. For this purpose we employ bid-ask quotes from Reuters. Lyons (2001) shows that these quotes are of a magnitude almost double inter-dealer spreads, but, fortunately, they do not exhibit any lag effects on monthly frequency. Hence, our bid-ask spreads can be viewed as realistic, if perhaps overly vigilant. Log net excess returns are further applied in portfolio construction (momentum and carry trade). The log monthly net excess return to an investor who takes the long position in foreign currency is therefore:

$$r^{long}_{t+1} = f^b_t - s^a_{t+1} \quad (2)$$

where the letters *b* and *a* indicate bid and ask quotes, respectively. In this case the investor buys the foreign currency in the forward market at the bid price and, subsequently, sells the foreign currency at the ask price in the spot market. In a similar vein, the log monthly net excess return if an investor goes short on foreign currency is:

$$r^{short}_{t+1} = -f^a_t + s^b_{t+1} \quad (3)$$

2.3. Portfolios

Our portfolio formation approach is similar to Lustig et al. (2011) and Menkhoff et al. (2012b). To form momentum and carry trade portfolios at the end of each month *t*, we allocate currencies to one of six groups based on their lagged excess returns and lagged forward discount, respectively. Currency excess returns over the previous one, six, and twelve-months periods are used to sort currencies into momentum sextiles, while one-month lagged forward discounts are used to construct carry trade portfolios. In both cases, portfolios are held for one month and rebalanced on a monthly basis. The top (bottom) sextile of currencies constitutes the "High" ("Low") portfolios. Thus, one-sixth of all currencies with the highest lagged excess returns (forward discounts) are placed into the sixth portfolio ("High") in case of momentum (carry trade). In a similar manner, the first portfolio comprises one-sixth of all currencies with the lowest lagged excess returns (forward discount). Finally, the portfolio holding period return in month *t* is the equally-weighted sum of currency excess returns in each sextile.

Overall, six portfolios are used in evaluating the momentum and carry trade strategies. To build the time series of momentum and carry trade payoffs, we go long in the winner portfolio (sixth portfolio) and go short in the loser (first portfolio). In order to account for transaction costs, we assume that currency speculators short all foreign currencies in the first portfolio, while taking the long position in the remainder. These portfolios are referred to as "high-minus-low", "long-short" or "winner-minus-loser" portfolios. It is noteworthy that the number of currencies in the portfolios varies greatly over the period. We start with 16 currencies available at the beginning of 1976 and finish with 43 currencies by the end of 2013. The minimum number of currencies is nine at the end of 1983.

2.4. Momentum and carry trade returns

First, we provide an overview of the currency portfolios without transaction costs. Table 1 (Panels A and B) presents descriptive statistics of average monthly profits of the momentum and the carry trade portfolios over the full sample period. We also report maximum and minimum values, standard deviation of returns, skewness, kurtosis, and the Sharpe ratio, in addition to alphas (as a percentage) adjusted with various traditional and unconventional risk factor models.

Panel A of Table 1 presents the characteristics of six momentum portfolios formed on the basis of a one-month formation period and a one-month holding period. We find that the high portfolio outperforms the low portfolio to yield a substantial full-sample average monthly high-minus-low (H-L) portfolio return of 1.09 percent. Consistent with the existing literature, these momentum profits are not due to exposure to traditional or currency-specific risk factors. Specifically, the CAPM-adjusted H-L portfolio return increases to 1.16 percent per month. Similarly, the Fama–French three-factor-adjusted high-minus-low return is also significant at 1.16 percent per month. Turning to currency-based risk factor models, we report the 0.10 percent per month decrease in return after adjusting for the dollar risk factor (the average excess returns to all of the portfolios) and the HML_{fx} (the long-short carry trade return) risk factor derived from Lustig et al. (2011). The returns are further adjusted with the Menkhoff et al. (2012a) model, which results in a slight decrease in returns. Overall, currency-based risk factors also fell short in explaining currency momentum profits.[4]

Panel B of Table 1 shows descriptive statistics for six carry trade portfolios. We find that the average raw return for the high-minus-low carry trade portfolio is highly significant at 1.04 percent per month. Similar to the currency momentum profits, adjustments for common risk factors do not significantly change carry trade payoffs. In this panel, we consider only traditional risk based models as currency-specific factors to a large extent constructed to explain the returns on carry trade.

Table 1 also presents other characteristics of the portfolios, including standard deviation, skewness, kurtosis, and the Sharpe ratio. These descriptive statistics are intended to address the concern that momentum and carry trade, being the two most prominent currency speculative strategies, capture the same information. As can be seen above, both strategies demonstrate similar patterns in portfolio returns. However, the distribution of these returns is in fact very different. For instance, the momentum payoff is positively skewed (0.70), while the carry trade profit exhibits negative skewness (−0.68), suggesting that carry trade strategy comes with occasional crashes.[5]

2.5. Aggregate market state variables

The following empirical part of this paper mainly focuses on the role played by aggregate market liquidity in explaining the time variation in currency momentum and carry trade payoffs. We utilize Amihud's illiquidity as our main measure of aggregate market liquidity. Although, our analysis focuses on the role of aggregate liquidity, it is important to consider other dimensions of market states. We therefore compute a dummy for a negative cumulative

[4] We are grateful to Kenneth French for making common risk factors publicly available.

[5] For a more comprehensive comparison of currency momentum and carry trade returns see Menkhoff et al. (2012b). For more evidence on carry trade crashes see Brunnermeier et al. (2008).

Table 1
Descriptive statistics for momentum and carry trade returns.

	Low	2	3	4	5	High	Average	H-L
Panel A: momentum (1,1)								
Raw returns	−0.371**	0.004	0.186	0.200	0.214*	0.716***	0.158	1.088***
	(−2.38)	(0.07)	(1.29)	(1.43)	(1.75)	(4.01)	(1.14)	(6.54)
CAPM alpha	−0.467***	−0.058	0.152	0.156	0.178	0.695***	0.109	1.162***
	(−2.71)	(−0.39)	(1.35)	(0.97)	(1.32)	(3.66)	(0.69)	(6.46)
3-FM alpha	−0.486***	−0.056	0.152	0.153	0.161	0.676***	0.100	1.162***
	(−2.67)	(−0.36)	(0.95)	(0.90)	(1.13)	(3.64)	(0.60)	(6.24)
Lustig's alpha	−0.592***	−0.088	0.100	0.109*	0.126**	0.475***	0.022	1.067***
	(−5.23)	(−1.21)	(1.58)	(1.72)	(2.29)	(4.30)	(0.81)	(5.42)
Menkhoff's alpha	−0.290	−0.202	−0.386**	0.215	0.049	0.817***	0.051**	1.107**
	(−1.05)	(−0.84)	(−2.38)	(1.28)	(0.27)	(2.80)	(2.15)	(2.19)
Max (in %)	13.02	7.87	10.25	8.07	11.34	8.98	6.80	21.25
Min (in %)	−17.59	−10.92	−10.07	−9.54	−9.10	−9.95	−8.37	−11.98
Std. Dev.	3.084	2.589	2.661	2.619	2.483	2.783	2.287	3.319
Skewness	−0.688	−0.381	−0.186	−0.167	0.025	−0.080	−0.368	0.811
Kurtosis	7.361	5.034	4.347	3.796	4.552	4.167	3.914	7.771
Sharpe ratio	−0.120	0.001	0.070	0.076	0.086	0.257	0.069	0.328
Panel B: carry trade								
Raw returns	−0.310**	−0.048	0.096	0.167	0.268**	0.733***	0.151	1.043***
	(−1.98)	(−0.38)	(0.76)	(1.21)	(2.00)	(3.14)	(1.09)	(5.26)
CAPM alpha	−0.344**	−0.089	0.056	0.152	0.255*	0.735***	0.137	0.997***
	(−2.02)	(−0.64)	(0.40)	(1.03)	(1.71)	(3.18)	(0.67)	(5.05)
3-FM alpha	−0.362**	−0.094	0.074	0.114	0.193	0.657***	0.097	1.019***
	(−2.05)	(−0.67)	(0.51)	(0.72)	(1.25)	(2.79)	(0.58)	(4.87)
Max (in %)	8.93	8.28	8.84	10.75	7.28	10.62	7.38	12.06
Min (in %)	−12.72	−9.52	−8.73	−10.19	−9.59	−17.59	−8.26	−12.55
Std. Dev.	2.777	2.549	2.432	2.526	2.533	3.320	2.307	3.287
Skewness	−0.140	−0.077	−0.067	−0.144	−0.527	−0.751	−0.323	−0.676
Kurtosis	4.702	3.968	4.201	5.285	4.467	5.912	3.959	5.259
Sharpe ratio	−0.122	−0.019	0.039	0.066	0.106	0.221	0.065	0.317

	H-L	Amihud's illiquidity	Market volatility	Down market	Crisis
Panel C: Correlation among market states (Momentum profit with f = 1 is used)					
H-L	1.000				
Amihud's illiquidity	−0.110	1.000			
Market volatility	0.123	−0.216	1.000		
Down market state	0.031	−0.226	0.442	1.000	
Crisis	0.090	−0.112	0.183	0.155	1.000
Panel D: Correlation among market states (Carry trade profit)					
H-L	1.000				
Amihud's illiquidity	−0.113	1.000			
Market volatility	0.170	−0.216	1.000		
Down market state	0.084	−0.226	0.442	1.000	
Crisis	−0.091	−0.112	0.183	0.155	1.000

This table presents descriptive statistics of average monthly profits of the momentum and the carry trade portfolios. The data period spans January 1976 to January 2014. The currency momentum and the carry trade payoffs are formed with one-month formation period and one-month holding period. In Panel A (Panel B) we report average equally-weighted holding period returns of each sextile portfolio, as well as the average and the momentum (the carry trade) profits (H-L portfolio). H-L denotes the currency momentum (the carry trade) trading strategy profits, where the equally-weighted bottom sextile portfolio (Low) is subtracted from equally-weighted top sextile portfolio (High). Further, we report alphas (in %) by adjusting returns with CAPM, Fama–French three-factor, Lustig et al. (2011) and Menkhoff et al. (2012a) models. We also report maximum and minimum values, standard deviation of returns, skewness, kurtosis, and the Sharpe ratio, computed as average monthly excess portfolio return divided by its standard deviation. Panel C (Panel D) shows the pairwise correlation between the momentum (1,1) strategy (the carry trade strategy) and market state variables, such as Amihud's illiquidity, down market state, market volatility and crisis control. Newey and West (1987) HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

two-year stock market return and the measure of aggregate stock market volatility. All of these variables have been found to predict the evolution of stock market momentum payoffs.[6]

We define the level of aggregate market illiquidity as *Amihud's illiquidity* or, simply, *illiquidity* in the rest of the paper. The measure is constructed in a similar way to that presented by Amihud (2002) and normalized. Specifically, it is the value-weighted average of a monthly Amihud's (2002) illiquidity measure of each NYSE and AMEX firm for the period from January 1976 to December 2011. The monthly illiquidity measure for a single firm is computed as the absolute value of the daily stock return divided by the daily trading volume of that stock, subsequently aggregated over the number of trading days in the month. The next market state variable is a dummy for a negative cumulative two-year stock market return (henceforth, "*the down market*"). The dummy variable takes the value of one if the past twenty-four months' return on the value-weighted CRSP market index is negative and zero otherwise. The volatility measure is calculated as the standard deviation of the value-weighted CRSP market index. Time spans for all three market state variables are matched. Additionally, in most of our analyses we control for potentially systemic macroeconomic events, introducing a dummy variable taking the value of one if a relevant macroeconomic event occurs. Specifically, the list of

[6] There is extensive literature on equity momentum and market state conditions. Avramov et al. (2015) show that a market illiquidity state is able to explain some variation in stock market momentum payoffs. Cooper et al. (2004) show that past performance of the market index also predicts equity momentum payoffs. Finally, Wang and Xu (2010) point out that equity momentum returns are lower following high market volatility periods.

relevant events includes: the devaluation of the Thai baht (1997:07), the Russian default (1998:08), the Icelandic currency crisis (2006:03), the Lehman Brothers collapse (2008:09) and many others.[7]

Panels C and D of Table 1 show the time-series correlation of market state variables with the high-minus-low momentum and carry trade returns, respectively. Correlation coefficients for both momentum and carry trade payoffs with market level variables are low, ranging from −0.11 to 0.12. In turn, aggregate market state variables are fairly well correlated. It is notable that Amihud's illiquidity proves to have a negative correlation with other predictors. This fact is counter-intuitive and arises owing to the limited period for which data is available, as when the data period was extended back to 1928, the correlations became positive. Additionally, we checked that the autocorrelation is far from 1.0 and that Stambaugh's (1999) small sample bias is clearly not an issue.

3. Currency momentum, carry trade in portfolio returns, and illiquidity

3.1. Equity market illiquidity and currency anomalies

This section presents empirical findings on the predictive power of equity market illiquidity to explain the evolution of currency momentum and carry trade payoffs, while investigating the full sample period. The analysis is based on eight time-series regression specifications, starting from the *iid* model (intercept only) and concluding with a comprehensive specification, where we control for other dimensions of equity market conditions. In these models, the dependent variable is either currency momentum or carry trade high-minus-low portfolio return, formed on the basis of a one-month formation period and one-month holding period. As the predictive variables, we consider three one-month lagged aggregate equity market state measures, namely, Amihud's illiquidity, a bear market return state, and market volatility. Additionally, we control for potentially disturbing macroeconomic events by introducing a crisis control variable.

Table 2 reports the coefficient estimates of all regression designs with adjustments for Fama–French common risk factors. All of the models in Panel A include a winner-minus-loser momentum return as the dependent variable, while Panel B reports results of analogous models with a high-minus-low carry trade payoff. The data period spans 1976:1 to 2011:12. Estimates of such regressions consistently support the notion that equity market illiquidity explains the inter-temporal variation of currency momentum and, possibly, carry trade payoffs. The slope coefficients of Amihud's illiquidity measure are −0.349 and −0.431 for momentum and carry trade, respectively, and are significant in the specification with the single predictor (Model 2 in Panels A and B). Further, inclusion of the down market and market volatility variables results in a drop in the coefficients for illiquidity for the two strategies and their significance. Noteworthy, the coefficient of Amihud's illiquidity exhibits only a slight decrease in significance and magnitude in the all-inclusive model (Model 8 in both panels), while in the carry trade regression the coefficient value is around 30 percent smaller relative to the *iid* model and significant only at a 10 percent level. Moreover, the illiquidity effect has a considerable economic impact, as one standard deviation increase in equity market illiquidity leads to a 0.303% per month decline in profit for momentum and, if coefficient considered significant, a 0.297% drop in the monthly return for a carry trade strategy. Such an effect can be considered economically significant as it approximates in value to one-third of average monthly profits.

[7] See the Internet Appendix for the detailed list of events.

The effect of aggregate market illiquidity dominates the other two measures of equity market conditions.[8] Their regression estimates are rather inconsistent throughout the analysis, occasionally verging on significance, but are usually statistically and economically insignificant. This is especially evident in the models with momentum payoffs as the dependent variable. The same patterns are found in our additional results, where we consider the same eight model specifications, while adjusting for currency-specific risk factor models or testing momentum strategies with various formation periods. These additional estimations confirm the dominant role of market illiquidity over other market states in both single-predictor and in joint models.

The results reported in this section moderately suggest a possible predictive role in explaining the two anomalies returns for the equity market illiquidity, suggesting a common intuition behind the intertemporal variations in currency momentum and carry trade payoffs. This is a puzzling finding, given that the two anomalies exhibit different patterns in returns and have been found to be largely unrelated to one another (see, e.g., Burnside et al., 2011; Menkhoff et al., 2012b). In the following sections, we perform a more systematic analysis and present evidence that the predictive role of equity market illiquidity is robust only for currency momentum, but not for carry trade strategy.

3.2. The illiquidity effect and the period of improved liquidity

In this section, we continue to explore the predictive effect of equity market illiquidity on currency momentum and carry trade strategies by investigating a period associated with unprecedented reduction in the overall cost of trading due to technological improvements and structural changes. French (2008) documents how institutional commission has palpably declined over time, while Chordia et al. (2014) show that the most recent decade is associated with low values of standard illiquidity proxies (e.g., bid-ask spread). Indeed, the time series of Amihud's illiquidity (Fig. 1) depict the improvements in aggregate market liquidity in recent years. Hendershott et al. (2011) connect the overall increase in market liquidity with the improvements in trading technology and the rise of algorithmic trading. Other studies have also documented changes in liquidity, trading volume, funding liquidity and trading technology in the post-decimalization period (see Roll et al., 2007; Chordia et al., 2011; Brogaart et al., 2014). In this regard, the recent regime of increased market-wide liquidity comprises a unique setting to test the effect of aggregate market illiquidity on currency anomalies.

Evidence on stock market anomalies indicates that some anomalies tend to attenuate over the previous decade (Chordia et al., 2014). Conversely, we find that currency market anomalies exhibit higher mean returns in the post-decimalization period (2001–2012) than in the prior sample period. Findings also indicate that the returns to the two currency strategies are positively correlated in the period of improved liquidity and reflect the increase in currency anomalies' payoffs relative to the former period. Next, we investigate the role of aggregate market illiquidity in predicting currency momentum and carry trade returns while splitting the sample into two periods, reflecting those before and after technological and structural changes occurred. Results are reported in Table 3.

The decision to implement the division into two sub-periods is motivated by the abundance of evidence on reduced trading costs, changes in market liquidity, funding liquidity and trading volume, and facilitation of algorithmic trading by institutions over the

[8] Additionally, in unreported results we document that results persist after controlling for an alternative proxy for equity market volatility, the CBOE VIX index.

Table 2
Momentum and carry trade profits and market states.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Panel A: Momentum profits regressed on lagged market state variables								
Intercept	1.165***	1.169***	1.027***	1.164***	1.062***	1.169***	1.013***	1.034***
	(6.24)	(6.32)	(5.79)	(6.22)	(5.92)	(6.30)	(5.50)	(5.65)
Illiquidity		−0.349***			−0.281**	−0.357***		−0.303**
		(−2.61)			(−2.26)	(−2.69)		(−2.42)
Down market			1.111		0.923		1.297*	1.148
			(1.61)		(1.32)		(1.83)	(1.61)
Volatility				0.038		−0.038	−0.149	−0.192
				(0.23)		(−0.23)	(−0.93)	(−1.22)
MKT-RF	−0.038	−0.039	−0.037	−0.037	−0.038	−0.040	−0.040	−0.041
	(−0.77)	(−0.80)	(−0.77)	(−0.76)	(−0.79)	(−0.82)	(−0.84)	(−0.88)
SMB	0.032	0.041	0.021	0.031	0.031	0.042	0.021	0.032
	(0.63)	(0.84)	(0.42)	(0.61)	(0.63)	(0.84)	(0.43)	(0.64)
HML	−0.005	−0.005	−0.004	−0.004	−0.004	−0.007	−0.010	−0.012
	(−0.11)	(−0.10)	(−0.07)	(−0.07)	(−0.08)	(−0.14)	(−0.21)	(−0.25)
Crisis control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.002	0.010	0.011	0.011	0.016	0.008	0.010	0.016
Obs	430	430	430	430	430	430	430	430
Panel B: Carry trade profits regressed on lagged market state variables								
Intercept	1.110***	1.116***	0.895***	1.114***	0.923***	1.119***	0.916***	0.936***
	(5.20)	(5.32)	(4.33)	(5.39)	(4.45)	(5.44)	(4.42)	(4.49)
Illiquidity		−0.431**			−0.308*	−0.370**		−0.297*
		(−2.39)			(−1.75)	(−2.07)		(−1.69)
Down market			1.874***		1.668**		1.708**	1.561**
			(2.78)		(2.42)		(2.35)	(2.11)
Volatility				0.378*		0.299	0.133	0.090
				(1.89)		(−1.57)	(0.65)	(0.46)
MKT-RF	0.114***	0.113***	0.116***	0.122***	0.115***	0.120***	0.119***	0.117***
	(3.27)	(3.25)	(3.24)	(3.40)	(3.23)	(3.37)	(3.25)	(3.25)
SMB	0.022	0.035	0.004	0.017	0.015	0.029	0.004	0.014
	(0.41)	(0.64)	(0.08)	(0.31)	(0.29)	(0.53)	(0.07)	(0.28)
HML	0.017	0.017	0.020	0.035	0.020	0.032	0.026	0.024
	(0.31)	(0.32)	(0.35)	(0.52)	(0.35)	(0.57)	(0.46)	(0.42)
Crisis control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.022	0.037	0.055	0.033	0.061	0.042	0.054	0.059
Obs	430	430	430	430	430	430	430	430

This table presents the results of the following monthly time-series regressions:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5 mkt\_rf_t + B_6 smb_t + B_7 hml_t + e_t$$

where *H-L* is the currency momentum (the carry trade in Panel B) trading strategy payoff, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t; *illiquidity* stands for the normalized market illiquidity measure adopted from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12; *down* is the dummy variable that takes the value of one if the past twenty-four months return on the value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month t; *mkt_rf*, *smb*, and *hml* are FF factors, including the market factor, the size factor and the book-to-market factor, respectively. Newey-West HAC based t-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

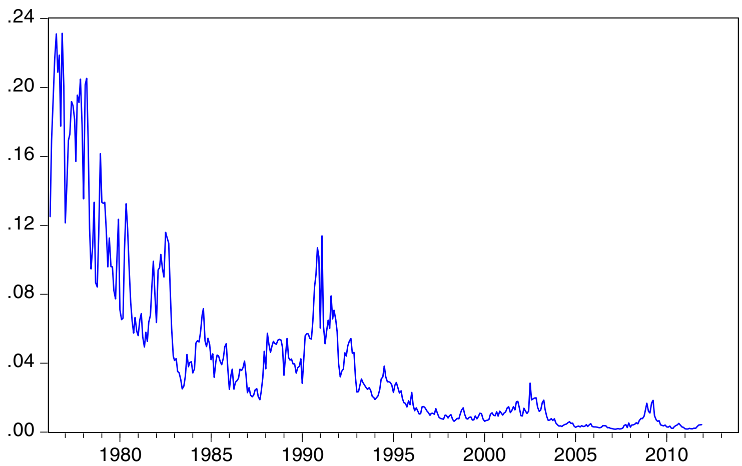

Fig. 1. Time-series of Amihud's (2002) illiquidity. Figure shows the time-series of the market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted average of stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12.

Table 3
Illiquidity effect in different sample periods.

	Momentum				Carry trade	
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2
Panel A: Profits regressed on lagged market state variables (1976–2001)						
Intercept	1.044***	1.062***	1.070***	1.219**	0.768***	0.707***
	(5.25)	(4.95)	(4.82)	(2.04)	(3.34)	(3.10)
Illiquidity	−0.384**	−0.429***	−0.416***	−0.422***	−0.190*	−0.126*
	(−2.35)	(−2.74)	(−2.75)	(−2.67)	(−1.85)	(−1.72)
Down market		2.611	2.392	2.400		0.446
		(3.58)	(1.05)	(1.07)		(0.23)
Volatility		−0.171	−0.125	−0.140		0.475**
		(−1.01)	(−0.79)	(−0.82)		(2.25)
FF factors		Yes				Yes
Lustig et al. factors			Yes			
Menkhoff et al. factors				Yes		
Crisis Control		Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.008	0.017	0.021	0.018	0.002	0.041
Obs	298	298	298	298	298	298
Panel B: Profits regressed on lagged market state variables (2001–2012)						
Intercept	1.580***	1.332***	1.108**	1.234	1.991***	2.092***
	(5.38)	(3.71)	(2.48)	(1.04)	(9.02)	(6.82)
Illiquidity	0.882***	0.919***	0.718*	0.926**	0.859***	1.416***
	(2.82)	(2.81)	(1.86)	(2.45)	(3.88)	(5.13)
Down market		0.291	0.529	0.577		0.159
		(0.46)	(0.72)	(0.77)		(0.30)
Volatility		−0.407	−0.552*	−0.764*		−1.011***
		(−1.42)	(−1.75)	(−1.80)		(−4.18)
FF factors		Yes				Yes
Lustig et al. factors			Yes			
Menkhoff et al. factors				Yes		
Crisis Control		Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.091	0.141	0.125	0.102	0.097	0.321
Obs	132	132	132	132	132	132

This table presents the results of the following monthly time-series regressions for the samples from 1976:1 to 2000:12 (Panel A) and from 2001:1 to 2011:12 (Panel B):

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5' F_t + e_t$$

where *H-L* is the currency momentum or the carry trade trading strategy payoff; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms; *down* is the dummy variable that takes the value of one if the past twenty-four months return on the value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month *t*; *mkt_rf*, *smb*, and *hml* are FF factors; *dol* and *hml_fx* are Lustig et al. (2011) factors; *dol* and *vol_fx* are Menkhoff et al. (2012a) factors. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

recent years. Further, we refer to the pre- and post-structural change sub-periods as high and low illiquidity sub-samples, respectively. The effect of equity market illiquidity is conspicuous. In Table 3 (both Panels), the *t*-statistics for all illiquidity coefficient estimates reject the null hypothesis of there being no predictive effect of aggregate equity market illiquidity on currency speculative strategies in favor of the alternative. However, the predictive effect varies in times of high and low illiquidity, being negative in the high illiquidity period and positive in the low illiquidity period.

The results of Panel A of Table 3 indicate that equity illiquidity negatively predicts profitability of the anomalies during the period associated with the high levels of illiquidity. This is consistent with the theoretical liquidity framework of Brunnermeier and Pedersen (2009) that links market liquidity and funding liquidity. In particular, during a period marked by an illiquid market, leveraged investors face margin calls, which subsequently triggers position unwinding and fire sales that drives prices away from their fundamental basis, causing losses. In addition, the theoretical model suggests that market liquidity and funding liquidity are mutually reinforcing concepts. Therefore, when market illiquidity is high and/or fluctuates traders are more exposed to the funding liquidity risk than during the liquid and stable market condition.

Conversely, equity illiquidity positively predicts profitability of the anomalies in the latter sub-period (Panel B). This sample period is associated with increased liquidity, high trading volume, highly integrated markets, excessive funding liquidity, and advances in trading technology. In the later period both currency anomalies become negatively correlated with the stock market and with some prominent equity anomalies (e.g., stock momentum), suggesting hedging opportunities. Thus, in conjunction with the evidence on the negative stock momentum returns following the months of high market illiquidity (Avramov et al., 2015), investors may switch to currency strategies in search of higher returns and diversification benefits. Finally, the later period is associated with the improved tradability of the currencies, as noted in Menkhoff et al. (2012b), which, alongside the improvements in trading technology and reductions in trading costs, results in increased currency market accessibility. Overall, we suggest that the evidence of high returns on currency anomalies following months of high equity market illiquidity originates from the observed structural changes, decreased role of funding liquidity, increased salience of the currency anomalies and changes in the diversification properties of currency strategies.

3.3. Equity market illiquidity or FOREX illiquidity?

The results thus far indicate a possible predictive role for aggregate equity market illiquidity in explaining the two anomalies returns. The evidence also suggests that the sign of the effect changes in a period of low illiquidity. At the same time, recent studies of Mancini et al. (2013) and Karnaukh et al. (2015) argue

Table 4
Equity market liquidity and FX liquidity.

	Momentum		Carry trade	
	Model 1		Model 1	
Panel A: FX liquidity (full sample)				
Intercept	1.581***		1.513***	
	(6.65)		(5.27)	
FX illiquidity	0.294		−1.348***	
	(0.60)		(−3.29)	
Adj-Rsq	0.003		0.069	
Obs	252		252	
	Momentum		Carry trade	
	Model 1	Model 2	Model 1	Model 2
Panel B: Profits regressed on lagged illiquidity variables (1991–2001)				
Intercept	1.531***	1.415***	0.961***	0.221
	(5.41)	(5.38)	(2.23)	(0.68)
FX illiquidity	1.663	1.595	−1.683*	−2.060***
	(1.57)	(1.53)	(−1.91)	(−2.77)
Equity market illiquidity		−0.321***		−0.936**
		(−2.63)		(−2.23)
Adj-Rsq	0.004	0.043	0.046	0.097
Obs	120	120	120	120
Panel C: Profits regressed on lagged illiquidity variables (2001–2012)				
Intercept	1.585***	1.635***	2.024***	2.084***
	(4.56)	(6.08)	(5.62)	(7.30)
FX illiquidity	−0.173	−0.552	−1.218***	−1.675***
	(−0.27)	(−0.77)	(−3.18)	(−5.28)
Equity market illiquidity		0.966***		1.166***
		(3.32)		(4.23)
Adj-Rsq	0.002	0.116	0.111	0.297
Obs	132	132	132	132

This table presents the results of the monthly time-series regressions with FX illiquidity as a single explanatory variable (Model 1) as well as jointly specified with equity illiquidity (Model 2) for the full sample (Panel A), and samples from 1976:1 to 2000:12 (Panel B) and from 2001:1 to 2011:12 (Panel C). *FX illiquidity* is the Karnaukh, Ranaldo and Söderlind (2015) aggregate Corwin-Schultz estimator based illiquidity measure in month $t-1$. *Equity market illiquidity* the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms. Newey-West HAC based t-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

that FX illiquidity can explain a substantial proportion of the variations in carry trade returns. The natural question arising is whether it is the currency market illiquidity, but not the equity market illiquidity, that is responsible for the observed relation.[9] Illiquidity can indeed be correlated across markets. In this subsection we address this concern and guard against the possibility that equity market illiquidity confers no marginal effect on currency anomalies. Specifically, we examine whether the predictive effects of equity market illiquidity on momentum and carry trade returns are subsumed by a variation in FX market illiquidity.

The measure of FX illiquidity is based on Karnaukh et al. (2015).[10] Specifically, the monthly FX illiquidity measure for each currency pair is computed based on the Corwin-Schultz spread estimator with adjustments for overnight returns as a simple average across positive two-day estimates. The simple average across individual currency pair's monthly estimators is the aggregate FX illiquidity measure in our paper. This measure is positively correlated with Amihud's (2002) equity illiquidity measure with the correlation coefficient of 0.03 in the sample from 1991:01 till 2011:12.

First, we consider the role of the state of FX illiquidity in the time-variation of currency anomalies returns in a model with a single predictor (Panel A of Table 4). Similar to the evidence in the prior literature, the FX illiquidity posts a negative and statistically significant coefficient estimate in the case of carry trade returns (right panel), however, the results for currency momentum (left panel) are statistically indistinguishable from zero. Next, we investigate the predictive role of the equity market illiquidity in addition to FX illiquidity in jointly specified models. These results are presented for the samples from 1991:1 to 2000:12 (Panel B) and from 2001:1 to 2011:12 (Panel C). The correlation coefficients between the two illiquidity measures are −0.24 and 0.37 for Panels B and C, respectively. The results on currency momentum strategy confirm the strong influence of equity market illiquidity states on momentum returns in both sub-samples, while revealing no evidence of an FX illiquidity-momentum relationship. Conversely, in the case of carry trade, the FX illiquidity dominates equity market illiquidity in terms of both magnitudes and statistical significance, albeit, the latter is not entirely subsumed by the variation in FX market illiquidity.

To conclude, the results of Section 3 indicate the dominant predictive role of the equity market illiquidity measure over other equity market state variables in explaining the variations in portfolio returns of currency market anomalies. Further, the structural change in equity market illiquidity results in the negative-to-positive sign reversal in the illiquidity-anomalies relationship. Furthermore, we document that the equity illiquidity-momentum effect is sustained upon the introduction of FX illiquidity into the analysis, while FX illiquidity overshadows equity market illiquidity in explaining carry trade returns. Overall, results of this section suggest the moderately possible predictive role of the aggregate equity illiquidity for both anomalies. However, in the following sections, we show that the predictive effect of equity market illiquidity is robust only for currency momentum, but not for carry trade.

[9] We thank an anonymous referee for the suggested analysis.

[10] We thank Angelo Ranaldo for making the time series of their FX illiquidity measure and instruction on its construction publicly available.

Table 5
Alternative measures of aggregate market illiquidity.

