Currency Carry Trades, Position-unwinding Risk, and Sovereign Credit Premia*

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Abstract

In this paper we derive the measure of position-unwinding risk of currency carry trade portfolios, which covers the moment information, from the currency option pricing model. We show that high interest-rate currencies are exposed to higher position-unwinding risk than low interest-rate currencies. We also investigate the sovereign CDS spreads as the proxy for solvency of a state and find that high interest-rate currencies load up positively on sovereign default risk while low interest-rate currencies provide a hedge against it. Sovereign credit premia, as the dominant economic fundamental risk, together with position-unwinding likelihood indicator as the market risk sentiment, captures over 90% of cross-sectional variations of carry trade excess returns. Sovereign default risk also explains large proportions of the cross sections of currency momentum and volatility risk premium portfolios. We further identify sovereign default risk as the country-specific fundamental risk that drives market volatility, and its global contagion channels. In this context, the forward premium puzzle can be understood as a composite story of sovereign credit premia, global

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liquidity imbalances and reversal. We also propose a threshold carry trade strategy, which is immunized from crash risk and hence presents a new challenge to theories attempting to explain the puzzle.

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1. Introduction

According to the Uncovered Interest Rate Parity (UIP) condition, if the investors with rational expectations are risk-neutral, the changes in the bilateral exchange rates will eliminate any profit arising from the appropriate interest differential. However, numerous empirical studies show that the appreciations of low interest-rate currencies do not compensate for the corresponding interest rate differentials. Instead, the high interest-rate currencies tend to appreciate rather than depreciate. Carry trade, as one of the most popular trading strategies in the foreign exchange (FX) market, exploits the profits from the violation of UIP by investing in high interest-rate currencies while financing in low interest-rate currencies. The excess returns of carry trades give rise to the so-called "forward premium puzzle" (Hansen and Hodrick, 1980; Fama, 1984): a projection of the forward premium onto the interest differential produces a coefficient that is closer to minus one than plus one. Given the high liquidity in global FX market and the free mobility of international capital, it is difficult to justify the unreasonably long-existing profits of carry trade strategies[1]. Time-varying risk premia is a straightforward and theoretically convincing solution towards this puzzle in the economic sense that high interest-rate currencies deliver high returns merely as a compensation for high risk exposures during periods of turmoil (Fama, 1984; Engel, 1996; Christiansen, Ranaldo, and Söderlind, 2011). Verdelhan (2010) shows that agents with preference settings in Campbell and Cochrane (1999) can generate notable deviation from UIP due to the consumption habit. Infrequent currency portfolio decision is another possible solution that also accounts for "delayed overshooting" (Bacchetta and Van Wincoop, 2010). Burnside, Eichenbaum, and Rebelo (2009) argue from the perspective

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[1] Although this type of trading strategies had suffered substantial losses since the outbreak of sub-prime mortgage crisis during 2007 (particularly after the bankruptcy of Lehman Brothers in the mid of September 2008, see Figure B.1. in Appendix B), it recovered soon around the mid of 2009 and the losses are relatively small compared to its historical cumulative returns (Brunnermeier, Nagel, and Pedersen, 2009).

of market microstructure that it is the adverse selection from which the forward premium puzzle arises. Burnside, Han, Hirshleifer, and Wang (2011) further suggest a behaviorial explanation of investors' overconfidence for the forward bias.

Bansal and Dahlquist (2000) are the first to examine the cross-section relations between currency risk premia and interest rate differentials. They show that UIP works better for currencies that experience higher inflation rates. In the more recent empirical literature, Lustig, Roussanov, and Verdelhan (2011) introduce a portfolio-sorting approach using forward discounts into the study of currency carry trades. Instead of analysing individual currencies, they focus on currency portfolios facilitating the elimination of a large amount of time-varying country idiosyncratic characteristics[2], in order to overcome the problem that these characteristics are potentially time-varying across countries, and to concentrate on their common characteristics. For those currencies that Covered Interest Rate Parity (CIP) holds, sorting by forward discounts is equivalent to sorting by interest rate differentials (see Akram, Rime, and Sarno, 2008). Lustig, Roussanov, and Verdelhan (2011) demonstrate that the first two principal components of the excess returns of the these portfolios account for most of the time series variations. The first principal component (PC_1) is essentially the average excess returns of all portfolios, which can be interpreted as the average excess returns of a zero-cost strategy that an investor borrows in USD for investing in the global money market outside U.S., so-called "dollar risk factor" (GDR). It is an intercept (level) factor because each portfolio shares roughly the same exposure to it. The second principal component, (PC_2), is a slope factor in the sense that the weight of each portfolio, from the one containing the highest interest-rate currencies to the one made up of low interest-rate currencies,

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[2] As highlight by Cochrane (2005), the prices of individual assets are highly volatile and thereby their expected returns, covariances and betas become difficult to measure accurately. a portfolio approach reduces the volatilities by diversification.

decreases monotonically from positive to negative. It is also very similar to the excess returns of another zero-cost strategy with long positions in highest interest-rate currencies funded by short positions in lowest interest-rate currencies. Hence, we call it "forward bias risk factor", denoted by HML_{FB}.

The two common factors first documented in Lustig, Roussanov, and Verdelhan (2011) are the key ingredients for a risk-based explanation of currency carry trades' excess returns. The risk factors identified by this data-driven approach are in fact in line with Arbitrage Pricing Theory by Ross (1976) while other standard risk factors, such as consumption growth (Lustig and Verdelhan, 2007) measured by durable Consumption-based CAPM (C-CAPM) setting of Yogo (2006), Chicago Board Options Exchange's (CBOE) VIX index as the measure of volatility risk, T-Bill Eurodollar (TED) Spreads as the illiquidity risk indicator, Pástor and Stambaugh's (2003) liquidity measure, and Fama and French (1993) factors, do not covary enough with the currency excess returns to explain the profitability of carry trades (Burnside, 2011; Burnside, Eichenbaum, Kleshchelski, and Rebelo, 2011). Grounded on the theoretical foundations of Merton's (1973) Intertemporal CAPM (I-CAPM)[3], Menkhoff, Sarno, Schmeling, and Schrimpf (2012a) propose the global volatility (innovation) risk (GVI) of FX market instead of HML_{FX} as the slope factor that, along with GDR as the level factor, also successfully explains the cross sectional excess returns of currency carry trades. They show that high interest-rate currencies deliver low returns in the times of high unexpected volatility while low interest-rate currencies offer a hedge a-

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[3] The ICAPM model assumes that investors are concerned about the state variables, which exert evolutionary influences on the investment opportunities set. Market-wide volatility (not the idiosyncratic volatility) is a good proxy for the investment sentiment of market states. As the result, a risk-averse agent wishes to hedge against unexpected changes (innovations) in market volatility, especially during the period of high unexpected volatility the hedging demand for assets that have negative exposures to systematic volatility risk drives up the prices of these assets. Campbell (1993), Ang, Hodrick, Xing, and Zhang (2006), Adrian and Rosenberg (2008) have made remarkable extensive researches on the volatility risk of stock markets.

gainst high volatility risk by yielding positive returns. However, these studies haven't bridged the gap between currency risk premia and macroeconomic fundamentals.

One contribution of our research to empirical asset pricing of currency carry trades is that we rationalize the carry trades' excess returns from the perspective of sovereign credit risk as the dominant macroeconomic fundamental (country-specific) risk, which is strongly supported by our empirical results. The investigation is founded on the theory of a country's external adjustment to the global imbalances through the valuation channel of exchange rates (Gourinchas and Rey, 2007). The heterogeneity in countries' ability to produce financial assets for global savers determines the dynamics of bilateral exchange rates in allocating portfolios between the imperfectly substitutable foreign and domestic assets (Caballero, Farhi, and Gourinchas, 2008). The currency of a debtor country must offer a risk premium for the financial intermediaries to absorb the exchange rate risk associated with the global imbalances arising from international capital flows (Gabaix and Maggiori, 2014), but it is exposed to large depreciation risk when their risk-bearing capacity declines, e.g. high market risk sentiment and funding liquidity constraint (Brunnermeier and Pedersen, 2009; Ferreira Filipe and Suominen, 2013). Moreover, global imbalances are the crucial macroeconomic determinant of sovereign credit risk. Hilscher and Nosbusch (2010) emphasize the volatility of terms of trade as the key component. Durdu, Mendoza, and Terrones (2013) show that a country with weak solvency needs to respond strongly to the Net Foreign Assets (NFA) to keep it on a sustainable path. In particular, Schularick and Taylor (2012) demonstrate that a credit boom is a powerful predictor of financial crises, only in which currency carry trades suffer substantial losses. However, global imbalances is weakly correlated with the financial distresses. This is why we resort to sovereign credit risk that embraces the information not only on global imbalances but also on financial distress.

Our investigation is also rooted in the implicit sovereign component of the term structure models of interest rates and currency forward rates. The yield curve factors forecast future spot rate movements of foreign exchange market from one month to two years ahead, which is robust to controlling for other predictors (Ang and Chen, 2010; Chen and Tsang, 2013). Clarida, Davis, and Pedersen's (2009) study indicates that yield curve factors are strongly correlated with carry trade excess returns. By decomposing the yield curve, Cochrane and Piazzesi (2009) incorporate bond risk premia in an affine term structure model. Longstaff, Pan, Pedersen, and Singleton (2011) decompose the term structure of sovereign CDS spreads (Pan and Singleton, 2008) and find a strong association between macroeconomic factors and the default risk component. In the multi-factor, two-country term structure and exchange rate model built by Ahn (2004), exchange rate risk premia are shown to be a function of the differentials in the sovereign bonds risk premia. In particular, both the short-term interest rates and the term spreads may be decomposed into the market liquidity risk component and a sovereign credit risk component that even short rates reflects the rollover risk of maturing debt and refinancing constraint of a country in short run (see Acharya, Gale, and Yorulmazer, 2011; He and Xiong, 2012 for the analyses of stock market). The currencies of debtor countries offer risk premia to compensate foreign creditors who are willing to finance the domestic defaultable borrowings, such as current account deficits. The business cycle theory of sovereign default proposed by Mendoza and Yue (2012) also implies that countercyclical sovereign credit risk may account for the currency risk premia. The advantage of tracking sovereign risk by a country's CDS spreads rather than its Net International Investment Position (NIIP) is that we cannot observe the net foreign assets in monthly frequency (see Lane and Milesi-Ferretti (2007) for annual panel data), but we can trade currencies on their sovereign CDS spreads daily.

Another contribution of our research is that we, motivated by the crash risk story about currency carry trades of Brunnermeier, Nagel, and Pedersen (2009), originally derive the position-unwinding likelihood indicator of carry trade portfolios from the extended version of classical option pricing model (Black and Scholes, 1973; Merton, 1974) for foreign exchanges by Garman and Kohlhagen (1983). That the crash (jump) risk is priced in currency excess returns is also stressed by other scholars' recent studies, such as Jurek (2007), Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2009), Chernov, Graveline, and Zviadadze (2012). And the option prices might in principle uncover latent disaster risk of exchange rates (Farhi and Gabaix, 2008). We thereby adjust the position-unwinding likelihood indicator for skewness and kurtosis by Gram-Charlier expansion for standard normal distribution density function. The position-unwinding risk factor is highly correlated with the global (dollar) risk factor, which may be deemed as supportive evidence for Brunnermeier, Nagel, and Pedersen's (2009) liquidity spiral story. Carry trade excess returns portray the "self-fulfilling" behavior that investors boost the price (appreciation of a currency) in good times and realize their profits by unwinding carry positions in bad times, triggering further dips. Currency carry trades give rise to global liquidity transfer. The liquidity will keep injecting into the high interest-rate currencies and generates the negative skewness phenomenon against the low interest-rate currencies[4] (and that's why the position-unwinding likelihood indicator is closely associated with the global skewness factor we construct) as long as the position-unwinding likelihood does not exceed a critical value of sustainable "global liquidity imbalances", which is intimately related to the market sentiment and economic fundamentals, e.g. the mismatch between short-term and otherwise maturing external debts and the pledgeable value of external assets of a nation, and the funding liquidity constraints (Gabaix and Maggiori, 2014). As pointed out by Hellwig, Mukherji, and Tsyvinski (2006), the UIP may be attributable to the

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[4] See Plantin and Shin (2011). They build a strategic games framework to demonstrate the destabilizing effect of currency speculative positions.

self-fulfilling expectations and multiple equilibria that traders have heterogeneous private information about the likelihood of a devaluation. When the line is believed to be crossed over, the traders begin to unwind their positions as the bubble-correcting behavior of the market (Abreu and Brunnermeier, 2003), followed up by abrupt price reversal and liquidity withdrawal from the investors (Plantin and Shin, 2011). The liquidity eventually dries up, leading to the crash of high interest-rate currencies (dramatic depreciations relative to the low interest-rate currencies). In this paper, we employ a Smooth Transition Model (STR) to identify this threshold level implied by the position-unwinding likelihood indicator. This will be discussed in detail later in this paper.

Furthermore, we show that the two-factor model of sovereign credit risk and position-unwinding risk performs well and has a robust performance in terms of cross-sectional pricing power in our data. Also following the economic intuition of the position liquidation story of currency crashes, we further construct aggregate realized skewness and kurtosis factors as proxy for crash risk. The global skewness factor again highly correlated with the global (dollar) risk factor. The position-unwinding risk of carry trades is closely linked with the aggregate level of volatility and skewness risk in FX market. Position-unwinding likelihood indicator and global skewness risk as intercept factors[5] mutually confirm that large depreciations usually are rarely an individual currency's behavior but the systemic risk of the global market or the regionally integrated market that currencies tend to depreciate sharply against USD at aggregate level during the high volatility regime, indicating the 'safe haven' feature of USD-denominated assets. This also suggests that although there was an initial shock to the U.S. economy in 2008, overall, the negative effect of the spillover of this shock to the global economy was even greater. Thus, we suggest the position-unwinding likelihood indicator as the gauge of market risk appetite, and propose an alternative carry trade

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[5] Their correlations with PC_2 are consistently very low, see Table B.4..

strategy that is immunized from crash risk by analyzing the threshold level.

We also examine the robustness of our main findings in various specifications without altering their qualitative features: (i) We use alternative measure of sovereign credit risk based on government bonds, which explains the excess returns of currency carry trades as well as the factor directly implied by the currencies and the innovations in global sovereign CDS spreads. (ii) By double sorting of the currencies on both sovereign CDS spreads and equity premia, we show that equity risk premium is not priced in the cross-section of currency carry trade excess returns. (iii) We winsorize the sovereign credit factor series at 95% and 90% levels, and confirm that this factor does not represent a peso problem. The factor price of the sovereign credit risk is statistically significant, about 3.3% per annum. (iv) We show that sorting currencies on their betas with sovereign credit risk is quite similar but not identical to those sorted on forward discounts. Currency portfolios doubly sorted on betas with both sovereign credit risk and position-unwinding risk also exhibit monotonic patterns in returns along both dimensions and are more close to currency carry portfolios. (v) Given that the position-unwinding risk and innovations in global CDS spreads are not return-based series, by building a factor-mimicking portfolio, we're able to confirm their validity and reliability as arbitrage-free traded factors. (vi) We verify that position-unwinding likelihood indicator is a good proxy for global crash risk by introducing two additional (moment) factors, global skewness and kurtosis risk. Moreover, we shows that it is trivial to adjust the standard normal probability distribution for skewness and kurtosis in the option pricing model to compute the position-unwinding likelihood indicator of carry trade positions. (vii) We compare the cross-sectional asset pricing power of our slope factor with volatility and liquidity factors and show that the sovereign credit risk dominates liquidity risk but not volatility risk. (viii) We assess the abrupt changes in risk exposures of the currency carry portfolios in a two-state Markov regime-switching model with smoothed transition probabilities and find that linear factor model is satisfactory and nonlinearity does not capture much additional cross-sectional variation. (ix) We find that the sovereign credit risk factor can also price the cross sections of currency momentum and volatility risk premium portfolios (see Huang, MacDonald, and Zhao, 2013). (x) We use both linear and nonlinear Granger causality test to analyze the dynamics among risk factors, and identify not only the sovereign credit risk as an impulsive factor that drives other country-specific factors, such as volatility and liquidity risk, but also the spillover channel of the contagious country-specific risk to the global economy, and accordingly propose the practice of a currency trading strategy that carry positions are immunized from crash risk through the analysis of the threshold level of position-unwinding likelihood indicator.

The rest of this paper is organized as follows: Section 2 introduces the measure of position-unwinding risk of carry trades by currency option pricing model. Section 3 describes the theoretical foundations for sovereign credit premia based on existing theories. Section 4 provides the information about the data set used in this paper, and the approaches for portfolio and risk factor construction. In Section 5, we introduce the linear factor model and the estimation methodologies. In Section 6, we show the empirical results, compare the asset pricing performance of our benchmark model with others, and discuss the implications for forward premium puzzle. Section 7 presents several additional robustness checks for our findings. In Section 8, we investigate the factor dynamics by both linear and nonlinear Granger causality tests. A threshold carry trade strategy is put forward in this section. Conclusions are drawn in Section 9. The main findings of this paper are delegated to Appendix A while Appendix B is complementary for additional interests in the intermediates of the empirical tests.

2. Measuring Position-unwinding Risk

Carry trades has been a very popular strategy in the FX market, and has experienced several periods[6] of "dramatic position-unwinding" in the past 30 years. Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) find that standard business cycle risk factors are unable to account for these major shortfalls of carry trades. Using currency options to protect the downside risk, they construct hedged carry positions and show that the payoffs to such hedged strategies are very close to those of unhedged carry trades. This result may imply the mispricing of currency options (particularly those trading away from money) used for hedging the carry positions, as pointed out by Farhi and Gabaix (2008), that option might in principle uncover the latent disaster risk. This is because if the crash risk of the underlying asset is ignored or underestimated, a currency option would be significantly undervalued, and in this situation the payoffs to the hedged carry trades could be different from those of the unhedged positions. This difference in between unhedged and hedged carry trade portfolios can be justified as the variance risk premium (Carr and Wu, 2009), the skewness risk premium (Kozhan, Neuberger, and Schneider, 2013), or even the kurtosis risk premium. Jurek (2007) shows that the excess returns of a crash-neutral currency carry position are statistically indistinguishable from zero. The crash risk premia contribute $30\% - 40\%$ to the total currency risk premia. In this sense, we put forward a measure of position-unwinding risk of currency carry trades from the option pricing model and argue that one possible way to understand the excess returns of the carry trades lies in the changes in the non-risk-neutral[7] market sentiment of the probability that the positions might be unwound.

We build the position-unwinding likelihood indicator in a similar way to

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[6] They're around the second quarter of 1986 - the mid of 1986, the last quarter of 1987 - the first quarter of 1988, the mid of 1992 - the mid of 1993, the first quarter of 1995, the mid of 1997 - the mid of 1998, the mid of 2008 - the mid of 2009.

[7] The term "risk neutrality" here does not refer to the "no-arbitrage" condition.

Vassalou and Xing's (2004) for evaluating the default risk premia in equity returns. We use the canonical option pricing formula (Black and Scholes, 1973) as they do. The difference is that their strike prices are the book value of firm's liabilities, as in Merton (1974), while we set the strike prices to be the forward rate so that both of the CIP and UIP are embodied in the option pricing model. We also compute the currency option prices based on Garman and Kohlhagen's (1983) version for currency option valuation for hedging the carry trade positions. The higher moments, such as skewness and kurtosis are ignored in these option pricing models. However, for the currency carry trades, Brunnermeier, Nagel, and Pedersen (2009) show a negative cross-sectional correlation between interest rate differentials and empirical skewness, also the implied (risk neutral) skewness of the out-of-money option "risk reversals". The tail risk is of paramount importance for illuminating currency crash premia (Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan, 2009) and the jump risk account for 25% of the total currency risk, and as high as 40% during the turmoil periods (Chernov, Graveline, and Zviadadze, 2012). They also show that the probability of the depreciation jump of a currency is positively associated with the increase in its interest rate. Moreover, if agents are averse to kurtosis, which measures the dispersion of the extreme observations from the mean, this is consistent with Dittmar's (2002) nonlinear pricing kernel framework. Hence, we adjust the option pricing model by introducing the third and fourth moments as the higher order terms expansion.

2.1. Currency Option Pricing Model

It is assumed that the spot rates S_t of a currency pair (indirect quotes[8]) follows a geometric Brownian motion (GBM) of the form with an instantaneous drift μ and an instantaneous volatility σ:

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[8] Units of foreign currency per unit of domestic currency (USD).

$$\mathrm{d}S_t = \mu\, S_t\, \mathrm{d}t + \sigma\, S_t\, \mathrm{d}W \tag{1}$$

where W is the standard Wiener process. Then the value of the spot rates at any time $t+T$ is given by:

$$\ln S_{t+T} = \ln S_t + \left(\mu - \frac{\sigma^2}{2}\right) T + \sigma\sqrt{T}\,\varepsilon_{t+T} \tag{2}$$

where

$$\varepsilon_{t+T} = \frac{W(t+T) - W(t)}{\sqrt{T}} \quad \text{and} \quad \varepsilon_{t+T} \sim \mathcal{N}(0,1) \tag{3}$$

$\mathcal{N}(0,1)$ is the Gaussian *i.i.d.* standard normal distribution. The value of a call option for a currency pair with the strike price of X_t and the time to maturity of T at time t is:

$$c_t = S_t\, \exp(-r_t\, T)\, \mathbb{N}(d_1) - X_t\, \exp(-r_t^*\, T)\, \mathbb{N}(d_2) \tag{4}$$

For the put option:

$$p_t = X_t\, \exp(-r_t^*\, T)\, \mathbb{N}(-d_2) - S_t\, \exp(-r_t\, T)\, \mathbb{N}(-d_1) \tag{5}$$

where

$$d_1 = \frac{\ln(S_t/X_t) + \left(r_t^* - r_t + \frac{1}{2}\,\sigma^2\right) T}{\sigma\sqrt{T}} \quad \text{and} \quad d_2 = d_1 - \sigma\sqrt{T} \tag{6}$$

r_t, r_t^* denotes domestic (U.S.) risk-free interest rate, and foreign risk-free interest rate, respectively. $\mathbb{N}(\cdot)$ is the cumulative density function of standard normal distribution. We can reproduce the currency prices for hedging the carry trade positions by setting $X_t = F_t$ and the implication of CIP, then Equation (6) is simplified as:

$$d_1 = \frac{\sigma\sqrt{T}}{2} \quad \text{and} \quad d_2 = -\frac{\sigma\sqrt{T}}{2} \tag{7}$$

Now, we turn to the application of this model for evaluating the position-unwinding risk.

2.2. Position-unwinding Likelihood Indicator

Under the condition that CIP holds, we have:

$$1 + r_t = (1 + r_t^*)\,\frac{S_t}{F_t} \tag{8}$$

F_t is the forward rate with the same maturity of T as r_t and r_t^*. Therefore, $\ln F_t - \ln S_t \simeq r_t^* - r_t$. When $r_t^* > r_t$, implying $F_t > S_t$, a U.S. investor takes a carry position to short USD for long foreign currencies which is equivalent to betting on $S_{t+T} < F_t$. This means that the future sport rate of the USD will not appreciate as much as the CIP predicts or even will depreciate because of the failure of UIP, which claims that $S_{t+T} = \mathbb{E}_t[S_{t+T}|S_t] = F_t$. If the U.S. investor does not enter a forward contract for the carry position he has already taken, the amount of the assets in USD on his wealth balance sheet will be $(1+r_t^*)\,S_t/S_{t+T}$ while $1+r_t$ is the amount of USD-denominated liabilities that he has to pay back at $t+T$. Thus, if it turns out that $S_{t+T} \geq F_t$ at time $t+T$, the U.S. investor will go bankrupt and have to liquidate his carry position. Then, the position-unwinding probability of a currency pair i at t is the probability that the S_{t+T} will be greater than the F_t.

$$\psi_{t+T} = \Pr\ (S_{t+T} \geq F_t \mid S_t) = \Pr\ (\ln S_{t+T} \geq \ln F_t \mid \ln S_t) \tag{9}$$

We can rewrite the position-unwinding risk for any long position of carry trades by plugging Equation (2) into Equation (9):

$$\psi_{t+T} = \Pr\left(\ln S_t - \ln F_t + \left(\mu - \frac{\sigma^2}{2}\right) T + \sigma\sqrt{T}\,\varepsilon_{t+T} \geq 0\right) \tag{10}$$

Equation (10) can be rearranged as below:

$$\psi_{t+T} = \Pr\left(-\frac{\ln(S_t/F_t) + \left(\mu - \frac{1}{2}\,\sigma^2\right)T}{\sigma\,\sqrt{T}} \leq \varepsilon_{t+T}\right) \tag{11}$$

Similarly, the position-unwinding probability for any short position in a currency pair i at t is given by:

$$\psi_{t+T} = \Pr\left(-\frac{\ln(S_t/F_t) + \left(\mu - \frac{1}{2}\,\sigma^2\right)T}{\sigma\,\sqrt{T}} \geq \varepsilon_{t+T}\right) \tag{12}$$

We define the distance to "bankruptcy" (DB) for a FX trader, then the position-unwinding risk for a single currency pair is computed as follows:

$$DB_{t+T} = -\frac{\ln(S_t/F_t) + \left(\mu - \frac{1}{2}\,\sigma^2\right)T}{\sigma\,\sqrt{T}} \tag{13}$$

$$\psi_{t+T} = \begin{cases} 1 - \Pr\left(DB_{t+T}\right) & \text{if the currency is in long position;} \\ \Pr\left(DB_{t+T}\right) & \text{if the currency is in short position.} \end{cases} \tag{14}$$

where $\Pr\left(DB_{t+T}\right) = \mathbb{N}(DB_{t+T})$. DB_{t+T} tells us by how many standard deviations the log of the ratio of S_t/F_t needs to deviate from its mean in order for the "bankruptcy" to occur. Notice that value of the currency option does not depend on μ but DB_{t+T} does. This is because DB_{t+T} is determined by the future spot rates given in Equation (6). At time $t{+}T$, we use the conditional mean μ_{t+T} over a period of T from time t for the estimation of μ, and the conditional volatility σ_{t+T} over a period of T from time t for the estimation of σ.

So far, we use the theoretical distribution implied by standard option pricing models, which is standard normal distribution. However, $\mathbb{N}(\cdot)$ does not represent the true probability distribution of the currency returns because the tail risk of the currencies (skewness and kurtosis) is considerably significant. Noting that the first four moments of the underlying asset's distribution should capture most of the information for option valuation (Jarrow and Rudd, 1982), the standard definition of Hermite Polynomials (Stuart and Ord, 2009) series is truncated after its fourth term for the skewness-and-kurtosis augmented probability density function of standard normal distribution (see Backus, Foresi, and Wu, 2004):

$$h(z) = n(z)\left[1 - \frac{\varsigma}{3!}\,H_3(z) + \frac{\kappa}{4!}\,H_4(z)\right] \tag{15}$$

where

$$H_a(z)\,n(z) = (-1)^a\,\frac{\mathrm{d}^a n(z)}{\mathrm{d}z^a} \tag{16}$$

Equation (15) can be rewritten as:

$$h(z) = n(z)\left[\,1 - \frac{\varsigma}{3!}(z^3 - 3z) + \frac{\kappa}{4!}(z^4 - 6z^2 + 3)\,\right] \tag{17}$$

where $n(z)$ is the probability density function of standard normal distribution. a represents the order of the moment. ς, κ denotes the excess skewness, and excess kurtosis, respectively. These terms are estimated by the methods of realized moments similar to realized volatility (see e.g. Andersen, Bollerslev, Diebold, and Labys, 2001). The details will be discussed in Section 5. z here is actually the values of DB_{t+T}. Hence, the skewness-and-kurtosis adjusted $\Pr(DB_{t+T})$ is:

$$\Pr(z) = \int_{-\infty}^{z} h(z)\mathrm{d}z = \mathbb{N}(z) + \left[\,\frac{\varsigma}{3!}(z^2 - 1) + \frac{\kappa}{4!}(3z - z^3)\,\right]\cdot n(z) \tag{18}$$

As the historical observations of the position-unwinding behavior of carry trades is a collapse across these currency portfolios, we then compute the aggregate level of the position-unwinding risk for the whole FX market as:

$$PUW_{t+T} = \frac{1}{K_{t+T}} \sum_{i=1}^{K_{t+T}} \psi_{i,t+T} \tag{19}$$

where K_{t+T} is the number of the currencies available at time $t+T$. Strictly speaking, PUW_{t+T} is not a "bankruptcy" probability faced by the FX traders because it does not correspond to the true probability of unwound positions in large observations across business cycles. Therefore, we call PUW_{t+T} the "position-unwinding likelihood indicator", which corresponds to the excess returns of currency carry trades over the period of T from time t. Reassuringly, we will show that it is a good proxy for currency crash risk in Section 5, confirmed by the global skewness (GSQ) factor. It is also robust to the unadjusted PUW since the adjustment for both skewness and kurtosis is very trivial compared with the magnitude of probability distribution.

3. Sovereign Credit Premia

In this section, we provide the theoretical foundations that link the excess returns of currency carry trades to the sovereign credit premia through two sources. One is a possible joint affine term structure model of interest rates and sovereign CDS spreads that market liquidity component and sovereign credit component are decomposed from the interest rates. We also count on the models of global imbalances that underscores the valuation channel of a nation's net foreign asset holdings towards exchange rate adjustments, and the liquidity provision role of financial intermediaries.

3.1. Joint Affine Term Structure Model

The arbitrage-free term structure models (AF-TSM) of interest rates are an affine dynamic function of a set of state vector with restrictive assumptions, allowing us to separate risk premia from risk-adjusted expectations about future short rates. The affine sovereign CDS model is useful for gauging the sovereign credit risk in currencies when jointly valuated with the interest rates. The TSMs of interest rates are well explored jointly with the UIP of currencies both theoretically and empirically but the TSMs of sovereign CDS are rarely linked to the study of forward premium anomaly.

Backus, Foresi, and Telmer (2001) translate Fama's (1984) condition for forward premium anomaly into restrictions on the pricing kernels, adapt those to the affine interest rate term structure models of Duffie and Kan (1996) class, and reveal that several alternative models (e.g. Cox, Ingersoll, and Ross, 1985) all have serious shortcomings in depicting the behavior of both exchange rates and interest rates in terms of the positive probability of negative interest rates or heterogeneous effects of factors on pricing kernels across different currencies. Bekaert, Wei, and Xing (2007) show that deviations from the Expectations Hypothesis of the Term Structure (EHTS) can only explain a minor fraction of the failure of UIP in the long run and imposing the EHTS does affect the currency risk premia.

Ahn (2004) studies the joint dynamics of interest rate term structures and exchange rates and shows that the currency risk premia are necessary to equalize the sovereign bond premia. Alvarez, Atkeson, and Kehoe (2009) point out that the risk premium of a currency pair is approximately equal to its interest rate differential. Clarida, Davis, and Pedersen (2009) show that the yield curve level factor is positively correlated with carry trade excess returns while the slope factor negatively, and the relationships are regime-irrelevant. The predictability of currency risk premia by the information extracted from the term structures of interest rates is consistent with the "no-arbitrage" condition (Diez, 2009). Ang and Chen (2010) find that yield curve predictors, e.g. term spreads and changes in interest rates, are capable of forecasting currency excess returns up to 12 months ahead. They also stress that any variable that impacts the price of sovereign bonds can potentially improve forecasting exchange rate movements. Chen and Tsang (2013) provide supportive evidence that the forward premium puzzle can be related to the inflation and business cycle risks via the yield curves. Nevertheless, Inci and Lu (2004) point out that currency risk premia are also attributable to other factors that does not lie in the yield curves.