	1976–2001				2001–2012			
	Momentum		Carry trade		Momentum		Carry trade	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Panel A: Profits regressed on lagged equity market state variables								
Intercept	1.107***	2.664***	0.948***	0.630	1.456***	1.946**	2.099***	2.558***
	(4.46)	(4.26)	(4.45)	(0.88)	(5.69)	(2.10)	(8.66)	(2.82)
Illiquidity	−0.296*	−0.167**	−0.857***	−0.721	0.262*	0.496*	0.228	0.113
	(−1.93)	(−2.11)	(−2.73)	(−1.16)	(1.72)	(1.91)	(1.40)	(0.23)
Down market		1.943		0.325		1.153*		1.633**
		(0.97)		(0.17)		(1.67)		(2.05)
Volatility		−1.714***		0.305		−1.045		−1.00
		(−3.06)		(0.46)		(−1.14)		(−1.20)
FF factors		Yes		Yes		Yes		Yes
Crisis control		Yes		Yes		Yes		Yes
Adj-Rsq	0.030	0.041	0.024	0.046	0.017	0.142	0.014	0.212
Obs	298	298	298	298	132	132	132	132

	1991–2001		2001–2012	
	Momentum	Carry trade	Momentum	Carry trade
	Model 3	Model 3	Model 3	Model 3
Panel B: Profits regressed on lagged equity and currency market illiquidity variables				
Intercept	1.529***	0.953**	1.234***	1.753***
	(5.47)	(2.44)	(3.64)	(5.15)
Illiquidity	−0.328**	−1.335**	0.809**	0.624*
	(−2.37)	(−2.21)	(2.52)	(1.67)
FX illiquidity	1.547	−2.154***	−1.378	−2.148***
	(0.78)	(−3.46)	(−1.49)	(−4.91)
Adj-Rsq	0.047	0.139	0.069	0.156
Obs	120	120	132	132

This table presents the results of the following monthly time-series regressions for the samples from 1976:1 to 2000:12 (left panel) and from 2001:1 to 2011:12 (right panel):
Panel A:

$$H\_L_t = a_t + B_1 CSilliquidity_{t-1} + B_2 down_{t-1} + B_3 volatility_{t-1} + B_4 crisis_t + B_5' F_t + e_t$$

Panel B:

$$H\_L_t = a_t + B_1 CSilliquidity_{t-1} + B_2 FXilliquidity_{t-1} + e_t$$

where in Panel A *H-L* is the currency momentum or the carry trade trading strategy payoff; *CSilliquidity* (denoted as Illiquidity below) stands for the normalized market illiquidity measure that is alternatively specified as in Corwin and Schultz (2012) in month $t-1$, specifically, it is the value-weighted average of the stock-level Corwin-Schultz illiquidity estimator of all NYSE and AMEX firms; *down* is the dummy variable that takes the value of one if the past twenty-four months return on the value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month *t*; *mkt_rf*, *smb*, and *hml* are FF factors. In Panel B *H-L* represents the strategy payoffs; *CSilliquidity*, as above, stands for the aggregate Corwin and Schultz (2012) illiquidity measure in month $t-1$; and *FXilliquidity* (denoted as FX illiquidity below) is the Karnaukh et al. (2015) aggregate FX market illiquidity measure. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

4. Robustness and additional tests

In this section we explore the robustness of our analysis and present supplementary empirical findings on the presence of the illiquidity-momentum effect under various restrictions.[11] In particular, we investigate the predictive power of equity market illiquidity on currency momentum and carry trade using an alternative measure of illiquidity. Furthermore, we report the results of a sample split test and check that the effect is not period-specific and not unduly stirred by outliers. Finally, we perform a battery of other supplementary robustness checks conducted to validate our findings.[12]

4.1. Alternative measure of equity market illiquidity

First, we consider an alternative measure of equity market illiquidity, that is, the Corwin and Schultz (2012) bid-ask spread estimator constructed from daily high and low stock prices. To obtain a monthly bid-ask spread estimator for a single stock, we follow the procedures outlined by Corwin and Schultz (2012). Accordingly, we compute the two-day high-to-low price measure, set negative two-day spreads to zero, and take a simple average across the observations. We do this for all NYSE and AMEX firms over the studied period. Finally, the value-weighted average of constructed Corwin-Schultz measure across all firms is the alternative measure equity market illiquidity. Corwin and Schultz (2012) argue that such a measure of aggregate illiquidity has similar power to the Amihud (2002) measure and outperforms other conventional estimators. The alternative measure is positively, but not perfectly, correlated with Amihud illiquidity and FX illiquidity with correlation coefficients of 0.25 (for the 1976–2012 sample) and 0.61 (for the 1991–2012 sample). The empirical estimation procedures are similar to those reported in Section 3, the only exception being the alternative illiquidity measure specified. Results are presented in Table 5.

The results of the analyses based on the alternative equity illiquidity measure are similar to their counterparts in Tables 3 and 4, thereby further reinforcing the evidence of the predictive role of equity market illiquidity in explaining the variations in currency

[11] We thank an anonymous referee for the suggested additional robustness checks.

[12] Additionally, in unreported results, we check that illiquidity effect is sustained when the market-wide sentiment (Baker and Wurgler, 2006) is introduced into the analysis. We find that the effect of equity market illiquidity is not subsumed by the investor sentiment. Results are available upon request.

momentum returns. Once again, the results of both panels consistently indicate that in a period of high illiquidity, momentum payoffs are low when the equity market is illiquid, while the effect is reversed in the latter period (see the right-hand panel of Table 5). The Corwin-Schultz illiquidity estimator dominates other market state variables as well as FX market illiquidity, and is significant (at least at a ten-percent level) throughout all of the model specifications in the upper panel. Hence, the predictive role of the aggregate equity market illiquidity for momentum returns remains robust against our alternate measures of illiquidity. However, results are the opposite for carry trade, that is, the Corwin-Schultz illiquidity only occasionally verges on significance, and is insignificant in most of the analysis. Importantly, the signs of the equity illiquidity variable are identical to their counterparts in previous tables.

4.2. Split sample tests

To further assess robustness, we perform a sample split test. Specifically, we split the full sample into four parts such that each part covers the period associated with the corresponding decade. The left-hand panel of Table 6 shows the results for momentum and the right-hand panel presents the results for the carry trade strategy.

The outcomes of the sample splitting procedure validate a previous finding of momentum-illiquidity relationship and indicate that results are not unduly affected by outliers. Regardless of the subsample, the coefficients on illiquidity are uniformly statistically significant in the case of momentum, albeit not as strongly as the corresponding estimates in Table 3. In contrast, the results for the carry trade strategy are not as convincing, reaching significant levels only in the latter decade. Nevertheless, the sign of the illiquidity coefficient aligns with the evidence from Section 3.2 indicating that the sign of the effect changes in the post-decimalization period. Additionally, to reassure readers of the robustness of this evidence, we show that the signs of illiquidity estimates remain unchanged when the samples are partitioned into twelve subsamples, each of three-years' length. We report results of three-year sample splits in the Internet Appendix.

4.3. Other robustness tests

Next, we perform a number of supplementary robustness checks. First, to guard against the possibility that currency-specific information may be lost while aggregating to portfolios, we follow Lo and MacKinlay (1990) suggestion and perform test at an individual currency level. The results of two-stage regressions (as in Avramov and Chordia, 2006) suggest that individual currency level momentum is weaker following illiquid months. Next, to ensure that our results do not originate from extreme observations, we repeat the decade-based split of Table 6, while winsorizing the illiquidity measure at 99%, 95% and 90% levels. Next, we check if the negative-to-positive change of the illiquidity coefficient occurs only once around the beginning of the post-decimalization period. To do this, we perform additional sample partitioning on the basis of the three-year-long sub-sample. Further, we repeat the empirical analysis of Table 2 and can report that the predictive role of market illiquidity in explaining the variation in momentum returns persists when adjusting for currency-specific risk factors. Moreover, the illiquidity effect exists for momentum portfolios constructed with various formation periods. In the next step, we introduce transaction costs to the data, report the descriptive statistics and re-estimate the models from Section 3.1 accounting for transaction costs. Finally, we check that the results of this paper are not affected by issues of currency tradability, by repeating the analysis of the paper with tradability-adjusted datasets, where we gradually correct the dataset for currencies that were untradeable in certain periods and eliminate currencies with the largest values of NDF trading.

Although ultimately the results of a few tests deviate from the central findings of the paper, principally, the robustness checks confirm the predictive role of the equity market illiquidity in explaining the variation in currency momentum returns. Additional results reinforce the findings on the negative-to-positive change in the illiquidity effect before and after structural changes. In sum, the predictive effect on the currency momentum strategy holds through the robustness procedures, while the effect on carry trade is not robust, and becomes attenuated in most of the additional robustness checks. In most of the tests the illiquidity variable delivers similar estimates to the counterpart's values in the benchmark specifications of the previous sections. Additionally, we report supplementary descriptive statistics on individual currencies and control variables, as well as time-series correlations between anomalies of interest. In the interest of conciseness space, the detailed discussion on the aforementioned robustness procedures appears alongside the corresponding empirical results in the supplementary Internet Appendix.

Table 6
Decade based time splits.

	Momentum			Carry trade		
	Intercept	Illiquidity	Adj-Rsq	Intercept	Illiquidity	Adj-Rsq
Panel A: splitting on decades						
70s	2.223***	−0.597**	0.056	0.980	−0.151	0.002
	(2.76)	(−2.00)		(0.85)	(−0.35)	
80s	0.688***	−0.391*	0.012	0.719*	−0.206	0.001
	(2.72)	(−1.68)		(1.96)	(−0.43)	
90s	1.504***	−0.502*	0.019	0.871**	−0.407	0.014
	(4.72)	(−1.85)		(2.07)	(−1.10)	
00s	1.564***	0.823***	0.082	1.925***	0.749**	0.080
	(5.72)	(2.85)		(5.78)	(2.55)	

This table presents the results of the decade based time sample splits. For each decade we estimate the model with the independent variable being either currency momentum trading or carry trade strategy returns, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t; and the explanatory variable is the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, specifically, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms. Newey-West HAC based t-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

5. Conclusions

The results of this paper indicate that aggregate equity market illiquidity explains the evolution of currency momentum payoffs, but the equity illiquidity effect is fairly inconspicuous in currency carry trade returns. Returns on currency momentum are low (high) following months of high (low) equity market illiquidity. The effect of equity market illiquidity dominates other measures of equity market conditions. The predictive effect of equity market illiquidity on currency momentum returns is robust to the alternative equity illiquidity specification and persists after controlling for aggregate FX liquidity, and also sustains a number of robustness checks. Finally, separate investigation of the role of equity market illiquidity in the most recent decade and prior periods reveals that the predictive effect is reversed in the latter period.

This study does not aim to present complete explanations of currency excess returns or to identify a new profitable trading strategy, but it does explore how equity market conditions contribute to the observed returns of the most prominent currency anomalies. In light of our findings, this paper significantly expands the existing literature by revealing novel evidence on the effect of equity market illiquidity on the currency market.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jbankfin.2016.02.010.

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The Internet Appendix to accompany

Currency momentum, carry trade, and market illiquidity

In this Appendix we report additional descriptive statistics for momentum and carry trade portfolios and the results of supplementary robustness checks. The remainder of the Internet Appendix is organized as follows. In Appendix A, we provide descriptive statistics of the dataset. Results for winsorized samples and findings from the in-depth sample split test are reported in Appendix B. Appendix C challenges the illiquidity effect in momentum with currency-specific risk factors and provides evidence for a momentum anomaly with various formation periods. In Appendix D, we examine the predictive role of aggregate market illiquidity in portfolio returns adjusted for transaction costs. Appendix E reports the results of the sample adjusted for tradability of the currencies and Appendix F further explores the illiquidity effect by shifting the analysis from portfolio returns to individual currencies, concluding the supplementary materials.

Appendix A. Additional descriptive statistics

This section provides additional descriptive statistics for 48 currencies in our dataset. Throughout the studied period the effective sample size varies greatly due to the availability of data. We extend the dataset back to 1976 by collecting historical data quotes against the British Pound from Reuters and convert it against the U.S dollar. This extension comprises the exchange rates of the following countries: Austria, Belgium, Canada, Denmark, France, Germany, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. The sample size increases significantly from October 1983 when Barclays data on quotes against the U.S. dollar becomes available. The size of the sample, however, varies with availability of data on new currencies and when currencies cease to exist, for example, with the introduction of the Euro. Table A.1 reports the time span of the sample period for each individual currency.

Insert Table A.1 here

Albeit most of analysis in the paper is performed with currency portfolios, we also report the average monthly momentum and carry trade profits for individual currencies in a similar fashion to Moskowitz, Ooi, and Pedersen (2012). We show profitability and report characteristics of momentum and carry trade strategies for each of the 48 individual currencies in Table A.2.

Insert Table A.2 here

Additionally, we examine the time-series correlation between currency momentum, carry trade and stock market momentum (see Table A.3). To form stock market momentum payoffs at the beginning of each month we sort all stocks listed on NYSE, AMEX, and NASDAQ into deciles based on their lagged eleven-month returns, skipping the *t-1* month to avoid short term reversal issues. Next, we extract the stock market momentum returns by subtracting the value-weighted (month t) return of the bottom decile portfolio from the top decile portfolio return of the same time period. Confirming the classic currency literature evidence we find that returns to the three strategies appear to be largely uncorrelated (coefficients are consistently around zero) in the full sample, despite some similarities in the evolution of portfolios of the similar deciles. The correlation, however, rises and becomes positive in the latter sample period (from 2001 to 2012) considered in this study. This is in line with the results on illiquidity effects presented in the main body of the paper. That is we observe discrepancies between the two strategies coefficients on equity and currency market illiquidity variables in the earlier sample, while the later sample period results are more similar for both anomalies.

Insert Table A.3 here

The crises periods dates are specified in Table A.4. Throughout the analysis we consider both currency crises and U.S. stock market turmoil periods. Currency crisis months are defined according to Reinhart and Rogoff (2011), that is, the month when the macroeconomic event occurs is considered to be relevant and, thereafter, marked as a crisis month if it caused at least one currency in our sample to depreciate by 15 percent or more. In addition we account for commonly acknowledged financial crises that are associated with high levels of U.S. market illiquidity. In Table A.4 we highlight only the above mentioned periods, for instance, the Asian financial crisis lasted from July 1997 until December 1998, but we mark only July 1997 when the Thai baht devaluated by 24.34% and August 1997 that is associated with the 16.78% devaluation of the Indonesian Rupiah. It should be noted that while there are more episodes of currency crashes, we only take into account crises that occurred within the time span of the sample period for each individual currency as in Table A.1.

Insert Table A.4 here

Appendix B. Winsorization, splitting samples and crisis periods

In this section we report additional robustness tests on our findings and guard against the possibility that extreme observations in illiquidity measure could influence our results. In particular, we repeat the analysis of Section 6.2, while performing winsorization at the 99%, 95%, and 90% levels; that is, we set the top 1%, 5% and 10% of observation within each decade to be equal to their cutoff values. The results of each percentile winsorization are reported in Table B.1. We find reassuring results that the predictive effect of equity market illiquidity on currency momentum is maintained after winsorization, even at 90th percentile, thus, it is not driven by the outliers in the illiquidity measure, the crisis periods.

Insert Table B.1 here

Further, we perform the in-depth time sample split test by splitting the sample every 3 years. Doing so allowed us to check if the sign of the illiquidity variable is consistent throughout the studied period. The results of the test are reported in Table B.2. Overall, the results confirm the findings of that the sign of illiquidity coefficient changes at the turn of the centuries. That is we observe a negative-to-positive shift in coefficient sign around the dates associated with the period of improved illiquidity, reinforcing the main findings of the paper. However, we find three episodes when signs for momentum and carry trade are contrariwise. These episodes are marked by shaded areas in Figure B.1. Interestingly, these periods are associated with episodes of crises, namely, Black Monday, the Asian crisis/the Russian default, and the financial crisis of 2008.

Insert Table B.2 here

Insert Figure B.1 here

Appendix C. Supplementary results for momentum

In the main body of the paper, we find the substantive predictive role of equity market illiquidity in explaining the variations in currency momentum returns. In Table C.1 we complement this finding by verifying if the illiquidity effect for currency momentum strategy gets attenuated when currency-specific risk factors are introduced into the analysis. These factors are: the dollar risk factor, the carry factor from Lustig et al. (2011), and global currency market volatility factor of Menkhoff et al. (2012a). In line with Burnside et al. (2011) we find no evidence that these unconventional risk factors can capture temporal variation in currency momentum payoffs. The coefficient estimates of the illiquidity variable are once again negative, significant, and similar in magnitude to their counterparts in Table 2 of the main paper.

Insert Table C.1 here

Next, we confirm the robustness of our findings and document that the illiquidity effect exists for currency momentum portfolios constructed with different formation periods, namely, six months and one year. The holding period remains at the one month horizon. Results are presented in Table C.2.

Insert Table C.2 here

Appendix D. Results after transaction costs

Burnside et al. (2006) and Burnside et al. (2007) indicate the importance of transaction costs to currency speculative strategies. In this subsection we compute currency excess returns net of bid-ask spreads, obtained from Reuters. In particular, the sort position return is defined as $r_{t+1}^{short} = -f_t^a + s_{t+1}^b$ and long position profit is $r_{t+1}^{long} = f_t^b - s_{t+1}^a$. Initially, investors take long positions in all of the portfolios, then trade short on portfolio 1 and long on portfolios 2 to 6, eventually selling every portfolio at the end of the sample period. If the currency stays in the portfolio in the next month, the spot market costs of such a position are not accounted for, but forward implied transaction costs occur every month. This measure of transaction costs is overly cautious, being made up of spreads larger than inter-dealer bank spreads. Such vigilance leads to an underestimation of currency momentum and carry trade returns.

Table D.1 shows the average monthly profits of momentum and carry trade portfolios after adjusting for bid-ask spreads. The average monthly profits are still significant, but drop to 1.021% and 0.715% for momentum and carry trade, respectively.

Insert Table D.1 here

In order to assess the robustness of the findings we re-estimate models from Sections 4.1 and 4.2 with transaction costs adjusted returns. The results of Table D.2 and Table D.3 indicate that transaction costs do not eliminate the effect of aggregate market illiquidity. Coefficient on illiquidity is uniformly statistically significant (at least at 10% level) throughout all model specifications for the momentum strategy, albeit less consistent in case of carry trade.

Insert Table D.2 here

Insert Table D.3 here

Appendix E. Market illiquidity and currency tradability

In this section in addition to transaction costs we adjust our dataset currency tradability issues. To this point the analysis has been based on a full data sample based on 48 currencies. The data sample includes small countries with emerging economies, which raises the concern of whether the illiquidity-strategy relationships can be driven by minor currencies that are incompatible with the notion of frequent trading. To address this tradability issue, we excluded currencies that were nearly impossible to trade from the dataset. To do so we follow Menkhoff et al. (2012b)[1] and exclude currencies of the following states from our sample: Czech Republic (prior to 1999), Hungary (prior to 2000), Indonesia (prior to 1999), Malaysia (prior to 1999), Philipines (prior to 1999), Singapore (prior to 1999), South Africa (prior to 2001), Taiwan (prior to 1999), Hong Kong (prior to 1986), and Thailand (prior to 1999). Imposing that restriction left us with a set of tradable currencies, and, from that we derived strategy payoffs. Next, we completely exclude currencies with large volumes of non-deliverable forwards offshore trading, those are: Brazil, Egypt, India, Indonesia, South Korea, Malaysia, the Philippines, and Taiwan.

The results of the re-estimated models are presented in Table E.1 (the full sample) and Table E.2 (the sample split). Findings of the paper remain unchanged, thus the effect is robust on transaction costs and does not rely on non-tradable currencies or currencies with high NDF trading.

Insert Table E.1 here

Insert Table E.2 here

Appendix F. Momentum, carry trade in individual currencies and illiquidity

[1] Menkhoff et al. (2012b) conducted a survey among large FX brokers, namely, Goldman Sachs, Deutsche Bank, UBS and Nomura, that resulted in the list of currencies with tradability issues. For more information on the set of restriction see the article and footnotes therein. Other currencies with limited tradability initially were not in our sample, due to data availability.

In this section we further explore the illiquidity effect by shifting the analysis from portfolio returns to individual currencies. There is evidence that security-specific information may be lost while aggregating to portfolios (Litzenberger and Ramaswamy, 1979). Accordingly, Lo and MacKinlay (1990) suggest researchers minimize data mining and do not neglect tests with individual securities.

In order to shift the analysis to the individual currency level, we perform two-stage regressions in accordance with the suggestions of Avramov et al. (2015). The first stage is similar to the first step of the Fama and MacBeth (1973) procedure; in that we estimate monthly cross-sectional regressions at an individual currency level. Specifically, currency momentum and carry trade profits are regressed on their lagged twelve-month accumulated excess returns and on a one-month lagged forward discount, respectively. Doing so provided a time-series of currency momentum and carry trade beta coefficients. Next, in the second stage, we ran various time-series regressions similar to the estimated models in Section 3. The dependent variables in these regressions are momentum and carry trade betas estimated from the first stage monthly cross-sectional regressions. The same three dimensions of market conditions are used as for the predictive variables, namely, equity market illiquidity, down market state and market volatility.

Insert Table F.1 here

Table F.1 provides point estimates in logs of proposed two-stage regressions. Model 1 in Panels A and B presents the estimates of monthly Fama-MacBeth regressions for momentum and carry trade, respectively. The findings suggest strong cross-section continuity in currency momentum returns, as the time series average of the beta coefficient is positive and highly significant. Conversely, carry trade returns do not reveal the same pattern. Further, Models 2 to 5 provide estimates of time-series regressions of beta series on market state variables. The results for carry trade in Panel B are once again rather inconclusive, as the illiquidity coefficient despite being negative is far from being significant. However, individual currency level momentum is, as expected, weaker following illiquid months, while currency momentum is more profitable during a liquid market period. In fact, Amihud’s illiquidity measure is the only market state variable found to affect individual currency level momentum payoffs.

Table A.1. Dates for individual currencies

This table shows the time span of the sample period for individual currencies.

Country	Start date	End date	Country	Start date	End date	Country	Start date	End date	Country	Start date	End date
Australia	1984.12	2014.01	Finland	1997.01	1998.12	Japan	1976.01	2014.01	S. Korea	2002.02	2014.01
Austria	1976.01	1998.12	France	1976.01	1998.12	Kuwait	1997.01	2014.01	Saudi A.	1997.01	2014.01
Belgium	1976.01	1998.12	Germany	1976.01	1998.12	Malaysia	1997.01	2014.01	Singapore	1984.12	2014.01
Brazil	2004.03	2014.01	Greece	1997.01	2000.12	Mexico	1997.01	2014.01	Slovakia	2002.02	2014.01
Bulgaria	2004.03	2014.01	Hong Kong	1983.01	2014.01	N. Zealand	1984.12	2014.01	Slovenia	2004.03	2014.01
Canada	1976.01	2014.01	Hungary	1997.01	2014.01	Nether.	1976.01	1998.12	Spain	1976.01	1998.12
Croatia	2004.03	2014.01	Iceland	2004.03	2014.01	Norway	1976.01	2014.01	Sweden	1976.01	2014.01
Cyprus	2004.03	2014.01	India	1997.01	2014.01	Philippines	1997.01	2014.01	Switz.	1976.01	2014.01
Czech Rep	1997.01	2014.01	Indonesia	1997.01	2014.01	Poland	2002.02	2014.01	Taiwan	1997.01	2014.01
Denmark	1976.01	2014.01	Ireland	1976.01	1998.12	Portugal	1976.01	1998.12	Thailand	1997.01	2014.01
Egypt	2004.03	2014.01	Israel	2004.03	2014.01	Russia	2004.03	2014.01	UK	1976.01	2014.01
EURO	1999.01	2010.01	Italy	1976.01	1998.12	S. Africa	1983.01	2014.01	Ukraine	2004.03	2014.01

Table A.2. Momentum and Carry Trade for individual currencies

This table presents descriptive statistics on the average monthly momentum and carry trade profits for individual currencies. The individual currency momentum and the carry trade payoffs are formed with a one-month formation period and a one-month holding period. Our strategies go long (short) in the foreign currency if it posted a positive (negative) return (forward discount) in the previous month. Panel A (Panel B) report average momentum (carry trade) payoffs for individual currencies, standard deviation of returns, skewness, and kurtosis.

Panel A: Momentum for individual currencies

Country	Mean	St. Dev.	Skew.	Kurt.	Country	Mean	St. Dev.	Skew.	Kurt.
Australia	0.506	3.515	0.657	5.616	Japan	0.431	3.386	0.150	4.420
Austria	0.364	3.149	-0.025	4.612	Kuwait	0.009	0.708	-0.616	16.410
Belgium	0.583	3.093	0.276	4.483	Malaysia	2.718	6.347	2.584	19.715
Brazil	0.561	4.483	0.672	4.681	Mexico	0.208	3.002	0.579	6.659
Bulgaria	0.287	3.137	0.405	4.424	N. Zealand	0.445	3.623	-0.011	4.730
Canada	-0.027	1.950	-0.301	7.477	Nether.	0.568	3.339	0.208	3.703
Croatia	0.215	3.191	0.423	4.135	Norway	0.277	3.058	0.207	4.336
Cyprus	0.069	3.133	0.387	4.551	Philippines	0.290	2.572	-0.123	7.843
Czech Rep.	0.121	3.780	0.048	3.172	Poland	0.311	4.483	0.289	4.374
Denmark	0.558	3.180	0.089	3.741	Portugal	0.393	3.131	0.309	6.459
Egypt	0.850	1.259	0.089	6.648	Russia	0.221	3.045	0.255	7.032
EURO	0.472	3.002	-0.039	3.992	S. Africa	0.760	5.212	1.103	5.637
Finland	0.398	2.994	0.241	3.888	S. Korea	0.054	3.538	0.360	7.093
France	0.333	3.215	0.019	3.543	Saudi A.	0.012	0.113	-7.368	76.487
Germany	0.521	3.339	0.179	3.625	Singapore	0.070	1.615	-0.822	5.767
Greece	0.369	3.041	0.063	4.132	Slovakia	0.210	3.464	0.231	3.540
Hong Kong	0.023	0.197	0.262	9.864	Slovenia	0.141	3.137	0.372	4.503
Hungary	0.358	4.202	0.009	5.940	Spain	0.562	2.951	-0.329	6.043
Iceland	0.502	4.906	1.641	10.193	Sweden	0.598	3.251	0.677	5.904
India	0.286	2.153	0.230	5.679	Switzerland	0.427	3.518	-0.218	3.992
Indonesia	4.238	10.151	3.605	29.487	Taiwan	0.187	1.643	-0.196	6.358
Ireland	0.360	2.790	-0.035	2.838	Thailand	0.207	3.307	-1.812	15.229
Israel	0.040	2.612	0.014	3.275	UK	0.296	3.044	0.136	4.559
Italy	0.703	3.077	-0.134	4.546	Ukraine	0.824	3.411	3.425	28.374

Table A.2. – Continued

Panel B: Carry trade for individual currencies									
Country	Mean	St. Dev.	Skew.	Kurt.	Country	Mean	St. Dev.	Skew.	Kurt.
Australia	0.454	3.023	0.029	4.758	Japan	0.183	2.188	-0.151	5.670
Austria	0.171	3.541	0.087	4.262	Kuwait	2.806	8.802	-0.552	11.720
Belgium	0.378	3.381	-0.257	4.073	Malaysia	0.036	0.705	-1.470	16.443
Brazil	0.153	1.956	0.152	8.908	Mexico	2.406	6.454	2.561	18.873
Bulgaria	0.556	3.425	-0.684	5.207	N. Zealand	0.447	2.918	-0.942	6.163
Canada	0.712	3.580	-0.159	4.892	Nether.	0.202	2.546	-0.875	7.577
Croatia	0.668	3.170	-0.551	5.469	Norway	0.480	4.413	-0.327	4.322
Cyprus	0.397	3.016	-0.392	4.260	Philippines	0.179	3.114	-0.371	5.560
Czech Rep.	0.732	3.142	0.032	3.773	Poland	0.028	0.110	5.235	77.657
Denmark	0.435	3.013	0.078	3.973	Portugal	0.310	3.493	-0.169	7.200
Egypt	0.146	3.346	0.056	3.604	Russia	0.279	3.037	-0.297	5.628
EURO	0.267	3.114	-0.296	4.307	S. Africa	-0.094	1.641	-0.123	6.347
Finland	0.498	3.194	-0.005	3.516	S. Korea	0.415	3.397	0.260	19.023
France	0.379	3.358	0.329	3.749	Saudi A.	1.031	4.270	-0.797	4.785
Germany	0.554	3.114	0.392	4.419	Singapore	0.893	1.224	0.513	6.109
Greece	0.531	3.004	0.299	3.768	Slovakia	0.227	2.988	-0.817	6.786
Hong Kong	0.051	2.783	0.005	2.832	Slovenia	0.560	3.444	0.448	3.395
Hungary	0.063	0.188	1.128	10.026	Spain	0.081	3.138	-0.472	3.866
Iceland	0.542	5.158	0.677	5.603	Sweden	0.181	3.136	0.563	4.476
India	0.053	1.630	0.366	6.100	Switzerland	0.029	2.594	-0.255	3.263
Indonesia	0.591	3.159	0.443	4.673	Taiwan	0.247	4.609	-0.869	8.273
Ireland	0.482	3.757	-0.037	3.222	Thailand	0.016	3.143	0.682	4.583
Israel	0.164	3.066	0.308	4.055	UK	-0.104	3.101	-0.069	4.245
Italy	0.560	4.108	-0.884	5.852	Ukraine	0.412	3.117	-3.080	23.119

Table A.3. Correlation of Momentum and Carry Trade

This table shows the correlation coefficients between currency momentum, currency carry trade, and stock market momentum. Panel A presents correlation coefficients between currency momentum portfolios with different formation periods, namely, one-month, six months, and one year (Mom(1,1), Mom(6,1), Mom(12,1), respectively) and forward discount-sorted portfolios (CT, standing for carry trade). We report correlation coefficients of average equally-weighted holding period returns for each sextile portfolio. Panel B shows the correlation coefficients for the full sample between currency momentum, currency carry trade, and stock market momentum profits. In this case currency momentum and carry trade payoffs are formed on the basis of a one-month formation period and a one-month holding period, while for stock market momentum the formation period is from t-12 to t-2 , skipping month t-1. For stock market momentum at the beginning of each month, all common stocks listed on NYSE, AMEX, and NASDAQ are sorted into deciles based on their lagged eleven-month returns. Further, to obtain the stock market momentum profits we subtract value-weighted (month t) return of bottom decile portfolio from top decile portfolio (month t) return. The data period spans January 1976 to January 2014 for the currency based strategy and January 1976 to January 2012 for the stock market momentum (Panel A, B). The data period spans January 1976 to December 2000 in Panel C. Panel D presents correlations for the data period from January 2001 to December 2011.

Panel A: Currency Momentum and Carry Trade

	Low	2	3	4	5	High
Mom(1,1) and Carry Trade	0.634	0.836	0.856	0.838	0.834	0.634
Mom(6,1) and Carry Trade	0.570	0.841	0.871	0.840	0.834	0.615
Mom(12,1) and Carry Trade	0.593	0.836	0.849	0.807	0.824	0.666

Panel B: Currency Momentum, Carry Trade and Stock Market Momentum (Full Sample)

	Stock Mom	Curr. Mom(1,1)	Curr. Mom(6,1)	Curr. Mom(12,1)	Carry trade
Stock Mom	1.000				
Curr. Mom(1,1)	0.061	1.000			
Curr. Mom(6,1)	0.088	0.576	1.000		
Curr. Mom(12,1)	0.061	0.463	0.704	1.000	
Carry trade	-0.096	0.000	-0.098	0.092	1.000

Panel C: Currency Momentum, Carry Trade and Stock Market Momentum (1976-2001)

	Stock Mom	Curr. Mom(1,1)	Curr. Mom(6,1)	Curr. Mom(12,1)	Carry trade
Stock Mom	1.000				
Curr. Mom(1,1)	0.063	1.000			
Curr. Mom(6,1)	0.074	0.567	1.000		
Curr. Mom(12,1)	0.013	0.433	0.664	1.000	
Carry trade	-0.040	-0.038	-0.208	-0.020	1.000

Panel D: Currency Momentum, Carry Trade and Stock Market Momentum (2001-2012)

	Stock Mom	Curr. Mom(1,1)	Curr. Mom(6,1)	Curr. Mom(12,1)	Carry trade
Stock Mom	1.000				
Curr. Mom(1,1)	0.120	1.000			
Curr. Mom(6,1)	0.177	0.638	1.000		
Curr. Mom(12,1)	0.198	0.591	0.817	1.000	
Carry trade	-0.164	0.208	0.242	0.398	1.000

Table. A.4. Crisis dates

This table illustrates the dates of currency crashes, as specified by Reinhart and Rogoff (2011) as well as of episodes of the U.S. illiquid market state. The corresponding financial/currency crisis that caused the episodes mentioned are presented on the left hand side of the table.