The existing literature has established a strong relationship between the macroeconomy (such as monetary policy, real output growth, inflation, etc.) and the yield curve using either VAR with orthogonal factors (see Ang and Piazzesi, 2003) or dynamic factor approach with Kalman filter (see Diebold, Piazzesi, and Rudebusch, 2005; Diebold, Rudebusch, and Boragan Aruoba, 2006; Rudebusch and Wu, 2008; for latent factor analysis, specifically, level, slope, and curvature). Hördahl, Tristani, and Vestin (2006) build a joint econometric model of macroeconomic and term-structure dynamics with forward-looking setting that has comparable explanatory power for yield curves to those based on unobservable factors. Bikbov and Chernov (2010) show that macroeconomic variables explain 80% of the variation in short rates, 50% of the slope, and roughly 50% to 70% of the term premia. Pan and Singleton (2008) explore the nature of the default arrival and recovery/loss implicit in the affine term structure of sovereign CDS spreads and reveal a close linkage between the unpredictable component of the credit events and the measures of macroeconomic policy, global risk aversion, and financial market volatility. All the evidence suggests the information about the sovereign credit risk as a composite indicator for macroeconomic conditions can be straightforwardly related to the changes of interest rates or term spreads, and thereby can be the possible solution to the forward premium puzzle. A joint valuation of the term structures of the interest rates, sovereign CDS spreads, and forward rates of currencies[9] is desirable in order to extract the implicit sovereign credit risk component from the yield curve

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[9] See Lustig, Stathopoulos, and Verdelhan (2013), who provide the first study of the term premia of currency carry trades.

for explaining the failure of UIP.

The reduced-form term structure model of sovereign bonds that are subject to default risk presented by Duffie and Singleton (1999) is an ideal analytical framework. Diebold, Li, and Yue (2008) further propose a global extension of Diebold and Li's (2006) dynamic version of Nelson and Siegel's (1987) TSM[10], allowing for both global and country-specific factors. Their model explains a large fraction of the yield curve dynamics and offers a guidance for the joint modeling in a global context. By decomposing the term structure of sovereign CDS spreads, Longstaff, Pan, Pedersen, and Singleton (2011) show that the default risk component is more associated with the global risk than with the country-specific risk. Cochrane and Piazzesi (2009) build an affine TSM that incorporates bond risk premia by decomposing the yield curve. Furthermore, given that sovereign credit premia not only is the risk in medium and long run but also, more importantly, represent the short-run rollover risk of maturing debts and refinancing constraint by the pledgeable claims (Acharya, Gale, and Yorulmazer, 2011; He and Xiong, 2012), both the short-term interest rates and the term spreads thereby can be decomposed into the market liquidity premium component and sovereign credit premium component for bridging the global liquidity imbalances (first component) and sovereign default risk (second component) with the excess returns of currency carry trades. Introducing the model is not the purpose of this paper, thereby it is not formulated and discussed in detail here.

3.2. Valuation Channel and Funding Liquidity Constraint of Global Imbalances

Gourinchas and Rey (2007) show that the external imbalances of a country must contains information about future portfolio returns on net foreign

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[10] Imposing Nelson and Siegel's (1987) structure on affine arbitrage-free TSMs can greatly facilitates the estimation and improve performance for forecasting (Christensen, Diebold, and Rudebusch, 2011).

assets and/or future path of current account surplus. A country currently running net external debt will inevitably experience a depreciation in its currency that is attributable to international financial adjustments through the balance sheet effect of the intertemporal budget constraint. Exchange rates not only adjust through the bilateral trade channel (Obstfeld and Rogoff, 1995) but also open a valuation channel on the external assets and liabilities that transfer wealth from creditor countries to debtor countries. They find that external imbalances predict the exchange rates at 1-quarter horizon ahead and beyond. Abhyankar, Gonzalez, and Klinkowska (2011) manage to price a large proportion of the variation in the cross-sectional excess returns (quarterly) of currency carry portfolios using conditioning information of a forward-looking net foreign assets via a standard C-CAPM.

Moreover, some recent studies reveal that market attitude towards crash risk (e.g. Baek, Bandopadhyaya, and Du, 2005; Borri and Verdelhan, 2011), macroeconomic fundamentals such as the volatility of terms of trades (see Hilscher and Nosbusch, 2010), and financial fragility (e.g. Ang and Longstaff, 2013) are well embodied in sovereign credit premia in terms of statistical and economic significance. Durdu, Mendoza, and Terrones (2013) also show that the solvency of a state responds sufficiently to the external adjustments, suggesting that sovereign credit risk plays a pivotal role of "meta information[11]" about external imbalances. Caceres, Guzzo, and Segoviano Basurto (2010) further accentuate the proper management of the debt sustainability and sovereign balance sheets as the necessary conditions for preventing the sovereign default risk from feeding back into broader financial instability. Sovereign spreads thereby contain complex information for the valuation of currency risk premia in response to external adjustments of a nation. Caballero, Farhi, and Gourinchas (2008) propose another analytical framework of global imbalances that emphasizes the countries' ability to produce financial assets for global savers/insurers. Gabaix and Maggiori (2014) show that

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[11] It refers to the concept of the information on information in informatics.

the currency of a debtor country must offer a risk premium for the financial intermediaries to absorb the exchange rate risk associated with the global imbalances arising from international capital flows, but it is exposed to the depreciation risk when their risk-bearing capacity declines, e.g. high market risk sentiment and funding liquidity constraint.

All the above-noted studies suggest a plausible linkage between currency premia and sovereign credit risk. A country with high sovereign default risk displays a high propensity to issue debts denominated in foreign (safe) currencies to make its debts more appealing to investors, and offers a high interest rate to attract foreign savings for funding its external deficit. Typically, when a country's external debts are denominated in foreign currencies, any initial depreciation of domestic currency as a consequence of e.g. a permanent negative demand shock will impose a destabilizing effect on the its net foreign asset positions via valuation channel, i.e. an increased burden of external obligations. The exchange rate will be forced to depreciate even greater or overshoot its long run equilibrium value to restore the external balance via the trade channel. The capital flight triggered by the weakened external imbalance will further result in a speculative attack and a crash on the debtor's currency. Given that the external liabilities of a creditor country are primarily denominated in domestic (safe) currency, even if it encounters with a negative global demand shock, any initial depreciation of the creditor's currency will bring a stabilizing effect via both valuation and trade channel. So during an economic recession (high volatility regime) the low sovereign default risk and low interest-rate currencies tend to appreciate against the high sovereign default risk currencies which offer high interest-rates for servicing its external liabilities. In contrast, during the expansion phase of the business cycle (low volatility regime), optimistic prospects in the future economy makes investors less risk-averse and more willing to take upon large positions of risky assets of the debtor country, including the high yield and high default risk sovereign debts. Appreciation pressures on the debtor's risky currency made by this behavior alleviates its debt burden but deteriorates the trade balance, which, in turn, increases sovereign credit risk. The relief in debt burden and the global demand of risky assets drive the debtor country to finance it external deficit via the issuances of more sovereign debts, rather than to depreciate its currency (destabilization). The liquidity keeps injecting into the debtor country to support its debt financing, creating the "global liquidity imbalances" (Gabaix and Maggiori, 2014) among the economies. However, when the liquidity dries up due to the funding liquidity constraint of financial intermediaries, and the pledgeable claims of debtor countries may not meet the short-run rollover needs of the maturing debts, then the liquidity will be withdrawn and the capital flow will reverse. The liquidity spiral brings about the crash of the debtor's currency. As for the creditor country, the heavier burden of the sovereign debts it is servicing brought by the depreciation pressure on its currency can be compensated by the amelioration of the trade balance and the decline in sovereign credit risk (stabilization). The retreat of liquidity back to the creditor country will give rise to the appreciation of its currency. This is concordant with Clarida, Davis, and Pedersen's (2009) findings that UIP holds when volatility is in the top quartile and that yield curve premia comove with the currency risk premia. Following this economic logic, we would expect a strong relationship between the currency risk premia and the sovereign credit risk.

4. Data, Portfolio Sorting and Risk Factors

Our data set, obtained from Bloomberg and Datastream, consists of spot rates and 1-month forward rates with bid, middle, and ask prices, 1-month interest rates, 5-year sovereign CDS spreads, at-the-money (ATM) option 1-month implied volatilities, 10-delta and 25-delta out-of-the-money (OTM) option 1-month risk reversals and butterflies of 35 currencies: EUR (EMU), GBP (United Kingdom), AUD (Australia), NZD (New Zealand), CHF (Switzerland), CAD (Canada), JPY (Japan), DKK (Denmark), SEK (Sweden), NOK (Norway), ILS (Israel), RUB (Russia), TRY (Turkey), HUF (Hungary), CZK (Czech Republic), SKK (Slovakia), PLN (Poland), RON (Romania), HKD (Hong Kong), SGD (Singapore), TWD (Taiwan), KRW (South Korea), CNY (China), INR (India), THB (Thailand), MYR (Malaysia), PHP (Philippines), IDR (Indonesia), MXN (Mexico), BRL (Brazil), ZAR (South Africa), CLP (Chile), COP (Colombia), ARS (Argentina), PEN (Peru), all against USD (United States); and corresponding countries' equity indices (MSCI) and government bond total return indices (Bank of American Merrill Lynch and J.P. Morgan TRI)[12] in USD.

Our sample period is restricted by the availability of sovereign CDS historical data, which only dates back to 2001 and begins with a limited coverage of countries. The unragged data for our sample countries starts from 2004, according to the database of Markit[13] and CMA Datavision[14]. To ensure consistency of time frame across assets, the sample period is chosen from September 2005 to January 2013 in a daily frequency. Furthermore, there is no existing sovereign CDS for EMU as the whole, thus we calculate its proxy spread as the external-debt weighted sovereign CDS spreads of EMU's 13 main member countries, Germany, France, Italy, Spain, Netherland, Belgium, Austria, Greece, Portugal, Ireland, Slovenia, and Luxembourg, which account for over 99% of the EMU's GDP on average in our sample period.

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[12] There are 26 countries' data available: EMU, Great Britain, Australia, New Zealand, Canada, Switzerland, Norway, Sweden, Denmark, Russia, Turkey, Hungary, Czech Republic, Poland, Japan, South Korea, Hong Kong, Taiwan, Singapore, China, India, Malaysia, Thailand, Indonesia, South Africa, and Mexico. China and India are only available from July 2007.

[13] Markit is also a leading global financial information services provider of independent data, valuation and trading process across all asset classes, also with a specialization in CDS data.

[14] CMA Datavision is the world's leading source of independent accurate OTC market pricing data and technology provider, typically specializing in the sovereign CDS pricing.

4.1. Portfolio Sorting

All currencies are sorted by forward premia from low to high, and allocated to five portfolios, e.g. Portfolio 1 (C_0) consists of the short position of currencies with the lowest 20% interest-rate differentials (lowest forward premia) while Portfolio 5 (C_5) is the long position of currencies with highest 20% interest-rate differentials (highest forward premia). The portfolios are rebalanced at the end of each forward contract according to the updated forward rate. The average monthly turnover ratio of five portfolios is about 25%, thereby the transaction costs should be considered for evaluating the profitability of carry trades. The log excess returns of a long position xr_{t+1}^{L} at time t+1 is computed as:

$$xr_{t+1}^{L} = r_t^* - r_t + s_t^B - s_{t+1}^A = f_t^B - s_{t+1}^A \tag{20}$$

where f, s is the log forward rate, and spot rate, respectively; Superscript B, A denotes bid price, and ask price respectively. Similarly, for a short position the log excess returns xr_{t+1}^{S} at the time t+1:

$$xr_{t+1}^{S} = -f_t^A + s_{t+1}^B \tag{21}$$

Currencies that largely deviate from CIP are removed from the sample for the corresponding periods[15]: IDR from the end of December 2000 (September 2005 in our data) to the end of May 2007, THB from the end of October 2005 to March 2007, TWD from March 2009 to January 2013. And due to the managed floating exchange rate regime of CNY, we also exclude it for the whole sample periods. Table A.1. below shows the descriptive statistics of currency carry portfolios.

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[15] ZAR from the end of July 1985 to the end of August 1985, MYR from the end of August 1998 to the end of June 2005, TRY from the end of October 2000 to the end of November 2001, UAE (United Arab Emirates) from the end of June 2006 to the end of November 2006. These currencies or periods are not included in our data.

[Insert Table A.1. about here]

C_1 is C_0 is long position. The statistics of portfolio mean, median, and standard deviation in excess returns all exhibit monotonically increasing patterns. We also see a monotonically decreasing skewness from C_1 to C_5, except that the skewness of C_4 is a little bit higher than that of C_5, probably due to the time span limitation. We will show in the empirical tests section that the position-unwinding risk matches with the skewness of excess returns of each carry trade portfolios. The unconditional average excess returns is 2.39% per annum from holding the equally-weighted foreign-currency portfolio, reflecting the low but positive risk premium demanded by the U.S. investors in holding foreign currencies. There is a sizeable spread of 2.29% per annum between C_5 and C_0 over the sample period when currency carry trades have suffered a huge loss in the September of 2008. The currency carry portfolios are adjusted for transaction costs, which is quite high for some currencies (Burnside, Eichenbaum, and Rebelo, 2006). Monthly excess returns and factor prices are annualized via multiplication by 12, the standard deviation is multiplied by $\sqrt{12}$, skewness is divided by $\sqrt{12}$, and kurtosis is divided by 12. All return data are in percentages unless specified. The Sharpe ratios are not as high as usual because our data span the recent financial crunch period (See Figure B.1.) for the cumulative excess returns of five currency carry portfolios (long positions) in the sample period. The cumulative excess returns of carry trades plummeted during the 2008 crisis but the positions recovered soon after a few months, especially for the high interest-rate currencies.

4.2. Risk Factors

We also follow Lustig, Roussanov, and Verdelhan (2011) to construct the dollar risk factor (GDR) and forward bias risk factor (HML_{FB}):

$$GDR = \frac{1}{5}\sum_{j=1}^{5} PFL_{FB,j} \tag{22}$$

$$HML_{FB} = PFL_{FB,5} - PFL_{FB,0} \tag{23}$$

GDR has a correlation of 0.99 with PC_1 and is almost uncorrelated with PC_2 in our data. HML_{FB} is 0.90 correlated with PC_2, however, remains a considerable correlation of 0.39 with PC_1[16]. Therefore, strictly speaking, it is not a pure slope factor. However, its correlated part may offer valuable information about the contagious country-specific risk that may spill over and contaminate the global economy.

In addition, we demonstrate the construction of other risk factors used in this paper, including the factors of sovereign credit risk, equity premium risk, currency crash risk, volatility risk, and liquidity risk.

4.2.1. Sovereign Credit

Foreign investors require compensation for a sudden devaluation of the local currency when a default on government bonds occurs. If the sovereign credit risk explains the cross-section of the excess return of currency carry trades, then high sovereign CDS-spread currencies are expected to be associated with high interest rates and tend to appreciate against low sovereign CDS-spread currencies that are expected to be accompanied with low interest rates. The countries with weak solvency conditions have higher propensity to issue sovereign debts denominated in foreign (safe) currencies. Currencies of debtor-countries offer risk premia to compensate foreign creditors who are willing to finance the domestic defaultable borrowings. We evaluate sovereign default risk by the excess returns of a strategy that invests in the highest $\frac{1}{3}$

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[16] See Table B.1. for principal component analysis of currency carry portfolios, and Table B.4. for the correlations between risk factors and principal components.

sovereign default risk currencies funded by the lowest $\frac{1}{3}$ sovereign default risk currencies as Fama and French (1993) did for their size (market capitalization) factor:

$$HML_{SC} = PFL_{SC,H} - PFL_{SC,L} \tag{24}$$

Sovereign credit risk has a correlation of 0.71 with PC_2, and is almost orthogonal to PC_1 (with a correlation of -0.08) and it can therefore be regarded with more accuracy as a slop factor. Since it is positively correlated with the slope factor, the factor price of sovereign credit risk is expected to be positive. Ideally, high interest-rate currencies should be positively exposed to sovereign credit risk while low interest-rate currencies with negative exposures provide a hedge to it (see principal component analysis of currency carry portfolios in Table B.1.). We also directly employ the AR(1) innovations in global (equally-weighted) sovereign CDS spreads (GSI) as the slope factor to price the cross section of currency carry trades.

4.2.2. Equity Premium

Foreign investors require a compensation for the risk to hold the local-currency denominated stock shares in a distressed market, which is usually accompanied with low interest rate policy. Since there is a high possibility of persistent recession trap, the risk of capital flight will lay considerable downside pressure upon the local currency. To check if any compensation for this type of risk is implied in currency excess return as well, it is necessary to examine the average excess return differences among the portfolios that are doubly sorted on both sovereign CDS spreads and equity premia over the U.S. market[17]. Constrained by the availability of the currencies, we sort

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[17] De Santis and Gerard (1998) employ a conditional ICAPM with a parsimonious multivariate GARCH process to unveil the currency risk implied in total equity premia. One can follow their approach to ask the reverse question simply by conditioning the currency premia on the equity risk. This would be our next task to decompose currency risk premia.

the currencies into 3×3 portfolios. Each dimension is partitioned into three portfolios, containing the currencies with the sort base in ascending order, denoted by "L" for low level, "M" for medium level, and "H" for high level of either sovereign CDS spreads or equity premia. This approach matches the currency sorting on sovereign default risk above:

$$HML_{EP} = PFL_{EP,H} - PFL_{EP,L} \tag{25}$$

Figure B.2. shows a very intriguing pattern that the equity premium risk seems to be priced in currency excess returns. A U.S. investor is compensated in terms of the appreciation of the local currency, not only for holding equities in a distressed market but also for investing in a boom equity market, which might be rationalized as a compensation for the crash risk of bubbles in an overheated economy. As a result, we do not see any favourable monotonic pattern of excess returns in the equity premia dimension. Clearly, on the other dimension, we observe a monotonic increase in excess returns of the currency portfolios sorted by sovereign CDS spreads in ascending order.

4.2.3. Position-unwinding Risk and Currency Crashes

In the research of Andersen, Bollerslev, Diebold, and Labys (2001) and Menkhoff, Sarno, Schmeling, and Schrimpf (2012a), volatility risk is measured with "realized" feature that assumes a zero unconditional mean of daily returns. This assumption embeds the martingale properties in daily return series. We follow this method to construct two factors that is meant to measure the crash risk in the FX market. At time $t+T$, the realized moments, realized volatility ($\hat{\sigma}_{t+T}$), realized (excess) skewness ($\hat{\varsigma}_{t+T}$), and realized (excess) kurtosis ($\hat{\kappa}_{t+T}$) over the period of T (time-to-maturity of the forward contract) for individual currency i are modelled as:

$$\hat{\sigma}_{i,t+T} = \sqrt{\frac{1}{T_\tau} \sum_{\tau=t}^{T_\tau} e_{i,\tau}^2} \tag{26}$$

$$\hat{\varsigma}_{i,t+T} = \frac{1}{T_\tau} \frac{\sum_{\tau=t}^{T_\tau} e_{i,\tau}^3}{\sigma_{i,t}^3} \tag{27}$$

$$\hat{\kappa}_{i,t+T} = \frac{1}{T_\tau} \frac{\sum_{\tau=t}^{T_\tau} e_{i,\tau}^4 - 3}{\sigma_{i,t}^4} \tag{28}$$

where $e_{i,\tau}$ represents daily returns and T_τ is the number of trading days available over the period of T from t. We substitute the annualized values[18] $\hat{\sigma}_{i,t+T} \cdot \sqrt{N_\tau}$ and $\hat{\mu}_{i,t+T} \cdot N_\tau$ in to Equation (13) for the calculation of distance to "bankruptcy", which is then the input of Equation (14). By combining it with the adjusted values of $\hat{\varsigma}_{i,t+T} \,/\, \sqrt{T_\tau}$ and $\hat{\kappa}_{i,t+T} \,/\, T_\tau$ as the inputs[19] of Equation (18), we get the position-unwinding likelihood indicator $\hat{\psi}_{i,t+T}$ for individual currency. Finally, we can compute the aggregate level of position-unwinding risk PUW by Equation (19). As shown in Figure A.1., position-unwinding likelihood indicator is closely associated with dollar risk (with a high negative correlation of -0.92) and with forward bias risk (with a correlation of -0.42). Therefore, we expect negative exposures of currency carry portfolios to PUW and a negative factor price. Currencies with higher position-unwinding likelihood will increase the risk premia of the portfolio into which it is allocated.

[Insert Figure A.1. about here]

There is a large literature that stresses the role of skewness in asset pricing exercise. Kraus and Litzenberger (1976) show that investors are in favour

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[18] N_τ is the number of trading days in a year and then $T = \frac{1}{12}$ in Equation (13).

[19] Time-aggregation scaling adjustments are necessary to match the statistical moment estimates with the option pricing model over the forward contract maturity T, based on the assumption of *i.i.d.* returns.

of positive return skewness under most preferences. As a result, it is rational to require more compensation for assets with negative return skewness. Grounded in Merton's (1973) ICAPM where skewness is also viewed as state variable that characterize investment opportunities, Conrad, Dittmar, and Ghysels (2013), and Chang, Christoffersen, and Jacobs (2013) find strong evidence in the cross-sectional pricing power of skewness on excess returns in stock market. Now we apply their thoughts to the FX market.

As emphasized by Harvey and Siddique (2000), the skewness of the returns distribution is also important for asset pricing, typically the crash risk for currency carry trades (Jurek, 2007; Brunnermeier, Nagel, and Pedersen, 2009; Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan, 2009; Chernov, Graveline, and Zviadadze, 2012), we also construct two other moment factors for measuring currency crash risk (besides the position-unwinding likelihood indicator) in the way that is grounded in the theories of moment risk premia developed by Carr and Wu (2009), Neuberger (2012). We can simply take the average of individual currency's skewness and the changes in kurtosis at aggregate level as in Equation (19).

$$GSQ_{t+T} = \frac{1}{K_{t+T}} \sum_{i=1}^{K_{t+T}} \left(\frac{\hat{\varsigma}_{i,t+T}}{\sqrt{T_\tau}} \right) \tag{29}$$

$$GKT_{t+T} = \frac{1}{K_{t+T}} \sum_{i=1}^{K_{t+T}} \left(\frac{\Delta \hat{\kappa}_{i,t+T}}{T_\tau} \right) \tag{30}$$

The skewness does not need to be signed by the interest rate differentials or equivalently by the forward premium, because skewness is already associated with the interest rate differential (Brunnermeier, Nagel, and Pedersen, 2009). For instance, the excess returns of low interest-rate currencies[20] exhibit negative skewness and vice versa for high interest-rate currencies. If

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[20] The exchange rates are in indirect quotes against USD, hence they have negative interest rate differentials.

crash risk explains carry trade excess returns, the portfolios are expected to have negative exposures to the global skewness factor and the factor price should be negative. The global kurtosis factor is constructed to match the concept of crash risk. Positive excess kurtosis is also called a Leptokurtic distribution (characterized by high peak and fat tail relative to standard normal distribution) in which volatility is driven by a few extreme events, and vice versa for Platykurtosis (negative excess kurtosis). Table A.2 below shows the comovement of global skewness and kurtosis risk with dollar risk. PUW has a high positive correlation with GSQ of 0.85. Since GSQ directly measures the tail risk associated with the underlying position, PUW possesses the consistent economic intuition of crash risk. Because the position-unwinding risk is closely associated with the skewness of the portfolio excess returns which is already shown highly related to the interest rate differentials (see Brunnermeier, Nagel, and Pedersen, 2009), it is straightforward to expect the portfolio with higher interest-rate currencies to have higher exposure to PUW. GKT is regarded as the volatility of volatility, and hence the complementary measure to volatility risk gauged by the second moment.

[**Insert Figure A.2. about here**]

We also construct the aggregate-level moment risk premium factors, i.e. variance risk premium, skewness risk premium, and kurtosis risk premium, as the difference between the realized moments (ex-post realizations) and its corresponding option-implied risk neutral moments (ex-ante expectations) using model-free approach[21] rather than direct calculations by Breeden and Litzenberger's (1978) method. They reflect the risk premia charged by investors for the difficulty to hedge their positions. But we find little evidence of the cross-sectional pricing power by these moment risk premium factors at aggregate level. The result for moment risk premia is not reported in this paper but we will be glad to provide on request.

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[21] See Bakshi, Kapadia, and Madan (2003) for details; Please also refer to our relevant paper "Global Currency Misalignments, Crash Sensitivity, and Moment Risk Premia".

4.2.4. Volatility and Liquidity

We employ Menkhoff, Sarno, Schmeling, and Schrimpf's (2012a) innovation of using an AR(1) process (GVI) in the global FX volatility (GVL) as the proxy for volatility risk in FX market, and compare it with the simple changes in Chicago Board Options Exchange's (CBOE) VIX index (ΔVIX) that is adopted e.g. by Ang, Hodrick, Xing, and Zhang (2006).

$$GVL_{t+T} = \frac{1}{T}\sum_{\tau\in T}\left(\frac{1}{K_\tau}\sum_{i\in K_\tau}|e_{i,\tau}|\right) \tag{31}$$

where K_τ denotes the number of currencies available on day τ. We then exploit a market microstructure approach that measures illiquidity risk in FX market as the global relative FX bid-ask spreads (GLR) (see also Menkhoff, Sarno, Schmeling, and Schrimpf, 2012a), and compare it with the changes in T-Bill Eurodollar (TED) Spreads Index (ΔTED)[22] as used by, for example, Brunnermeier, Nagel, and Pedersen (2009).

$$GLR_{t+T} = \frac{1}{T}\sum_{\tau\in T}\left[\frac{1}{K_\tau}\sum_{i\in K_\tau}\left(\frac{S^A_{i,\tau} - S^B_{i,\tau}}{S^M_{i,\tau}}\right)\right] \tag{32}$$

where a superscript, *M*, denotes the mid price of spot rates. This measure is grounded in Glosten and Milgrom's (1985) theory which is the first to investigate the adverse selection behavior in market transactions. They show that informational asymmetry leads to positive bid-ask spreads. Amihud and Mendelson (1986) further set forth a model that predicts the market observed expected returns as an increasing and concave function of the bid-ask spreads, wherein expected holding periods play a vital role. Amihud (2002) show that expected excess returns in equity markets represents an illiquidity premium[23].

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[22] Originally, it is a 3-month index. Thus, it has to be divided by $\frac{1}{3}$ to match the monthly excess returns.

[23] The difference is that he measures illiquidity as the average daily ratio of absolute

5. Linear Factor Model and Estimation Methodologies

In this section, we introduce the linear factor model for time-series and cross-sectional analyses of the tested assets, and the econometric methodology to estimate the model.

5.1. Linear Factor Model

Here we briefly summarize the methodologies used for risk-based explanations of the currency carry trades' excess returns. The benchmark asset pricing Euler equation with a stochastic discount factor (SDF) implies the excess returns must satisfy the no-arbitrage condition (Cochrane, 2005):

$$\mathbb{E}_t[m_{t+1} \cdot xr_{j,t+1}] = 0 \tag{33}$$

where $\mathbb{E}_t[\,\cdot\,]$ is the expectation operator with the information available at time t. The unconditional moment restrictions is given by applying the law of iterated expectations to Equation (33):

$$\mathbb{E}[m_t \cdot xr_{j,t}] = 0 \tag{34}$$

The SDF takes a linear form of:

$$m_t = \xi \cdot \left[\, 1 - (xf_t - \rho)^\top b \,\right] \tag{35}$$

where ξ is a scalar, xf_t is a $k \times 1$ vector of risk factors, $\rho = \mathbb{E}[xf_t]$, and b is a conformable vector of factor loadings. Since ξ is not identified by Equation (35), we set it equal to 1, implying $\mathbb{E}[m_t] = 1$. Rearranging Equation (34) with Equation (35) gives:

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return to dollar volume across stocks. But this measurement is not exploitable for FX market since it is a highly liquid market with massive daily trading volume. Instead, we adopt relative bid-ask spread approach.

$$\mathbb{E}[xr_t] = \text{cov}[xr_t \cdot xf_t{}^{\top}] \cdot b \tag{36}$$

or

$$\mathbb{E}[xr_{j,t}] = \underbrace{\text{cov}[xr_{j,t}, xf_t]\, \Sigma_{xf,xf}^{-1}}_{\beta_j} \cdot \underbrace{\Sigma_{xf,xf}\, b}_{\lambda} \tag{37}$$

where $\Sigma_{xf,xf} = \mathbb{E}[(xf_t - \rho)(xf_t - \rho)^{\top}]$. Equation (37) is the beta representation of the asset pricing model. β_j is the vector of exposures of portfolio j to n risk factors, it varies with the portfolios. λ is a $k \times 1$ vector of factor prices associated with the tested risk factors, and all portfolios confront the same factor prices. The beta representation of the expected excess returns by our two-factor linear model can be written as:

$$\mathbb{E}[xr_{j,t}] = \beta_{j,PUW} \cdot \lambda_{PUW} + \beta_{j,SC} \cdot \lambda_{SC} \tag{38}$$

The subscripts denote the corresponding risk factors. The higher position-unwinding risk (PUW), the higher expected excess returns of the currency carry trades. Thereby, we expect negative betas (β_{PUW}) and negative factor price (λ_{PUW}) across all portfolios. The exposures to the sovereign credit risk (HML_{SC}) vary across the portfolios. Its factor price (λ_{SC}) should be positive, high expected excess-return portfolios should have a positive beta (β_{SC}) while low expected excess-return portfolios with a negative beta provide a hedge against sovereign credit risk.

5.2. Estimation Methodology

We reply on two procedures for the parameter estimates of the linear factor model: Generalized Method of Moments (Hansen, 1982), as known as "GMM", and Fama-MacBeth (FMB) two-step OLS approach (Fama and MacBeth, 1973).

5.2.1. Generalized Method of Moments

In the first procedure, we estimate the parameters of the SDF - b and ρ - using the GMM and the moment restrictions in Equation (36) which can be rewritten as:

$$\mathbb{E}\{xr_t \cdot [\, 1 - (xf_t - \rho)^\top \, b\,]\} = 0 \tag{39}$$

The GMM estimators of ρ is set equal to a vector of the sample mean of risk factors, $\overline{xf}$. While b is given by:

$$\hat{b} = \left(\hat{\Sigma}^\top_{xr,xf}\, W_N\, \hat{\Sigma}_{xr,xf}\right)^{-1} \hat{\Sigma}^\top_{xr,xf}\, W_N\, \overline{xr} \tag{40}$$

where $\hat{\Sigma}_{xr,xf}$ is the sample covariance matrix of xr_t and xf_t, W_N is a weighting matrix, $\overline{xr}$ is the sample mean of excess returns. Then the estimates of factor prices $\hat{\lambda} = \hat{\Sigma}_{xf,xf}\, \hat{b}$, where $\hat{\Sigma}_{xf,xf}$ is the sample covariance matrix of xf_t. Following Burnside (2011), we include an additional set of corresponding moment restrictions on the factor mean vector and factor covariance matrix:

$$g(\phi_t, \theta) = \begin{bmatrix} xr_t \cdot [\, 1 - (xf_t - \rho)^\top \, b\,] \\ xf_t - \rho \\ (xf_t - \rho)(xf_t - \rho)^\top - \Sigma_{xf,xf} \end{bmatrix} = 0 \tag{41}$$

where θ is a parameter vector containing $(b, \rho, \Sigma_{xf,xf})$, ϕ_t represents the data (xr_t, xf_t). By exploiting the moment restrictions $\mathbb{E}[g(\phi_t, \theta)] = 0$ defined by Equation (41), the estimation uncertainty[24] is thus incorporated in the standard errors of λ, and this method of point estimates is identical to that of Fama-MacBeth two-pass OLS approach (see Burnside, 2011). The standard errors are computed based on Newey and West's (1987) VARHAC procedure with the data-driven approach of Andrews's (1991) optimal number of lags

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[24] It is due to the fact that factor mean vector and covariance matrix have to be estimated.

selection in a Bartlett kernel. In the first stage of GMM estimator, $W_N = I_n$; In the subsequent stages of GMM estimator, W_N is chosen optimally. The empirical results for the first stage GMM and the iterate-to-convergence GMM are reported.

5.2.2. Fama-MacBeth Approach

Additionally, we report the empirical results from the second procedure, FMB estimates. The first step is a time-series regression of each portfolio's excess returns on proposed risk factors to obtain corresponding risk exposures:

$$xr_{j,t} = \alpha_j + \beta_{j,PUW}\, PUW_t + \beta_{j,SC}\, HML_{SCt} + \varepsilon_{j,t} \tag{42}$$

where $\varepsilon_{j,t}$ is $i.i.d.$ $(0, \sigma^2_{j,\varepsilon})$. The second step is a cross-sectional regression of each portfolio's average excess returns on the estimated betas from the first step to acquire the risk prices:

$$\overline{xr}_j = \hat{\beta}_{j,PUW} \cdot \hat{\lambda}_{PUW} + \hat{\beta}_{j,SC} \cdot \hat{\lambda}_{SC} \tag{43}$$

Since PUW has a correlation of -0.24 with the slope factor, it may have a cross-sectional relation with the currency carry portfolios with statistically significant factor price[25]. It also seems to serve as a constant that allows for a common mispricing term as it is highly correlated (-0.75) with the level factor[26]. Therefore, we do not include a constant in the second step of FMB. The estimates of the risk prices from FMB is numerically identical to those from GMM. The standard errors adjusted for measurement errors by Shanken's (1992) approach are also reported besides Newey and West (1987)

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[25] We find the position-unwinding likelihood indicator alone captures over about 55% of the cross-sectional variation of currency carry trade portfolios with statistically significant factor price.