Crisis name	Months marked by crisis
Energy crisis	06/1976, 11/1976, 11/1978
Early 80's recession	05/1980, 06/1982, 08/1984
Black Monday	10/1987
Early 90's recession	11/1990, 02/1992
Mexican crisis	12/1994
Asian financial crisis	07/1997, 08/1997
Russian default	08/1998
Dotcom crash	03/2000, 04/2000, 07/2002-11/2002
Icelandic krona devaluation	03/2006
Global financial crisis	09/2008-12/2008

Table B.1. Decade based time splits with winsorization

This table presents the results of the decade based time sample splits, while winsorizing the illiquidity measure at the 99%, 95%, and 90% levels (Panels A, B and C, respectively). For each model the independent variable is either currency momentum trading or carry trade strategy returns, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t. The explanatory variable is the normalized market illiquidity measure constructed from Amihud (2002) in month t-1, specifically, it is the value-weighted stock-level of Amihud's (2002) illiquidity measure of all NYSE and AMEX firms. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

Panel A: 99th percentile winsorization

	Momentum			Carry Trade		
	Intercept	Illiquidity	Adj-Rsq	Intercept	Illiquidity	Adj-Rsq
70s	0.849***	-0.563**	0.057	0.631	-0.143	0.002
	(2.61)	(-2.00)		(1.27)	(-0.35)	
80s	0.624*	-0.323*	0.009	0.673**	-0.111	0.001
	(1.88)	(-1.64)		(2.16)	(-0.46)	
90s	1.50***	-0.501*	0.019	0.870**	-0.408	0.014
	(4.72)	(-1.81)		(2.07)	(-1.09)	
00s	1.635***	0.852***	0.092	2.024***	0.713**	0.067
	(5.71)	(2.76)		(5.78)	(2.18)	

Panel B: 95th percentile winsorization

	Momentum			Carry Trade		
	Intercept	Illiquidity	Adj-Rsq	Intercept	Illiquidity	Adj-Rsq
70s	0.842***	-0.550*	0.052	0.629	-0.172	0.002
	(2.62)	(-1.90)		(1.27)	(-0.42)	
80s	0.617*	-0.344	0.007	0.670**	-0.135	0.001
	(1.86)	(-1.32)		(2.17)	(-0.50)	
90s	1.477***	-0.508*	0.014	0.843**	-0.520	0.016
	(4.74)	(-1.79)		(2.08)	(-1.11)	
00s	1.641***	0.871***	0.093	2.030***	0.718**	0.065
	(5.71)	(2.71)		(5.78)	(2.10)	

Panel C: 90th percentile winsorization

	Momentum			Carry Trade		
	Intercept	Illiquidity	Adj-Rsq	Intercept	Illiquidity	Adj-Rsq
70s	0.827***	-0.559*	0.049	0.623	-0.222	0.005
	(2.61)	(-1.89)		(1.26)	(-0.52)	
80s	0.603*	-0.341	0.005	0.663**	-0.167	0.001
	(1.82)	(-1.07)		(2.17)	(-0.54)	
90s	1.461***	-0.502*	0.012	0.820**	-0.585	0.018
	(4.73)	(-1.71)		(2.09)	(-1.13)	
00s	1.687***	1.021***	0.082	2.068***	0.751*	0.057
	(5.79)	(2.82)		(5.76)	(1.91)	

Table B.2. Splitting samples on 3 year basis

This table presents the results of the three-year based time sample splits. For each model the independent variable is either currency momentum trading or carry trade strategy returns, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t. The explanatory variable is the normalized market illiquidity measure constructed from Amihud (2002) in month t-1, specifically, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

	Momentum			Carry Trade		
	Intercept	Illiquidity	Adj-Rsq	Intercept	Illiquidity	Adj-Rsq
02/76-12/78	1.061	-0.846**	0.103	0.327	0.077	0.000
	(2.67)	(-2.55)		(0.44)	(0.12)	
01/79-12/81	0.448	-0.738***	0.131	1.255***	-0.393	0.037
	(1.23)	(-3.22)		(3.82)	(-1.36)	
01/82-12/84	0.665	-0.074	0.000	0.154	-0.168	0.002
	(0.97)	(0.17)		(0.25)	(-0.46)	
01/85-12/87	2.594***	1.715	0.026	-0.770	-1.360	0.012
	(3.24)	(1.29)		(-0.72)	(-1.21)	
01/88-12/90	0.483	-0.360	0.002	1.539***	-0.439	0.003
	80.76)	(-0.25)		(2.77)	(-0.34)	
01/91-12/93	1.809***	-0.381	0.011	0.330	-0.234	0.006
	(3.57)	(-0.77)		(0.62)	(-0.59)	
01/94-12/96	0.683	-0.788	0.008	-0.346	-2.768*	0.095
	(0.93)	(-0.52)		(-0.53)	(-1.93)	
01/97-12/99	-4.582	-8.152	0.017	14.273	14.689	0.058
	(-0.52)	(-0.79)		(1.42)	(1.21)	
01/00-12/02	1.919***	0.516	0.030	1.922***	0.668*	0.063
	(2.65)	(0.94)		(3.69)	(1.95)	
01/03-12/05	3.006***	1.750***	0.377	4.09***	1.653***	0.311
	(9.48)	(5.46)		(11.07)	(5.94)	
01/06-12/08	1.816**	1.054	0.053	-0.569	-1.831***	0.155
	(2.29)	(1.07)		(-1.15)	(-3.58)	
01/09-12/11	0.354	0.380	0.014	1.180***	0.808***	0.179
	(0.83)	(0.81)		(6.56)	(4.17)	

Table C.1. Momentum and market states with adjustments for currency risk factors

Left hand side presents the results of the following monthly time-series regressions:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5 dol_t + B_6 hml\_fx_t + e_t$$

Right panel presents the results of the following monthly time-series regressions:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5 dol_t + B_6 vol\_fx_t + e_t$$

where *H-L* is the currency momentum trading strategy payoff, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, specifically, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12; *down* is the dummy variable that takes the value of one if the past twenty-four months return on value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes a value of one if potentially systemic macroeconomic events occur in month t; *dol* is the average excess returns to all of the portfolios (*RX* risk factor from Lustig (2011)); hml_fx is the long-short carry trade return in month t (Lustig et al. (2011)); vol_fx is the global FX volatility factor (Menkhoff et al. (2012a)). Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

Momentum profits, Lustig et al. (2011) and Menkhoff et. al (2012a) models						
	Lustig et al. (2011)			Menkhoff et. al (2012a)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	1.189***	1.241***	1.080***	1.201***	1.420***	1.219**
	(5.21)	(5.40)	(4.95)	(2.49)	(2.72)	(2.20)
Illiquidity		-0.411***	-0.364***		-0.426***	-0.365***
		(-3.15)	(-2.96)		(-3.07)	(-2.89)
Down market			1.617*		1.273*	1.597**
			(1.96)		(1.65)	(2.07)
Volatility			-0.239			-0.220
			(1.49)			(-1.30)
DOL	-0.083	-0.087	-0.106	-0.083	-0.090	-0.107
	(-0.76)	(-0.81)	(-0.99)	(-0.78)	(-0.85)	(-1.02)
FX factor	0.028	0.011	-0.008	0.060	-0.040	0.362
	(0.24)	(0.10)	(-0.07)	(0.04)	(-0.32)	(0.26)
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.004	0.016	0.018	0.003	0.016	0.029
Obs	429	429	429	429	429	429

Table C.2. Momentum (6,1) and momentum (12,1) profits and market states

This table presents the results of the following monthly time-series regressions with currency momentum portfolios constructed with different formation periods, namely, six months and one year:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5' F_t + e_t$$

where *H-L* is the currency momentum (6,1) (momentum (12,1) in Panel B) trading strategy payoff in Panel A, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12; *down* is the dummy variable that takes a value of one if the past twenty-four months return on the value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month t; *mkt_rf*, *smb*, and *hml* are FF factors, *dol* is the average excess returns to all of the portfolios (*RX* risk factor from Lustig et. al (2011)); hml_fx is the long-short carry trade return in month t (Lustig et al. (2011)); vol_fx is the global FX volatility factor (Menkhoff et al. (2012a)). Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

Momentum (6,1) and (12,1) Profits Regressed on Lagged Market State Variables						
	Momentum (6,1)			Momentum (12,1)		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	2.95***	3.07***	2.66***	1.94***	1.92***	2.78***
	(13.90)	(11.66)	(4.75)	(14.56)	(9.98)	(4.87)
Illiquidity	-0.211*	-0.328*	-0.268*	-0.370**	-0.403**	-0.427***
	(-1.72)	(-1.82)	(-1.75)	(-2.36)	(-2.49)	(-2.68)
Down market	0.514	1.056	0.770	1.063	1.278	1.352
	(0.67)	(1.02)	(0.85)	(1.34)	(1.41)	(1.53)
Volatility	0.357*	0.372	0.325	0.085	0.108	0.221
	(1.79)	(0.24)	(1.41)	(0.43)	(0.50)	(0.98)
MKT-RF	-0.065			-0.031		
	(-1.32)			(-0.64)		
SMB	-0.072			-0.004		
	(-1.15)			(-0.08)		
HML	-0.052			-0.041		
	(-0.75)			(-0.66)		
DOL		-0.216	-0.209		-0.110	-0.122
		(-1.59)	(-1.49)		(-0.87)	(-0.95)
HML_FX		-0.154			0.044	
		(-1.11)			(0.39)	
VOL_FX			0.602			-1.969
			(-1.54)			(-1.40)
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.026	0.056	0.027	0.015	0.030	0.033
Obs	424	424	424	424	424	424

Table D.1. Descriptive statistics for momentum and carry trade returns after transaction costs

This table presents descriptive statistics of average monthly profits of the momentum and the carry trade portfolios after adjusting for bid-ask spreads. The data period spans January 1976 to January 2014. In Panel A (Panel B) we report the average equally-weighted holding period returns of each sextile portfolio and the momentum (the carry trade) profits (H-L portfolio). Whereas H-L denotes the currency momentum (the carry trade) trading strategy profits, where the equally-weighted bottom sextile portfolio (Low) is subtracted from equally-weighted top sextile portfolio (High). Further, we report alphas (in %) by adjusting returns with CAPM, Fama-French three-factor, Lustig, Roussanov, and Verdelhan (2011) and Menkhoff, Sarno, Schmelling, and Schrimpf (2012a) models. We also report maximum and minimum values, standard deviation of returns, skewness, kurtosis and the Sharpe ratio, computed as the average monthly excess portfolio return divided by its standard deviation. Panel C (Panel D) shows the pairwise correlation between the momentum (1,1) strategy (the carry trade strategy) and market state variables, such as Amihud's illiquidity, down market state, market volatility and crisis control. Newey-West HAC based *t*-statistics are presented in parenthesis. Asterisks ** and *** indicate the significance at the 5% and 1% level.

Panel A: Momentum (1,1)							
	Low	2	3	4	5	High	H-L
Raw Returns	-0.574***	-0.154	0.006	0.050	0.062	0.448***	1.021***
	(-3.65)	(-1.15)	(0.044)	(0.35)	(0.51)	(2.61)	(5.95)
CAPM Alpha	-0.673***	-0.202	-0.031	0.001	0.022	0.419**	1.092***
	(-3.90)	(-1.37)	(-0.202)	(0.00)	(0.16)	(2.29)	(5.91)
3-FM Alpha	-0.686***	-0.194	-0.030	-0.007	0.005	0.399**	1.085***
	(-3.77)	(-1.28)	(-0.19)	(-0.04)	(0.04)	(2.21)	(5.74)
Lustig alpha	-0.694***	-0.178**	-0.031	0.036	0.042	0.314***	1.008***
	(-3.89)	(-2.51)	(-0.42)	(0.47)	(0.609)	(2.60)	(5.17)
Menkhoff alpha	-0.441	-0.343	(-0.323)	0.300	0.072	0.581***	1.022***
	(-1.14)	(-1.49)	(-1.44)	(1.47)	(0.26)	(3.20)	(2.79)
Max (in %)	12.04	8.01	10.07	7.67	11.11	8.77	17.51
Min (in %)	-17.65	-10.93	-10.11	-10.07	-9.30	-10.19	-12.68
Std. Dev.	3.076	2.580	2.677	2.623	2.459	2.729	3.187
Skewness	-0.775	-0.378	-0.234	-0.213	0.077	-0.194	0.419
Kurtosis	7.257	4.982	4.509	3.887	4.817	4.481	6.518
Sharpe Ratio	-0.186	-0.059	0.002	0.019	0.025	0.164	0.321
Panel B: Carry trade							
	Low	2	3	4	5	High	H-L
Raw Returns	-0.466***	-0.138	-0.017	0.057	0.079	0.248	0.715***
	(-2.95)	(-1.08)	(-1.08)	(0.43)	(0.59)	(1.15)	(3.45)
CAPM Alpha	-0.505***	-0.180	-0.060	0.003	0.018	0.199	0.705***
	(-2.94)	(-1.29)	(-0.42)	(0.01)	(0.12)	(0.86)	(3.29)
3-FM Alpha	-0.523***	-0.186	-0.042	0.003	0.003	0.168	0.691***
	(-2.92)	(-1.31)	(-0.296)	(0.02)	(0.017)	(0.71)	(3.17)
Max (in %)	8.78	8.01	8.71	10.58	7.33	9.98	9.92
Min (in %)	-13.09	-9.75	-9.74	-10.32	-9.76	-17.65	-13.41
Std. Dev.	2.779	2.544	2.415	2.502	2.523	3.335	3.273
Skewness	-0.216	-0.093	-0.163	-0.133	-0.518	-0.775	-0.861
Kurtosis	4.825	3.973	4.728	5.331	4.556	5.676	5.223
Sharpe Ratio	-0.168	-0.054	-0.007	0.023	0.031	0.074	0.218

Table D.2. Momentum and carry trade profits after transaction costs and market states

This table presents the results of the following monthly time-series regressions:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5 mkt\_rf_t + B_6 smb_t + B_7 hml_t + e_t$$

where *H-L* is the currency momentum and carry trade trading strategy payoff after adjusting for bid-ask spreads, where the equally-weighted loser portfolio is subtracted from equally-weighted winner portfolio in month t; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12; *down* is the dummy variable that takes the value of one if the past twenty-four months return on value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month t; FF factors include the market factor, the size factor and the book-to-market factor, respectively. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

Momentum and Carry Trade profits after transaction costs regressed on lagged market state variables						
	Momentum			Carry Trade		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	1.037***	1.041***	1.352***	0.739***	0.729***	0.448
	(5.78)	(5.83)	(5.08)	(3.43)	(3.67)	(1.26)
Illiquidity		-0.262*	-0.234*		-0.646***	-0.516***
		(-1.94)	(-1.81)		(-3.42)	(-2.79)
Down market			1.148*			1.537
			(1.71)			(2.20)
Volatility			-0.493*			0.136
			(-1.98)			(0.41)
FF factors	Yes	Yes	Yes	Yes	Yes	Yes
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.005	0.010	0.014	0.020	0.035	0.066
Obs	430	430	430	430	430	430

Table D.3. Momentum and carry trade profits after transaction costs in different sample periods

This table presents the results of the following monthly time-series regressions for the samples from 1976:1 to 2000:12 and from 2001:1 to 2011:12:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5' F_t + + e_t$$

where *H-L* is the currency momentum or the carry trade trading strategy payoff; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002); *down* is the dummy variable for the past twenty-four months negative CRSP market index return; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable for systemic macroeconomic events that occur in month t; *mkt_rf*, *smb*, and *hml* are FF factors; *dol* and *hml_fx* are Lustig et al. (2011) factors; *dol* and *vol_fx* are Menkhoff et al. (2012a) factors. Panels present the results of the above mentioned time-series regressions after accounting for transaction costs for the full sample. Newey-West HAC based *t*-statistics are presented in parenthesis. Asterisks "*", ** and *** are significant at the 10%, 5% and 1% level, respectively.

Profits after transaction costs and market states

	1976-2001				2001-2012			
	Momentum			Carry Trade	Momentum			Carry Trade
Intercept	1.172***	1.140***	1.173**	-0.675	2.231***	2.831***	2.659***	3.467***
	(3.35)	(3.31)	(2.21)	(-1.49)	(3.52)	(4.33)	(2.50)	(6.90)
Illiquidity	-0.399**	-0.400**	-0.401**	-0.165	1.020**	1.073*	1.107**	1.321***
	(-2.32)	(-2.32)	(-2.34)	(1.04)	(2.37)	(1.93)	(2.01)	(4.86)
Down market	2.801	2.798	2.830	0.571	0.224	0.457	0.427	0.131
	(1.47)	(1.32)	(1.25)	(0.66)	(0.36)	(0.52)	80.48)	(0.24)
Volatility	-0.272	-0.244	-0.235	1.227**	-0.858*	-1.289***	-1.41***	-1.316***
	(-0.65)	(-0.63)	(-0.55)	(2.41)	(-1.95)	(-3.05)	(-2.73)	(-4.68)
FF factors	Yes			Yes	Yes			Yes
Lustig et. al factors		Yes				Yes		
Menkhoff et. al factors			Yes				Yes	
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.016	0.017	0.017	0.019	0.138	0.109	0.113	0.318
Obs	298	298	298	298	132	132	132	132

Table E.1. Momentum and carry trade profits and tradability

This table presents the results of the following monthly time-series regressions:

$$H\_L_t = a_t + B_1 \text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3 \text{volatility}_{t-1} + B_4 crisis_t + B_5 mkt\_rf_t + B_6 smb_t + B_7 hml_t + e_t$$

where *H-L* is the currency momentum (the carry trade) trading strategy payoff after adjusting for bid-ask spreads and tradability concerns, where the equally-weighted loser portfolio is subtracted from the equally-weighted winner portfolio in month t; *illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12; *down* is the dummy variable that takes a value of one if the past twenty-four months return on value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable that takes value of one if potentially systemic macroeconomic events occur in month t; *mkt_rf*, *smb*, and *hml* are FF factors, including the market factor, the size factor and the book-to-market factor, respectively. Panel A shows the results of the above mentioned time-series regressions for the set of "investable" currencies as identified in a survey conducted by Menkhoff et al. (2012b), while in Panel B we impose additional restriction on the dataset by eliminating currencies with large trading in NDF in offshore markets from the "investable" currency universe. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks "*", ** and *** are significant at the 10%, 5% and 1% level, respectively.

Panel A: "Investable" currency universe

	Momentum			Carry trade		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	0.797***	0.800***	0.851***	0.922***	0.933***	0.746**
	(4.99)	(5.01)	(3.34)	(4.57)	(4.93)	(2.26)
Illiquidity		-0.190*	-0.109*		-0.665***	-0.557***
		(-1.76)	(-1.67)		(-3.68)	(-3.15)
Down market			1.494**			1.441**
			(2.29)			(2.11)
Volatility			-0.249			0.022
			(-0.99)			(0.07)
FF factors	Yes	Yes	Yes	Yes	Yes	Yes
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.007	0.007	0.036	0.017	0.061	0.080
Obs	430	430	430	430	430	430

Table E.1. - Continued

Panel B: "Investable" currency universe ex NDF

	Momentum			Carry trade		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Intercept	0.514***	0.513***	0.438*	0.476***	0.482***	0.404
	(3.68)	(3.68)	(1.67)	(2.97)	(3.08)	(1.36)
Illiquidity		-0.195*	-0.172*		-0.375**	-0.326**
		(-1.79)	(-1.69)		(-2.37)	(-2.03)
Down market			0.721			0.66
			(1.56)			(1.43)
Volatility			-0.010			0.001
			(-0.04)			(0.00)
FF factors	Yes	Yes	Yes	Yes	Yes	Yes
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.005	0.004	0.011	0.041	0.056	0.057
Obs	430	430	430	430	430	430

Table E.2. Momentum and carry trade profits and tradability in different sample periods

This table presents the results of the re-estimated models from Table D.3 with restricted datasets for the samples from 1976:1 to 2000:12 and from 2001:1 to 2011:12.*illiquidity* stands for the normalized market illiquidity measure constructed from Amihud (2002); *down* is the dummy variable for the past twenty-four months negative CRSP market index return; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$; *crisis* stands for the dummy variable for systemic macroeconomic events that occur in month t; *mkt_rf*, *smb*, and *hml* are FF factors; *dol* and *hml_fx* are Lustig et al. (2011) factors; *dol* and *vol_fx* are Menkhoff et al. (2012a) factors. Panels present the results of the above mentioned time-series regressions after accounting for transaction costs for the set of "investable" currencies (Panel A), and for the dataset without currencies with large trading in NDF in offshore (Panel B). Newey-West HAC based *t*-statistics are presented in parenthesis. Asterisks "*", ** and *** are significant at the 10%, 5% and 1% level, respectively.

Panel A: "Investable" currency universe

	1976-2001				2001-2012			
	Momentum			Carry Trade	Momentum			Carry Trade
Intercept	0.856***	0.948***	0.983***	0.320	1.899***	2.529***	2.355*	3.469***
	(3.16)	(3.44)	(4.07)	(0.69)	(2.66)	(3.45)	(1.78)	(6.91)
Illiquidity	-0.171*	-0.165*	-0.169*	-0.202	0.885*	0.890*	0.871	1.322***
	(-1.76)	(-1.71)	(-1.64)	(-1.14)	(1.92)	(1.65)	(1.50)	(4.86)
Down market	2.806***	2.756***	2.810***	1.929***	0.229	0.518	0.498	0.125
	(4.55)	(4.22)	(4.03)	(2.97)	(0.36)	(0.56)	(0.53)	(0.23)
Volatility	-0.358	-0.458*	-0.216	1.153**	-0.545	-0.899*	-0.937	-1.31
	(-1.35)	(-1.75)	(-0.76)	(2.16)	(-1.11)	(-1.71)	(-1.51)	(-4.67)
FF factors	Yes			Yes	Yes			Yes
Lustig et. al factors		Yes				Yes		
Menkhoff et. al factors			Yes				Yes	
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.019	0.022	0.037	0.029	0.138	0.098	0.097	0.318
Obs	298	298	298	298	132	132	132	132

Panel B: "Investable" currency universe ex NDF

	1976-2001				2001-2012			
	Momentum			Carry Trade	Momentum			Carry Trade
Intercept	0.903***	0.951***	0.989***	-0.147	1.076	1.719	1.281	1.612***
	(3.31)	(3.44)	(4.10)	(-0.37)	(1.13)	(1.14)	(1.22)	(3.91)
Illiquidity	-0.204*	-0.202*	-0.211*	-0.107	0.351	0.606*	0.456	0.770***
	(-1.84)	(-1.72)	(-1.69)	(-0.68)	(0.85)	(1.66)	(0.91)	(3.03)
Down market	3.202	4.215**	5.071**	1.939*	0.296	0.431	0.312	0.264
	(1.54)	(2.13)	(2.42)	(1.90)	(0.54)	(0.59)	(0.43)	(0.63)
Volatility	-0.474*	-0.528**	-0.283	0.049	0.309	-0.034	-0.274	-0.771***
	(-1.95)	(-2.21)	(-1.02)	(1.04)	(0.80)	(-0.08)	(-0.55)	(-2.95)
FF factors	Yes			Yes	Yes			Yes
Lustig et. al factors		Yes				Yes		
Menkhoff et. al factors			Yes				Yes	
Crisis Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-Rsq	0.025	0.025	0.020	0.021	0.112	0.088	0.057	0.308

Table F.1. Individual currency momentum, carry trades, and market states

Model 1 in both panels presents the results of the following Fama-MacBeth regressions:

$$\text{for momentum: } R_{i,t} = a_0 + B_{0,t}R_{i,t-12:t-1} + e_t$$

$$\text{for carry trade: } R_{i,t} = a_0 + B_{0,t}F_{i,t-1} + e_t$$

where $R_{i,t}$ is the log excess return of currency i in month t; $R_{i,t-12:t-1}$ is the accumulated log return in the previous t-12 to t-1 months; $F_{i,t-1}$ is log forward discount of currency i in the previous month. Panel A shows results for currency momentum and Panel B presents results for carry trade.

In models 2 to 5 the results of the following regression are presented:

$$B_{0,t} = a_0 + B_1\text{illiquidity}_{t-1} + B_2 down_{t-1} + B_3\text{volatility}_{t-1} + e_t$$

here the estimated beta series from the first regression is regressed on market state variables, namely, ; *illiquidity* – the normalized market illiquidity constructed from Amihud (2002) measure in month $t-1$; *down* is the dummy variable that takes a value of one if the past twenty-four months return on value-weighted CRSP market index is negative and zero otherwise; *volatility* is the standard deviation of the value-weighted CRSP market index in month $t-1$. Newey-West HAC based *t*-statistics are presented in parenthesis. Numbers annotated with asterisks *, ** and *** are significant at the 10%, 5% and 1% level, respectively.

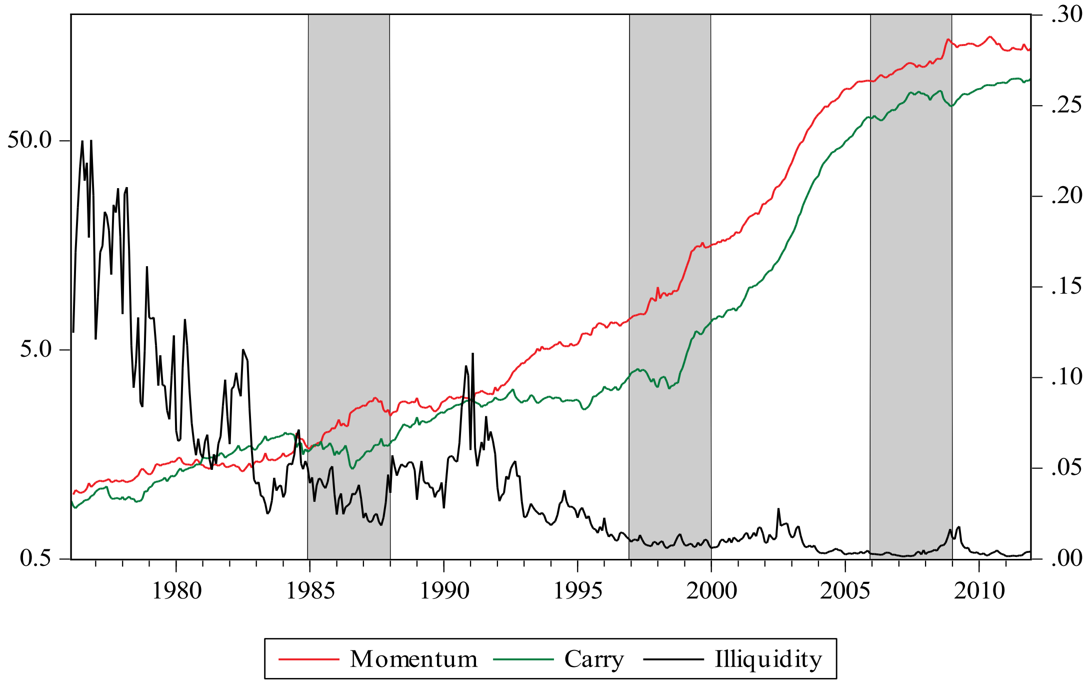
Panel A: Estimates of two-stage regressions for momentum

	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	0.003***	0.022***	0.020***	0.023**	0.018**
	(2.76)	(3.23)	(2.81)	(2.05)	(2.53)
Returns (t-12,t-1)	0.022***				
	(2.85)				
Illiquidity		-0.010*			-0.010*
		(-1.68)			(-1.67)
Down market			0.018		0.027
			(0.88)		(1.18)
Volatility				-0.005	-0.012
				(-0.86)	(-1.54)
Adj-Rsq	0.206	0.002	0.002	0.002	0.003
Obs	11709	419	419	419	419

Panel B: Estimates of monthly Fama-MacBeth regressions for carry trade

	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	0.002***	-0.019	-0.046	-0.019	-0.017
	(3.68)	(-0.20)	(-0.42)	(-0.84)	(-1.50)
Forward discount(t-1)	-0.026*				
	(1.85)				
Illiquidity		-0.046			-0.012
		(-0.68)			(-0.17)
Down market			0.213		-0.011
			(1.12)		(-0.05)
Volatility				0.164**	0.163*
				(2.33)	(1.82)
Adj-Rsq	0.065	0.001	0.002	0.006	0.002
Obs	11805	429	429	429	429

Figure B.1. Cumulative momentum and carry trade returns, market illiquidity, and periods of divergence
The figure shows the time-series of the market illiquidity measure plotted against the cumulative momentum and carry trade returns. The illiquidity measure is constructed from Amihud (2002) in month $t-1$, in particular, it is the value-weighted stock-level Amihud's (2002) illiquidity measure of all NYSE and AMEX firms for the period from 1976:1 to 2011:12 (right axis). Cumulative returns are on the log scale (left axis). Shaded areas indicate periods from Table B.2 when signs for momentum and carry trade are contrariwise.



Solvency Risk Premia and the Carry Trades[1]

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Abstract

This paper shows that currency carry trades can be rationalized by the time-varying risk premia originating from the sovereign solvency risk. We find that solvency risk is a key determinant of risk premia in the cross section of carry trade returns, as its covariance with returns captures a substantial part of the cross-sectional variation of carry trade returns. Importantly, low interest rate currencies serve as insurance against solvency risk, while high interest rate currencies expose investors to more risk. The results are not attenuated by existing risks and pass a broad range of various robustness checks.

JEL classifications: F31, G15

Keywords: Solvency Risk; Carry Trades; Risk Premia

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1. Introduction

This paper studies risk-return characteristics of the currency carry trade strategy that is implemented by borrowing in a low interest rate currency and subsequent investing in a high interest rate currency. Provided that uncovered interest parity holds, investment currency depreciation offsets the interest rate differential (forward premium) and returns to carry are zero. In fact, the opposite holds true and the long-standing phenomena of currency carry trade has its roots in persistent deviations from uncovered interest parity and empirical rejection of the forward rate unbiasedness hypothesis; that is, the forward premium is an apparent biased predictor of a future spot exchange rate change (Fama, 1984). These feasible discrepancies in macroeconomic parity conditions give rise to positive average historical returns of the carry trade strategy and the forward premium puzzle.

Seeking an explanation of the forward premium puzzle and carry trade returns has been a prime topic in international finance for over three decades, the debate being initiated by Hansen and Hodrick (1980, 1983) and Fama (1984). The main avenue for research perceives the carry trade returns as a compensation for a common risk. Therein currencies are prone to deliver low/high carry trade returns in bad/good times due to persistent heterogeneity in risk exposures between investment and funding currencies. Several recent studies suggest a number of possible explanations for observed patterns of heterogeneous risk exposures (see, e.g., Lustig, Roussanov, and Verdelhan, 2011; Menkhoff, Sarno, Schmeling, and Schrimpf, 2012; Lettau, Maggiori, and Weber, 2013; and others cited below). Overall, the cumulative evidence points to time-varying risk premia as the pervasive source of the carry trade returns and to the forward premium puzzle not being without costs. Nonetheless, the identification of an appropriate risk premia that explains the carry trade profitability remains an ongoing debate.