[26] See also Burnside (2011); Lustig, Roussanov, and Verdelhan (2011) on the issue of whether or not to include a constant.

HAC standard errors with automatic lag length selection (Andrews, 1991).

The predicted expected excess returns by the model is thereby $\hat{\Sigma}_{xr,xf}\,\hat{b}$, and the pricing errors are the model residuals $\hat{\varepsilon} = \overline{xr} - \hat{\Sigma}_{xr,xf}\,\hat{b}$. Then a statistic for over-identifying restrictions, $N\,\hat{\varepsilon}'\,V_N^{-1}\,\hat{\varepsilon}$, can be constructed to test the null hypothesis that all pricing errors across portfolios are jointly zero, where N is the sample size, V_N is a consistent estimate of asymptotic covariance matrix of $\sqrt{N}\,\hat{\varepsilon}$ and its inverse form is generalized. The test statistic is asymptotic distributed as χ^2 with $n-k$ degrees of freedom. We report its $p-values$ based on both Shanken (1992) adjustment and Newey and West (1987) approach for FMB procedure, and the simulation-based $p-values$ for the test of whether the Hansen-Jagannathan (Hansen and Jagannathan, 1997) distance ($HJ-dist$) is equal to zero[27] for the GMM procedure. The cross-sectional R^2 and Mean Absolute Errors (MAE) are also reported. When factors are correlated, we should look into the null hypothesis test $b_j = 0$ rather than $\lambda_j = 0$, to determine whether or not to include factor j given other factors. If b_j is statistically significant (different from zero), factor j helps to price the tested assets. λ_j only asks whether factor j is priced, whether its factor-mimicking portfolio carries positive or negative risk premium (Cochrane, 2005).

6. Empirical Results

In this section, we show and discuss the empirical results from the asset pricing tests. The factor prices are all annualized. By using a different slope factor rather than the forward bias risk constructed directly from the

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[27] Hansen-Jagannathan (Hansen and Jagannathan, 1997) distance gives a least-square distance between the tested pricing kernel and the closest pricing kernel among a set of pricing kernels that price the tested assets correctly. It is calculated by a weighted sum of random variables that follow a χ^2 distribution. For more details, see Jagannathan and Wang (1996); Parker and Julliard (2005).

currency carry portfolios with a persistent monotonic excess returns pattern, we no longer need to restrict the intercept betas that $\beta_{g,1} = \beta_{g,5}$, and the slope betas that $\beta_{c,5} - \beta_{c,1} = 1$. As a result, we are able to observe more objective estimates on global risk exposures of the lowest and highest interest-rate currencies portfolios. The following paragraphs will reveal that the higher interest-rate currencies are exposed to higher systematic risk, which is not detectable when imposed with above two restrictions.

6.1. Sovereign Credit as the Dominant Fundamental Risk

The top panel of Table A.2. shows the asset pricing results with GDR and HML_{SC}. The highest interest-rate currencies are positively exposed to sovereign credit risk and the low interest-rate currencies offer a hedge against it. The risk exposures are monotonically increasing with the interest rate differentials. The cross-sectional R^2 is very high, about 0.933[28]. The coefficients of β, b and λ are all statistically significant. The statistically significant price of sovereign credit risk is 3.287% per annum, and the Mean Absolute Error (MAE) is about 30 basis points (bps), which is very low. The $p-values$ of χ^2 tests from Shanken (1992) and Newey and West (1987) standard errors, and those of the $HJ-dist$ (Hansen and Jagannathan, 1997) all suggest to accept the model. By using alternative slope factor to relax the constraints on βs of the lowest and highest interest-rate currencies portfolios, we are able to detect that the exposures to the global risk increase with the interest rate differentials. Since the interest rate differentials covary with skewness of the portfolio excess returns, the global risk represents the crash risk and this can be confirmed by our other two risk factors PUW and GSQ.

[Insert Table A.2. about here]

Table A.3. below shows the the asset pricing results with GDR and HML_{PC}, which is the principal component of HML_{SC} and HML_{FB}. So

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[28] So do the time-series R^2s that are persistently over 0.90 across portfolios.

HML_{PC} can be deemed as the sovereign credit risk implied in the forward bias risk. The empirical results are very similar to those obtained from using the direct sovereign credit risk measure, with a little higher factor price of 5.695% per annum and an even higher R^2 of 0.968. This might mean that there is informational "noise" captured by HML_{SC} that is not valuable for explaining currency carry trade excess returns. However, we will verify that this noisy component is not useless in the next test. The model is also confirmed correct by χ^2 and $HJ - dist$ tests, with a MAE of about 19 bps.

[**Insert Table A.3. about here**]

Both orthogonal components (to HML_{PC}) of forward bias and sovereign credit risk factors, $HML_{FB_\perp}$ and $HML_{SC_\perp}$, do not capture additional cross-sectional variations of currency carry trades. These findings confirm that sovereign credit risk is a good substitutive slope factor. In fact it is even better than the forward bias risk because it not only relaxes the estimation restrictions, but also offers a traceable source of risk against which we are able to hedge.

6.2. Alternative Measures of Sovereign Credit Risk

We also resort to government bonds for an alternative measure of sovereign credit risk by sorting government bond total return indices into five portfolios based on their respect redemption yields. By doing this, we not only form the government bond portfolios for robustness test later, but also evaluate the sovereign credit risk from the excess returns of a total-return-index investment strategy that holds long positions in the highest 20% sovereign default risk government bonds funded by the lowest 20% sovereign default risk government bonds[29]:

$$HML_{GB} = PFL_{GB,5} - PFL_{GB,1} \tag{44}$$

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[29] Please refer to Table B.2. for descriptive statistics of government bond portfolios.

In Figure A.3. as shown below, we can see the inextricably tied-up fluctuations of the three factors, HML_{FB}, HML_{SC}, and HML_{GB}, implying that forward premia, to some degree, represent the sovereign credit risk, which could be the dominant source of country-specific fundamental risk priced in cross section of currency carry trade excess returns[30]. The correlation between HML_{SC} and HML_{GB} is 0.96, which mutually manifests that our measures are valid for evaluating sovereign credit risk and the short-term exchange rates move in the directions to compensate for sovereign credit risk. This means that when holding high default risk sovereign debts denominated in local currencies, the investors still confront a high probability of large currency devaluations that may not yet be compensated enough by the bond yields. However, it seems that in the short run the demand for the government bond holders to hedge currency devaluation risk would be small because, according to our empirical results, the currencies of high sovereign default risk tend to appreciate in short run.

The bottom panel of Table A.2. shows the asset pricing results with GDR and HML_{GB}. Again, we can see monotonic exposures of the currency carry portfolios to HML_{GB}. Our alternative measure of sovereign credit risk from government bonds total return indices has slightly higher cross-sectional pricing power (an R^2 of 0.952). Again, the coefficients of β, b and λ are all statistically significant. The price for sovereign credit risk implied in government bond is much higher, 9.544% per annum, owing to greater variation in the factor as the compensation for liquidity risk; and the Mean Absolute Error (MAE) is still low, about 27 bps. The $p - values$ of χ^2 tests and the $HJ - dist$ all suggest to accept the model. These results add additional credibility on the measure of sovereign credit risk and its cross-sectional pricing power. The success of the pricing power of sovereign

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[30] In time-series analysis, both HML_{SC} and HML_{GB} cannot outperform HML_{FB} in pricing the currency carry portfolios since the forward bias risk is directly constructed from the portfolios themselves. And these portfolios already shows a persistently monotonic pattern in excess returns.

credit premia measured by government bonds is consistent with the findings by Ludvigson and Ng (2009) that investors must be compensated for the countercyclical sovereign credit premia, which is strongly associated with macroeconomic activity. In this economic sense, our findings to some extent testify that the disconnect puzzle of currency risk premia may not exist.

[**Insert Figure A.3. about here**]

Figure A.3. shows the aggregate level of sovereign CDS spreads across over 30 countries and its innovations of AR(1) process. There are pronounced upswings at the outbreaks of the Subprime Mortgage Crisis and Sovereign Debt Crisis in Europe, during which currency carry trade position began to unwind. Table A.4. further confirms that the global sovereign credit risk proxy GSI is able to price about 0.786 of the cross-sectional variation of the currency carry trade portfolios with statistically significant factor price (-0.943 per annum) while passing the pricing-error and $HJ - dist$ tests.

[**Insert Table A.4. about here**]

Since our two-factor models with alternative measures of sovereign default risk explain a large proportion of the cross-sectional variance of currency carry trade excess returns, it is reasonable to believe that one solution towards forward premium puzzle is sovereign credit premia, even in short run. Because sovereign credit premia not only reflect a country's medium to long run risk, but also indicate the short-run rollover risk of maturing sovereign debt, which would particularly be exacerbated during the market liquidity deterioration (Acharya, Gale, and Yorulmazer, 2011; He and Xiong, 2012).

6.3. Forward Position-unwinding Premia

To show that the position-unwinding likelihood indicator is a good measure of global (crash) risk, we run time-series and cross-sectional regressions of currency carry portfolios on PUW and HML_{SC} as our benchmark model.

[Insert Table A.5. about here]

As shown in Table A.5. above, the lower (negative) skewness (crash risk) of the excess return distribution (see Table A.1.), the higher position-unwinding risk of the corresponding carry trade position, in terms of lower negative factor exposures. Brunnermeier, Nagel, and Pedersen (2009) find a strong correlation between the interest rate differential and the crash risk measured by skewness of individual currency, which is further conformed by the carry trade portfolios conducted in asset pricing literature, such as Lustig, Roussanov, and Verdelhan (2011), Menkhoff, Sarno, Schmeling, and Schrimpf (2012a). Our data also exhibits very similar but not exact results, possibly owing to the fact that the time span of our data is not long enough. Nevertheless, we may still reach a quite robust conclusion that the higher interest-rate currencies are exposed to higher position-unwinding risk when allocated into the carry trade portfolios, as the correlation between interest rate differentials and the skewness of the excess returns' distribution is well established. We will show that this conclusion is also robust to using the global skewness factor (GSQ) as the proxy for crash risk (in the horse race section), and the PUW_{UA} that is unadjusted for skewness and kurtosis.

In both cases, the coefficients of β, b and λ are all statistically significant. The prices for position-unwinding risk are consistently negative as expected, -27.269% per annum for PUW and -27.420% per annum for PUW_{UA}, respectively. The R^2s are 0.912 and the MAEs are also approximately the same, about 32 bps. The $p-values$ of χ^2 tests and the $HJ-dist$ all suggest acceptance of the model. These empirics add additional credibility to the measure of position-unwinding risk and its cross-sectional pricing power.

6.4. Factor-mimicking Portfolios

To better scrutinize the factor price of the global sovereign credit risk (innovations) and position-unwinding risk in a natural way, it is necessary to convert it into a return series by following Breeden, Gibbons, and Litzenberger (1989), Ang, Hodrick, Xing, and Zhang (2006) to build a factor-mimicking portfolio of position-unwinding likelihood indicator. If this factor is a traded asset, its risk price should equal to the mean return of the traded portfolio for satisfying the no-arbitrage condition.

We regress the risk factor xf_t (GSI and PUW respectively) on the vector of excess returns of five carry trade portfolios xr_t to obtain the factor-mimicking portfolio $xr_{FMP,t}$:

$$xf_t = \alpha + \beta' \, xr_t + \upsilon_t \tag{45}$$

where $\upsilon_{j,t}$ is $i.i.d.$ $(0, \sigma^2_{j,\upsilon})$. Then the factor-mimicking portfolio $xr_{FMP,t} = \hat{\beta}' \, xr_t$ is given by:

$$xr^{FMP}_{GSI,t} = -0.015 \cdot xr_{1,t} + 0.098 \cdot xr_{2,t} - 0.063 \cdot xr_{3,t} - 0.061 \cdot xr_{4,t} - 0.049 \cdot xr_{5,t}$$
$$xr^{FMP}_{PUW,t} = 2.222 \cdot xr_{1,t} - 1.330 \cdot xr_{2,t} - 0.287 \cdot xr_{3,t} - 3.749 \cdot xr_{4,t} - 0.295 \cdot xr_{5,t}$$

The factor-mimicking portfolio of innovations in global sovereign credit risk (GSI_{FMP}) is -0.62 correlated with forward bias factor, that of position-unwinding risk (PUW_{FMP}) is -0.93 correlated with dollar risk factor. It is natural to expect this high correlation since they play a role of slope, and level factor, respectively. The estimated annualized factor price of the global sovereign CDS spreads (innovations) $\lambda^{FMP}_{GSI} = -0.504\%$ per annum, which is very close to the average annual excess return of the factor-mimicking portfolio $\overline{xr}^{FMP}_{GSI} = -0.512\%$ per annum. That of position-unwinding risk $\lambda^{FMP}_{PUW} = -16.361\%$ per annum, and there is a monthly nuance to $\overline{xr}^{FMP}_{PUW} = -16.162\%$ per annum. These results confirm that the risk price of our factors, GSI and PUW, are arbitrage-free and has economically meaningful implications for dynamic hedging against currency sovereign credit and crash risk, especially we will show that by analyzing the threshold level of PUW we're able to predict the position-unwinding behavior of the market before any finance turmoil occurs.

[Insert Table A.6. about here]

6.5. Horse Races

We run two horse races of the sovereign credit risk, one with volatility risk measures, i.e. global FX volatility (innovation) risk factor (GVI) by Menkhoff, Sarno, Schmeling, and Schrimpf (2012a), and simple changes in Chicago Board Options Exchange's (CBOE) VIX index (ΔVIX); another one with illiquidity risk measures, i.e. global FX bid-ask spreads (GLR), and changes in T-Bill Eurodollar (TED) Spreads Index (ΔTED). Our empirical results corroborate Bandi, Moise, and Russell's (2008) evidence that stock market volatility drives out liquidity in cross-sectional asset pricing exercises, FX market shares this similarity.

[Insert Table A.7. about here]

[Insert Table A.8. about here]

In the horse races, ΔVIX cannot dominate HML_{SC} and the cross-sectional pricing power does not improve much (see Table A.7.). As shown in Table A.8., when racing with GVI, the estimates of b and λ with respect to HML_{SC} become statistically insignificant in pricing the cross section of currency excess returns, although both factor exposures exhibit monotonic and statistically significant patterns in time-series regressions. This is caused by multicollinearity problem that GVI dominates HML_{SC} in cross-sectional regression. The rationale behind this suggests that there must be some other ingredients containing valuable information about the cross section of currency excess returns that drives the cross-sectional volatility in the FX market, but sovereign credit risk already constitutes a major part of the FX volatility innovation because HML_{SC} and HML_{GB} as the proxy for sovereign default risk both possess very close cross-sectional pricing power to GVI. When comparing GVI with the direct measure of sovereign credit risk using the innovations in global sovereign CDS spreads GSI, we find neither of them can dominate in both cross-sectional and time-series dimensions, and both factor prices are statistically significant (see Table A.9.). Thereby, we take a further step to employ both linear and nonlinear Granger causality tests to show that sovereign default risk leads to innovations in global FX volatility in the Section 8 of this paper.

[Insert Table A.9. about here]

GLR performs badly in terms of statistically insignificant parameter estimates when racing with HML_{SC} (see Table A.10.). While Table A.11. shows that HML_{SC} also dominates ΔTED in both time-series and cross-sectional regressions. Unlike HML_{SC}, ΔTED loses its monotonic risk exposure pattern and its estimates of b and λ become very statistically insignificant. A-gain, this is not surprising because ΔTED is also an indicator of credit risk in the general economy while HML_{SC} is constructed directly from the currency excess returns, admittedly, it should be more specialized in gauging (sovereign) credit risk in currency market. Given the fact that credit risk and liquidity risk are always the twins that interact dynamically in the global economy, credit risk is usually the trigger of liquidity risk, and liquidity risk sequentially amplifies credit risk. So we should expect that HML_{SC} overwhelms ΔTED in terms of cross-sectional risk information.