This paper contributes to current debate by revealing a new economic-based time-varying risk premia in the currency market– the sovereign solvency risk premium– that depends upon a country's ability to payout an outstanding external debt. We argue that the financial capacity of the economy, captured by the solvency measure, lies at heart of persistent heterogeneity across currencies' exposures to a common risk, and incites the differences in average excess returns. In other words, the profitability of currency carry trades can be rationalized by the time-varying risk premia that originate from the sovereign solvency risk. Consistently, we find that high interest rate currencies demand a higher risk premium, as they deliver low carry trade returns at times of high solvency risk, therefore exposing investors to more risk, whereas low interest currencies are a hedge against the solvency risk.

Importantly, this paper proposes a new risk-adjusted version of uncovered interest parity (UIP). Bridging the macroeconomic concepts of debt elastic interest rate and risk premium associated with lending to the economy, we lay out a UIP that is disturbed by country-specific risk premia given by the increasing convex function of the debt service capacity of the economy. Therein, time-varying solvency risk premia offset the disparity between actual and expected exchange rate, establishing equilibrium. This provides a simple and intuitive risk-based view on exchange rate determination by a risk premium varying in the solvency of the economy.

The empirical findings of the paper indicate that solvency risk preserves the substantial power to explain the cross-section of carry trade returns. This paper introduces a new, solvency-based, risk factor and show that its covariance with returns accounts for almost all of the variation in the cross-section of carry trade returns. Our empirical approach relies on much of the recent literature (Lustig, Roussanov, and Verdelhan, 2011; and Ready, Roussanov, and Ward, 2015). We perform portfolio sorts on forward discounts and the solvency measure, identify risk factor as the returns on zero-cost long-short strategy between the last and first solvency-sorted portfolios and label it IMS, for indebted-minus-solvent economies. The IMS factor explains the substantial part of the cross-sectional variation in carry trade portfolios, exhibiting monotonically increasing factor loadings and significant prices of risk, consistent with risk premia explanation. Moreover, the factor is empirically powerful in various model specifications and sample splits, prices different test assets, stands out horse races with other currency-specific risk factors, robust against an alternative funding currency (the Japanese Yen) and alternative solvency measure specifications, and passes several other robustness checks, pointing to the solvency risk factor being a persuasive tool for pricing the cross-section of carry returns.

This study contributes to the literature in several important ways. First, the empirical findings of this paper lend additional support to the risk-based view of the forward premium puzzle. In line with findings of studies, such as those of Hansen and Hodrick (1980), Fama (1984) and Engel (1996), this paper shows that the apparent slump of UIP can be interpreted as a compensation for risk. Second, this paper extends the findings of prior research searching for an appropriate time-varying currency risk premium that rationalizes returns to the carry trade strategy (see, e.g., Lustig and Verdelhan, 2007; Lustig, Roussanov, and Verdelhan, 2011; Menkhoff, Sarno, Schmeling, and Schrimpf, 2012; Lettau, Maggiori, and Weber, 2013; and Ready, Roussanov, and Ward, 2015). This paper identifies a new source of risk premia and shows that currency carry trades can be comprehended as a compensation for sovereign solvency risk. Third, relying on fundamental measures of the financial competence of the economy, this study adds to the prior literature on a country's creditworthiness as an explanation of currency carry trades (see, e.g., Hui and Chung, 2011; Coudert and Mignon, 2013; and Huang and MacDonald, 2014), while addressing the critique of Longstaff, Pan, Pedersen, and Singleton (2011) of applying market measures to assess sovereign financial solvency.

The remainder of the paper is organized as follows. In Section 2 we provide an overview of the essential theories behind carry trade, initiate the discussion of our main solvency measure, and derive risk-adjusted UIP. Section 3 is dedicated to descriptions of the data, portfolios, and risk factors, and supplying descriptive statistics. The empirical approach and asset pricing tests are discussed in Section 4, followed by a review of the main empirical evidence on solvency risk in Section 5. The results of the robustness checks are presented in Section 6. Section 7 concludes the paper. This paper also incorporates an Appendix that provides supplementary derivations and results. Moreover, the results of additional robustness checks are presented in the Internet Appendix.

2. Background Ideas

In this section we present the theoretical background and the analytical framework underpinning this paper. We start with an overview of the existing literature and focus on rational risk premia interpretations. Next, we specify our measure of creditworthiness of the economy, and the rationale behind it. Finally, we consider the highly indebted economy and introduce the sovereign risk premium through the specification of an upward sloping foreign debt supply function and present risk-adjusted version of UIP.

2.1. Essential theory

The exercise of the carry trade strategy is firmly related to the forecasting shortcomings of forward rates, which is commonly referred to as the forward premium anomaly. Specifically, forward premia, contrary to the unbiasedness hypothesis, fall short in predicting future spot exchange rate appreciation. If forward rates were unbiased, the carry trade returns would be indistinguishable from zero. The explanation of positive historical carry trade payoffs has become a cornerstone of understanding the forward premium puzzle. Historically, foreign exchange market arbitrage is a long standing issue of international finance stretching back as far as the pre-gold standard study of Keynes (1923). Nevertheless, literature on the forward premium puzzle emerged in the early 1980's and has often identified four major ways to interpret the existence of carry trade returns and the empirical rejection of the forward unbiasedness hypothesis.

The first stream of literature strives to provide a risk-based explanation for the puzzle through defining carry trade returns as a compensation for an appropriate risk. Building on the classic contribution of Hansen and Hodrick (1980), Fama (1984) brings the discussion to the efficient markets framework and shows the apparent failure of UIP across various currencies and time periods, which manifests in negative estimates of the slope parameter of the so-called Fama-regression. Importantly, the residual component of that regression is interpreted as the time-varying currency risk premium that rationalizes returns to the carry trade strategy.

Alternatively, the existence of that residual component is taken as evidence of market inefficiency, constituting the second interpretation. Pioneered by Bilson (1981), one can show that the nature of forward premium bias is broadly coherent with the behavioral finance perspectives found in Froot and Thaler (1990). Burnside, Han, Hirshleifer, and Wang (2011) argue that the forward premium puzzle can be interpreted by investor overconfidence causing overreaction to macro information and discrepancies in forward and spot rate responses.

The third class of explanations focuses on errors in market expectations due to the potential for "peso problems", and was first introduced by Krasker (1980). That is, uncertainty about a future shifts in regimes results in biased measures of market expectations and, hence, a skewed distribution of forecast errors. In addition, Kaminsky (1993), Evans (1996), and Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) examine peso problems, measurement errors and rare disasters, and infer that forward rates are biased. Furthermore, Lewis (2011) shows that potentially rare disasters may bias slope estimates of the Fama-regression. Building on evidence of peso problems, Lewis (1989) demonstrates that learning effects can account for as much as half of the magnitude of forward premium bias.

Finally, several studies focus on the interpretation of the puzzle from the microstructure point of view. Evans and Lyons (2002) adopting the microstructure approach find evidence of order flow related determinants of exchange rates. Lyons (2001) proposes limits to the speculation hypothesis and demonstrates that order flow information may reveal additional insights into the forward premium puzzle.

Perhaps the major avenue for research to comprehend the forward premium puzzle is the identification of a convenient time-varying risk premia. The inability of conventional risk factors to indisputably reconcile the puzzle, manifested in Burnside, Eichenbaum, and Rebelo (2011), has spurred a number of original currency-specific interpretations. Lustig, Roussanov, and Verdelhan (2011) adopt a Fama and French (1993) style approach to forward-sorted currencies and find heterogeneity in exposures to common risks across portfolios, related to rational risk premia. In a similar vein, Menkhoff, Sarno, Schmeling, and Schrimpf (2012) demonstrate that global currency market volatility shocks exert a compelling pricing power in the cross-section of carry trade returns. Rafferty (2012) indicate that global foreign exchange market skewness is also a valid risk factor. Mancini, Ranaldo, and Wrampelmeyer (2013) and Karnaukh, Ranaldo, and Söderlind (2015) reveal the substantial role of currency market liquidity in explaining the carry trade strategy payoffs. Orlov (2015) points out the significant role of temporal variations in equity market illiquidity. Hassan (2013) and Martin (2013) adopt theoretical models to argue that the spread between two countries' currency returns is related to the size of the countries. Jylhä and Souminen (2011) show that hedge fund capital flows affect interest rates and exchange rates, in turn affecting carry trade profitability, in a manner consistent with the risk-based explanation. Ready, Roussanov, and Ward (2015) in the model of equilibrium show that heterogeneity in excess returns between high and low interest rate currencies arises from the differences in composition of the trade balance. Bakshi and Ponayotov (2013) document the predictive role of commodities in explaining the time-series of carry trade returns. Lettau, Maggiori, and Weber (2013) argue that 'investment' currencies exhibit large beta loadings conditional on the state of the market, particularly in times of market downturn. Correspondingly, Jurek (2014) shows that returns on short put position in such currencies explain carry trades. Daniel, Hodrick and Lu (2015), however, find no evidence of downside risk in dollar-neutral carry trades. Ranaldo and Soderlind (2010) find that low interest rate currencies serve as a hedge against market turmoil, appreciating when the aggregate risk is high. Mueller, Stathopoulos, and Vedolin (2015) find a counter cyclicality in cross-sectional correlation dispersion between high and low carry trade currencies which is consistent with the rational risk premia interpretation. Finally, Koijen, Pedersen, Moskowitz, and Vrugt (2012) provide a comprehensive overview of carry trade strategy in different markets and reviews of research within the area.

2.2. Solvency measure

The macroeconomics literature has a long history of investigating optimal borrowing. The first study to assume imperfect capital markets for debt is that of Bardhan (1967) who suggested that cost of debt increases at the aggregate level of foreign debt. Diamond (1965) investigates the effects of the stock of external debt on the economy dynamics with a neoclassical growth model. More recent studies also investigate equilibrium dynamics with debt level elastic interest rates (see, e.g., Obstfeld, 1982; Eaton and Turnovsky, 1983; Bhandari, Haque, and Turnovsky, 1990; and Schmitt-Grohe and Uribe, 2003). Another way to incorporate the idea of imperfect markets is to consider the measure of a country's ability to service the outstanding debt, as creditworthiness of the economy can be a function of more than just a level of foreign debt. Otani and Villanueva (1988) model the risk premium charged on foreign debt as a function of the debt-to-export ratio. Cohen and Sachs (1986) and Escudé (2013) assume that risk premia depend on a country's ability to cover the debt as represented by debt-to-output or capital ratio. In this paper we assume risk premium is a function of external debt service capacity measured by a ratio of foreign debt to economy's earning ability (henceforth, the *solvency measure*). Risk premium is then represented by an increasing convex function of that measure. In the most of our analysis, we consider foreign debt-to-output ratio as a measure of solvency of the country, expressed as:

$$\gamma_t^i = \frac{Gross\ Foreign\ Debt_t^{USD}}{GDP_t^{USD}}, \tag{1}$$

where we quantify the ability of the economy i to pay external debt by expressing gross foreign debt as the percentage of gross domestic product in period t. To ensure comparability between countries we convert both quantities into U.S. dollars at an average exchange rate for that period. The change in this measure can be altered by variations in the level of foreign debt and/or a shift in the output measure. This measure is empirically quantifiable and within our framework indicates the level of solvency of the economy, reflecting the degree to which the country bears the risk. Later in the paper we describe the data collection process and consider alternative ways to quantify the financial competence of the economy.

Importantly, we abstract from the market measures of country's creditworthiness and rely on fundamentals. Several recent studies identify the marginal value of sovereign CDS spreads in interpreting the forward premium puzzle around the financial crisis as being broadly consistent with the crash risk explanations. Hui and Chung (2011) show that CDS implied information is transmitted to the currency options and, consequently, to the Euro crash risk probability. Similarly, Coudert and Mignon (2013) find the crash-consistent behavior of emerging currencies, such that default risk contributes to higher returns during expansion and massive losses during market turmoil. Nevertheless, no evidence on reconciliation of the forward premium puzzle using CDS spreads emerges from the most common carry trade currencies. Huang and MacDonald (2014) consider the cross-sectional pricing ability of CDS spreads and its link to currency market volatility around the financial crisis. Along with that, there is also evidence that market-based measures (CDS spreads) do not offer a true prediction of financial distress, if they contain country-specific information at all. Longstaff, Pan, Pedersen, and Singleton (2011) demonstrate that sovereign CDS spreads are plagued by time-varying systemic risk, global risk premia and other global and regional economic forces, while exhibiting almost no evidence of sovereign-specific credit risk premia. Among others, Mauro, Sussman, and Yafeh, (2002), Pan and Singleton (2008), and Ang and Longstaff (2013) also show that sovereign CDS spreads do not in fact capture country-specific information, but are rather related to market-wide factors. Capitalizing on that evidence, this study considers the fundamental measures of the financial competence of the economy.

2.3. UIP with the Solvency Risk disturbance term

As noted earlier, the key assumption of the paper is that the domestic economy does not face a perfectly elastic supply of debt, but rather an upward sloping supply curve for debt. Kharas (1983) and Kharas and Shishido (1986) show that this supposition appears to be realistic as repayment commitments for various reasons are not always made on time. Thus, foreign lenders are likely to form expectations about the ability of an economy to repay debt, requiring a risk premium over the international interest rate for lending to each economy. Merging the concepts of debt elastic interest rate and risk premium associated with lending to the economy, the interest rate charged on foreign debt is:

$$i(y)_t = i_t^* + v(y)_t, \qquad v' > 0, \quad v'' > 0, \tag{2}$$

where the interest rate $i(y)$ faced by domestic agents in time t depends on the level of world interest rate (i^*) and the country-specific risk premium ($v(y)$), which varies with the debt service capacity of the economy as measured by solvency measure (y_t). Sovereign risk premium is assumed to be an increasing and convex function ($v \equiv 1 + \bar{v} > 1,\ v'' > 0$), so that the interest rate grows at an increasing rate with the level of indebtedness of the economy until a predetermined borrowing constraint is reached. Thus, the risk premium inversely related to the debt service capacity of the economy. Next, we assume risk-adjusted interest rate parity, so that domestic agents can borrow from and lend to the government at rate $i(y)$. Thus, rewriting equation (2) in a form that represents domestic rate provides the following expression for foreign currency gross interest rate that households must deal with:

$$(1 + i_t) = (1 + i_t^*)\ v(y)_t\ , \tag{3}$$

In this setup, we devote our attention to shocks associated with the imperfect debt supply confronting an indebted domestic economy. There are two sources of shocks: exogenously derived world interest rate; and, specifically, an endogenous risk premium associated with the financial capacity of the domestic economy. The change in the former reflects the general tightening/relaxing of global credit conditions, while a change to the latter reflects country-specific borrowing constraints. Importantly, we derive the risk-adjusted UIP of the following form:[1]

$$(1 + i_t) = (1 + i_t^*) v(\gamma_t) E_t(\delta_{t+1})\ , \tag{4}$$

The result is a UIP that is disturbed by the endogenous risk premium given by the increasing convex function of the debt service capacity of the economy as measured by the foreign debt-to-output ratio. Independent of the presence of the risk premium and under the rational expectation assumption, UIP stipulates the

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[1] To save space, we provide the description of the setup, the detailed derivation of UIP disturbed by the solvency risk premia in the Appendix A.

exchange rate (δ_{t+1}) depreciation (appreciation) equivalent to the interest rate differential. Conversely, equation (4) suggests the risk-adjusted version of UIP such as the time-varying risk premium ($v(\gamma_t)$) balances the difference between the actual and expected exchange rate. Importantly, since the risk premium is plausibly assumed to be an increasing and convex function such a parity condition predicts that interest rate differentials should increase in the solvency measure, followed by higher excess returns. In addition, a positive change in the interest rate differential can produce an even larger change in the risk premium, as it results in an upward shift in the increasing convex risk premium function.

Summing up, the resulting risk-adjusted equilibrium parity condition of currency pricing implies: First, highly indebted countries have higher interest rates and forward discounts on average than solvent countries; second, an indebted currency earns positive expected return, that increases in the solvency measure; third, the interest rate differential and the solvency currency risk premium both increase in measures of an economy's financial capacity; and, finally, indebted currency is risky, as it appreciates in good times and depreciates in bad times. Overall, this section provides an intuitive risk-based view of exchange rate determination with risk premium varying with the debt service capacity of the economy. Notably, we propose a new version of risk-adjusted UIP, and outline the abovementioned qualitative predictions, which we also evaluate empirically.

3. Data, Currency Portfolios and Risk factor building

3.1. Currency data

The full sample of this study consists of 48 currencies. For each currency we collect end-of-month data of spot exchange rates and of one-month forward exchange rates from Barclays and Reuters via Datastream. The countries in the sample are those of: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Euro area, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Iceland, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Ukraine, United Kingdom. The sample coverage for spot and forward rates spans January 1985- December 2014.[2] All of the rates are expressed as units of foreign currency per one U.S. dollar. Our analysis is executed on a monthly frequency.

Also, we consider a subsample of spot and forward rates of the ten most actively traded currencies, henceforth referred to as *developed countries*. These ten counties are: Australia, Canada, Denmark, Germany/Euro area, Japan, New Zealand, Norway, Sweden, Switzerland, United Kingdom. We merge the time series on forward discount and excess returns of the German Deutschemark prior to 1999 and those for the Euro. To further assess robustness, we repeat the empirical analysis with data samples identical to Lustig, Roussanov, and Verdelhan (2011) (37 currencies) and Burnside, Eichenbaum, and Rebelo (2011) (20 currencies).[3]

In this study we estimate currency excess returns from the U.S. investor point of view, so that the U.S. dollar is considered to be a domestic currency. In the empirical analysis we operate with logarithms, denoting s and f as log spot and log forward rate, respectively. We rely on the relation implied by covered interest parity, where the interest rate differential is approximately equal to the log forward discount ($i_t^* - i_t \approx f_t - s_t$), spot exchange rate appreciation or depreciation is defined by $s_{t+1} - s_t$ and the currency excess return is then defined such that $r_{t+1} = i_t^* - i_t - s_{t+1} + s_t \approx f_t - s_{t+1}$.

3.2. Solvency data

In our empirical analysis we consider the ratio of foreign debt to GDP as a measure of the indebtedness of the economy. Specifically, we collect the

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[2] Burnside, Eichenbaum, and Rebelo (2011) and Menkhoff, Sarno, Schmeling, and Schrimpf (2012) extend their datasets back to 1976 by complementing BBI and Reuters data (available from October 1983) with historical Reuters data quoted against the British Pound, resulting in the longest possible time series of currency data. Lustig, Roussanov, and Verdelhan (2011) operate with the sample that starts in 1983. However, data on only nine currencies is available prior to 1985 and, as noted in Ready, Roussanov and Ward (2015), major carry trade currencies were undergoing transition to a floating exchange rate regime before 1985. Motivated by this and due to the availability of data on solvency measure our sample period begins in 1985.

[3] Results are unreported, but available upon request.

estimated foreign debt and estimated GDP at the end of each year for each country in our sample from International Financial Statistics, subsequently putting quantities at an equal footing by converting estimates into U.S. dollars at an average exchange rate for the year in question. The data period is matched with the one for currency data and spans the period December 1984- December 2014.

Table 1 presents unconditional average monthly estimates for forward discounts, excess returns and average values of solvency measure for the most actively traded currencies (sample of developed countries) over the sample period. Notably, countries with high average excess returns are associated with high values of forward discount (high interest rate differentials), which is consistent with the evidence from the previous studies (see, e.g., Brunnermeier, Nagel and Pedersen, 2009; Lustig, Roussanov, and Verdelhan, 2011). Importantly, we observe a remarkable heterogeneity in the average solvency measures across countries aligning with the unconditional carry trade returns and forward discounts. Countries with a high foreign debt to GDP ratio also have high interest rate differentials and exhibit high carry trade returns; examples include Australia and New Zealand. Conversely, low interest rate currencies (like Japan and Switzerland) have relatively low solvency ratio values as well as low carry trade returns. To further assess the observed pattern, we plot the average monthly interest rate differential and average excess returns of developed countries against the average foreign debt to GDP ratio over the full sample period (Figure 1). Both graphs expose clear cross-sectional differences between low and high interest rate currencies, commonly referred to as funding and investment currencies.

Insert Table 1 here

Insert Figure 1 here

In addition, to test the robustness of the findings, we consider another measure of the economy's ability to finance its official, commercial, and trade debt obligations. Specifically, we rely on the current account-to-exports of goods and services measure (CAXGS) obtained from the International Country Risk Guide published by the PRS Group. This measure is calculated by dividing the current account of the balance of payments for the year in question by the estimated aggregate of total exports of goods and services for that year. Both quantities are converted into a U.S. dollar amount beforehand. Results for our alternative measure are reported in the robustness section. Finally, we also consider a composite financial risk measure of the PRS Group, as an alternative solvency measure.[4] The main results of the paper remain unchanged.

3.3. Carry trade portfolios and portfolios sorted on solvency ratio

In order to empirically test the prediction of the model of heterogeneity in carry trade returns exposure to a common risk factor we construct currency portfolios. In particular, to form carry trade portfolios, following Ready, Roussanov and Ward (2015), we sort all of the currencies in our sample into six portfolios (four portfolios for the subsample of developed countries) on the lagged forward discount. Similarly, in order to construct portfolios sorted on a solvency measure we use the foreign debt–to–GDP ratio as in (1).

To ascertain that the portfolio construction process results in empirically implementable trading strategies we operate only with solvency measure data that is available at the time of portfolio construction. Thus, our approach differs from the conventional sorting on one-month lagged forward discount as in Lustig, Roussanov, and Verdelhan (2011) and Menkhoff, Sarno, Schmeling, and Schrimpf (2012). Specifically, due to the availability of macroeconomic data, we adopt an annual portfolio formation period, that is, we rebalance currency portfolios at the end of January of year t based on solvency ratios available for year $t-1$. Similarly, to put carry trade sorts on a par with solvency ratio portfolios, we sort currencies on a one-month forward discount at an annual frequency, rebalancing portfolios at the end of January of each year based on a one-month forward discount at the end of December in year $t-1$. Thus, in both cases, portfolios are rebalanced annually, but average returns are calculated on a monthly basis. Table 2 presents summary statistics for average excess returns of portfolios sorted on forward discounts (Panel A) and solvency measures (Panel B) as well as for components of excess returns, namely, average forward discounts and average change in spot exchange rate.

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[4] See the supplementary Internet Appendix for the detailed description of PRS group composite financial risk measure and estimation results.

Insert Table 2 here

Performing sorts on the forward discount results in six equally weighted portfolios where the top (low) sextile comprises currencies with the highest (lowest) forward discounts (interest rate differential) relative to the U.S. dollar. The spread in average excess returns between extreme portfolios in the full sample is similar to that obtained using a traditional sorting procedure with monthly rebalancing as in Menkhoff, Sarno, Schmeling, and Schrimpf (2012). The sample results arising exhibit a monotonic increase in average excess returns across portfolios, a smaller spread in developed sample relative to the full sample results and magnitudes that are similar to the conventional monthly sorts in Lustig, Roussanov, and Verdelhan (2011). In both subsamples the average profitability of the carry trade strategy originates mainly from the average forward discounts across portfolios.

The results of sorting on the solvency measure are reported in Panel B of Table 2. The high portfolio (portfolio 6) captures currencies with the largest values for the economy's solvency measure, while the low portfolio consists of currencies with the smallest values for the foreign debt-to-GDP ratio. The results indicate that the average excess return of portfolios monotonically increases when moving from a low to a high portfolio, in other words, from solvent to insolvent countries. The spread in average excess returns between extreme portfolios is around 2% per annum in the full sample, which is smaller than the one for carry trade portfolios.[5] However, the magnitudes of spread in average excess returns between the two sorts are largely identical (around 4% per annum) in the sample of developed counties.

Importantly, and consistent with the outcome predicted, the average forward discount of portfolios also monotonically increases in the values of solvency measure. Specifically, the most solvent countries report low average forward discounts, indicating that those are the countries with the lowest interest rate differentials from the perspective of the U.S. investor. Conversely, the most indebted countries are associated with the highest forward discounts. Similar

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[5] Note that we operate with a large dataset in order to maintain the most complete currency universe possible. Sorting in a smaller set of currencies (e.g., as in Ready, Roussanov and Ward, 2015) results in a larger high-minus-low spread, thus a smaller gap between spreads in forward discount and solvency sorted portfolios. See the separate Internet Appendix for a detailed description.

patterns are evident in the sample of developed countries. The spreads in the average forward discounts between extreme portfolios are close in magnitudes to those from the sort based on forward discount, regardless of the subsample.

3.4. IMS risk factor and other currency-based risk factors

Arbitrage pricing theory (APT) (see Ross, 1976) implies that the expected return of assets is approximately linearly related to the factor loadings, in that risk factors capture the common variation in asset returns. The general version of APT, however, is silent on the factors to be used. Lustig, Roussanov, and Verdelhan (2011) show that forward discount sorted portfolios exhibit a strong factor structure, specifically, the large proportion of the average carry trade returns in the cross-section can be explained by two risk factors.

Relying on a similar empirically motivated approach, we strive to pin down heterogeneity in pricing kernels' exposure to a common source of risk, which we previously referred to as a solvency risk. In order to form a candidate risk factor we estimate the difference between the return on the sixth (fourth for developed countries) and the first portfolios sorted on the solvency measure. This factor can be thought of as the U.S. investor's return on a zero-cost strategy that takes long position in the currencies of the countries that are the most indebted and goes short in the currencies of the most solvent countries. We refer to such a strategy as IMS (Indebted-Minus-Solvent). The IMS factor is essentially the implementable trading strategy. In a further estimation, the no arbitrage condition is satisfied, so the price of risk of the IMS factor is equivalent to its average excess return.

The results of principal component analysis indicate that the cross-section of carry trade returns can be explained by two principal component factors: the first is the *level* factor with similar loadings across portfolios, and the second is the *slope* factor with a monotonic increase in factor loadings. IMS risk factor is most closely related to the latter principal component (the *slope* factor) with a correlation coefficient of .71. This is important because the second principal component captures most of the cross-sectional information in the space of portfolio returns.[6] A further analysis considers both a single IMS factor model

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[6] See Lustig, Roussanov, and Verdelhan (2011) for principal component analysis on currency portfolios and the importance of the second principal component.

and a two factor model with IMS and the *level* factor depicted by average currency excess returns against the U.S. dollar (DOL_{FX}).

Additionally, we compare the performance of the IMS factor in explaining cross sectional heterogeneity in the average excess returns of portfolios sorted on the forward discount against other currency-specific risk factors. Specifically, along with the DOL_{FX} risk factor we consider the HML_{FX} risk factor of Lustig, Roussanov, and Verdelhan (2011) constructed directly from the sorted portfolios as high-minus-low carry trade portfolio returns. Moreover, we construct a global volatility risk factor VOL_{FX} as introduced by Menkhoff, Sarno, Schmeling, and Schrimpf (2012) as an intra-month realized standard deviation of the daily log changes of the spot exchange rates.

4. Empirical Strategy

In this section we specify our empirical approach and asset pricing tests used to identify if the carry trade returns can be understood as a compensation for solvency risk. First, since the risk factor in this paper is a portfolio of traded assets, we apply the standard time-series tests. To be precise, we run time-series regressions (5) of each carry trade portfolio's excess return as well as high-minus-low portfolio on a candidate risk factor(s). Further, we check if beta loadings are statistically significant and if alphas both individually and jointly are equal to zero.

$$r_{it} = \alpha_i + \beta_i f_t' + \varepsilon_{it} , \tag{5}$$

where r_{it} excess return on portfolio i at time t, α is an intercept, f' is the vector of candidate risk factors, and ε is the residual. To assess significance we rely on Newey and West (1987) HAC standard errors with optimal lags based on Andrews (1991). A J-test ($\alpha' V_\alpha^{-1} \alpha$) is used to test if intercepts are jointly equal to zero.

Next, we turn to the cross-sectional asset pricing, where the empirical approach is based on the argument that there is a stochastic discount factor (henceforth, SDF) that prices all the assets, as in Cochrane (2005). To estimate the market price of risk and the portfolio's betas we rely on two widely used procedures: first, the Generalized Method of Moments (henceforth, GMM) as in Hansen

(1982) with linear SDF and, second, Fama and MacBeth (1973) procedure (henceforth, FMB).

In order to rationalize returns to the carry trade strategy one can assume that a currency risk premium defined by a residual (ε_t) exists:

$$i_t^* - i_t = s_{t+1} - s_t + \varepsilon_t \,, \tag{6}$$

Backing out the risk premium from equation (6), one can show that the risk premium should offset the difference between the actual and expected exchange rate. Revolving around the classic pricing kernel equation, the risk-based explanation implies the absence of arbitrage opportunities and a zero price for such a risk-adjusted excess return. In particular, an excess return to a carry trade strategy must satisfy the Euler equation ($E_t\left(M_{t+1}r_{t+1}^i\right) = 0$). Applying the law of iterated expectations, we derive the unconditional version of it with a suppressed expectation time subscript:

$$E(M_t r_t^i) = 0 \,, \tag{7}$$

where E is an unconditional the mathematical expectation; $\alpha = 1 + b'E(f)$, so M_t is a linear SDF that takes the form of $M_t = 1 - b'(f_t - \mu)$ with b is a vector of factor loading, f_t is a vector of factors and $\mu = E(f)$ stands for factor means. In this manner, we force the mean of the SDF to be equal to 1 and the GMM-estimation then performs a cross-sectional regression of mean excess returns on their covariances with the factors. Thus, GMM tests the theoretical prediction that excess returns should be proportional to the covariances between returns and factors, so that:

$$E(r_{t+1}^i) = cov\left(r_t^i, \tilde{f}_t{}'\right)\Sigma_f{}'\Sigma_f b \,, \tag{8}$$

where $\tilde{f}_t \equiv f_t - E(f)$. Alternatively, in a traditional beta pricing model form with factor risk prices λ and factor loadings β of portfolio i, equation (8) takes the form of $E(r_t^i) = \lambda'\beta_i$ with $\lambda = \Sigma_f b$ representing the prices of risk, where $\Sigma_f = E(f_t - E(f))(f_t - E(f))'$ is the covariance matrix of the risk factor and b is the coefficient estimates of returns regressed on a factor. We use the GMM procedure (Hansen, 1982) with the following moment conditions as in (9) from (7) for $n \times 1$ vector of excess returns along with $\mu = E(f_t)$ restrictions to empirically estimate the prices of risk and the factor loadings.

$$E([1 - b'(f_t - \mu)r_t^i) = 0 , \tag{9}$$

The GMM estimator of b then takes the following form:

$$\hat{b} = (d_T' W_T d_T)^{-1} d_T' W_T \bar{r} , \tag{10}$$

where d_T is a covariance matrix of z with f, W_T is the weighting matrix.

Throughout the estimations we operate with overidentified GMM systems with a larger number of assets (moment conditions) than number of parameters. In such overidentified systems, it is generally impossible to set all the moments to zero simultaneously, thus we try to set a linear combination of these moments to be as close to zero as possible. In the first step of the procedure to minimize the objective function we use a pre-defined weighting matrix set to be identical matrix ($W_T = I_n$) as a covariance of the moment conditions. This works alongside the starting values, the prices of risk, and the pricing errors computed using an FMB regression. In the second step, we iterate values obtained from the first stage to obtain the optimal weighting matrix and an asymptotically efficient estimate of $\hat{b}$. The price of risk is calculated as $\hat{\lambda} = \hat{\Sigma}_f \hat{b}$. We also report Newey-West based standard errors, cross-sectional R^2, and a J-test of pricing errors ($\alpha' V_\alpha^{-1} \alpha$). In the following table we report estimates of the iterated GMM procedure.

Furthermore, we report the results of the traditional FMB procedure, which is similar to the first stage of the GMM. In particular, to obtain estimates of interest we run a cross-sectional regression of average portfolio excess returns on the previously estimated first step time-series betas. Note, that we do not include the constant in the second stage in the following models with dollar risk factor as dollar risk factor exhibits no cross-sectional relation to the carry trade portfolios' returns and acts like a constant in the cross-sectional regression (all of the beta loadings on this factor are almost equal to one, as shown in Panel A of Table 4).[7] For FMB we report both Shanken (1992) and Newey-West standard errors.

5. Empirical Evidence

This section presents our main empirical results regarding the predictions of heterogeneity in carry trade returns exposure to a common solvency risk factor. First we estimate exposure of the portfolios' covariances to common risk by estimating the model with only one linear risk factor (IMS). Subsequently, we assess the performance of the model enhanced with dollar risk factor (DOL_{FX}). Finally, the performance of the model is compared to alternative currency-specific risk factor models.

5.1. Explaining the carry trade with the solvency factor

Table 3 reports the results of benchmark asset pricing tests described in the previous section, as we test the ability of the candidate pricing kernel, linearly defined by the single IMS risk factor, to price the six (four for developed countries) carry trade portfolios sorted on forward discount.

Insert Table 3 here

Panel A of Table 3 presents results of time series regressions of each portfolio's log carry trade excess returns r^i on an intercept and solvency risk factor alone. We report estimates for the constant α^i and the slope coefficient β_{IMS} as well as adjusted R-squares and joint test for alphas. The alphas are annualized and presented in percentage points. The individual portfolio's alphas are statistically different from zero, albeit high carry trade portfolios in both samples (all and

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[7] See Lustig, Roussanov, and Verdelhan (2011); Burnside, Eichenbaum, Rebelo (2011); and Menkhoff, Sarno, Schmeling, and Schrimpf (2012) for more discussion on whether to include a constant or not.

developed countries) record alphas that are significant at 1% and 5%, respectively. The joint test for alphas yields mixed results for the two subsamples, as the null that the alphas are jointly zero is rejected in the full sample, while confirmed in the sample of developed countries at 5% level (p-value of 0.07).

The IMS factor loadings of each individual portfolio are reported in the second column. Betas for the IMS risk factor increase monotonically from -0.16 for low portfolio (low interest rate currencies) to 0.34 for high portfolio ones, while being significantly different from zero for the extreme portfolios. Essentially, a similar monotonic pattern in solvency risk exposure occurs in the sample of developed countries (the right-hand side of the table). Additionally, the IMS risk factor is capable of pricing the high-minus-low carry trade strategy (last row of Panel A).

Panel B of Table 3 reports results of standard cross-sectional asset pricing tests. GMM refers to the iterated SDF-GMM estimation and FMB stands for the Fama-MacBeth approach. Importantly, the IMS risk factor exhibits a positive and significant price of risk (λ_{IMS}) in most of the tests. The risk price is 17.19 for the full sample and 6.19 for the developed country sample, while both values are more than two standard errors away from zero (with GMM errors equal to 353 and 284 b.p., respectively), and are thus statistically significant. Overall, the results broadly indicate that the IMS factor is priced in the data and, alone can partially explain the cross-sectional variation in expected returns with the R^2 of 43% (in the full sample).[8]

Next, we consider the model with two risk factors, namely the dollar risk factor (DOL_{FX}) and the solvency risk factor (IMS). The dollar risk factor is highly correlated with the first principal component (0.98), captures common variation across portfolios and naturally can be interpreted as a currency-specific market level risk factor. Table 4 shows the estimates of factors loadings and cross sectional asset pricing results for the two factor model.

Insert Table 4 here

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[8] Additionally, since the factor is traded return, we check that the IMS risk factor is able to price itself and that the risk price of the IMS factor is roughly equal to the mean return of the IMS trading strategy. We find that this is indeed the case, thus no-arbitrage condition is satisfied. The relevant results are reported in Appendix B.

The upper panel of Table 4 presents time series regression statistics for the two factor model with carry trade portfolios as the test assets. The introduction of the dollar risk factor (DOL) results in smaller pricing errors, greater explanatory power, and an overall better fit for the model. Factor loadings on the DOL factor (the *level* factor) are all close to one in value, and statistically significant. Importantly, the IMS factor betas are essentially unchanged from those in a single factor model. Again, we observe a striking monotone increase in IMS factor betas when moving from portfolio 1 (low interest rate currencies) to portfolio 6 (high interest rate currencies), which precisely produces a large spread in portfolio's mean returns (see Table 2). The IMS betas for the first three portfolios are negative and uniformly statistically significant. The betas for the last two portfolios are positive. The individual pricing errors are low for all six regressions, while (mostly) being not statistically different from zero. Similar results are observed in the sample of developed countries (the right-hand side of the table); furthermore, alphas are not statistically significant either individually or jointly.

Next, we suggest that observed unconditional betas are driven by covariances between the log spot exchange rate change and the solvency risk. Essentially, we run time series regression of logarithmic exchange rate change for each portfolio on the DOL and IMS factors and find beta coefficients on the IMS factor are identical in magnitude, but opposite in sign to those in Table 4. As expected, conditional covariance between carry returns and solvency risk factor ($cov_t(r^i_{t+1}, IMS_{t+1})$) equates to negative covariance between the spot rate change and solvency risk ($cov_t(\Delta s^i_{t+1}, IMS_{t+1})$).[9] These findings indicate that low carry trade currencies (often referred as funding currencies) provide a hedge against solvency risk (in that they commove negatively with the IMS risk factor) as they appreciate during episodes of low solvency risk. Conversely, high carry trade currencies (investment currencies) payoff badly (depreciate) when the IMS factor exhibits low returns, expose investors to more risk, and thus demand a higher risk premium.

The bottom panel of Table 4 shows the results of cross-sectional asset pricing tests for the two factor model. We perform tests on carry trade excess returns in levels, not on logarithmic returns, and do not include the constant in the second stage of FMB procedure ($\lambda_0 = 0$) to avoid redundancy with the dollar risk factor. The price of risk of the IMS factor is once again large and highly statistically significant in both samples, being more than two standard errors away from zero.

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9 We report results of these regressions in the Appendix B.

The dollar risk factor is, however, on the borderline of statistical significance. Inclusion of the DOL factor results in low values for the square root of mean-squared errors (RMSE) for both iterated GMM and FMB procedures. At the same time, regardless of the subsample, the cross-sectional R^2 values are as high as 96%.

Overall, the results indicate that the model with DOL and IMS factors provides a good cross-sectional fit. The solvency-sorted and forward-discount-sorted portfolios are exposed to a risk of a common origin that spurs the heterogeneity in average excess returns. The results suggest that the IMS factor is an empirically powerful risk factor and explains the cross sectional variation in carry trade returns.

The question, however, is whether the IMS risk factor conveys any additional pricing information that is not captured by the existing currency-specific risk factors. This is important because the previously proposed HML_{FX} and VOL_{FX} factors are found to have a large cross-sectional pricing capacity and both, as well as IMS, are closely related to the second principal component. Next we address this concern.

5.2. Horse races between currency-specific factors

Thus far results indicate that the IMS factor is a powerful pricing factor and, being closely related to the second principal component, provides a high cross-sectional fit. Next, we challenge the pricing competency of the proposed factor against well-established currency based risk factors, namely, the high-minus-low carry trade returns (HML_{FX}) and the global FX volatility innovations risk factor (VOL_{FX}). First, we test factors by concurrently including them in the SDF together with the dollar risk factor. The result is two models where the SDF is linearly defined as in Lustig et al. (2011) (Panel A of Table 5) or in Menkhoff et al. (2012) (Panel B of Table 5), but enhanced with the IMS factor. Second, we test two modifications of the model comprising the DOL, the HML_{FX} and the IMS risk factors in which we sequentially orthogonalize the latter two factors against each other.

Insert Table 5 here

Importantly, the results of the iterated GMM procedure in Panels A and B indicate that the solvency risk factor (IMS) does not become attenuated when included in the model with the HML_{FX} and VOL_{FX}, respectively. In both panels all of the factors, including the IMS factor, are significantly priced with lambdas that are more than two standard errors away from zero, albeit the HML_{FX} dominates the solvency factor in significance. Notably, jointly specified SDFs improve on the cross-sectional explanatory power (R^2 of 97% and 92%) and the mean-squared errors (RMSE of 0.84 and 1.49) relative to any of the individual specifications.

Panels C and D report iterated GMM estimates for the SDFs enhanced with either the IMS or the HML_{FX} orthogonal components. Specifically, the IMS factor is orthogonalized with respect to the HML_{FX} in Panel C and, conversely, the HML_{FX} is orthogonalized with respect to the IMS in Panel D. As a result, in that test design we are able deconfound the effects of the slope factors and avert the statistical inference problems. First, the orthogonalized component of the solvency risk factor is priced (the GMM *t-stat*. of 3.70) in the joint SDF specification (Panel C). This indicates that the IMS factor has a supplementary pricing capacity over the HML_{FX} factor. The results presented in Panel D confirm that the orthogonalized constituent of the HML_{FX} lacks pricing power when jointly estimated with the IMS factor, while the latter is still significantly priced with the GMM t-statistic being 2.23.

Armed with the aforementioned evidence, we suggest that the IMS factor is not only significantly priced, but also captures additional information in the cross-section of carry trade returns that is unexplained by other currency-specific risk factors, namely the carry risk factor and the FX volatility. It is notable that, the HML_{FX} risk is clearly pervasive in the cross-section of currency carry trade returns and dominates in significance. However, the HML_{FX} is extracted directly from the forward-discount-sorted returns; and thus reflects the monotonic patterns of carry returns and is strongly related to the second principal component. Diversely, the IMS has to be estimated and, potentially, embodies measurement error problems, as solvency ratio is calculated using macroeconomic data. Nevertheless, the IMS factor is a competitive risk factor, seizes additional information ancillary to that commonly explained by prominent risk factors and, furthermore, improves on standard errors and explanatory power. Thus, it seems fair to conclude that the solvency risk is priced in the cross-section of currency carry trade returns.

6. Robustness

This section presents a battery of supplementary empirical findings on the robustness of the solvency risk-based explanation of carry trade returns under various modifications.

6.1 Asset pricing: Splitting Samples

First, we perform a conventional sample split test. Specifically, we split the full sample in halves so the left-hand panel of Table 6 covers the period from January 1985 to December 1999 and the right-hand panel presents results for the second half of the period (January 1999 to December 2014).

Insert Table 6 here

The outcomes of the half-splitting procedure applied to the sample validate a previous finding that solvency risk is priced in the cross-section, and the process also ensures that results are not unduly affected by outliers and are not prone to a mechanical returns-factor relationship. Regardless of the subsample, the beta loadings on the IMS risk factor increase when moving from a low to a high carry portfolio, albeit not as monotonically as corresponding estimates in Table 4. In addition, both individual and joint pricing errors are mainly low and not significant, while cross-sectional fit is high. Risk premia differ considerably in magnitudes and significance between the two subsamples, perhaps due to small sample period. Nevertheless, at least for the latter sample we find that the implied price of solvency risk estimates remains significant. Overall, the results are reassuring.

6.2 Asset pricing: Alternative solvency measure

To further assess robustness, we consider an alternative solvency measure: current account-to-export of goods and services (CAXGS), which is the ratio of the balance of the current account of the balance of payments for the year in question to the estimated aggregate of total exports of goods and services for that year (both quantities are converted to USD at an average annual FX rate). The portfolios sorting and empirical estimation procedures are similar to that shown in Table 4, with only exception that SDF is now linearly defined by the dollar risk factor (DOL) and the alternatively specified indebted-minus-solvent risk factor (further IMS_{CAXGS}). Not surprisingly, the IMS_{CAXGS} is positively, but not perfectly correlated, with the IMS with a correlation coefficient of .58 for the full sample.

Insert Table 7 here

Essentially, the results of the analysis based on the alternatively specified solvency measure (Table 7) are very similar to those reported in Table 4. The dispersion in the intercepts is now a little larger compared to the IMS results, consistent with the larger dispersion in the IMS_{CAXGS} beta loadings. Importantly, we still observe an increasing monotonic pattern in factor loadings (β_{CAXGS}^{IMS}) from the first to the last portfolio. Moreover, the solvency price of risk estimates, obtained by the abovementioned cross-sectional asset pricing tests, is positive and significant, with the magnitudes of the premia, in either sample, being like its counterparts in Table 4. Moreover, we find a cross-sectional R^2 of 86% and a square root of mean-squared errors of 1.92 for the full sample, indicating weaker explanatory capacity relative to IMS enhanced model, but still a high level of cross-sectional fit. Overall, the findings again suggest that investors require a risk premium on currencies that co-vary more with the solvency risk factor, as they are riskier and thus deliver higher excess returns. Hence, the solvency risk-based explanation of carry trade returns is robust against alternative measures of solvency.

6.3 Various portfolio formation dates

Thus far, in our empirical analysis we formed portfolios based on advance macroeconomic estimates available at the end of January. Although, such estimates are usually reliable and accurate projections of the actual values, they are often further revised and corrected. In order to ensure that constructed portfolios reflect an implementable trading strategy based on accurate macroeconomic estimates, we repeat the empirical analysis with portfolios sorted on the solvency measure data available on various dates. To do so, we run asset pricing tests with portfolios sorted on both the previous month's forward discount and previous year's macroeconomic data available to investors at the end of March (second estimates), June (third estimates) and December (final updates). The results of these estimations are reported in Table 8.

Insert Table 8 here

The results presented in Table 8 are analogous to those in Table 4, as we observe a similar monotonic increasing pattern in factor betas and significant risk prices for the information sets available on the aforementioned dates. Thus, it seems reasonable to conclude that the IMS risk factor is an empirically powerful risk factor and robust in the face of various formation dates. In this regard, the finding of the time-varying solvency risk premia are the source of the carry trade returns is further reinforced by the evidence from the solvency trading strategies' temporal implementable efficacy.

6.4 Other robustness tests

We also perform a number of supplementary robustness checks of various types. First, we ensure that main results of the paper do not originate from a small number of funding/investment currencies and are not sample-specific, but rather comprehensively robust in the cross-section of carry trade returns. For this purpose, we exclude currencies with the most of extreme portfolio hits on both sides from the dataset and re-estimate the model from Section 5.1. Further, we repeat the empirical analysis using various data samples identical to several prominent carry trade literature studies.

Second, we examine if the results of the paper are robust internationally. Daniel, Hodrick, and Lu (2015) argue that carry trade performance and risk characteristics depend on the choice of funding (base) currency. In order to demonstrate that our findings are robust in the face of an alternative funding currency, we take the Japanese investor point of view and consider the Japanese Yen as a base currency, and repeat the empirical analysis.

Third, we consider another alternative proxy for solvency risk - the composite financial risk measure - that essentially is the aggregate estimate of country's financial competency indicators, such as, alternatively specified external debt service capacity, exchange rate stability, and the country's international liquidity, converted into scores.

Fourth, to guard against the known shortcomings of portfolio construction, such as the possibility of security-idiosyncratic information loss (Litzenberger and

Ramaswamy, 1979), we follow the prescriptions of Lo and MacKinlay (1990) and perform currency-level asset pricing tests.[10] Specifically, we test the pricing ability of the solvency risk factor using the sample of individual currencies as test assets.

Although ultimately the results of a few tests deviate from the central findings of the paper, principally, the robustness checks confirm that the solvency risk is priced in these cross sections of carry trade returns. In most of the tests the solvency risk factor posts a similar asset pricing estimates to the counterpart's values in the benchmark specifications of the previous sections. In the interest of conciseness, we provide the detailed discussion on the aforementioned robustness procedures and document the corresponding empirical results in the supplementary Internet Appendix.

7. Conclusions

Currency carry trade profitability emerges from exploitable failures of foreign exchange parity relations, that is, currencies traded on a forward premium are apt to appreciation, contrarily to the UIP predicted depreciation. There is abundant evidence suggesting the existence of common determinants of inter-temporal variations in carry trade returns, which lends support to a rationalization of strategy returns as a compensation for common risk. This implies that there are persistent differences in global risk exposures across countries and this heterogeneity is the source of carry trade profitability. This paper sheds light on a possible origin of such heterogeneity and offers a new risk-based explanation for currency risk premia.

This study builds on the classic APT approach in explaining the cross-section of carry trade returns and identifies persistent heterogeneity in loadings on a common component across countries' pricing kernels. We argue that currency carry trade returns can be rationalized by the time-varying risk premia that originate from the sovereign solvency risk. Specifically, we suggest that solvency risk maintains the substantial power to explain the cross-section of carry trade returns. The solvency sorted and forward discount sorted portfolios exposed to a risk of a common origin that spur on the heterogeneity in average excess returns. In line with that, heterogeneous risk exposures of currencies reveal that low carry

[10] For more evidence on importance of security-level tests see, e.g. Brennan, Chordia, and Subrahmanyam (1998), Avramov and Chordia (2006) and the references therein.

trade currencies serve as hedge against solvency risk, while high carry trade currencies depreciate, exposing investors to more risk and requiring a higher risk premium. Hinging on classic asset pricing procedures we introduce a new, solvency-based, risk factor and show that its covariance with returns accounts for almost all cross-sectional variation across portfolios. The factor is empirically powerful and withstands a battery of different robustness checks.

The cumulative evidence points to the solvency risk factor as a persuasive tool for pricing the cross-section of carry returns. Accordingly, the overall results offer a new interpretation of currency risk premia, and, *inter alia*, an unambiguous risk-based perspective on the forward premium puzzle.

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Table 1: Developed currencies and solvency measures

Currency	Forward discount	Excess Return	Solvency Measure
GBP	0.16	0.24	16.17
CHF	-0.13	0.14	7.44
JPY	-0.21	0.00	16.52
CAD	0.07	0.11	14.68
AUD	0.27	0.27	62.10
NZD	0.36	0.50	76.86
SEK	0.13	0.17	39.47
NOK	0.18	0.23	6.64
DKK	0.08	0.25	22.47
EUR/DEM	-0.02	0.35	16.39

Note: Table presents descriptive statistics for average monthly forward discounts, average monthly excess returns (without bid-ask spread) and average foreign debt to GDP ratio (solvency measure) for the ten most traded carry trade currencies. Time period spans from 01/1985 to 12/2014. Pre-1999 data on German Mark is merged with post-1999 data on Euro.

Table 2: Portfolios sorted on forward discount and solvency measure

Portfolio	1	2	3	4	5	6	1	2	3	4
	Panel A: Portfolios Sorted on Forward Discounts									
	All Countries						Developed countries			
	Spot change: Δs^i						Δs^i			
Mean	-2.34	-1.74	-2.05	-0.51	1.07	3.07	-2.37	-2.47	0.07	-1.28
SD	7.79	7.07	8.16	8.08	9.24	9.68	9.89	8.78	8.73	11.25
	Forward discount: $f^i - s^i$						$f^i - s^i$			
Mean	-2.07	-0.59	0.45	2.10	3.34	13.09	-1.96	0.18	1.89	4.23
SD	3.16	0.49	1.45	0.56	1.49	3.96	0.69	0.50	0.69	1.00
	Excess returns: r^i						r^i			
Mean	0.27	1.15	2.50	2.62	2.27	10.02	0.42	2.65	1.81	5.51
SD	8.26	6.95	8.21	7.94	9.08	10.59	9.94	8.81	8.79	11.35
SR	0.03	0.17	0.30	0.33	0.25	0.95	0.04	0.30	0.21	0.49
	Panel B: Portfolios Sorted on Solvency Measure									
	All Countries						Developed countries			
	Spot change: Δs^i						Δs^i			
Mean	-1.94	-0.85	-0.10	-0.31	-0.67	1.92	-2.36	-0.79	-0.93	-1.95
SD	9.44	7.92	6.38	6.66	8.44	10.75	10.50	8.47	8.87	10.56
	Forward discount: $f^i - s^i$						$f^i - s^i$			
Mean	0.25	1.82	2.89	3.23	3.64	6.23	-0.77	1.25	1.58	3.01
SD	0.80	0.73	0.84	1.63	3.05	4.07	0.68	0.69	0.95	0.70
	Excess returns: r^i						r^i			
Mean	2.18	2.66	2.99	3.54	4.30	4.31	1.59	2.04	2.51	4.96
SD	9.43	7.95	6.45	7.03	8.87	11.36	10.54	8.52	8.98	10.66
SR	0.23	0.34	0.46	0.50	0.49	0.38	0.15	0.24	0.28	0.47

Note: The table reports descriptive statistics (annualized) for portfolios sorted on forward discounts (carry trade) and on solvency measure (foreign debt to GDP) for the full sample (left side) and developed countries (right side). Mean and standard deviation are reported for spot exchange rate changes, forward discounts and excess returns for each portfolio. Returns are monthly and updated on the annual basis based on previous year values of solvency measure and current forward discounts. Returns do not take into account bid-ask spreads. The sample period is January 1985 - December 2014.

Table 3. Asset Pricing: IMS risk factor

Panel A. Factor Betas								
	All Countries				Developed Countries			
Portfolio	α	β_{IMS}	adj.-R^2	J	α	β_{IMS}	adj.-R^2	J
1	1.05	-0.16	3.37		2.59	-0.44	16.70	
	(0.53)	(-2.20)			(1.35)	(-6.00)		
2	1.73	-0.12	2.71		3.68	-0.17	3.10	
	(1.20)	(-1.89)			(1.79)	(-2.41)		
3	3.09	-0.09	1.11		2.39	-0.05	0.22	
	(1.50)	(-1.16)			(1.22)	(-0.65)		
4	2.94	0.00	0.00		5.35	0.21	3.08	
	(1.54)	(0.03)			(2.27)	(1.87)		
5	2.63	0.03	0.11					
	(1.37)	(0.34)						
6	9.75	0.34	10.14					
	(3.81)	(2.67)						
J-test				32.82				8.71
(p-value)				0.00				0.07
High-Low	8.70	0.50	22.11		2.75	0.66	31.73	
	(3.82)	(5.61)			(1.59)	(7.36)		

Panel B. Risk Prices							
	All Countries				Developed Countries		
GMM	IMS	R^2	RMSE		IMS	R^2	RMSE
λ	17.91	42.97	3.64		6.19	12.44	3.86
[s.e.]	[3.53]				[2.84]		
FMB	IMS	R^2	RMSE		IMS	R^2	RMSE
λ	19.17	43.16	3.64		1.13	0.66	3.62
[NW]	[3.63]				[3.29]		
[Sh.]	[3.64]				[3.31]		

Note: The table reports time-series regressions and cross-sectional asset pricing test results for the linear factor model based on a single IMS (indebted-minus-solvent) factor. The IMS factor is based on solvency measure (foreign debt-to-GDP) sorts. Returns are monthly and portfolios are rebalanced on an annual basis. Results for the sample of all countries are presented in the left-hand panel and for developed countries in the right-hand panel. Panel A reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept and the IMS risk factor for each forward discount sorted portfolio and the high-minus-low carry trade portfolio. These estimates are: the constant (α) (annualized and in percentage points); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. The J-test of pricing errors ($\alpha' V_{\alpha}^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the IMS factor price of risk (λ), the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e.] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 to December 2014.

Table 4. Asset Pricing: Two factor model

Panel A. Factor Betas										
	All Countries					Developed Countries				
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2	J	α	β_{DOL}	β_{IMS}	adj.-R^2	J
1	-2.18	0.91	-0.16	65.94		-0.65	0.92	-0.34	76.34	
	(-1.77)	(12.74)	(-4.16)			(-0.62)	(18.05)	(-8.09)		
2	-1.25	0.85	-0.12	78.52		0.40	0.94	-0.06	81.39	
	(-1.80)	(18.37)	(-5.84)			(0.66)	(29.09)	(-1.89)		
3	-0.49	1.01	-0.09	79.28		-0.95	0.95	0.06	82.49	
	(-0.67)	(23.29)	(-2.39)			(-1.22)	(31.44)	(1.63)		
4	-0.54	0.98	0.00	78.98		1.20	1.19	0.35	79.45	
	(-0.69)	(18.21)	(0.08)			(1.31)	(25.11)	(6.79)		
5	-1.34	1.12	0.03	78.79						
	(-1.33)	(26.26)	(0.63)							
6	5.80	1.12	0.34	66.79						
	(3.83)	(16.17)	(5.40)							
J-test					24.48					3.87
(p-value)					(0.00)					(0.42)

Panel B. Risk Prices								
	All Countries				Developed Countries			
GMM	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.49	16.94	96.29	0.93	3.10	6.03	96.88	0.64
[s.e.]	[1.26]	[3.38]			[1.48]	[2.82]		
FMB	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.49	17.71	96.36	0.92	3.10	6.09	96.88	0.64
[NW]	[1.33]	[3.59]			[1.53]	[2.87]		
[Sh.]	[1.35]	[3.61]			[1.55]	[2.91]		

Note: The table set up is identical to that in Table 3 with the only exception being that the results are reported for time-series regressions and cross-sectional asset pricing tests based on the two factor model. These factors are: the dollar risk factor (DOL) from Lustig, Roussanov, and Verdelhan (2011) and the IMS (indebted-minus-solvent) factor. The IMS factor is based on a solvency measure (foreign debt-to-GDP) sorts. Returns are monthly and portfolios are rebalanced on an annual basis. Results for the sample of all countries are presented in the left panel and for developed countries in the right panel. Panel A reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the IMS factor for each forward discount sorted portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. The J-test of pricing errors ($\alpha' V_\alpha^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e] are reported in brackets and based on Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 to December 2014.

Table 5. Asset pricing: *IMS* vs. HML_{FX} and VOL_{FX} risk factors

Panel A. Lustig et. al (2011) model and IMS					Panel B. Menkhoff et. al (2012) model and IMS				
Factor	λ	[s.e.]	R^2	RMSE	Factor	λ	[s.e.]	R^2	RMSE
DOL	3.49	[0.65]	96.96	0.84	*DOL*	3.88	[1.35]	91.97	1.49
HML_{FX}	10.18	[1.54]			VOL_{FX}	1.12	[0.40]		
IMS	9.95	[2.69]			*IMS*	11.72	[3.15]		
Panel C. IMS (orth.) and HML					Panel D. IMS and HML(orth.)				
Factor	λ	[s.e.]	R^2	RMSE	Factor	λ	[s.e.]	R^2	RMSE
DOL	3.50	[0.97]	96.96	0.84	*DOL*	3.49	[0.27]	96.96	0.84
HML_{FX}	10.18	[1.04]			$HML_{FX}^{Orth.}$	5.22	[3.39]		
$IMS^{Orth.}$	5.41	[0.28]			*IMS*	9.95	[4.49]		

Note: The table reports the results of the iterated GMM procedure where SDF is linearly defined as in Lustig, Roussanov, and Verdelhan (2011) (Panel A) or in Menkhoff, Sarno, Schmeling, and Schrimpf (2012) (Panel B), but enhanced with the various modifications of the IMS factor. Returns of test assets (six carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL, the *IMS* factors and either HML_{FX} (Panels A, C and D) or VOL_{FX}(Panel B), the cross-sectional R^2 and the square root of mean-squared errors (RMSE). In Panels C the *IMS* factor is orthogonalized w.r.t. HML_{FX}, and in Panel D we orthogonalize HML_{FX} w.r.t. *IMS.* The GMM standard errors [s.e] are reported in brackets. The sample period is January 1985 to December 2014.

Table 6. Asset Pricing: Sample split

Panel A. Factor Betas										
	First half					Second half				
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2	J	α	β_{DOL}	β_{IMS}	adj.-R^2	J
1	-2.90	0.94	-0.17	63.72		-1.61	0.86	-0.10	70.50	
	(-1.45)	(8.64)	(-3.88)			(-1.19)	(12.13)	(-2.39)		
2	-0.60	0.87	-0.12	79.72		-1.97	0.81	-0.10	76.73	
	(-0.58)	(13.24)	(-5.60)			(-2.07)	(14.07)	(-3.73)		
3	0.59	0.94	-0.11	75.14		-1.73	1.08	-0.06	84.93	
	(0.50)	(17.06)	(-2.54)			(-2.06)	(19.52)	(-1.49)		
4	0.56	0.88	-0.01	71.49		-1.62	1.11	-0.03	87.57	
	(0.46)	(12.12)	(-0.37)			(-2.24)	(18.53)	(-1.07)		
5	0.25	1.17	0.07	79.22		-2.66	1.12	-0.05	79.36	
	(0.19)	(17.26)	(1.13)			(-2.05)	(20.08)	(-0.61)		
6	2.10	1.20	0.35	69.23		9.59	1.03	0.34	65.11	
	(1.32)	(14.22)	(5.13)			(3.98)	(9.56)	(3.47)		
J-test					4.41					26.01
(p-value)					(0.62)					(0.00)

Panel B. Risk Prices								
	First half				Second half			
GMM	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.08	6.88	92.91	0.95	3.87	27.12	96.75	1.17
[s.e.]	[1.86]	[4.86]			[1.61]	[3.82]		
FMB	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.08	6.88	92.91	0.95	3.85	32.34	98.31	0.85
[NW]	[1.94]	[5.27]			[1.82]	[4.95]		
[Sh.]	[1.97]	[5.27]			[1.86]	[5.17]		

Note: The table set up is identical to the one in Table 4 with the only exception being that results of time-series regressions and cross-sectional asset pricing tests are reported for the 50/50 time split of the full sample. Results for the first half of the sample (January 1985 to December 1999) are presented in the left panel and for the second half (January 1999 to December 2014) in the right panel. Returns are monthly and portfolios are rebalanced on an annual basis. Panel A reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the IMS factor for each carry trade portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. The J-test of pricing errors ($\alpha' V_\alpha^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression.

Table 7. Asset Pricing: Alternative measure of solvency

Panel A. Factor Betas										
	All Countries					Developed Countries				
Portfolio	α	β_{DOL}	β_{CAXGS}^{IMS}	adj.-R^2		α	β_{DOL}	β_{CAXGS}^{IMS}	adj.-R^2	
1	-2.27	0.90	-0.24	70.35		-0.68	0.94	-0.35	81.09	
	(-1.94)	(13.37)	(-6.36)			(-0.71)	(19.93)	(-10.16)		
2	-1.63	0.85	-0.09	77.11		0.42	0.94	-0.07	81.81	
	(-2.20)	(17.31)	(-3.78)			(0.68)	(27.30)	(-2.56)		
3	-0.86	1.02	-0.05	78.25		-0.94	0.95	0.06	82.82	
	(-1.04)	(24.00)	(-1.66)			(-1.23)	(31.30)	(1.80)		
4	-0.74	0.99	0.01	78.68		1.20	1.17	0.37	84.03	
	(-0.94)	(18.11)	(0.31)			(1.34)	(24.50)	(7.17)		
5	-1.75	1.19	0.10	77.92						
	(-1.49)	(23.77)	(2.26)							
6	7.25	1.05	0.28	58.33						
	(3.77)	(13.15)	(4.69)							
J-test					33.27					4.32
(p-value)					(0.00)					(0.36)

Panel B. Risk Prices								
	All Countries				Developed Countries			
GMM	DOL	IMS_{CAXGS}	R^2	RMSE	DOL	IMS_{CAXGS}	R^2	RMSE
λ	3.64	17.81	86.46	1.92	3.10	5.89	96.89	0.64
[s.e.]	[1.18]	[3.43]			[1.47]	[2.65]		
FMB	DOL	IMS_{CAXGS}	R^2	RMSE	DOL	IMS_{CAXGS}	R^2	RMSE
λ	3.61	18.40	86.49	1.92	3.10	5.94	96.89	0.64
[NW]	[1.31]	[3.72]			[1.53]	[2.74]		
[Sh.]	[1.34]	[3.73]			[1.55]	[2.76]		

Note: The table reports time series regressions and cross-sectional asset pricing tests results with SDF linearly defined by the dollar risk factor (DOL) and the alternatively specified indebted-minus-solvent risk factor (CAXGS). The CAXGS factor is of a similar nature to the IMS factor, but is based on an alternative solvency measure, which is current account-to-export of goods and services. As before, returns are monthly and portfolios are rebalanced on an annual basis. Results for the sample of all countries are presented in the left panel and for developed countries in the right panel. Panel A reports estimates of monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the CAXGS factor for each carry portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the CAXGS factor loading (β_{CAXGS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. A J-test of pricing errors ($\alpha' V_\alpha^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the CAXGS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 - December 2014.