[Insert Table A.10. about here]

[Insert Table A.11. about here]

To summarize, global FX volatility risk cannot dominate sovereign default risk in pricing the cross section of currency carry portfolios. Sovereign default risk is the dominant country-specific fundamental risk in terms of persistent monotonic time-series factor exposures and very high cross-sectional pricing power. Follow the economic intuition, sovereign credit conditions should be the driver of volatility and illquidity risk in FX market and the reverse may not necessarily be true. These will be testified by both linear and nonlinear Granger causality later in this paper.

7. Robustness

We stick to conditional risk premia, since it is more reasonable to look at the empirical results obtained from managed investments that in reality FX traders open, close, or adjust their positions based on daily updated information. Given the sample period is not long enough, splitting sample by time and/or category (advanced economies[31] and emerging market) is not ideal because these will introduce measurement errors in betas in terms of smaller variations in their estimated values, which will in turn make the market prices appear higher and less accurately estimated than on full sample. However, our reported results are still robust to peso problem, state-dependent factor exposures, beta-sorted portfolios and nonlinearity checks besides alternative measures of sovereign credit risk and crash risk, and unadjusted position-unwinding likelihood indicator, and factor-mimicking portfolios. By removing the illiquid currencies from the portfolios, we also confirm that our asset pricing results remain qualitatively very similar. These results are not presented in this paper, again we will be glad to provide on request.

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[31] Although currencies of these countries are involved in over 90% of the daily transactions in FX markets, the average excess returns of their carry trade portfolios do not exhibit the monotonic patterns during the financial crunch because these positions were unwound in distinctive ways of collapse.

7.1. Peso Problem

To show that the sovereign credit risk does not represent a "peso problem" because sovereign default is a rare event and the factor price for GSI is very small, we winsorize the sample outliers of the GSI at the 95% and 90% levels, respectively, to cut off the spikes, since Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) argue that the key characteristics of a peso state is a high value of SDF, not large losses in carry trades.

[Insert Table A.12. about here]

As shown in Table A.15., we still obtain very robust empirical results with R^2s of from 0.850 to 0.862. The quantitative changes are the estimates of risk exposures and factor prices of GSI, and the price of the factor estimated with it. Due to the winsorization, the variance of GSI becomes smaller, hence λ_{GSI} would naturally become smaller as well. The factor prices and loadings (b_{GSI}) remain statistically significant, -0.486% per annum when 5% of the extreme observations are excluded; -0.443% per annum when 10% of the extreme observations are excluded. So, the qualitative attributes of the sovereign credit risk story about the UIP puzzle do not change.

7.2. Regime-switching Exposures

Regime-switching models are popular among scholars for conducting time-series analysis, ranging from Hamilton's (1989) business cycle application to Ang and Bekaert's (2002) asset allocation application, and can be employed to evaluate the possibility of abrupt changes in risk exposures. We consider a simple two-state (η) Markov regime-switching model that uses the filtering procedure of Hamilton (1990) and the smoothing algorithm of Kim and Nelson (1999, 2003):

$$xr_{j,t} = \begin{cases} \alpha_j^0 + \beta_{j,xf^L}^0 \cdot xf_t^L + \beta_{j,xf^S}^0 \cdot xf_t^S + \zeta_{j,t} & \text{if } \eta = 0; \\ \alpha_j^1 + \beta_{j,xf^L}^1 \cdot xf_t^L + \beta_{j,xf^S}^1 \cdot xf_t^S + \zeta_{j,t} & \text{if } \eta = 1. \end{cases} \tag{46}$$

where xf_t^L, and xf_t^S denotes level, and slope factor, respectively; $\zeta_{j,t}$ is *i.i.d.* $(0, \sigma^2_{j,\zeta})$. The matrix Π consists of the transition probabilities, e.g. p_{10} denotes the transition probability from state 1 to state 0:

$$\Pi = \begin{bmatrix} p_{00} & p_{10} \\ p_{01} & p_{11} \end{bmatrix} \tag{47}$$

We reject the null hypothesis of linearity except for the portfolio with lowest interest-rate currencies. However, the validity of the LR-statistic for linearity test is questioned by Teräsvirta (2006) because it does not have a standard asymptotic χ^2 distribution. And the turmoil-state regime does not last for more than three months except for the portfolio with high interest-rate currencies. The Wald test is employed for testing identical parameters and systematically alternating regimes (opposite to arbitrarily switching between two regimes) in terms of smoothed transition probabilities. And the Wald statistics are computed by asymptotic covariance matrix.

[**Insert Table A.13. about here**]

The Wald tests suggests that we reject the null hypotheses of no difference in parameter estimates between two regimes, except for portfolio C_4, and the β_{SC}s of portfolio C_2 and C_5. This means that the regime dependence is mainly driven by the assessment of systemic (position-unwinding) risk exposures (β_{PUW}). We argue that it is not necessary to consider regime-switching risk exposures in the cross-sectional asset pricing exercise for the following two reasons: (i) The average duration of high volatility regime for portfolio C_1, C_3, and C_4 is very short (1-month, 1-month, and 2.5-month, respectively), and the shifts only occur three times on average. Comparing this to the time length of the data, the impact of the shifts is trivial on each portfolio. (ii) The slope factor plays a “solo” role in the cross section of currency carry trades (see the factor loadings in Table B.1.). Even though portfolio C_2 and C_5 are substantially affected by the regime switching, the changes in their exposures to sovereign default risk are not statistically significant, as indicated by the Wald tests. (iii) The linear factor models already perform quite well, with a cross-sectional R^2 persistently over 0.90. The remaining cross-sectional variance that can be captured by state-dependent risk exposures is limited. The cross-sectional R^2 obtained from regime-splitting regressions in the second stage of FMB approach does not improve much. We further examine the quadratic effect of position-unwinding risk and do not find notable improvement in explaining the cross-sectional variations.

7.3. Beta-sorted Portfolios

We adopt 60-month rolling window for the estimation of betas which is commonly used for the studies in the field of stock markets because it always generates relatively stable parameter estimates. We do not need to dynamically rebalance our portfolios over the sample period as the rank of the factor exposures across currencies is quite stable in our data. Instead, we sort the currencies into portfolios according to their average betas. Table A.14., Table A.15. shows the descriptive statistics of the currency portfolios sorted on betas with HML_{SC}, and doubly sorted on betas with both HML_{SC} and PUW, respectively.

[**Insert Table A.14. about here**]

CHF and JPY are the currencies with the lowest and the third lowest exposure to sovereign credit risk, their average β_{SC} over the sample period are -0.794 and -0.658 respectively. These results are coherent with the findings by Ranaldo and Söderlind (2010) that CHF and JPY are characterized as "safe-heaven" currencies because they have negative exposures to risky assets and appreciates when market risk increase. Intriguingly, JPY is also the currency with the lowest position-unwinding risk, it has a unique positive average β_{PUW} of 0.014, while all other currencies all have average negative β_{PUW}s. This implies a weak hedge position of JPY for global currencies against position-unwinding risk. CHF's average β_{PUW} is -0.145, a medium position-unwinding risk exposure among the currencies in the sample.

[Insert Table A.15. about here]

The countries with the highest exposures to HML_{SC} are "BRIC[32]", "MIST", and "CIVETS[33]" coined by Jim O'Neil in Goldman Sachs' "Global Economic Paper" series in order to differentiate them from a variety of emerging markets. The corresponding average β_{SC}s of these currencies are shown in the parentheses in descending order: COP (1.107), TRY (1.102), ZAR (0.931), MXN (0.801), INR (0.559), BRL (0.489), KRW (0.471), IDR (0.452). The next group contains the currencies of the countries from "EAGLEs'[34] Nest" members, e.g. PHP, PEN, MYR, ARS. Nordic currencies, such as SEK, NOK, and DKK, feature safe assets with respect to low negative β_{SC}. All these countries do not have a common level of exposures to the PUW. AUD and NZD, among the most popular carry trade currencies, are in the group of high position-unwinding risk. HKD with an average $\beta_{PUW} = -0.003$ seems to be isolated from the position-unwinding risk, as it is known pegged to USD, which provides additional supportive evidence that our position-unwinding likelihood indicator essentially substantiates the (global) dollar risk as a systematic risk.

[Insert Figure A.5. about here]

Furthermore, the excess returns and forward discounts "$f - s$" increase monotonically with both β_{SC} and β_{PUW} dimensions across portfolios, which

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[32] Except for China which is excluded in our currency portfolio, and Russia which ranks medium in the exposure to sovereign credit risk.

[33] Except for Vietman and Egypt which are not included in our sample.

[34] EAGLEs is a grouping acronym created by BBVA Research in late 2010, standing for Emerging and Growth-leading Economies, whose expected contribution to the world economic growth in the next 10 years is greater than the average of the G6 advanced economies (G7 excluding U.S.).

confirms that our beta-sorted portfolios reproduces the cross section of currency carry portfolios' excess returns. However, the skewness of our beta-sorted portfolios exhibit very similar, but not exactly the same, pattern of those sorted on forward discounts. Moreover, unlike the volatility of the currency carry portfolios, the portfolios sorted solely on β_{SC} does not show a monotonic pattern. These suggest that sorting currencies on β_{SC} alone is closely related to, but not utterly identical to the currency carry portfolios. Sorting currencies on both β_{SC} and β_{PUW} is much more close to the currency carry portfolios in terms of volatility and skewness patterns, because the position-unwinding risk drives volatility innovations in FX market. This reasonably suggests that forward bias risk reflects not only sovereign credit premia but also forward crash premia, as it is correlated with both level factor and slope factor[35].

7.4. Currency Momentum and Volatility Risk Premium Portfolios

Besides global government bond market, we further look into global equity market. The equity momentum factor (see Jegadeesh and Titman, 1993, 2001) is given by the differences in the excess returns between the top 20% winner portfolio and the bottom 20% loser portfolioPlease refer to Table B.3. for descriptive statistics of equity momentum portfolios.:

$$HML_{EM} = PFL_{EM,5} - PFL_{EM,1} \tag{48}$$

It would be interesting to check if equity momentum risk is also priced in currency carry portfolios as well. However, we don't find any supportive evidence. We then turn to the currency momentum strategy. Menkhoff, Sarno, Schmeling, and Schrimpf (2012b) argue that it is the limits to arbitrage that

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[35] Figure A.5. shows the cross-sectional fitness of five currency carry portfolios of six different models.

prevent this type of trading profitability from being exploitable. We offer evidence analogous to that of Avramov, Chordia, Jostova, and Philipov (2007) in equity market that stock momentum is mainly found in high credit risk firms[36] which are subject to illiquidity risk. And the difficulty in selling short can hinder the arbitrage activity as well. The top panel of Table A.16. below reveals that sovereign credit risk (HML_{SC}) drives currency momentum over our sample period in which the investors have experienced Subprime Mortgage Crisis and Europe Sovereign Debt Crisis. We also find strictly monotonic risk exposures across currency momentum portfolios, winner currencies load negatively on HML_{SC} while loser currencies positively, implying that winner currencies perform well when sovereign credit risk is low and loser currencies provide a hedge against it when sovereign credit risk is high. This is concordant with poor performance of currency momentum strategy during the recent period of credit crunch. The factor price of HML_{SC} is negative, so sovereign credit risk offers a high premium about -13.496% per annum (with an acceptable statistical significance) to the currency momentum investors. This model has a R^2 of 0.651 with a MAE of about 42 bps, and is accepted by χ^2 and $HJ-dist$ tests for zero pricing errors. Sovereign credit risk is the only factor that yields statistical significant factor price and good cross-sectional pricing power among the canonical risk factors used in this paper and Huang, MacDonald, and Zhao (2013).

[**Insert Table A.16. about here**]

We also investigate the currency volatility risk premium strategy by testing the cross-sectional pricing power and statistical significance in factor price of each of these canonical risk factors, and find that only the sovereign credit risk contributes to the volatility risk premia. The bottom panel of Table A.16. indicates that the profit brought by a trading strategy which borrows low downside-insurance-cost (high volatility risk premium) currencies

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[36] For instance, those whose corporate bonds are rated at non-investable grade.

to invest in the currencies characterized by high position-protection cost (low volatility risk premium) can be understood from the angle of sovereign credit risk as well. The crash-averse investors are actually paying an insurance premia to protect their currency positions against sovereign credit risk implied in the currencies (Huang, MacDonald, and Zhao, 2013). Higher sovereign default probability makes the downside risk of a currency more expensive to hedge. The price for this factor to this trading strategy is 5.198% per annum and statistically significant. The cross-sectional R^2 is 0.820 with a MAE of approximately 55 bps. The χ^2 and $HJ-dist$ tests all indicate that the model is correctly specified.

8. Factor Dynamics and Application

The existing literature in empirical asset pricing of currency carry trades do not highlight the spillover effect of country-specific fundamental risk to the global economy nor test the impulsive country-specific risk that drives others of its kind. The contagion channels can be international trade linkages (e.g. Krugman, 1979; Eichengreen, Rose, and Wyplosz, 1996), international bank lending (e.g. Kaminsky and Reinhart, 1999, 2000; Allen and Gale, 2000; Van Rijckeghem and Weder, 2001), international portfolio holdings and rebalancing (e.g. Kodres and Pritsker, 2002; Pericoli and Sbracia, 2003), or more generally speaking, international capital flows, such as sudden stop and flight-to-quality (see Calvo, 1998; Forbes and Warnock, 2012). There are various econometric techniques that can be employed for testing factor dynamics, which, however, is not the main purpose of this paper. Therefore, we only choose both linear and nonlinear Granger causality test.

The interactions between the global risk factor and country-specific factor is the principal concern of testing contagion. Position-unwinding likelihood indicator is embedded with the global risk aversion. At the early stage of the financial crisis, global risk aversion is a significant factor influencing sovereign CDS spreads; and at the later stage, country-specific factor, such as short-term refinancing constaint and long-term fiscal sustainability, becomes more important and begins to feed back into broader financial instability (Caceres, Guzzo, and Segoviano Basurto, 2010). Furthermore, hedging design of currency portfolios against idiosyncratic risk can be oriented by testing the stimulative source of risk among the country-specific factors.

We employ both linear and nonlinear Granger causality tests to identify which factor drives the cross-sectional risk, and to investigate the dynamic propagation between global risk and country-specific risk, especially the spillover of the country-specific risk to the global economy, because the degree of Granger causality in the asset return-based risk factors can also be viewed as a proxy for the spillover of information among market participants as suggested by some recent relevant research, e.g. Daníelsson, Shin, and Zigrand (2009), Battiston, Delli Gatti, Gallegati, Greenwald, and Stiglitz (2012), and Billio, Getmansky, Lo, and Pelizzon (2012). Hiemstra and Jones (1994) propose a nonparametric test for general (both linear and nonlinear) Granger non-causality (HJ-test), which is questioned by Diks and Panchenko (2006). They show that HJ-test tends to incur spurious discovery of nonlinear Granger causality, and the probability to reject the Granger non-causality increases with the sample size. Instead, they provide an alternative nonparametric test for nonlinear Granger causality that circumvents the problem in HJ-test through replacing the global statistic by the average of local conditional dependence measures. We follow their method to test the nonlinear Granger causality among risk factors. The bandwidth of 1.50 is chosen to accommodate the sample size. We adopt Akaike's Final Prediction Error (as known as AIC) as the lag-length selection criterion because Anderson (2004) find that Akaike's Final Prediction Error[37] works quite well for small samples

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[37] Although nonlinear techniques suggested by Tjøstheim and Auestad (1994) might improve the accuracy, they're very difficult to implement.

even if the true model is nonlinear, and contrarily, Schwarz (Bayesian) Information Criterion (SIC) and Hannan-Quinn Information Criterion performs poorly unless the sample size is large enough.

8.1. Impulsive Country-specific Risk

Table A.17. shows that sovereign credit risk seems to be the impetus of other country-specific factors: HML_{SC} both linearly and nonlinearly Granger causes HML_{FB}, GVI, ΔVIX, and ΔTED. And the reverse is not true except that HML_{FB} and ΔTED feedback into HML_{SC} nonlinearly.