Table 8. Asset Pricing: Various information sets

	Factor Betas						Risk Prices	
Set A (updated 03/31)								
Portfolio	1	2	3	4	5	6		GMM
α	-2,31	-1,72	-0,04	0,75	-1,82	5,15	λ_{DOL}	3,82
	(-1.83)	(-2.05)	(-0.07)	(1.02)	(-1.48)	(3.51)		[1.31]
β_{DOL}	0,80	0,94	0,99	1,02	1,19	1,07	λ_{IMS}	14,73
	(9.35)	(16.78)	(24.97)	(23.19)	(23.36)	(18.06)		[3.49]
β_{IMS}	-0,21	-0,08	-0,06	-0,05	0,03	0,36	J-test	52,15
	(-3.77)	(-2.28)	(-2.39)	(-0.86)	(0.85)	(6.15)		(0.00)
adj.-R^2	58,68	74,96	84,30	79,31	78,33	67,76	R^2	92,94
Set B (updated 06/30)								
Portfolio	1	2	3	4	5	6		GMM
α	-2,00	-1,23	-0,57	-0,63	0,16	4,27	λ_{DOL}	3,50
	(-1.90)	(-1.65)	(-0.89)	(-0.89)	(0.16)	(3.23)		[1.33]
β_{DOL}	0,89	0,84	1,04	1,02	1,06	1,16	λ_{IMS}	9,92
	(11.22)	(16.94)	(23.32)	(18.71)	18.27)	(23.01)		[2.65]
β_{IMS}	-0,24	-0,11	-0,05	-0,01	-0,05	0,47	J-test	40,45
	(-6.65)	(-3.60)	(-1.24)	(-0.38)	(-1.52)	(8.23)		(0.00)
adj.-R^2	69,05	74,82	82,77	81,57	78,01	74,20	R^2	98,98
Set C (updated 12/31)								
Portfolio	1	2	3	4	5	6		GMM
α	-2,09	-1,06	-0,30	-0,29	-1,42	5,12	λ_{DOL}	3,21
	(-1.73)	(-1.48)	(-0.39)	(-0.36)	(-1.37)	(3.29)		[1.32]
β_{DOL}	0,89	0,83	1,03	1,00	1,12	1,13	λ_{IMS}	13,94
	(11.32)	(17.51)	(23.19)	(17.33)	(24.75)	(14.32)		[2.96]
β_{IMS}	-0,20	-0,14	-0,11	-0,02	0,07	0,41	J-test	55,84
	(-4.22)	(-5.65)	(-3.06)	(-0.62)	(1.23)	(5.43)		(0.00)
adj.-R^2	64,50	77,46	79,13	78,80	78,77	67,73	R^2	94,57

Note: The table reports time series regressions and cross-sectional asset pricing tests results with SDF linearly defined by the dollar risk factor (DOL) and the indebted-minus-solvent risk factor (IMS). As before, returns are monthly and portfolios are rebalanced on an annual basis, but using the macro data for previous year that is available at the end of March (Set A), June (Set B) and December (Set C) of the current year. Carry trade portfolios are updated at the end of each of the above mentioned periods using the previous month's forward discounts. Results for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the IMS factor for each carry portfolio are presented in the left-hand panel. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. The right-hand panel reports results of the iterated GMM. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). J-test of pricing errors ($\alpha' V_{\alpha}^{-1} \alpha$) tests if intercepts are jointly equal to zero. We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2. The standard errors [s.e] are reported in brackets and based on Newey-West [NW] approach with optimal lags and p-values for the J-test are in parentheses. A constant is not included in the second stage of FMB regression.

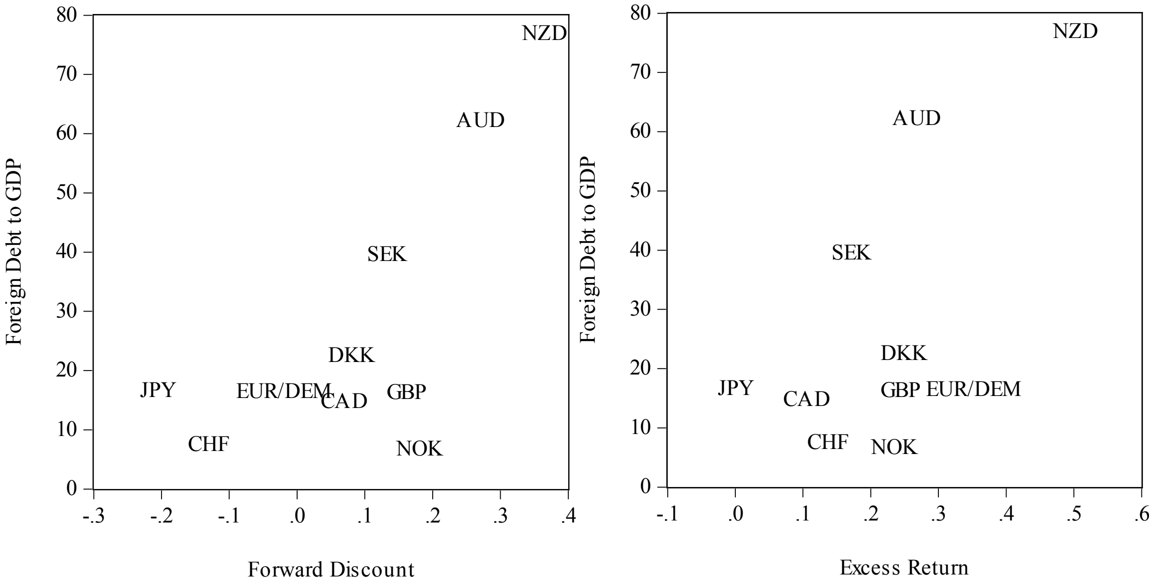

Figure 1. Developed countries and Solvency measure.

Note: The figure plots forward discount and excess return for each country in the developed sample against the corresponding solvency measure. The sample period is January 1985 to -December 2014. Pre-1999 data on the German Mark is merged with post-1999 data on the Euro. The solvency measure is defined by the foreign debt to GDP ratio.

Appendix

In the Appendix, we present the detailed derivation of UIP disturbed by the solvency risk premia (Appendix A) and additional results (Appendix B). In Appendix A, we describe the basic structure of the world economy and briefly remark on notation. Further, we outline the representative household preferences, followed by UIP derivations. Finally, in Appendix B we present the results of asset pricing tests from Section 4 using solvency-measure-sorted portfolios (Table B1), and DOL and IMS factor loadings on log currency returns (Table B2).

Appendix A

The Setup

Consider two economies populated with consumers and a government (central bank). Households are assumed to be identical in both economies and consume a CES bundle of domestic and imported products. Governments are allowed to borrow from the international capital market and consumers may borrow from and lend to the government. The only financial instrument in the world is a traded bond. Governments can issue both domestic and foreign currency denominated one-period bonds, paying an interest rate of i_t and i_t^*, respectively. In the following model, we mainly focus on one economy and its interaction with the second economy, and with the world as a whole. Thus, we specify variables for the economy of interest (domestic) without any subscripts, while using a superscript asterisk when referring to the foreign economy.

UIP with the disturbance term

The households in the domestic economy are maximizing the utility function, which is given by the following constant relative risk aversion function of consumption:

$$E_t \sum_{k=0}^{\infty} \beta^k \left\{\frac{C_{t+k}^{1-\varepsilon}}{1-\varepsilon}\right\}, \qquad \text{(A-1)}$$

where E_t stands for the mathematical expectation conditional upon complete information related to period t and earlier. The composite consumption index (C_t) is given by standard CES functions of domestic and imported goods. The subjective intertemporal discount factor is denoted by β (0< β<1), ε is the constant relative risk aversion coefficients for consumption.

A household possesses net stocks of one-period domestic (D) and foreign (F) currency bonds, receives interest (i), and spends on consumption and taxes (Tax). Its period t nominal budget constraint is:

$$P_tC_t + D_t + S_tF_t = (1 + i_{t-1})D_{t-1} + (1 + i^*_{t-1})S_tF_{t-1} - Tax_t, \qquad \text{(A-2)}$$

where P_t is price index of the consumption bundle, Tax_t are lump sum taxes net of transfers payable in period t, and S_t is the nominal exchange rate. Next we derive the real budget constraint by introducing equation (3) in equation (A-2) and dividing by the price index of domestic goods (P^d_t):

$$p_tC_t + d_t + e_tf_t = (1 + i_{t-1})\frac{d_{t-1}}{\pi_t} + (1 + i^*_{t-1})v(\gamma_{t-1})e_t\frac{f_{t-1}}{\pi^*_t} - tax_t, \qquad \text{(A-3)}$$

where

$$p_t \equiv \frac{P_t}{P^d_t},\quad d_t \equiv \frac{D_t}{P^d_t},\quad f_t \equiv \frac{F_t}{P^*_t},\quad e_t \equiv \frac{S_tP^*_t}{P^d_t},\quad \pi_t \equiv \frac{P^d_t}{P^d_{t-1}},\quad \pi^*_t \equiv \frac{P^*_t}{P^*_{t-1}},\quad \gamma_t \equiv \frac{e_tf_t}{\Upsilon_t},$$

are the relative price of consumption goods, the real stock of domestic and foreign bond, the real exchange rate, the gross rates of domestic and foreign inflation, and the foreign debt to economy's earning capacity ratio, respectively. Moreover, tax_t is the real lump sum tax, and P^*_t is the price index of foreign goods. As noted earlier, each household seeks to maximize it lifetime expected utility (A-1). To do so it chooses the optimal strategy of $\{C_{t+k}, d_{t+k}, f_{t+k}\}^{\infty}_{k=0}$ subject to its real budget constraint (A-3) and initial values of d_0, and f_0. Lagrangian with a no-Ponzi game condition, where $\lim_{t\to\infty} \beta^t d_t = 0$, is presented by:

$$E_t \sum_{k=0}^{\infty} \beta^k \left\{ \frac{C_{t+k}^{1-\varepsilon}}{1-\varepsilon} + \lambda_{t+k} \left\{ (1+i_{t-1+k}) \frac{d_{t-1+k}}{\pi_t+k} + (1+i_{t-1+k}^*) v(\gamma_{t-1+k}) e_{t+k} \frac{f_{t-1+k}}{\pi_{t+k}^*} - tax_{t+k} - p_{t+k} C_{t+k} - d_{t+k} - e_{t+k} f_{t+k} \right\} \right\}, \tag{A-4}$$

First order conditions for C_t, d_t, f_t are:

$$C_t: \quad C_t^{-\varepsilon} = \lambda_t p_t \,, \tag{A-5}$$

$$d_t: \quad 1 = \beta(1+i_t) E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}} \right), \tag{A-6}$$

$$f_t: \quad 1 = \beta(1+i_t^*) v(\gamma_t) E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{e_{t+1}}{e_t} \frac{1}{\pi_{t+1}^*} \right), \tag{A-7}$$

where equations (A-6) and (A-7) are corresponding classic Euler conditions for d_t and f_t.

Next by definition the real exchange rate change is given by:

$$\frac{e_{t+1}}{e_t} = \frac{S_{t+1}}{S_t} \frac{\pi_{t+1}^*}{\pi_{t+1}}, \tag{A-8}$$

Henceforth, we define a nominal change in the domestic currency exchange rate as δ, where $\delta_{t+1} \equiv S_{t+1}/S_t$. Multiplying both sides of (A-6) by δ_{t+1} and substituting (A-8) in (A-7) we have:

$$E_t(\delta_{t+1}) = \beta(1+i_t) E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{\delta_{t+1}}{\pi_{t+1}} \right), \tag{A-9}$$

$$1 = \beta(1+i_t^*) v(\gamma_t) E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{\delta_{t+1}}{\pi_{t+1}} \right), \tag{A-10}$$

Combining equations (A-9) and (A-10) we have solvency risk-adjusted UIP:

$$(1 + i_t) = (1 + i_t^*)v(\gamma_t)E_t(\delta_{t+1}) \,. \quad \text{(A-11)}$$

Appendix B

Table B1. Asset Pricing: Solvency sorted test assets

Panel A. Factor Betas										
	All Countries					Developed Countries				
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2	J	α	β_{DOL}	β_{IMS}	adj.-R^2	J
1	-0.68	1.17	-0.31	91.51		0.17	1.10	-0.37	93.71	
	(-1.11)	(42.17)	(-13.48)			(0.33)	(41.43)	(-18.03)		
2	-0.04	0.93	-0.10	75.28		-0.32	0.86	0.00	75.33	
	(-0.04)	(15.86)	(-4.00)			(-0.36)	(18.74)	(-0.09)		
3	-0.40	0.76	-0.03	73.81		0.62	0.88	-0.11	70.22	
	(-0.60)	(26.07)	(-1.43)			(0.72)	(19.81)	(-2.77)		
4	1.95	0.82	-0.02	71.68		-0.25	1.10	0.63	94.03	
	(2.47)	(19.40)	(-0.62)			(-0.48)	(45.88)	(31.29)		
5	1.06	1.08	-0.07	79.83						
	(0.94)	(22.15)	(-2.24)							
6	-0.97	1.16	0.70	94.11						
	(-1.59)	(42.56)	(30.69)							
J-test					30.97					34.55
(p-value)					(0.00)					(0.00)

Panel B. Risk Prices								
	All Countries				Developed Countries			
GMM	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.91	2.58	92.33	1.07	3.21	3.42	99.11	0.33
s.e.	[1.32]	[1.62]			[1.54]	[1.70]		
FMB	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE
λ	3.65	1.64	93.51	0.99	3.15	3.26	99.17	0.32
[NW]	[1.33]	[1.88]			[1.54]	[1.73]		
(Sh)	[1.36]	[1.89]			[1.56]	[1.75]		
Mean	**3.53**	**2.64**			**3.08**	**3.81**		

Note: The table reports time series regressions and cross-sectional asset pricing tests results for the two factor model using a solvency measure (foreign debt to GDP) sorted portfolios as test assets. The risk factors are: the dollar risk factor (DOL) from Lustig, Roussanov, and Verdelhan (2011) and the IMS (indebted-minus-solvent) factor. The IMS factor is based on solvency measure sorts. Returns are monthly and portfolios are rebalanced on an annual basis. Results for the sample of all countries are presented in the left panel and for developed countries in the right panel. Panel A reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept and the IMS risk factor for each solvency sorted portfolio. These estimates are: the constant (α); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. A J-test of pricing errors ($\alpha' V_{\alpha}^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the IMS factor price of risk (λ), the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e.] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 - December 2014.

Table B2. The log currency returns and the risk factors

Panel A. Factor Betas								
	All Countries				Developed Countries			
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2	α	β_{DOL}	β_{IMS}	adj.-R^2
1	0.00	-0.85	0.16	67.67	-0.00	-0.91	0.34	76.06
	(0.01)	(-12.98)	(4.28)		(-1.14)	(-16.80)	(8.14)	
2	0.00	-0.84	0.13	78.31	-0.00	-0.93	0.07	81.06
	(0.91)	(-18.16)	(-5.89)		(-0.43)	(-29.04)	(2.00)	
3	0.00	-1.00	0.08	80.40	0.00	-0.95	-0.06	81.99
	(1.34)	(-21.80)	(2.43)		(-0.95)	(-30.25)	(-1.64)	
4	0.00	-0.98	0.00	78.29	0.00	-1.17	-0.35	78.33
	(3.10)	(-17.70)	(0.07)		(2.68)	(-22.30)	(-6.63)	
5	0.00	-1.12	-0.02	78.10				
	(4.48)	(-0.02)	(-0.43)					
6	0.01	-1.02	-0.24	65.12				
	(5.57)	(14.04)	(-3.11)					

Note: The table reports estimates for monthly time-series regressions of the logarithmic change in the spot exchange rate for each carry trade portfolio on the currency-specific risk factors, namely, the dollar risk factor (DOL) from Lustig, Roussanov, and Verdelhan (2011) and the IMS (indebted-minus-solvent) factor. The IMS factor is based on the solvency measure (foreign debt to GDP) sorts. Returns are monthly and portfolios are rebalanced on an annual basis. Results for the sample of all countries are presented in the left panel and for developed countries in the right panel. These estimates are: the constant (α); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. A J-test of pricing errors ($\alpha' V_{\alpha}^{-1} \alpha$) tests if intercepts are jointly equal to zero. The sample period is January 1985 - December 2014.

The Internet Appendix to accompany

Solvency Risk Premia and the Carry Trades

By Vitaly Orlov

Table A1. Asset Pricing: Adjusted currency samples

Panel A. Factor Betas										
	All Countries (minus 6 currencies)					Developed Countries (minus 2 currencies)				
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2	J	α	β_{DOL}	β_{IMS}	adj.-R^2	J
1	-2.05	0.89	-0.16	58.28		-1.28	0.90	-0.12	66.49	
	(-1.48)	(10.40)	(-3.64)			(-1.08)	(14.27)	(-1.77)		
2	-1.48	0.94	-0.09	68.91		0.38	0.98	0.00	82.94	
	(-1.57)	(14.39)	(-2.35)			(0.54)	(28.58)	(0.03)		
3	-0.53	0.98	-0.05	74.16		-0.63	0.99	0.01	80.42	
	(-0.60)	(17.90)	(-1.49)			(-0.70)	(24.64)	(0.26)		
4	0.174	0.95	-0.06	76.27		1.96	1.12	0.11	78.93	
	(0.22)	(17.10)	(-2.16)			(2.24)	(25.75)	(2.18)		
5	-2.37	1.19	0.06	73.32						
	(-1.83)	(20.51)	(0.86)							
6	6.25	1.06	0.30	60.77						
	(3.54)	(13.72)	(3.63)							
J-test					62.64					45.35
(p-value)					(0.00)					(0.00)

Panel B. Risk Prices									
GMM	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE	
λ	4.00	18.41	90.56	1.61	3.07	15.61	97.81	0.51	
s.e.	[1.30]	[3.66]			[1.50]	[7.63]			
FMB	DOL	IMS	R^2	RMSE	DOL	IMS	R^2	RMSE	
λ	3.69	21.22	91.48	1.61	3.07	15.61	97.81	0.51	
[NW]	[1.31]	[4.04]			[1.50]	[7.28]			
(Sh)	[1.34]	[4.11]			[1.52]	[7.32]			

Note: The table set up is identical to the one in Table 4 of the main text with the only exception being that currencies with the largest number of extreme portfolio inclusions are excluded from the sample. We exclude three currencies that most frequently appear in portfolios 1 or 6 from the full sample (6 currencies in total) and a currency with largest hits of portfolios 1 or 4 from developed sample (2 currencies in total). Time-series regressions and cross-sectional asset pricing tests are based on the two factor model: the dollar risk factor (DOL) from Lustig, Roussanov, and Verdelhan (2011) and the IMS (indebted-minus-solvent) factor. The IMS factor is based on solvency measure (foreign debt-to-GDP) sorts. Returns are monthly and portfolios are rebalanced on an annual basis. Results for the adjusted sample of all countries are presented in the left-hand panel and for developed countries (adjusted) in the right-hand panel. Panel A reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the IMS factor for each forward discount sorted portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. The J-test of pricing errors ($\alpha' V_{\alpha}^{-1}\alpha$) tests if intercepts are jointly equal to zero. Panel B reports cross-sectional asset pricing tests results, namely iterated GMM and FMB. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE) for each procedure. The standard errors [s.e] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 - December 2014.

Table A2. Asset Pricing: Alternative funding currency – Japanese Yen

Panel A. Carry trade portfolios with the Japanese Yen as base currency				
Portfolio	1	2	3	4
Mean	-1.36	-0.27	-0.87	2.65
SD	10.94	11.25	11.96	12.52
Panel B. Factor Betas				
Portfolio	α	β_{DOL}	β_{IMS}	adj.-R^2
1	-1.00	0.93	-0.13	85.19
	(-1.20)	(36.33)	(-3.96)	
2	-0.22	0.99	-0.03	90.90
	(-0.37)	(46.77)	(-0.77)	
3	-1.14	1.03	0.08	89.00
	(-1.47)	(43.67)	(2.15)	
4	2.35	1.05	0.09	84.97
	(2.76)	(30.96)	(1.79)	
Panel C. Risk Prices				
	DOL	IMS	R^2	RMSE
GMM λ	0.72	11.56	52.45	1.22
s.e.	[1.96]	[5.74]		
FMB λ	0.72	11.56	52.45	1.22
[NW]	[1.96]	[5.70]		
(Sh)	[1.96]	[5.76]		

Note: The table reports annualized descriptive statistics (Panel A) for portfolios sorted on forward discounts using the Japanese Yen as a funding currency, and also results for time-series regressions (Panel B) and cross-sectional asset pricing tests (Panel C) results with SDF linearly defined by the dollar risk factor (DOL) and the alternatively (with different base currency) specified indebted-minus-solvent risk factor. Results are presented for developed sample. Panel A reports mean and standard deviation for excess returns for each portfolio. Panel B reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the IMS factor for each forward discount sorted portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the IMS factor loading (β_{IMS}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. A J-test of pricing errors ($\alpha' V_\alpha^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel C reports results for iterated GMM and FMB procedures. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE). The standard errors [s.e] are reported in brackets and based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. A constant is not included in the second stage of FMB regression. The sample period is January 1985 - December 2014.

Table A3. Asset Pricing: Alternative solvency measure - Composite financial risk index

Panel A. Portfolios Sorted on Solvency Measure				
Portfolio	1	2	3	4
Mean	1.89	1.97	1.42	4.68
SD	10.92	8.88	8.73	10.74
Panel B. Factor Betas				
Portfolio	α	β_{DOL}	β_{FINCOM}	adj.-R^2
1	-1.36	0.98	-0.28	74.76
	(-1.48)	(31.25)	(-11.10)	
2	0.24	0.95	-0.01	81.01
	(0.34)	(39.12)	(-0.75)	
3	-0.79	0.95	0.05	82.71
	(-1.18)	(41.14)	(2.88)	
4	1.91	1.13	0.24	76.38
	(1.88)	(32.46)	(8.66)	
Panel C. Risk Prices				
GMM	DOL	FINCOM	R^2	RMSE
λ	3.11	8.60	96.44	0.69
s.e.	[1.47]	[3.51]		

Note: The table reports annualized descriptive statistics (Panel A) for portfolios sorted on solvency measure (composite financial risk index), results for time-series regressions (Panel B) and cross-sectional asset pricing tests (Panel C) results with SDF linearly defined by the dollar risk factor (DOL) and the alternatively specified indebted-minus-solvent risk factor (FINCOM). Results are presented for developed sample. The FINCOM factor of the similar nature with the IMS factor, but based on alternative solvency measure, which is the composite financial risk index of the PRS Group. Panel A reports mean and standard deviation for excess returns for each portfolio. Panel B reports estimates for monthly time series regressions of (log) carry trade excess returns on the intercept, the DOL factor and the FINCOM factor for each forward discount sorted portfolio. These estimates are: the constant (α) (annualized and in percentage points); the DOL factor loading (β_{DOL}); the FINCOM factor loading (β_{FINCOM}); and the adjusted-R^2 (in percentage points). T-statistics based on HAC Newey and West (1987) standard errors with Andrews (1991) lag selection are reported in parentheses. J-test of pricing errors ($\alpha' V_{\alpha}^{-1} \alpha$) tests if intercepts are jointly equal to zero. Panel C reports results for iterated GMM. Returns of test assets (carry trade portfolios) are in levels and annualized (multiplied by 12). We report the factor price of risk (λ) for the DOL and the FINCOM factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE). The standard errors [s.e] are reported in brackets. The sample period is January 1985 - December 2014.

Table A4. Asset Pricing: Individual currency level

Panel A. Factor Betas				
Currency	α	β_{DOL}	β_{IMS}	adj.-R^2
GBP	3,04	0,70	-0,13	35,87
	(1.75)	(7.27)	(-2.46)	
CHF	2,56	-0,76	0,13	31,53
	(1.30)	(-5.61)	(1.42)	
JPY	4,02	-0,58	0,27	25,05
	(1.89)	(-5.51)	(3.00)	
CAD	1,19	0,07	0,05	0,00
	(0.92)	(0.73)	(0.89)	
AUD	1,96	0,83	0,50	44,26
	(1.05)	(8.44)	(6.76)	
NZD	3,00	1,01	0,56	57,58
	(1.63)	(12.72)	(7.20)	
SEK	7,55	0,58	-0,05	19,27
	(3.62)	(4.49)	(-0.68)	
NOK	2,22	0,71	-0,04	30,89
	(1.31)	(6.72)	(-0.55)	
DKK	6,53	0,38	-0,07	8,82
	(3.29)	(3.15)	(-0.95)	
EUR/DEM	2,07	-0,15	0,09	1,66
	(1.05)	(-0.98)	(1.04)	
Panel B. Risk Prices				
FMB	DOL	IMS	R^2	RMSE
λ	5,80	6,04	62,10	3,51
[NW]	[1.80]	[2.98]		
(Sh)	[1.83]	[3.01]		

Note: This table presents results of asset pricing tests at an individual currency level. In Panel A we report results of time-series regressions of each of ten individual developed currencies carry trade returns on the two factor model: the dollar risk factor (DOL) from Lustig, Roussanov, and Verdelhan (2011) and the IMS (indebted-minus-solvent) factor. The IMS factor is based on solvency measure (foreign debt-to-GDP) sorts. Panel B presents the results of the following Fama-MacBeth regressions:

$$R_{i,t} = a_0 + B_{0,t}F_{i,t-1} + e_t ,$$

where $R_{i,t}$ is the excess return of currency i in month t; $F_{i,t-1}$ is forward discount of currency i in the previous month. In the next step we estimate the following regression:

$$B_{0,t} = B_1 \mathrm{DOL}_t + B_2 IMS_t + e_t ,$$

here the estimated beta series from the first regression is regressed on the two factor model: the dollar risk factor (DOL) and the IMS (indebted-minus-solvent) factor. We report the factor price of risk (λ) for the DOL and the IMS factors, the cross-sectional R^2 and the square root of mean-squared errors (RMSE). The standard errors are based on the Newey-West [NW] approach with optimal lags and Shanken (1992) correction [Sh]. Noteworthy, constant is not included in the second stage. The sample period is January 1985 - December 2014.

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The effect of political risk on currency carry trades☆

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This paper explores the risk profile of individual currency carry trades. Findings indicate that carry trade profitability depends on a country's political risk, supporting the risk-based view on forward bias. Political risk effect originates as a component of government actions and is more pronounced in emerging economies and in countries with high interest differentials.

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1. Introduction

This paper investigates the risk characteristics of currency carry trades. The international economics phenomenon of carry trade has its roots in macroeconomic parity condition failures owing to the inefficiency of the forward rate in forecasting a future spot rate, referred as the forward premium puzzle. Several studies argue that this puzzle can be explained by a carry trade exposure to a common risk, owing to fundamental differences between countries (Hansen and Hodrick, 1980; Fama, 1984). The contribution of this study lies in revealing that currency carry trade profitability depends on a country's political risk characteristics, thus providing new support for the risk-based view on the forward premium puzzle.

Despite the abundance of research searching for rational risk premia, only a few studies have attempted to explain forward bias as a risk premium originating from political risk. Bachman (1992) shows that political regime changes between 1973 and 1985 in the major developed countries can affect forward bias. Bernhard and Leblang (2002) argue that democratic processes (in eight industrial countries between 1974 and 1995) distorted forward rate forecasting ability, and thereby contributing to resolving the forward premium puzzle. Capitalizing on previous evidence, the current research adopts a large set of carry trades (48 currencies over the period 1985–2013) and investigates a comprehensive set of political risk components with the goal of comprehending the determinants of carry trade returns and, thereby, forward bias.

The findings of this paper indicate that political risk may contribute to the existence of the forward premium puzzle. In particular, carry trade returns are high/low in countries with high/low values of composite political risk measure. However, we show that the political risk effect originates in emerging economies, while it is not evident in developed countries. Further, we find that only the competence of government actions as a stand-alone component of political risk endures the adjustment for common risk factors. Finally, political risk is priced only in the subsample of high interest rate differential

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countries. To sum up, evidence suggests that individual carry trades are heterogeneously exposed to political risk that, potentially, makes it more difficult for economic agents to predict future spot exchange rates of politically distressed countries, reinforcing the forward premium bias.

The remainder of the study is organized as follows. Sections 2 and 3 describe the data and the empirical strategy, respectively. Section 4 presents the results, followed by Section 5 that concludes the paper.

2. Data

The full sample comprises 48 monthly spot exchange rates and one-month forward rates obtained from Thomson Reuters Datastream. The sample of currencies is identical to that in Menkhoff et al. (2012) and the sample period spans 01/1985 to 12/2013. Data quotes are in units of foreign currency per U.S. dollar. It should be noted that the effective sample size varies widely for some currencies due to the availability of data quotes. Data on the political risk measure and its components for each of the 48 countries were acquired from the International Country Risk Guide (ICRG) of the Political Risk Services Group. The data periods are matched. The political risk measure is in the form of annual rating scores for each individual country, where the country risk is inversely related to the score. In addition, we organized the components of political risk into four subgroups as in Bekaert et al. (2014), those subgroups being: quality of institutions, conflicts external/internal, democratic tendencies, and government actions.[1]

3. Empirical strategy

Monthly currency excess returns (r^i_{t+1}) are defined as follows:

$$r^i_{t+1} = f^i_t - s^i_{t+1} \tag{1}$$

where f^i_t stands for the log forward rate in units of foreign currency i per U.S. dollar in month t and s^i_{t+1} denotes the log spot exchange rate in the following month. Note, under covered interest parity log forward discount ($f^i_t - s^i_t$) approximates interest rate differentials ($i^i_t - i^{US}_t$). In a similar way to Moskowitz et al. (2012), we construct monthly individual carry strategies that go long (short) in the foreign currency if forward discount was positive (negative) in the previous month. Subsequently, carry returns are placed on an equal footing with political risk data by taking average monthly returns for the year in question, resulting in an unbalanced panel dataset with yearly observations.

In addition, we controlled for currency-specific risk factors, namely the dollar (*DOL*), the carry (*HML*) and the volatility (*VOL*) risk factors, as constructed by Lustig et al. (2011) and Menkhoff et al. (2012).[2] Moreover, we partitioned the sample into *developed* (10 countries) and *emerging* (31 countries) subsamples based on their classification by the MSCI and into *low, medium* and *high* carry trade subsamples of equal size based on historical average forward discounts ($\bar{f}^i - \bar{s}^i$).

We estimated various modifications of the following fixed-effect panel regression models:

$$r_{i,t} = a_0 + B_1 Polit\_risk_{i,t} + B_2 QI_{i,t} + B_3 \mathrm{Dem}_{i,t} + B_4 Gov_{i,t} + B_j X_t + e_{i,t} \tag{2}$$

where $r_{i,t}$ is the carry trade return for country i at time t, a_0 is the intercept, *Polit_risk* is the political risk score, QI_i, Con_i, Dem_i, and Gov_i stand for the four political risk subgroups (*Quality of Institutions, Conflict external/internal, Democratic Tendencies,* and *Government Actions*), X_t refers to the set of the abovementioned currency-specific controls and $\varepsilon_{i,t}$ is the disturbance term.

4. Empirical evidence

This section explores the role of political risk in explaining individual currency carry trades. Panel A of Table 1 shows that, in the full sample, individual carry trade returns are high when political risk is high (the score is low), suggesting a conventional risk-return relationship. The aggregate political risk measure is uniformly statistically significant at the 1% level in all of the model specifications. Although, Bachman (1992) suggests that political regime change in developed countries increases the political risks contributing to the forward bias, we find no evidence of a composite political risk effect in developed economies. Conversely, results indicate a significant impact of political risk on currency carry trades in the subsample of emerging countries. Accordingly, studies like Erb et al. (1996) and Dimic et al. (2015), also document the increasing importance of political risk for the financial markets of emerging economies.

Next, we investigated the provenance of the aforementioned political risk effect. Panel B of Table 1, suggests that the results primarily originate in the subgroups of government actions and, to a lesser degree, quality of institutions. Specifically, carry trade returns are high in countries where there is a risk of the government being unable to implement an announced program, and where there is socioeconomic pressure on government actions, and also in countries with legal systems characterized by low levels of impartiality, of institutional strength, and with low quality bureaucratic processes. In

[1] See Dimic et al. (2015) and tables therein for more information on political risk, its components and subgroups.

[2] We also controlled for traditional risk proxies, e.g., market risk (CRSP value-weighted index), market uncertainty (VIX), and for changes of GDP growth and inflation. The main results were unchanged.

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Table 1
Carry trades and Political risk.

Panel A. Individual carry trades and composite political risk score

	All Countries			Developed economies			Emerging economis		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Political risk	−0.018***	−0.048***	−0.020***	0.027*	0.011	0.013	−0.039***	−0.090***	−0.038***
	(−3.35)	(−3.31)	(−3.88)	(1.86)	(0.49)	(0.87)	(−4.27)	(−3.89)	(−4.45)
DOL			1.009***			0.961***			0.812**
			(5.01)			(4.36)			(2.43)
VOL			0.158			0.052			−0.062
			(0.77)			(0.22)			(−0.18)
HML			−0.621			−0.119*			0.141
			(−0.10)			(−1.76)			(1.34)
Constant	1.731***	4.069***	1.464***	−1.961	−0.539	−0.993	3.136***	6.800***	2.588***
	(4.19)	(3.63)	(3.75)	(−1.57)	(−0.29)	(−0.79)	(4.80)	(4.10)	(4.22)
Country effects	no	yes	no	no	yes	no	no	yes	no
Year effects	no	yes	no	no	yes	no	no	yes	no
R-squared	0.01	0.17	0.13	0.01	0.15	0.10	0.04	0.23	0.17

Panel B. Individual carry trades and components of political risk

	All Countries			Developed economies			Emerging economies		
	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
Quality of institutions	−0.043*	−0.186***	−0.024	0.175**	0.267**	0.192**	−0.130***	−0.178*	−0.279***
	(−1.76)	(−2.66)	(−0.98)	(2.18)	(2.06)	(2.52)	(−3.38)	(−1.81)	(−3.60)
Conflict external/internal	0.000	0.012	0.000	0.034	0.059	0.0183	0.008	−0.018	0.007
	(−0.03)	(0.42)	(−0.03)	(1.13)	(1.22)	(0.59)	(0.34)	(−0.37)	(0.18)
Democratic tendencies	0.000	0.037	0.001	−0.087	−0.046	−0.092	−0.047	0.036	0.021
	(−0.012)	(0.43)	(0.03)	(−0.54)	(−0.26)	(−0.60)	(−1.06)	(0.31)	(0.20)
Government actions	−0.024*	−0.074***	−0.050***	0.020	−0.024	0.001	−0.039	−0.140***	−0.081***
	(−1.94)	(−3.14)	(−3.95)	(1.33)	(−0.89)	(0.06)	(−1.63)	(−3.51)	(−2.90)
DOL			0.923***			0.901***			0.713**
			(4.51)			(4.10)			(2.19)
VOL			0.047			−0.143			0.054
			(0.22)			(−0.57)			(0.15)
HML			0.048			−0.069			0.149
			(0.73)			(−0.99)			(1.40)
Constant	1.499***	3.718***	1.474***	−2.841	−4.413	−2.232	2.789***	5.686***	4.228***
	(3.12)	(2.83)	(3.27)	(−1.47)	(−1.48)	(−1.19)	(4.15)	(3.29)	(2.91)
Country effects	no	yes	no	no	yes	no	no	yes	no
Year effects	no	yes	no	no	yes	no	no	yes	no
R-squared	0.01	0.19	0.14	0.02	0.16	0.12	0.05	0.24	0.26

Panel A of this table presents the results of regressing individual currency carry trade returns on aggregate political risk variable, currency risk controls and a constant for the full sample of countries and also for developed and emerging countries. Currency risk controls are the dollar (*DOL*), the carry (*HML*) and the volatility (*VOL*) risk factors, as in Lustig, Roussanov, and Verdelhan (2011) and Menkhoff, Sarno, Schmelling, and Schrimpf (2012) models. Panel B presents the results of the regression with a similar set up, but using four subgroups of political risk as explanatory variables. We report *t*-statistics in parentheses. Coefficients marked by asterisks

* are significant at the 10% level.
** are significant at the 5% level.
*** are significant at the 1% level.

contrast to the findings of Bernhard and Leblang (2002), we find no evidence of democratic tendencies and accountability affecting carry returns, however, we do find support for their supposition that political uncertainty that stems from government actions contributes to a forward premium bias. Similarly to the composite political risk measure, the magnitude and significance of government actions and the quality of institutions variables are greater in the subsample of emerging countries.

Lustig and Verdelhan (2007), Lustig et al. (2011) and Burnside et al. (2011) show that curry trade returns increase in interest rate differentials; such that sorting currencies in portfolios based on forward discounts results in a monotonic pattern in carry returns. Accordingly, we investigated whether the effect of political risk on individual currency carry trades varies in forward discounts. Table 2 presents the results on the relationship between carry trade returns, partitioned into three subgroups based on average historical forward discounts, and the aggregate political risk, as well as the four subgroup variables.

The results presented in Table 2 suggest that only the profitability of high forward discount (interest rate differential) carry trades depends on aggregate political risk, whereas no evidence of a political risk effect was found in the subgroups

Table 2
Forward discount sorted carry trades and Political risk components.

	Low carry		Medium carry		High carry		Low carry	Medium carry	High carry
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Constant	0.230	0.347	−0.005	1.140	1.640**	7.873***	−0.115	−0.812	1.447***
	(0.30)	(0.23)	(−0.72)	(0.79)	(2.26)	(3.55)	(−0.12)	(−1.40)	(2.91)
Political risk	−0.002	−0.004	0.005	−0.010	−0.022**	−0.100***			
	(−0.19)	(−0.23)	(0.71)	(−0.55)	(−2.22)	(−3.25)			
Quality of institutions							0.107**	−0.016	−0.012
							(1.87)	(−0.68)	(−0.23)
Conflict external/internal							0.018	0.010	0.049
							(0.50)	(0.56)	(1.52)
Democratic tendencies							−0.066	0.018	−0.140*
							(−1.57)	(0.35)	(−1.68)
Government actions							−0.041**	0.015	−0.057**
							(−2.55)	(1.01)	(−1.83)
Country effects	no	yes	no	yes	no	yes	no	no	No
Year effects	no	yes	no	yes	no	yes	no	no	no
Controls	yes	no	yes	no	yes	no	yes	yes	yes
R-squared	0.02	0.18	0.28	0.28	0.25	0.32	0.07	0.28	0.28

The table set up is identical to that in Table 1 except that the regression results are reported for the samples conventionally partitioned by the average forward discounts (interest rate differentials). That is *Low carry, Medium carry* and *High carry* samples comprise an equal number of countries with low, medium and high average forward discounts. The controls are identical to those in Table 1. The left panel reports the results from regressing individual currency carry trade returns on the aggregate political risk variable, and the right panel shows coefficient estimates for the subgroups of political risk. We report *t*-statistics in parentheses. Coefficients marked by asterisks

* are significant at the 10% level.
** are significant at the 5% level.
*** are significant at the 1% level.

defined by low and medium average interest rate differentials. The results for the high forward discount currencies subgroup indicate that greater political risk leads to higher individual carry trade returns regardless of the type of economy. Although, we found a monotonic pattern in political risk coefficient estimates when moving from the low to the high subgroups, the magnitudes are too low to entirely explain the spread in carry trade returns. Nevertheless, political risk has a significant impact on carry trade returns of high forward discount currencies, demonstrating a remarkably high explanatory power. Furthermore, results for the political risk subgroups are similar to their counterparts in Table 1, that is to say, the prime source of political risk effect is uncertainty over government actions.

5. Conclusion

This paper shows that political risk affects currency carry trade returns. Scrutinizing a comprehensive currency universe, composite political risk and the set of political risk components, this study shows that individual carry trade profitability depends on a country's political risk. Carry trade returns are high (low) when political risk is high (low). The political risk effect originates with the component of government actions and is more pronounced in the subsample of emerging economies and in countries with high interest differentials.

Overall, the evidence points to individual carry trades exhibiting heterogeneous exposure to political risk across market categories and across currencies sorted by forward discounts. However, the economic magnitudes are not high enough to claim that political risk completely explains the forward premium puzzle. Nevertheless, the findings of this paper lend support to the point of view that political science theory can provide insights into financial market anomalies, and suggest that future research should not neglect information on fundamental political processes.

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Full length article

Benefits of wavelet-based carry trade diversification☆

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ABSTRACT

This study investigates carry trade diversification opportunities and linkages of major carry trade currencies on five different investment horizons. Using daily data on eight currencies and LIBOR rates, we examine the temporal structure of correlations and assess portfolio diversification benefits with wavelet techniques. Our results indicate that positive and economically significant carry trade excess returns are observed on all investigated investment horizons. We document that strategies built on the basis of wavelet correlation lead to significant diversification benefits. These findings indicate the importance of the dynamic structure of exchange rate correlations to currency arbitrage strategies.

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1. Introduction

The volume of transactions in the global currency market on some days reaches four trillion U.S. dollars. In annual terms, the global currency market trading volume is 12 times more than that of all the world's stock markets (Triennial Central Bank Survey, 2010). Interestingly, only 10% of the volume is associated with the maintenance of international trade while the rest is partly attributed

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to speculative activity. The most popular strategy for speculative currency trading is the carry trade. In order to execute the carry trade, investors sell borrowed currency at a low interest rate and buy investment instruments denominated in currencies with high interest rates. The interest rate parity condition predicts that the national currency will depreciate if the domestic interest rate is higher than the foreign interest rate. However, the evidence suggests that in the real world it is strengthened indicating Uncovered Interest Parity failure[1]. The existence of these excess returns has received vast attention in the recent literature[2].

Earlier studies show that diversification across several currencies leads to carry trade risk reduction. Burnside et al. (2006) show that the Sharpe ratio generated by an equally weighted portfolio of carry trade strategies is positive and statistically different from zero. Continuing their research Burnside et al. (2008) find that diversification among currencies boosts the Sharpe ratio. An equally weighted carry trade portfolio appears to provide a higher Sharpe ratio and other benefits of diversification in comparison to individual carry trade strategies and stock market benchmark. Inter alia, Burnside et al. (2011a) and Bakshia and Panayotov (2013) show that returns are better for portfolios of currencies and that diversification leads to a higher Sharpe ratio and decrease in volatility. These studies imply that diversification across currencies is the key factor to portfolio features adjustment.

The purpose of the study is three-fold: (i) to examine carry trade returns in excess of Uncovered Interest Parity (UIP) on different time scales (ii) to analyze the temporal structure of the correlations of the most liquid carry trade currencies; and (iii) to investigate carry trade diversification opportunities with a focus on these correlations. For these purposes we use wavelet correlation analysis, which allows breaking the time series of exchange rate returns into a series of wavelet coefficients and revealing the temporal structure of the correlations[3].

This study attempts to add to the carry trade literature in two respects. First, the study extends the analysis of carry trade diversification opportunities and examines the temporal structure of correlations among the most common carry trade currencies. Knowing correlation structure, we are able to maximize the diversification benefits in carry trade portfolio construction. Second, the study investigates carry trade excess returns on five different time scales. Therefore the study aims to extend the existing literature that employs static correlation and a single investment horizon approach in portfolio construction.

We find that positive and economically significant excess returns are observed on different investment horizons, namely the one-day, one-week, one-month, quarterly, and yearly horizons. Individual currency carry trades show a positive Sharpe ratio on every horizon[4]. Most importantly, the findings of the study suggest that strategy building on the basis of wavelet correlation analysis leads to significantly higher Sharpe ratios than those of Equally Weighted portfolio and S&P 500. For example, on the 3-month horizon the Sharpe ratios are twice as high for Wavelet portfolio. The results are even more pronounced in the pre-crisis sample. Further, wavelet diversified portfolios

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[1] In similar vein, if the forward premium is positive, the evidence suggests that in practice the currency will strengthen over time (Fama, 1984; Engel, 1995; Obstfeld and Rogoff, 2001; Lewis, 2011; Doukas and Zhang, 2013).

[2] Two broad classes of explanations are proposed: (i) excess returns as a premium for risk; (ii) excess returns stems from market inefficiency. The risk premium class of explanation stems from the idea that investors are not risk neutral, and the bias in the forward rate's prediction of the spot rate reflects a risk premium (see e.g. Villanueva, 2007; Lustig et al., 2011; Menkhoff et al., 2011; Baillie and Chang, 2011). Market inefficiency explanations assess the forward premium puzzle under the condition that investors make mistakes when forming expectations and/or in processing information (see e.g. Krasker, 1980; Lewis, 1989; Kaminsky, 1993). Another way to look at the puzzle is the market microstructure approach considering limits to speculations (see e.g. Lyons, 2001; Evans and Lyons, 2002). Finally, it should be noted that the strategy of investing in high interest rate currencies and borrowing in currencies with low rates is associated with a negative skewness. Thus, carry trades are exposed to crash risk (Brunnermeier et al., 2009).

[3] Study by Nekhili et al. (2002) indicates the importance of scale-based analysis. The Wavelet Analysis of financial time series and maximum overlap discrete transform (MODWT) techniques have been used extensively to study the co-movements of major stock market indices. See, e.g. Graham and Nikkinen (2011), Graham et al. (2012), Kiviaho et al. (2012), Nikkinen et al. (2012) and Loh (2013).

[4] The results of the study are consistent with previous findings of carry trade excess returns over uncovered interest parity (e.g. Fama, 1984; Engel, 1995; Fan and Lyons, 2003; Gagnon and Chaboud, 2007; Galati et al., 2007; Clarida et al., 2009).

have better skewness-return characteristics, being more positively skewed than individual carry trade strategies and Equally Weighted portfolios, while posting similar or better returns. In addition, the wavelet diversification approach seemed to perform better on longer time scales (from one month upward) in low volatile environment rather than on short horizons in a highly volatile market.

The remainder of this paper is organized as follows. Section 2 describes the dataset and provides descriptive statistics. Wavelet methodology and portfolio composition description are given in Section 3, followed by the main findings in Section 4. Section 5 concludes the paper.

2. Data

The study uses daily nominal exchange rates to the U.S. dollar (USD) and BBA London Interbank Offered Rates for eight most liquid currencies. These currencies are: Australian dollar (AUD), Canadian dollar (CAD), Danish krone (DKK), Swiss franc (CHF), Euro (EUR), Great Britain pound (GBP), Japanese yen (JPY) and New Zealand dollar (NZD)[5]. Data is collected from Thompson Reuters Datastream. The time period starts as LIBOR data become available (June 16, 2003) and spans to the end of 2012[6]. In total, the dataset consists of 2313 daily observations for each currency. Undoubtedly the financial crisis of 2008 had a considerable impact on the currency market and, subsequently, affected carry trade payoffs. To compare prior- and post-crisis carry trade returns we also split the data into before and after the Lehman Brothers collapse (September 15, 2008) subsamples. First the convention of nominal exchange rate is utilized (units of domestic currency per unit of foreign currency).We use the U.S. dollar as the base currency. To compare the results with the stock market we use S&P 500 index as the benchmark.

As a robustness check, we also study a data set that contains currencies of 12 emerging countries: Brazil, Czech Republic, Egypt, Hungary, India, Indonesia, Mexico, Philippines, Poland, Russia, South Africa, South Korea. Data period is matched with the one of developed countries sample.

Similar to the standard carry trade literature (see e.g., Evans and Lyons, 2002; Lustig and Verdelhan, 2007; Brunnermeier et al., 2009) we assume that to execute carry trade strategy investors take a short position on U.S. dollars to finance an investment denominated in foreign currency. Executing carry trade an investor can obtain both a higher nominal cash flow return and the subsequent exchange rate change also yields a capital gain (Lewis, 2011). Carry trade returns (Z_{t+1}) are expressed as:

$$Z_{t+1} = (i_t^* - i_t) + \Delta S_{t+1} \quad (1)$$

the notion of ΔS_{t+1} is basically the indicator of logarithmic exchange rate excess returns to the prediction of uncovered interest parity. Hence, analogously with other researchers (e.g. Brunnermeier et al., 2009) we denote the logarithm of foreign interest rate as i_t^* and log-domestic rate as i_t. Interest rate differentials and excess returns of exchange rates quoted against USD are used to test uncovered interest parity.

We test excess returns to UIP on five different horizons, namely, overnight, one week, one month, three months and one year. The time period for LIBOR matches the time period of nominal exchange rate obtained. Instead of focusing on the monthly or quarterly horizon as in earlier studies, we extend the analysis by aiming attention at more time horizons.

Table 1 reports the summary statistics for analyzed individual currency carry trade strategies for all time horizons investigated. Average excess log returns over UIP with the corresponding standard deviation are shown. Individual currency carry trade strategies exhibit returns significantly different from zero, hence violating the uncovered interest parity. Standard carry trade strategies post higher excess returns prior to the global financial crisis with a subsequent drop in returns and a rise in standard deviations after the Lehman Brothers collapse. "Active overnight" carry trade implies switching between

[5] A similar set of currencies was used in earlier papers, such as: Lustig and Verdelhan (2007), Darvas (2009), Campbell et al. (2010), Ranaldo and Söderlind (2010), Brunnermeier et al. (2009), Burnside et al. (2011b) and Farhi et al. (2011).

[6] An exception is 3-month rate data spanning from September 15, 2003 to December 31, 2012 (limited due to availability of data).

Table 1
Descriptive statistics for carry trade returns (log-returns on annualized basis).

Currency	Overnight		Active overnight		1 Week		1 Month		3 Months		1 Year		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
AUD	Full	0.07	0.15	0.07	0.15	0.07	0.15	0.08	0.15	0.07	0.15	0.07	0.14
	Prior	0.08	0.11	0.08	0.11	0.05	0.12	0.08	0.12	0.08	0.09	0.08	0.07
	After	0.07	0.18	0.07	0.18	0.08	0.18	0.09	0.17	0.07	0.19	0.07	0.17
CAD	Full	0.02	0.11	0.00	0.11	0.03	0.11	0.04	0.10	0.03	0.09	0.03	0.09
	Prior	0.05	0.09	−0.01	0.09	0.04	0.09	0.06	0.08	0.05	0.08	0.06	0.05
	After	0.00	0.12	0.02	0.12	0.01	0.13	0.02	0.12	0.01	0.11	0.01	0.11
CHF	Full	0.03	0.11	−0.06	0.11	0.02	0.11	0.03	0.12	0.03	0.11	0.02	0.10
	Prior	0.00	0.10	−0.04	0.10	0.00	0.10	0.02	0.10	0.03	0.09	0.01	0.08
	After	0.05	0.12	−0.07	0.12	0.04	0.13	0.04	0.14	0.03	0.12	0.03	0.11
DKK	Full	0.02	0.10	−0.01	0.10	0.01	0.11	0.02	0.11	0.02	0.10	0.00	0.09
	Prior	0.04	0.09	0.00	0.09	0.02	0.09	0.05	0.09	0.05	0.08	0.04	0.08
	After	0.00	0.12	−0.03	0.12	0.00	0.12	−0.01	0.13	−0.02	0.12	−0.02	0.09
EUR	Full	0.02	0.10	−0.02	0.10	0.01	0.11	0.02	0.11	0.01	0.10	0.00	0.09
	Prior	0.04	0.09	−0.01	0.09	0.02	0.09	0.05	0.09	0.05	0.08	0.04	0.07
	After	−0.01	0.12	−0.02	0.12	−0.01	0.12	−0.01	0.13	−0.02	0.12	−0.03	0.09
GBP	Full	0.01	0.10	0.00	0.10	0.00	0.10	0.01	0.11	0.00	0.11	−0.01	0.10
	Prior	0.03	0.08	0.01	0.08	0.02	0.09	0.04	0.09	0.04	0.07	0.03	0.06
	After	−0.01	0.12	−0.01	0.12	−0.03	0.12	−0.03	0.12	−0.03	0.13	−0.04	0.11
JPY	Full	0.01	0.11	−0.03	0.11	0.00	0.10	0.01	0.10	0.00	0.10	0.01	0.09
	Prior	0.00	0.09	−0.05	0.09	−0.02	0.09	−0.01	0.10	−0.03	0.08	−0.04	0.08
	After	0.02	0.12	0.00	0.12	0.03	0.11	0.03	0.11	0.04	0.11	0.05	0.07
NZD	Full	0.07	0.15	0.07	0.15	0.06	0.15	0.07	0.15	0.07	0.14	0.05	0.14
	Prior	0.07	0.12	0.07	0.12	0.05	0.13	0.07	0.13	0.07	0.11	0.06	0.10
	After	0.08	0.17	0.08	0.17	0.08	0.18	0.08	0.17	0.06	0.17	0.05	0.17

The table provides results for the whole sample, which ranges from June 16, 2003 to December 31, 2012. Prior and after sections show summary statistics for the sample before and after the Lehman Brothers collapse (September 15, 2008), respectively. For all time scales we build carry trade strategy in straightforward fashion. “Active overnight” carry trade assumes switching between funding and domestic currencies with respect to interest rate differentials. All results are presented on an annualized basis.

Table 2
Skewness and kurtosis for carry trade returns (individual strategies).

Currency		Overnight		1 Week		1 Month		3 Months		1 Year	
		Skew.	Kurt.	Skew.	Kurt.	Skew.	Kurt.	Skew.	Kurt.	Skew.	Kurt.
AUD	F	−0.96	14.79	−1.16	12.01	−1.30	9.42	−1.64	10.23	−0.56	4.01
	P	−0.78	6.04	−0.66	4.08	−0.61	4.34	−0.41	3.98	−0.20	1.96
	A	−0.93	13.56	−1.27	11.91	−1.50	9.49	−1.53	7.49	−0.44	2.80
CAD	F	0.12	8.15	−0.26	7.79	−1.23	10.73	−0.81	6.59	−0.97	4.40
	P	−0.05	3.62	−0.21	3.60	−0.13	3.41	0.30	2.67	0.13	2.42
	A	0.20	8.47	−0.23	7.78	−1.58	11.58	−1.12	6.63	−0.58	3.15
CHF	F	0.20	5.79	−0.11	6.98	−0.25	5.40	−0.15	3.19	0.38	3.70
	P	−0.02	3.60	0.02	2.97	0.31	3.03	0.29	3.03	0.08	2.65
	A	0.32	6.57	−0.20	7.84	−0.54	5.80	−0.34	2.87	0.37	3.50
DKK	F	0.19	5.78	−0.05	5.27	−0.28	4.33	−0.65	3.85	0.02	2.02
	P	−0.20	3.73	−0.31	3.03	−0.17	3.17	−0.21	3.09	−0.62	2.62
	A	0.37	5.79	0.09	5.34	−0.22	4.10	−0.55	3.21	0.54	2.48
EUR	F	0.18	5.73	−0.06	5.27	−0.30	4.33	−0.67	3.87	−0.01	2.00
	P	−0.18	3.64	−0.31	3.02	−0.17	3.20	−0.20	3.10	−0.60	2.63
	A	0.35	5.73	0.08	5.33	−0.24	4.06	−0.57	3.21	0.50	2.43
GBP	F	−0.08	7.21	−0.70	7.40	−0.83	6.29	−0.99	6.89	−1.33	4.70
	P	−0.15	3.73	−0.14	3.11	−0.41	4.03	0.03	3.82	−0.34	2.37
	A	−0.02	7.35	−0.85	7.64	−0.91	6.40	−0.84	5.38	−0.99	3.27
JPY	F	0.43	7.85	0.41	5.21	0.04	3.42	0.06	3.67	−0.33	2.16
	P	0.34	4.98	0.46	3.77	0.41	2.88	0.38	3.03	0.52	2.40
	A	0.47	8.88	0.35	5.81	−0.29	3.86	−0.28	3.66	−1.08	4.64
NZD	F	−0.43	7.95	−0.67	6.92	−0.55	5.09	−0.59	4.74	−0.76	3.97
	P	−0.72	5.97	−0.70	4.59	−0.69	4.01	−0.33	2.64	−0.05	2.16
	A	−0.28	7.61	−0.64	6.97	−0.46	4.91	−0.62	4.47	−0.75	3.35

The table provides skewness and kurtosis results for individual currency carry trades over the period from June 16, 2003 to December 31, 2012. F stands for the full sample results, P and A lines present the results for pre- and post-crisis samples, respectively.

funding and domestic currencies with respect to interest rate differentials. This strategy resulted in negative or zero returns for most of the individual carry trade strategies.

The highest carry trade returns over the last decade are obtained by investing in the New Zealand dollar and the Australian dollar, which are commonly known as investment currencies. In addition, executing New Zealand dollar and Australian dollar carry trades leads to a relatively high Sharpe ratio. By contrast the Euro and the Japanese yen provide negative average logarithmic returns[7]. The Japanese yen carry trade exhibits low returns prior to the financial crisis of 2008, while after the Lehman Brothers collapse the yen carry trade provides higher average returns. After the financial crisis of 2008 carry trade returns are associated with high levels of standard deviation in most individual strategies. The highest standard deviations are associated with the New Zealand dollar and the Australian dollar carry trades. Taking into account the fact that carry trade is often high leveraged and bears substantial downside risk, the results indicate dangers for carry traders associated with sudden fluctuations in currencies.

Brunnermeier et al. (2009) show that carry trades are exposed to crash risk, thus leading to negative skewness of excess to UIP return distribution. The summary statistic in Table 2 confirms Brunnermeier's observation of negative skewness for high interest rate differential carry trades on

[7] The results are closely associated with negative interest rate differentials. These countries had lower interest rates than in the United States most of the time.

Table 3
Pairwise correlations of currencies studied.

	AUD	CAD	CHF	DKK	EUR	GBP	JPY	NZD
Panel 1: whole sample								
AUD	1							
CAD	0.68	1						
CHF	0.46	0.40	1					
DKK	0.64	0.55	0.83	1				
EUR	0.64	0.55	0.83	1.00	1			
GBP	0.62	0.51	0.55	0.69	0.70	1		
JPY	−0.03	−0.05	0.41	0.25	0.25	0.11	1	
NZD	0.86	0.61	0.45	0.61	0.61	0.61	0.00	1
Panel 2: prior the crisis								
AUD	1							
CAD	0.65	1						
CHF	0.46	0.42	1					
DKK	0.65	0.56	0.90	1				
EUR	0.65	0.56	0.90	1.00	1			
GBP	0.64	0.52	0.60	0.72	0.72	1		
JPY	−0.04	−0.01	0.48	0.31	0.31	0.14	1	
NZD	0.86	0.58	0.45	0.62	0.62	0.63	−0.01	1
Panel 3: after the crisis								
AUD	1							
CAD	0.75	1						
CHF	0.42	0.41	1					
DKK	0.64	0.60	0.76	1				
EUR	0.64	0.60	0.76	1.00	1			
GBP	0.63	0.57	0.46	0.66	0.66	1		
JPY	−0.23	−0.20	0.26	0.08	0.08	−0.09	1	
NZD	0.88	0.70	0.45	0.65	0.65	0.63	−0.15	1

Notes: All correlations are significant at the 5% level.

time scales from one month upward. However, carry trades conducted on an overnight and weekly basis provide mixed evidence, e.g. the British pound and Canadian dollar posted zero and positive skewness, respectively.

Table 3 documents the pairwise return correlations for all pairs of currencies studied. The highest correlation coefficient is reported for the Euro and the Swiss franc, the Euro and the Danish krone and the Australian dollar and the New Zealand dollar throughout all periods. Among all pairs of currencies, the Japanese yen and investment currencies (Australian dollar, New Zealand dollar and Canadian dollar) appear to have the lowest correlation (around zero). Correlation coefficients vary in the range 0.00–0.87 from pair to pair. Prior to the financial crisis the European currencies were strongly correlated, reflecting the linkages of economies within Europe. Yet there is a noticeable decline in correlations after the crisis, as shown in panel 3. Investment currencies have a very strong bond which is consistent with Brunnermeier et al., 2009.

3. Methods

Earlier studies approach the dependencies of the currencies straightforwardly, as they do not take account of the temporal structure of correlations in portfolio formation. In this study we apply a maximum overlap discrete transform method which provides an opportunity to approach the interdependence of the currencies more thoroughly. Wavelet technique helps to better assess the dynamic behavior of currencies, as it allows analyzing the structure of the data on different scales.

3.1. The Wavelet method

Wavelet cross-correlation and cross-covariance methods are based on the discrete wavelet transform with maximum overlap (MODWT), such that wavelet coefficients indicate a change in a certain scale of measurement. We apply MODWT for time series data to split data on the components of different scales (scale-to-scale decomposition). We employ scale-to-scale decomposition to assess the temporal structure of correlations and to approach the dynamic structure of exchange rate correlations. Following Percival and Walden (2000) we start with estimating MODWT coefficient at the first level by convolving low-pass and high-pass filters with the input signal to estimate approximation coefficients and detail coefficients. At the next levels of the MODWT the process is recursively continued with modified filters, obtained by dyadic upsampling. Mathematically such MODWT procedure for $j = 1, 2, \ldots, J_0 = 1$ is expressed as:

$$a_{j+1}(n) = l_{j+1}(n) \times a_j(n) = l_{j+1}(n) \times l_j(n) \times s(n) \quad (2)$$

$$d_{j+1}(n) = h_{j+1}(n) \times a_j(n) = h_{j+1}(n) \times l_j(n) \times s(n) \quad (3)$$

where $s(n)$ is the signal of length $N = 2^j$ for some integer J. $l_j(n)$ and $h_j(n)$ are low- and high-pass wavelet filters, respectively. Further, $l_{j+1}(n) = U(l_j(n))$ and $h_{j+1}(n) = U(h_j(n))$, with U being the upsampling operator. The approximation coefficient is defined as $a_{j+1}(n)$ and detail coefficient (wavelet coefficient) is $d_{j+1}(n)$. The series of detail coefficients $d_1(n)$, $d_2(n)$, $d_3(n)$, ..., $d_{j0}(n)$ is the main output of MODWT procedure.

Wavelet covariance breaks sample covariance into different time scales. In other words, the wavelet covariance in a specified time space provides the covariance coefficient estimation for two stochastic variables at a given point in time. Wavelet covariance at a particular scale $\lambda_j \equiv 2^{j-1}$ is expressed mathematically as follows (Gencay et al., 2001; Percival and Walden, 2000):

$$cov_{XY}\left(\lambda_j\right) \equiv \frac{1}{\check{N}} \sum_{t=L_{j-1}}^{N-1} d_{j,t}^X \, d_{j,t}^Y \quad (4)$$

where $d_{j,t}^i$ —is MODWT wavelet coefficient of variable X or Y in the scale of λ_j at time t. $\check{N}_j = N - L_j + 1$ stands for the number of coefficients, which are unaffected by the boundary, and $L_j = (2^j - 1)(L - 1) + 1$ is the length of the wavelet filter on the scale λ_j.

This ratio of covariance is to some extent inaccurate, as covariance depends on the changes in the time series. In order to measure the correlation we estimate the coefficient of wavelet variance. Analogously to wavelet covariance, the idea of the wavelet variance concept is to break down the temporal structure of the sample and replace the concept of variability for a given scale by a global variability measure estimated for the full sample (Percival and Walden, 2000). The following expression depicts the variance of the stochastic process for scale (λ_j) (Percival, 1995).

$$V_i(\check{N}_j) \equiv \frac{1}{\lambda} \sum_{t=L_j-1}^{N-1} \left[d_{j,t}^i\right]^2 \quad (5)$$

where $d_{j,t}^i$ —is MODWT wavelet coefficient of variable i in the scale of λ_j at time t. $\check{N}_j$ is, similarly to covariance, the number of coefficients unaffected by the boundary, and L_j is the length of the wavelet filter on the scale λ_j.

Subsequently we measure the wavelet correlation on each time scale in a straightforward way:

$$\rho_{XY}\left(\lambda_j\right) \equiv \frac{cov_{XY}\left(\lambda_j\right)}{\sqrt{V_X\left(\lambda_j\right)}\sqrt{V_Y\left(\lambda_j\right)}} \quad (6)$$

where $cov_{XY}\left(\lambda_j\right)$ and $V_i\left(\lambda_j\right)$ stand for wavelet covariance and wavelet variance, respectively.