[Insert Table A.17. about here]

The relationship between HML_{SC} and GLR seems to be dynamic and nonlinear. From the aspect of market microstructure, liquidity spreads (bid-ask spreads) are endogenously set by the market makers, whose reaction function to perceived sovereign credit risk should be nonlinear to rationalize this nonlinear and dynamical Granger causality between HML_{SC} and GLR. All these with the asset pricing tests vindicate that sovereign credit risk is the dominant country-specific fundamental risk.

8.2. Global Contagion

Table A.18. reveals the spillover of country-specific risk to the global economy. Sovereign default risk (HML_{SC}) is contagious to the global money market (GDR) and drives the currency crash risk (GSQ), which in turn amplifies the global volatility risk (both GVI and ΔVIX).

[Insert Table A.18. about here]

Baek, Bandopadhyaya, and Du (2005) find that the market risk appetite imposes larger impact on the bond yield spreads than the economic fundamentals. The mechanism is reverse in currency market that the market risk sentiment, e.g. the FX volatility innovation (GVI), broad market volatility (ΔVIX), and position-unwinding likelihood indicator (PUW) are driven by the sovereign credit risk measured directly in the currency excess returns. Moreover, GVI is naturally triggered by the position-unwinding likelihood, which measures the precautionary risk attitude of the investors. PUW is also fed into ΔVIX. We also find that position-unwinding risk of the currency carry trades is driven by ΔVIX and by the forward bias risk (HML_{FB}).

8.3. Threshold Trading

Given that the position-unwinding likelihood indicator measures the probability of the currency crashes against the speculative carry trade positions taken by the investors, and that it solely represents the (global) systematic risk in terms of high correlation with the equally loaded PC_1 of the currency carry portfolios and also with the global skewness risk (GSQ) while is nearly uncorrelated with the PC_2 that can be intensified by the (country-specific) forward bias risk (see Table A.18.), we can continue earning on the forward bias risk as long as the positions are not forced unwounded. However, once the currency crashes in the opposite direction of the carry trade positions, the risk reverses and we will suffer losses by taking up any more forward bias risk. So focusing on the position-unwinding risk is the principal concern of currency carry trades.

In this section, we propose an alternative carry trade strategy that is immunized from currency crash risk by identifying the threshold level of the position-unwinding likelihood indicator. Brunnermeier and Pedersen (2009), Clarida, Davis, and Pedersen (2009) reveal the regime-sensitivity of Fama regression parameters that the βs are much smaller than unity or even negative during the tranquil period and shift to positive values or even become greater than unity during the turmoil period. Thus, we can gain both statistical and economic significance by analyzing the transition dynamics between regimes, e.g. reverse the carry trade positions during the currency crashes. And according to the reality observed in our data, the position-unwinding behavior would be triggered when PUW exceeds a certain precautionary threshold. The procedure to search for the threshold level could be done using a Smooth Transition Model (STR) specifying that the carry trade excess returns depend linearly on HML_{FB} and nonlinearly on GDR. The nonlinear relationship is dependent on the level position-unwinding likelihood. More generally, our model is given by:

$$xr_{j,t} = (\alpha_j^0 + \beta_j^0 \ f_t^0) + (\alpha_j^1 + \beta_j^1 \ f_t^1) \cdot \omega(\nu_t; \gamma_j, c_j) + \zeta_{j,t} \tag{49}$$

where $\zeta_{j,t}$ is $i.i.d.$ $(0, \sigma_{j,\zeta}^2)$. PUW acts as the transition variable ν_t and $\omega(\cdot)$ is the transition function which is conventionally bounded by zero and one. $\gamma_j > 0$ denotes the slope parameter that determines the smoothness[38] of the transition from one regime to the other. When γ_j approaches zero, the STR process reduces to a linear model; and as γ_j goes to infinity, the STR process becomes an absolute two-regime threshold model with abrupt transition (Tong, 1990). c_j is the threshold level of the abruptness in transitional dynamics. f_t^0 (f_t^1) is a vector of risk factors that enter the linear (nonlinear) part of the STR model. Two types of transition functions (Teräsvirta and Anderson, 1992) universally appeal to scholars and they are:

Logistic STR Model (LSTR):

$$\omega(\nu_t; \gamma_j, c_j) = \{1 + \exp[-\gamma_j(\nu_t - c_j)]\}^{-1} \tag{50}$$

Exponential STR Model (ESTR):

$$\omega(\nu_t; \gamma_j, c_j) = 1 - \exp[-\gamma_j(\nu_t - c_j)^2] \tag{51}$$

Unlike the ESTR model, the LSTR specification accounts for asymmetric realizations of the transition variable at two sides of the threshold level. We

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[38] This implies that there exists a continuum of states between two polar regimes.

follow Teräsvirta's (1994) methodology to choose the appropriate STR model and utilize $LM-test$ for examining the null hypothesis of no remaining nonlinearity (Eitrheim and Teräsvirta, 1996). That no residual autocorrelation in the STR model is confirmed by Teräsvirta's (1998) procedure.

[**Insert Table A.19. about here**]

The threshold levels of the position-unwinding risk in-sample (2005 September - 2009 September) are indicated in Table A.19. that a *PUW* above 0.462 is suggested as a signal for reverse the positions of conventional carry trades. In our principal trading rule, we use ex-ante 3-month moving average of *PUW* for comparison with the threshold level of 0.462. Moreover, that the *PUW* becomes persistently volatile during the recent financial crisis is noteworthy. As a result, we set the ex-ante 12-month *PUW* volatility as the complementary trading rule, which suddenly exceeds 15% at the outbreak point and remains above this level in the aftermath of the financial crunch. If it drops below 15%, the positions are reversed back to the plain vanilla carry trade strategy.

[**Insert Figure A.6. about here**]

Figure A.6. show that the cumulative excess returns of the threshold carry trade strategy is immunized from currency crashes, in comparison with the plain vanilla one. The out-of-sample performance (2009 October - 2013 January) of this trading strategy is better. The annualized (compounded) excess return of the threshold carry trading strategy is about 9.41%, which is much higher than that of the plain vanilla one (1.98%). And it has a Sharpe ratio of 0.78, more than twice as big as its original version. The success of our novel strategy lies in the fact that the risk of currency carry trades is highly predictable by our position-unwinding likelihood indicator.

9. Conclusions

In this paper we argue that what we label sovereign credit condition is the dominant fundamental risk that drives the cross-sectional excess returns of currency carry trades. This conclusion is based on the striking and robust time-series and cross-sectional evidence presented here. The cross-sectional pricing power of sovereign credit does not reflect a "Peso problem" and it impulsively drives other country-specific risk, such as volatility and liquidity risk in both linear and nonlinear Granger causality tests. High interest-rate currencies load up positively on sovereign default risk while the low interest-rate currencies provide a hedge against it, which is consistent with the external valuation adjustment story of Gourinchas and Rey (2007). A country with high sovereign default risk displays high propensity to issue debts denominated by foreign (safe) currencies to make them more appealing to investors, and inclines to offer high interest rate to attract foreign savings for funding its external deficit. The destabilizing effect on a debtor's currency drives the currency risk premia. This is robust to alternative measure of sovereign default risk directly by government bonds. Given that sovereign credit premia contains substantial information about the macroeconomy (Ludvigson and Ng, 2009), currency risk premia does not disconnect from their fundamentals. The sovereign credit premia not only reflects a country's medium to long run fundamental risk, but also response to short-run rollover risk of maturing debt and liquidity constraint of a nation. Interest rates imply market liquidity premium component and sovereign credit premium component, which should be taken into account for measuring the "effective" forward premia.

We also explain a "self-fulfilling" nature of currency carry trades according to the analysis of position-unwinding risk. Its factor-mimicking portfolio confirms that position-unwinding risk is an arbitrage-free traded asset. It is fed by the forward bias risk in both linear and nonlinear Granger causality tests, in which complicated global contagion channels are highlighted. The position-unwinding likelihood indicator is also consistent with the liquidity spiral story of Brunnermeier, Nagel, and Pedersen (2009) as it measures the currency crash risk in terms of high correlation with the global skewness factor. We show high interest-rate currencies are exposed to higher position-unwinding (crash) risk than low interest-rate currencies, owing to the global liquidity transfer brought by carry trades themselves. Once the risk-bearing capacity (e.g. funding liquidity constraint) of the financial intermediaries is unable to sustain the "global liquidity imbalance", the global liquidity reversal/withdrawal of the investors triggers currency crashes (Gabaix and Maggiori, 2014). Accordingly, we propose a threshold carry trade strategy that is immunized from currency crash risk and earns a much higher annualized excess return than the plain vanilla one. Our threshold carry trades is a risk-managed strategy, it works because it eliminates the exposure to the crashes and increases the Sharpe ratio substantially (approximately three times as big as its original version). This presents a new challenge to any theory that attempts to explain currency carry trade excess returns.

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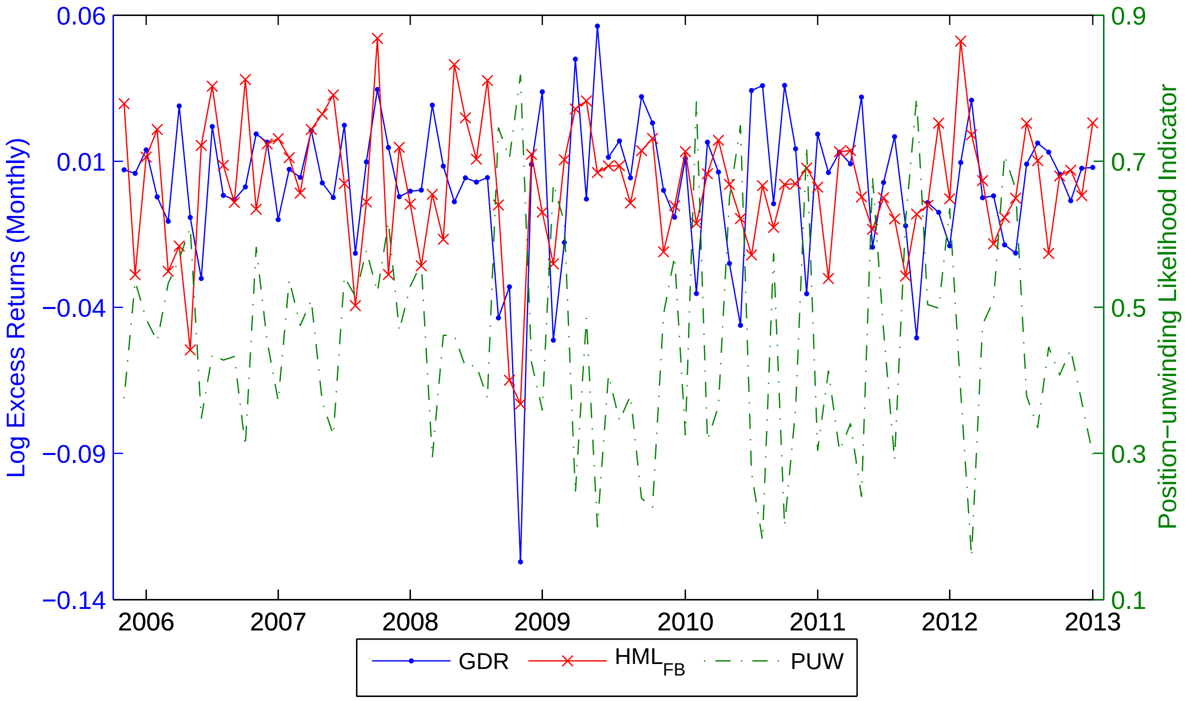
Appendix A.

Table A.1. Descriptive Statistics of Currency Carry Portfolios

All Countries with Bid-Ask Spreads								
Portfolios	C_0	C_1	C_2	C_3	C_4	C_5	Avg.	H/L
Mean (%)	-2.28	0.45	1.57	2.44	2.94	4.57	2.39	2.29
Median (%)	-6.35	3.67	3.71	6.02	8.34	11.17	5.33	2.74
Std.Dev. (%)	7.40	7.41	8.56	9.31	10.61	10.71	8.69	7.86
Skewness	0.14	-0.16	-0.26	-0.56	-0.53	-0.51	-0.49	-0.17
Kurtosis	0.17	0.18	0.21	0.82	0.62	0.57	0.60	0.11
Sharpe Ratio	-0.31	0.06	0.18	0.26	0.28	0.43	0.28	0.29
AC(1)	0.01	0.01	-0.09	0.05	0.15	0.14	0.07	0.14

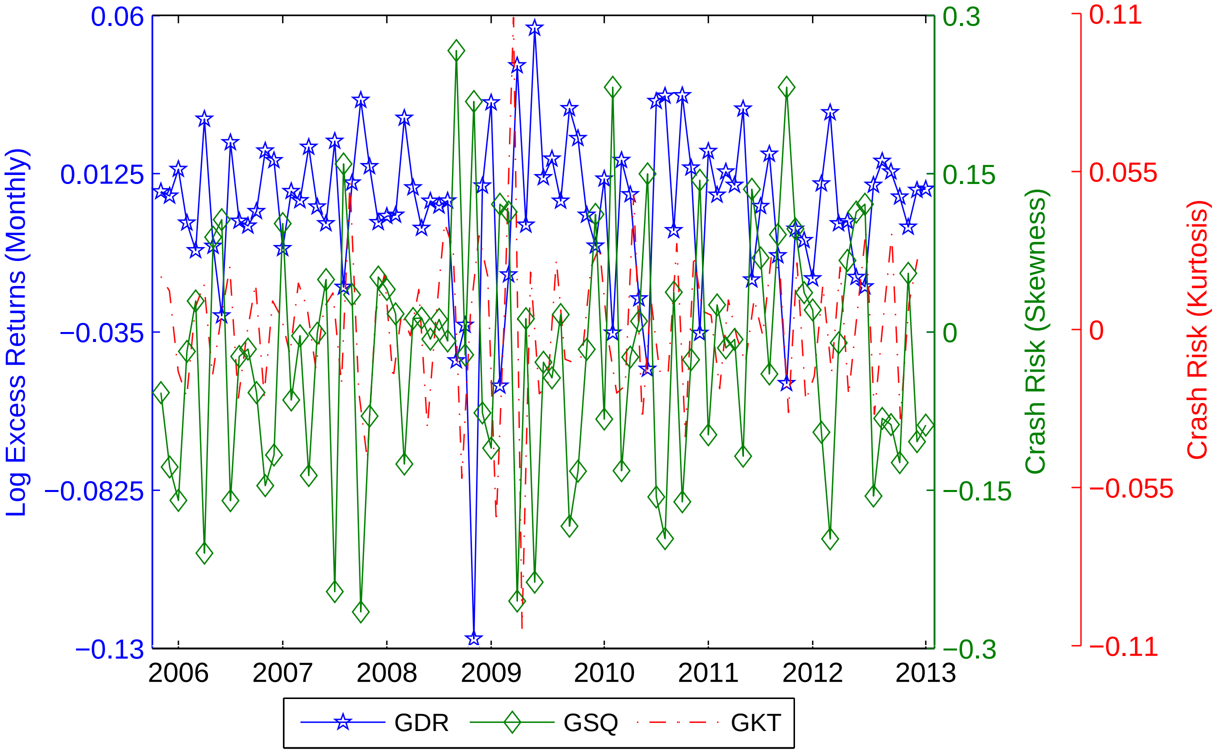
This table reports descriptive statistics of the excess returns in USD of currency carry portfolios sorted on 1-month forward premia. The 20% currencies with the lowest forward premia are allocated to Portfolio C_1, and the next 20% to Portfolio C_2, and so on to Portfolio C_5 which contains the highest 20% forward premia. Portfolio C_0 is Portfolio C_1 in short position and others are in long positions. The portfolios are rebalanced at the end of each former forward-rate agreement according to the updated contract. 'Avg.', and 'H/L' denotes the average excess returns of five portfolios in long positions, and difference in the excess returns between Portfolio C_5 and Portfolio C_0 respectively. All excess returns are monthly and adjusted for transaction costs (bid-ask spreads) with the sample period from September 2005 to January 2013 with daily availability. The mean, median, standard deviation and higher moments are annualized (so is the Sharpe Ratio) and in percentage. Skewness and kurtosis are in excess terms. AC(1) is the first order autocorrelation coefficient of the monthly excess returns in monthly frequency.