In the confidence interval estimations we follow Whitcher et al., 1999. We estimate the wavelet correlation on each scale and provide an approximate $100 \times (1-2p)\%$ confidence level. Mathematically expressed as:

$$\left[\tan h\left\{h\left[p_{XY}\left(\lambda_j\right)\right]-\frac{\varphi^{-1}(1-p)}{\sqrt{N_j-3}}\right\},\quad \tan h\left\{h\left[p_{XY}\left(\lambda_j\right)\right]-\frac{\varphi^{-1}(1-p)}{\sqrt{N_j-3}}\right\}\right] \tag{7}$$

We calculate the wavelet (MODWT) estimator for wavelet correlation from the daily return series with eight scales decomposition. The time scale spans from one day to approximately one year in dyadic steps. Filter length can be anywhere from two to eight. Different variations of wavelet method utilize filters of different length, e.g., Haar wavelet offers a filter of length two, Daubechies introduces a filter length of four, and the least-asymmetric wavelet model described by Burrus et al. (1997) has a filter length of eight. In finance literature, filter lengths from four (Helder and Jin, 2007; Nielsen and Frederiksen, 2005) to eight (Gencay et al., 2001) were used. Ideally, the filter length should be positively proportional to the length of the time-series. In this analysis, we follow the least-asymmetric wavelet model with filter length of eight. For the largest decomposition level, the filter length eight represents 128–256 day averages, while the lowest decomposition level, the filter length one represents one to two days[8].

3.2. Portfolio formation

We divide currencies into groups according to the Sharpe ratio in different time periods. For the whole sample the Canadian dollar, the Australian dollar and the New Zealand dollar are included in the group of investment currencies on the scales from one week to one year. Separation is based on the correlation dynamics on different time scales and time periods (before and after the crisis).

We construct carry trade portfolios for five different time scales, namely overnight, one week, one month, three months, and one year. Following Lustig and Verdelhan (2007) and Bakshia and Panayotov (2013) we dynamically re-balance each portfolio annually. We use an estimation window of two years in order to access wavelets on long time scales. Further, we identify three individual currency carry trades with the highest Sharpe ratios in the panel and estimate the wavelet correlation coefficients for those currencies. Wavelet portfolio 1 consists of two carry trade currency pairs with the lowest wavelet correlation providing the greatest diversification gains on different horizons. In addition, to check the robustness of our results, we include Wavelet portfolio 2, which is composed of two currency pairs with the second lowest wavelet correlation. In comparison to earlier studies (e.g. Lustig and Verdelhan, 2007; Burnside et al., 2008) we include a High Sharpe portfolio consisting of four equally weighted annually rebalanced carry trade currencies with the highest Sharpe ratio as well as stock market benchmark. Additionally, we consider minimum-variance and minimum-CVaR portfolios consisting of two or more currency pairs and rebalanced on annual basis[9].

Our approach strives to reflect the practical implementation of carry trades, in which the currency pairs to be included in wavelet based portfolios are chosen on the basis of the two-stage ranking of Sharpe ratios and wavelet correlation coefficients.

4. Results

4.1. Wavelet correlation of exchange rates

Figs. 1 and 2 report the results of the wavelet correlation analysis of returns between selected carry trade currencies before and after the financial crisis of 2008, respectively. Scales are presented on the

[8] The dynamics of various filter levels and the corresponding time horizons are outlined as: scale 1 (1–2 days)—overnight horizon, scale 2 (2–4 days), scale 3 (4–8 days)—one week horizon, scale 4 (8–16 days), scale 5 (16–32 days)—one month horizon, scale 6 (32–64 days), scale 7 (64–128 days)—three months horizon, and scale 8 (126–256 days) is treated as one year horizon. Such scale-horizon interpretation is commonly used in the literature.

[9] We thank anonymous referee for this suggestion.

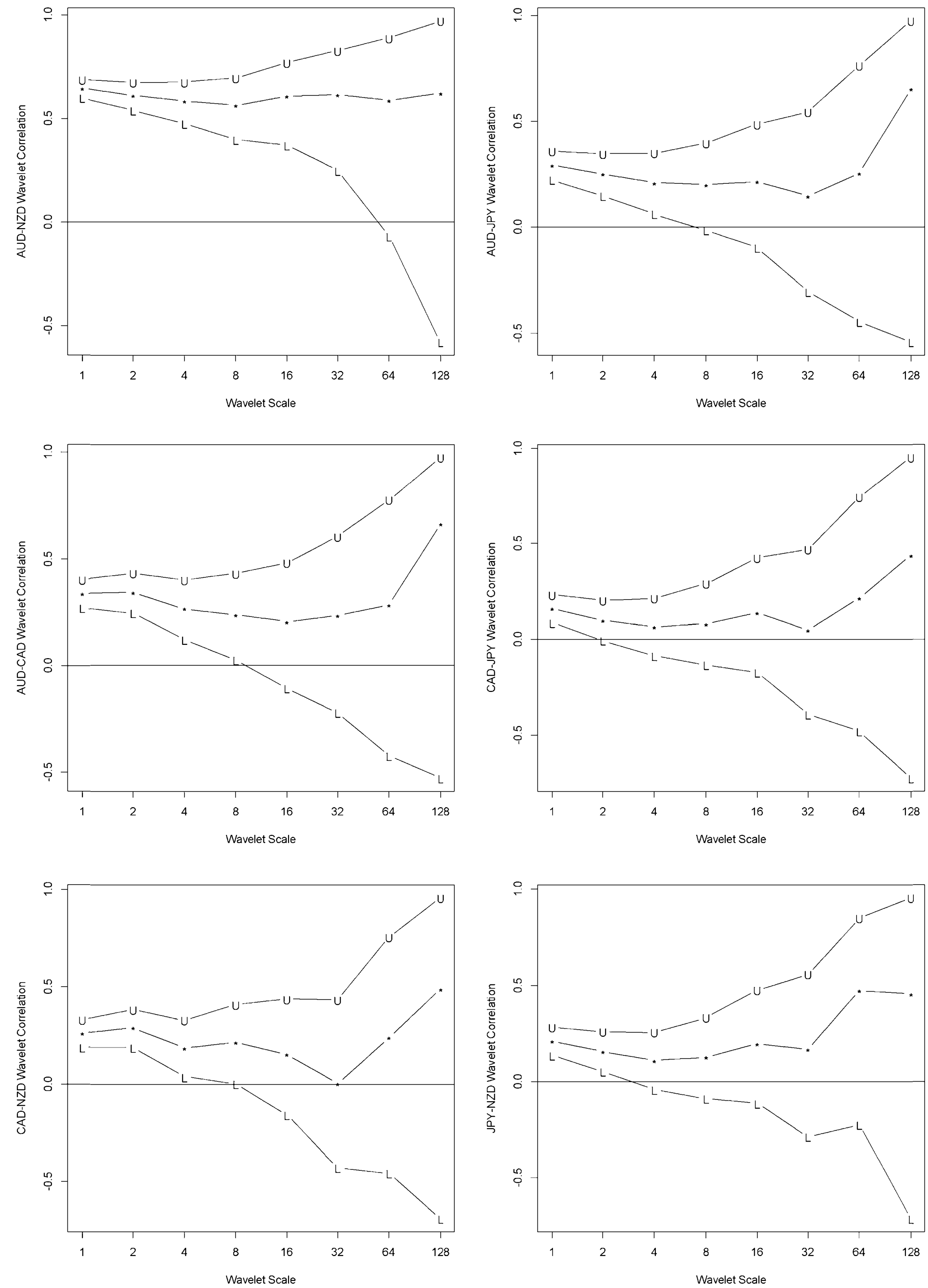

Fig. 1. Wavelet correlation of returns between selected carry trade currencies before the crisis.

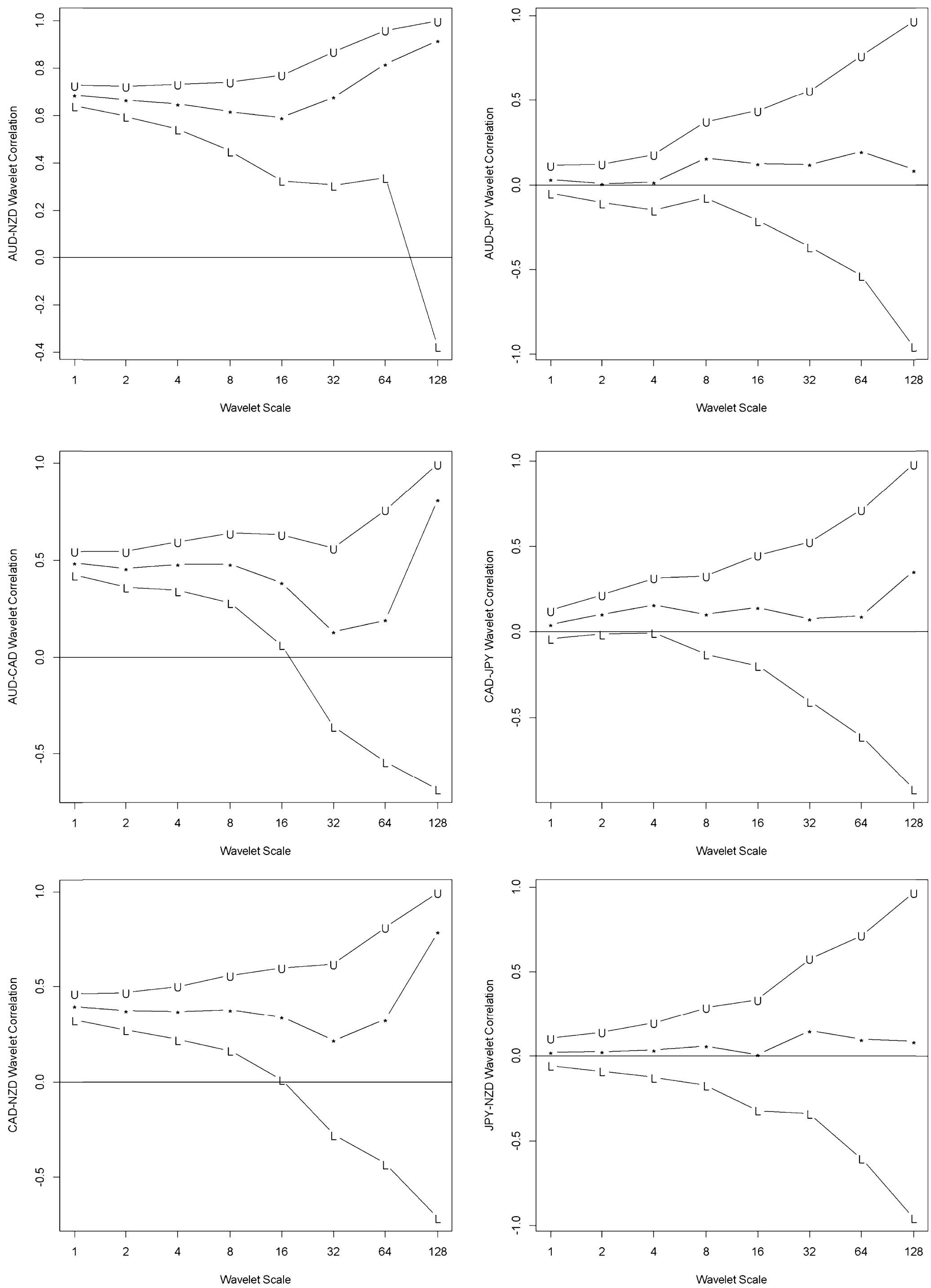

Fig. 2. Wavelet correlation of returns between carry trade currencies after the crisis.

horizontal axis while correlations appear on the vertical axis. Corresponding currencies are shown on the left side of every subfigure. Time scale spans from one day to approximately one year in dyadic steps. The first scale presents 1–2 day averages and the scale number eight presents 128–256 day averages. The upper and lower boundary filters are presented in the following graphs as bound lines with *U* and *L* markers, respectively.

The group of investment currencies (Australian dollar, New Zealand dollar and Canadian dollar) is characterized by an increasing correlation when moving to a longer investment horizon (see Figs. 1 and 2). Pairwise wavelet correlation of these currencies spikes in value at the last two levels (time scale of 3 months onwards). At the same time, the two most popular carry trade currencies, namely the Australian dollar and the New Zealand dollar exhibit the highest correlation among all pairs over all periods. This is probably caused by a simultaneous building up and unwinding of carry trade positions in these two currencies. Furthermore, Fig. 2 indicates that the period after the financial crisis of 2008 is associated with an increase in the correlation between the pair Canadian dollar and New Zealand dollar, Australian dollar and New Zealand dollar. On the other hand, Fig. 2 shows that in the post-crisis period the correlation structures between the Japanese yen and investment currencies almost flattens to around zero relative to the pre-crisis period results (see Fig. 1)[10].

4.2. Wavelet based diversification of carry trades

Panel A of Table 4 reports the mean, standard deviation, and Sharpe ratios associated with the excess returns of five constructed carry trade strategies for the full sample. The Sharpe ratios are mainly positive for all strategies and the S&P 500 index on all five time scales. Following Burnside et al. (2008), the equally weighted portfolio consists of every carry trade currency, even of those with negative average logarithmic returns (e.g. Japanese yen and Swiss franc). The Equally weighted carry trade portfolio has relatively low Sharpe ratios (0.13 to 0.35), which are nevertheless similar to those for the HML (high-minus-low) portfolios posted by the currency portfolios of developed countries in Lustig et al. (2011). The Sharpe ratios of High Sharpe portfolios over all time scales vary from 0.08 to 0.27. Both these results are similar to the Sharpe ratios of S&P 500, which vary from 0.16 to 0.30. Thus it seems that equally weighted portfolios (first column of Table 4, panel A) do not exhibit markedly improved Sharpe ratios over all time scales. These results differ from those of Burnside et al. (2008) most likely because we account for the global financial crisis[11].

The third column of Table 4 reports the mean, standard deviation and Sharpe ratios of Wavelet correlation based portfolio with annual dynamic re-balancing. Wavelet based diversification leads to improved Sharpe ratios on average, suggesting that there are benefits of using wavelet techniques in portfolio diversification. For the whole sample, carry trade strategy based on wavelet correlation analysis (Wavelet portfolio 1 in Table 4) Sharpe ratios vary from 0.07 to 0.74, posting Sharpe coefficients almost twice as high as those of Equally Weighted portfolio and S&P 500 on a time scale of 3 months. The comparison of results between wavelet based re-balanced portfolio and equally diversified portfolio demonstrates that the specific design of the carry trade has a substantial impact on average payoffs and other characteristics.

Table 4 panel B reports the results from the pre-crisis period. For the sample before the crisis on the 3-month horizon, wavelet diversification resulted in a Sharpe ratio of 1.20. This is significantly higher than that of equally weighted (0.61) and S&P 500 portfolios (0.31). In addition, the Sharpe ratios of Wavelet portfolio (Equally weighted) on the 1-week, 1-month and 1-year horizons are 0.26 (−0.14), 0.39 (0.11) and 1.06 (0.73), suggesting significant improvements in performance when using the Wavelet correlation method. The improvements in the results are also consistent if we compare against the SP500. Inconclusive evidence is obtained from the post-crisis period (panel C in Table 4), as

[10] We also perform wavelet correlation analysis for European currencies. We find a strong connection between European currencies (Euro, Swiss franc, Danish krone and Great Britain pound) on all time scales. However with investment currencies, European currencies show no unambiguous trend in the term structure of correlations. All additional results are available from the authors upon request.

[11] However, in the pre-crisis period the results are similar to Burnside et al. (2008).

Table 4
Logarithmic excess returns to carry trade strategies (annualized basis).

Strategy	Equally weighted carry trade portfolio			High Sharpe equally weighted portfolio			Wavelet correlation based portfolio 1			Wavelet correlation based portfolio 2			Wavelet correlation based portfolio 3			Minimum variance portfolio			Minimum CVaR portfolio			U.S. stock market (S&P 500 index)		
	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe
Panel A: full sample																								
Overnight	0.02	0.09	0.27	0.01	0.09	0.08	0.01	0.10	0.07	0.00	0.10	−0.01	0.00	0.09	0.03	0.02	0.09	0.23	0.02	0.09	0.19	0.05	0.21	0.22
1 week	0.01	0.09	0.13	0.01	0.10	0.10	0.02	0.11	0.18	0.01	0.10	0.06	0.01	0.10	0.13	0.02	0.07	0.27	0.01	0.07	0.14	0.06	0.20	0.29
1 month	0.02	0.09	0.23	0.00	0.11	0.04	0.02	0.10	0.23	0.01	0.09	0.12	0.02	0.10	0.18	0.03	0.07	0.45	0.03	0.07	0.46	0.06	0.19	0.30
3 months	0.03	0.09	0.35	0.03	0.11	0.30	0.06	0.08	0.74	0.03	0.10	0.28	0.04	0.08	0.54	0.02	0.06	0.34	0.02	0.06	0.40	0.04	0.18	0.25
1 year	0.02	0.09	0.29	0.03	0.10	0.27	0.03	0.10	0.27	0.02	0.11	0.15	0.02	0.10	0.22	0.01	0.05	0.21	0.02	0.05	0.40	0.03	0.19	0.16
Panel B: prior the crisis																								
Overnight	0.03	0.08	0.42	0.01	0.07	0.11	0.01	0.08	0.09	0.00	0.08	0.05	0.01	0.08	0.07	0.02	0.06	0.38	0.04	0.07	0.52	0.02	0.14	0.17
1 week	−0.01	0.07	−0.14	0.00	0.09	0.01	0.02	0.09	0.26	0.00	0.08	−0.05	0.01	0.08	0.12	0.01	0.06	0.22	0.03	0.07	0.40	0.03	0.14	0.21
1 month	0.01	0.08	0.11	0.01	0.09	0.13	0.04	0.09	0.39	0.02	0.08	0.21	0.03	0.08	0.32	0.03	0.06	0.49	0.05	0.07	0.65	0.04	0.13	0.32
3 months	0.04	0.07	0.61	0.07	0.06	1.19	0.08	0.07	1.20	0.04	0.06	0.73	0.06	0.06	1.05	0.02	0.05	0.42	0.04	0.06	0.72	0.03	0.10	0.31
1 year	0.04	0.06	0.73	0.06	0.05	1.05	0.05	0.05	1.06	0.02	0.05	0.45	0.04	0.05	0.76	0.03	0.04	0.87	0.06	0.05	1.23	0.06	0.08	0.73
Panel C: after the crisis																								
Overnight	0.04	0.10	0.36	0.01	0.10	0.08	0.01	0.11	0.08	0.00	0.11	−0.02	0.00	0.11	0.03	0.00	0.07	0.06	0.00	0.07	0.02	0.06	0.26	0.23
1 week	0.03	0.10	0.31	0.02	0.11	0.15	0.02	0.12	0.13	0.01	0.11	0.12	0.02	0.11	0.13	0.01	0.06	0.14	0.03	0.07	0.40	0.06	0.26	0.25
1 month	0.03	0.11	0.31	0.00	0.12	−0.01	0.01	0.11	0.11	0.01	0.11	0.08	0.01	0.10	0.09	0.03	0.06	0.51	0.04	0.06	0.60	0.05	0.25	0.21
3 months	0.02	0.11	0.18	0.01	0.12	0.05	0.05	0.09	0.52	0.02	0.11	0.14	0.03	0.09	0.34	0.03	0.06	0.47	0.03	0.06	0.50	0.03	0.23	0.15
1 year	0.01	0.10	0.15	0.01	0.11	0.06	0.01	0.12	0.11	0.01	0.13	0.09	0.01	0.12	0.10	0.02	0.05	0.42	0.01	0.06	0.20	0.00	0.25	0.02

The table provides results for the whole sample, which ranges from June 16, 2003 to December 31, 2012. Prior and after sections (panels B and C) show summary statistics for the sample before and after the Lehman Brothers collapse (September 15, 2008), respectively. SD stands for the sample standard deviation, Sharpe for Sharpe ratio. Wavelet portfolio 1 consists of two carry trade currency pairs with lowest wavelet correlation re-balanced annually. Wavelet portfolio 2 is composed of two currency pairs with the second lowest wavelet correlation. Wavelet portfolio 3 is composed of two wavelet portfolios (1 and 2) with equal weights. High Sharpe portfolio consists of four equally weighted annually rebalanced carry trade currencies with highest Sharpe ratio. Equally weighted carry trade portfolio consists of all studied currencies with equal weights assigned to each. Also, point estimates of minimum variance and minimum CVaR portfolios are reported. All results are presented on an annualized basis.

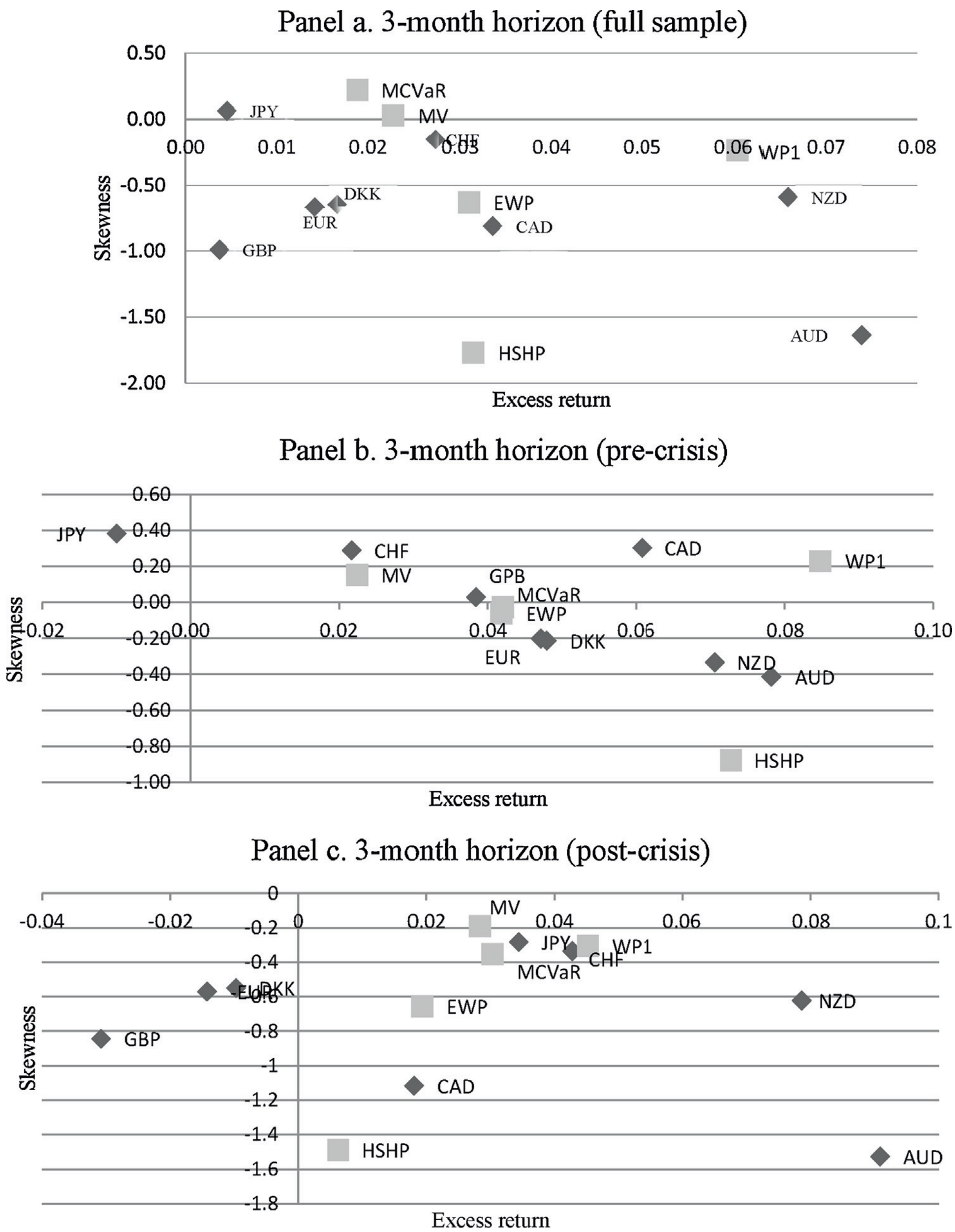

Fig. 3. Skewness and excess returns. EW, WP1, MV, MCVaR and HSHP stand for equally weighted, Wavelet 1, minimum variance, minimum CVaR and high Sharpe portfolios, respectively.

the wavelet diversification resulted in low Sharpe ratios compared to Equally weighted portfolio, yet higher relative to High Sharpe portfolios on most of the time scales. This happens due to peculiarities of portfolio formation, as two year window to estimate wavelet coefficients on longer scales was used. In summary, wavelet based diversification provided Sharpe ratios mostly higher than S&P 500 and equally weighted portfolio in most of time scales over the full and pre-crisis samples.

Table 5
Logarithmic excess returns to carry trade strategies (emerging countries, annualized basis).

Strategy	Equally weighted carry trade portfolio			High Sharpe equally weighted portfolio			Wavelet correlation based portfolio 1			Wavelet correlation based portfolio 2			Wavelet correlation based portfolio 3			Minimum Variance portfolio			Minimum CVaR portfolio			U.S. stock market (S&P 500 index)		
	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe	Mean	SD	Sharpe
Panel A: full sample																								
Overnight	0.01	0.06	0.11	0.03	0.06	0.54	0.06	0.10	0.63	0.04	0.09	0.46	0.05	0.09	0.59	0.08	0.08	1.00	0.04	0.07	0.59	0.05	0.21	0.22
1 week	0.00	0.10	0.02	0.03	0.05	0.52	0.03	0.09	0.35	0.02	0.09	0.23	0.03	0.09	0.28	0.02	0.02	1.06	0.01	0.02	0.83	0.06	0.20	0.29
1 month	0.00	0.10	0.02	0.02	0.04	0.47	0.04	0.08	0.60	0.04	0.10	0.41	0.04	0.09	0.48	0.01	0.03	0.45	0.01	0.03	0.34	0.06	0.19	0.30
3 months	0.01	0.08	0.07	0.03	0.07	0.41	0.05	0.07	0.81	0.03	0.03	0.85	0.04	0.04	1.00	0.01	0.03	0.38	0.01	0.04	0.27	0.04	0.18	0.25
1 year	0.00	0.08	0.04	0.03	0.11	0.27	0.03	0.06	0.58	0.02	0.05	0.43	0.03	0.05	0.52	0.01	0.03	0.26	0.01	0.03	0.26	0.03	0.19	0.16
Panel B: prior the crisis																								
Overnight	0.04	0.04	0.84	0.06	0.08	0.71	0.11	0.13	0.85	0.06	0.09	0.65	0.09	0.11	0.76	0.12	0.19	0.62	0.14	0.15	0.92	0.02	0.14	0.17
1 week	0.03	0.05	0.52	0.07	0.05	1.25	0.05	0.07	0.66	0.06	0.10	0.61	0.05	0.09	0.64	0.04	0.04	0.89	0.04	0.03	1.09	0.03	0.14	0.21
1 month	0.03	0.06	0.56	0.03	0.04	0.72	0.07	0.06	1.09	0.05	0.06	0.78	0.06	0.06	0.97	0.03	0.03	1.07	0.03	0.03	1.11	0.04	0.13	0.32
3 months	0.04	0.04	0.94	0.09	0.07	1.33	0.09	0.08	1.14	0.06	0.07	0.91	0.08	0.07	1.02	0.03	0.03	1.12	0.04	0.03	1.22	0.03	0.10	0.31
1 year	0.04	0.03	1.28	0.07	0.06	1.09	0.04	0.06	0.74	0.03	0.06	0.51	0.04	0.06	0.63	0.02	0.08	0.29	0.03	0.02	1.45	0.06	0.08	0.73
Panel C: after the crisis																								
Overnight	−0.03	0.08	−0.35	0.01	0.15	0.07	0.02	0.05	0.34	0.02	0.07	0.24	0.02	0.06	0.24	0.02	0.03	0.91	−0.10	0.17	−0.56	0.06	0.26	0.23
1 week	−0.02	0.10	−0.24	0.01	0.11	0.13	0.01	0.05	0.22	−0.01	0.09	−0.16	0.00	0.07	−0.02	0.00	0.03	0.10	0.00	0.03	0.10	0.06	0.26	0.25
1 month	−0.03	0.10	−0.26	0.00	0.11	−0.03	0.02	0.06	0.37	0.02	0.09	0.27	0.02	0.07	0.37	−0.07	0.20	−0.34	0.00	0.03	−0.13	0.05	0.25	0.21
3 months	−0.03	0.11	−0.31	0.00	0.09	0.02	0.01	0.08	0.17	0.00	0.04	0.10	0.01	0.06	0.13	−0.01	0.03	−0.19	0.00	0.04	−0.12	0.03	0.23	0.15
1 year	−0.03	0.10	−0.36	0.00	0.09	−0.02	0.01	0.05	0.20	0.00	0.05	0.00	0.00	0.05	0.09	−0.01	0.03	−0.20	−0.01	0.03	−0.19	0.00	0.25	0.02

The table provides results for the sample of emerging countries, ranging from June 16, 2003 to December 31, 2012. Prior and after sections (panels B and C) show summary statistics for the sample before and after the Lehman Brothers collapse (September 15, 2008) respectively. SD stands for the sample Standard Deviation, Sharpe for Sharpe ratio. Wavelet portfolio 1 consists of two carry trade currency pairs with lowest wavelet correlation re-balanced annually. Wavelet portfolio 2 is composed of two currency pairs with the second lowest wavelet correlation. Wavelet portfolio 3 is composed of two wavelet portfolios (1 and 2) with equal weights. High Sharpe portfolio consists of four equally weighted annually rebalanced carry trade currencies with highest Sharpe ratio. Equally weighted carry trade portfolio consists of all studied currencies with equal weights assigned to each. Also, point estimates of Minimum Variance and Minimum CVaR portfolios are reported. All results are presented on an annualized basis.

Fig. 3 depicts the skewness-return characteristics of individual carry trades and constructed portfolios on a 3-month time scale, which is the most common horizon for carry trade studies. Breaking the time series of exchange rate returns into a series of wavelet coefficients and revealing the temporal structure of correlations helps us to identify the currency pairs with the lowest correlation coefficient on each time scale. These currency pairs yield the greatest diversification benefits and, largely, the best possible return-skewness characteristics (see WP1 in Fig. 3). As shown in Fig. 3, the distribution of Wavelet diversified portfolio returns (see WP1 in Fig. 3) has better skewness (around zero) and higher mean, than individual currency carry trade or equally weighted portfolio (see EWP in Fig. 3). Wavelet correlation based portfolio appears to have better skewness on a time scale of 3 months. Even though carry trades are often viewed by market practitioners as "picking up a penny in front of the moving truck", assuming possible sudden losses, our empirical analysis proves that a strategy built by accounting for the temporal structure of correlations largely provides downside protection from sudden currency crashes.

5. Additional results

In order to further investigate the benefits of wavelet carry trade diversification and provide the robustness of our previous results, we extend our analysis to currencies of emerging countries. In this additional analysis, we consider the data sample of twelve emerging countries. By using daily exchange rates of the selected countries, we carry out the analysis of carry trade diversification opportunities and examine the temporal structure of correlations among the most common carry trade currencies[12] (Table 5).

The results obtained with subsample of emerging countries are largely similar to previous findings, supporting the notion that portfolio composition on the basis of wavelet correlations of returns with dynamic re-balancing lead to Sharpe ratios higher than the benchmark portfolios on most of the time scales. Similar to subsample of developed countries, wavelet diversification benefits are more pronounced in the pre-crisis period.

6. Conclusions

This study focuses on the analysis of linkages between major carry trade currencies and carry trade diversification opportunities. The study extends the analysis of carry trade diversification by examining the temporal structure of correlations and assessing the portfolio diversification benefits with wavelet techniques. Moreover, the paper investigates carry trade payoffs on five different time scales and provides evidence of Uncovered Interest Parity condition on different investment horizons.

The empirical findings reported in this study demonstrate that portfolio composition on the basis of wavelet correlations of returns with dynamic re-balancing led to Sharpe ratios higher than the simply diversified portfolios and stock market proxy on most of the time scales. Results are more pronounced in the pre-crisis period. Wavelet diversified portfolios had better skewness-return characteristics on a 3-month time scale, showing more positive skewness than individual carry trade strategies while posting similar returns. The results of the wavelet correlation analysis suggest that patterns in exchange rate movements exist and interdependencies with portfolio diversification implications may be found and exploited by investors.

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[12] Also, we carry out the wavelet correlation analysis of returns between selected emerging currencies before and after the financial crisis of 2008, respectively. To save space, these results are not reported, but are available upon request.

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