Figure A.1. Position-Unwinding Risk (Skewness-&-Kurtosis Adjusted)



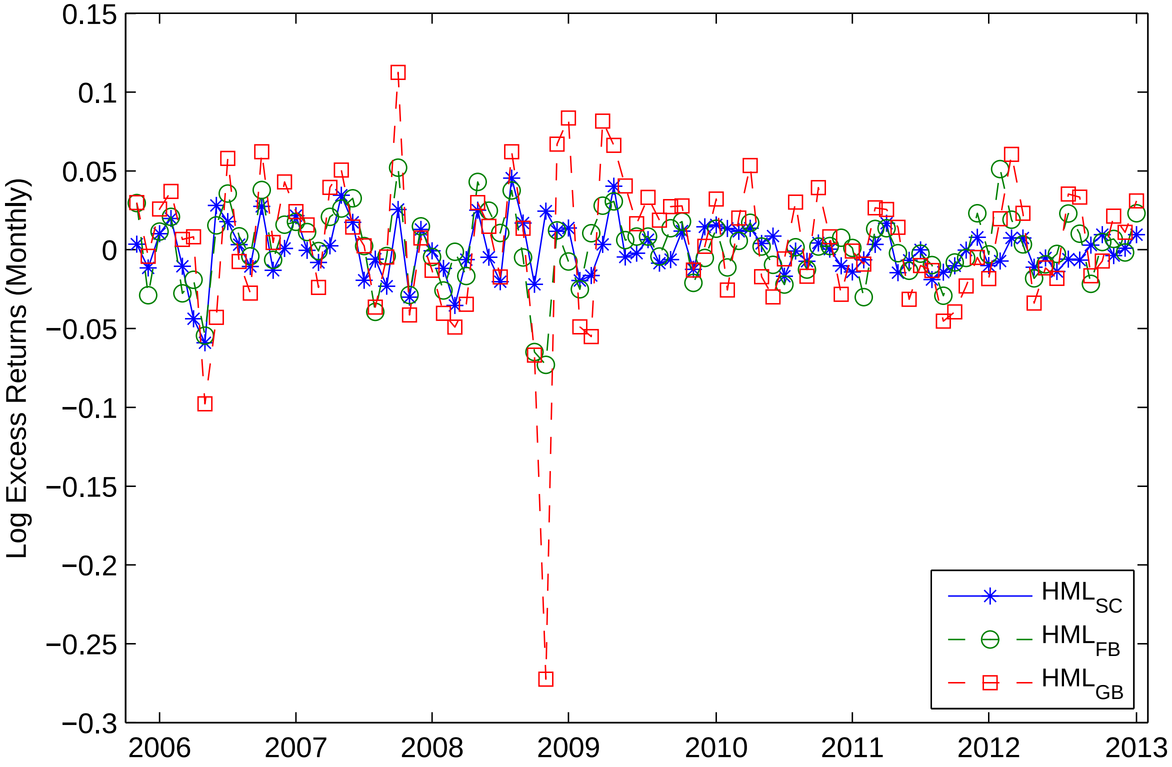
This figure shows skewness-and-kurtosis adjusted position-unwinding likelihood indicator (PUW) of the currency carry trades in comparison with Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) and forward bias risk (HML_{FB}) from September 2005 to January 2013.

Figure A.2. Dollar Risk vs. Crash Risk



This figure shows global skewness risk (GSQ) and global kurtosis risk (GKT) both as the proxy for currency crash risk in the graph for easier comparison with Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) from September 2005 to January 2013.

Figure A.3. Forward Bias Risk vs. Sovereign Credit Risk



This figure shows sovereign credit risk (HML_{SC} implied by currencies, and HML_{GB} implied by government bonds) in comparison with Lustig, Roussanov, and Verdelhan's (2011) forward bias risk (HML_{FB}) from September 2005 to January 2013.

Table A.2. Asset Pricing of Currency Carry Portfolios: HML_{SC} vs. HML_{GB}

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{GDR}	β_{SC}		b_{GDR}	b_{SC}	λ_{GDR}	λ_{SC}	R^2	$p-value$	$MAPE$
C_1	0.726	-0.324							χ^2	
	(0.050)	(0.051)	FMB			2.395	3.287	0.933		0.302
C_2	0.900	-0.187				(2.196)	(1.413)		(0.893)	
	(0.073)	(0.063)				[2.174]	[1.270]		[0.901]	
C_3	1.022	-0.153								
	(0.039)	(0.031)							$HJ-dist$	
C_4	1.192	0.189	GMM_1	0.327	0.833	2.395	3.287	0.933	0.819	0.302
	(0.041)	(0.053)		(0.200)	(0.385)	(1.787)	(1.568)			
C_5	1.160	0.474	GMM_2	0.311	0.695	2.340	2.717	0.915		0.359
	(0.076)	(0.054)		(0.206)	(0.258)	(1.811)	(1.055)			
	β_{GDR}	β_{GB}		b_{GDR}	b_{GB}	λ_{GDR}	λ_{GB}	R^2	$p-value$	$MAPE$
C_1	0.997	-0.186							χ^2	
	(0.059)	(0.030)	FMB			2.386	9.544	0.952		0.268
C_2	1.110	-0.147				(2.196)	(3.829)		(0.940)	
	(0.054)	(0.026)				[2.174]	[3.507]		[0.940]	
C_3	1.057	-0.019								
	(0.048)	(0.028)							$HJ-dist$	
C_4	1.047	0.098	GMM_1	-0.279	0.408	2.386	9.544	0.952	0.849	0.268
	(0.047)	(0.023)		(0.384)	(0.227)	(1.633)	(3.750)			
C_5	0.788	0.253	GMM_2	-0.224	0.388	2.633	9.563	0.920		0.288
	(0.038)	(0.024)		(0.425)	(0.208)	(2.159)	(3.345)			

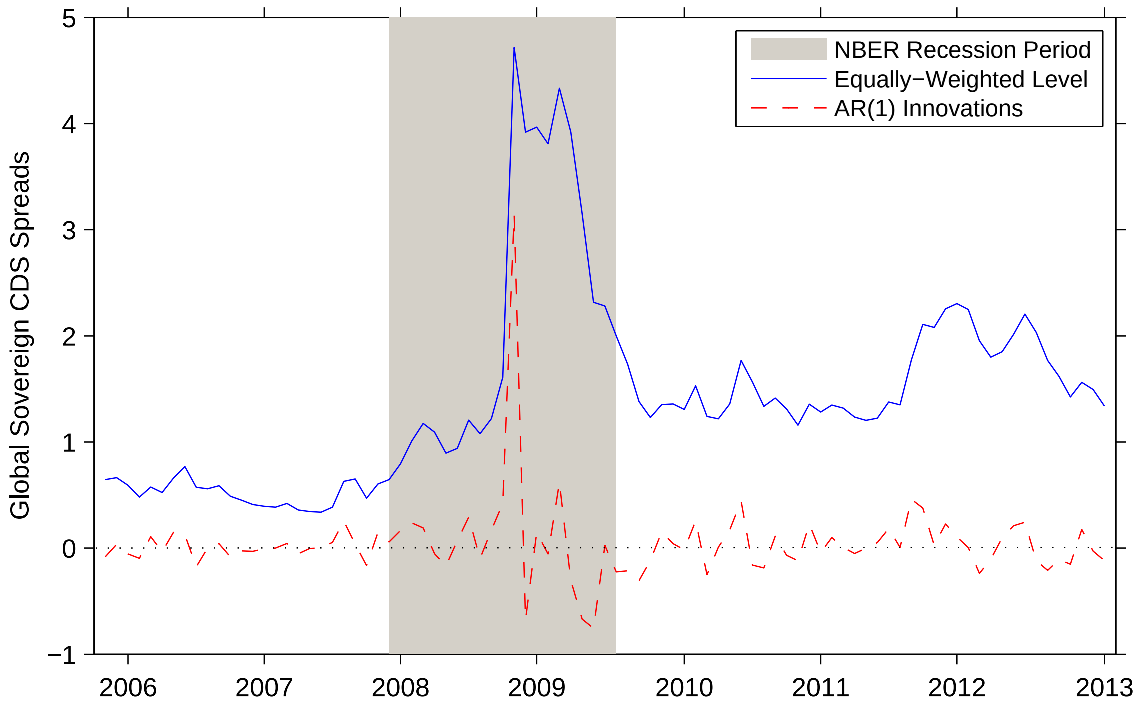
This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for comparison between two linear factor models (LFM) both based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor but differ in slope (country-specific) factor. The LFM in the top panel employs sovereign credit risk (HML_{SC}) implied in currencies and the LFM in the bottom panel adopts alternative measure of sovereign credit risk via government bonds total return indices (HML_{GB}). The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.3. Asset Pricing of Currency Carry Portfolios: $GDR + HML_{PC}$

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{GDR}	β_{PC}		b_{GDR}	b_{PC}	λ_{GDR}	λ_{PC}	R^2	$p-value$	$MAPE$
C_1	0.872	-0.283							χ^2	
	(0.038)	(0.024)	FMB			2.388	5.695	0.968		0.193
C_2	0.942	-0.122				(2.191)	(2.545)		(0.960)	
	(0.065)	(0.029)				[2.174]	[2.476]		[0.963]	
C_3	1.048	-0.069								
	(0.045)	(0.019)							$HJ-dist$	
C_4	1.154	0.104	GMM_1	0.182	0.364	2.388	5.695	0.968	0.895	0.193
	(0.038)	(0.024)		(0.202)	(0.179)	(1.728)	(2.607)			
C_5	1.049	0.335	GMM_2	0.181	0.355	2.351	5.549	0.967		0.210
	(0.039)	(0.022)		(0.213)	(0.152)	(1.852)	(2.303)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for a linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, the first principal component (HML_{PC}) of sovereign credit risk (HML_{SC}) and Lustig, Roussanov, and Verdelhan's (2011) forward bias risk (HML_{FB}) as the slope (country-specific) factor. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ - dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Figure A.4. Global Sovereign CDS Spreads: Aggregate Level & Shock



This figure shows global sovereign CDS spreads at aggregate level of the whole sample countries with equal weights (GSR), and the innovations of its AR(1) process without a constant (GSI) from September 2005 to January 2013.

Table A.4. Asset Pricing of Currency Carry Portfolios: $GDR + GSI$

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{GDR}	β_{GSI}		b_{GDR}	b_{GSI}	λ_{GDR}	λ_{GSI}	R^2	$p-value$	$MAPE$
C_1	0.875	0.925							χ^2	
	(0.047)	(0.261)	FMB			2.420	-0.943	0.786		0.616
C_2	1.145	1.994				(2.209)	(0.444)		(0.758)	
	(0.056)	(0.365)				[2.174]	[0.446]		[0.766]	
C_3	0.978	-0.472								
	(0.047)	(0.288)							$HJ-dist$	
C_4	1.077	-0.874	GMM_1	-0.463	-6.320	2.420	-0.943	0.786	0.576	0.616
	(0.051)	(0.325)		(0.440)	(3.067)	(1.601)	(0.425)			
C_5	0.944	-1.573	GMM_2	-0.109	-3.481	2.643	-0.672	0.692		0.655
	(0.051)	(0.375)		(0.136)	(1.357)	(1.846)	(0.286)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for a linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, the innovations of the AR(1) process of the global (weighted-average) sovereign CDS spreads (GSI) as the slope (country-specific) factor. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.5. Asset Pricing of Currency Carry Portfolios: PUW + HML_{SC}

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{PUW}	β_{SC}		b_{PUW}	b_{SC}	λ_{PUW}	λ_{SC}	R^2	$p-value$	$MAPE$
C_1	-0.091	-0.591							χ^2	
	(0.012)	(0.114)	FMB			-27.269	3.334	0.912		0.325
C_2	-0.125	-0.538				(12.671)	(1.049)		(0.866)	
	(0.013)	(0.085)				[12.874]	[1.080]		[0.875]	
C_3	-0.139	-0.548								
	(0.019)	(0.117)							$HJ-dist$	
C_4	-0.167	-0.279	GMM_1	-0.069	0.677	-27.269	3.334	0.912	0.764	0.325
	(0.021)	(0.133)		(0.033)	(0.385)	(13.393)	(1.674)			
C_5	-0.148	0.042	GMM_2	-0.058	0.559	-22.849	2.762	0.812		0.429
	(0.023)	(0.135)		(0.029)	(0.227)	(10.969)	(1.050)			
	$\beta_{PUW_{UA}}$	β_{SC}		$b_{PUW_{UA}}$	b_{SC}	$\lambda_{PUW_{UA}}$	λ_{SC}	R^2	$p-value$	$MAPE$
C_1	-0.090	-0.591							χ^2	
	(0.012)	(0.114)	FMB			-27.420	3.331	0.913		0.325
C_2	-0.124	-0.538				(12.802)	(1.049)		(0.866)	
	(0.013)	(0.085)				[12.005]	[1.080]		[0.875]	
C_3	-0.138	-0.548								
	(0.019)	(0.117)							$HJ-dist$	
C_4	-0.166	-0.279	GMM_1	-0.068	0.676	-27.420	3.331	0.913	0.764	0.325
	(0.021)	(0.133)		(0.033)	(0.386)	(13.910)	(1.588)			
C_5	-0.148	0.042	GMM_2	-0.057	0.559	-22.975	2.760	0.812		0.429
	(0.023)	(0.135)		(0.028)	(0.228)	(11.063)	(1.050)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for comparison between two linear factor models (LFM) both based on sovereign credit risk (HML_{SC}) as the slope (country-specific) factor but differ in intercept (global) factor. The LFM in the top panel employs skewness-and-kurtosis adjusted position-unwinding risk (PUW) and the LFM in the bottom panel adopts unadjusted position-unwinding risk (PUW_{UA}). The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.6. Asset Pricing of Currency Carry Portfolios: GSI_{FMP} & PUW_{FMP}

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{GDR}	$\beta_{GSI_{FMP}}$		b_{GDR}	$b_{GSI_{FMP}}$	λ_{GDR}	$\lambda_{GSI_{FMP}}$	R^2	$p-value$	$MAPE$
C_1	1.073	2.829							χ^2	
	(0.082)	(0.580)	FMB			2.416	-0.504	0.821		0.558
C_2	1.583	5.856				(2.182)	(0.224)		(0.806)	
	(0.029)	(0.183)				[2.174]	[0.222]		[0.784]	
C_3	0.924	-0.946								
	(0.087)	(0.538)							$HJ-dist$	
C_4	0.895	-2.474	GMM_1	-0.520	-6.907	2.416	-0.504	0.821	0.764	0.558
	(0.076)	(0.531)		(0.605)	(4.594)	(1.711)	(0.212)			
C_5	0.524	-5.265	GMM_2	-0.188	-4.150	2.572	-0.431	0.748		0.565
	(0.070)	(0.574)		(0.580)	(3.964)	(1.845)	(0.188)			
	$\beta_{PUW_{FMP}}$	β_{SC}		$b_{PUW_{FMP}}$	b_{SC}	$\lambda_{PUW_{FMP}}$	λ_{SC}	R^2	$p-value$	$MAPE$
C_1	-0.123	-0.504							χ^2	
	(0.010)	(0.082)	FMB			-16.361	2.996	0.913		0.325
C_2	-0.175	-0.423				(7.542)	(0.987)		(0.868)	
	(0.016)	(0.073)				[8.162]	[1.061]		[0.874]	
C_3	-0.197	-0.419								
	(0.011)	(0.064)							$HJ-dist$	
C_4	-0.245	-0.130	GMM_1	-0.068	0.676	-16.361	2.996	0.913	0.787	0.325
	(0.005)	(0.039)		(0.032)	(0.338)	(8.484)	(1.416)			
C_5	-0.224	0.171	GMM_2	-0.057	0.555	-13.530	2.463	0.796		0.444
	(0.015)	(0.090)		(0.028)	(0.235)	(7.393)	(1.008)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for examining the arbitrage-free attribute of non-return risk factors, innovations in global sovereign CDS spreads (GSI) and position-unwinding likelihood indicator (PUW). The LFM in the top panel $GDR + GSI$ and the LFM in the bottom panel $PUW + HML_{SC}$. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ - dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.7. Asset Pricing of Currency Carry Portfolios: $GDR + HML_{SC} + \Delta VIX$

All Countries with Transaction Costs													
	Factor Exposures			Factor Prices									
	β_{GDR}	β_{SC}	$\beta_{\Delta VIX}$		b_{GDR}	b_{SC}	$b_{\Delta VIX}$	λ_{GDR}	λ_{SC}	$\lambda_{\Delta VIX}$	R^2	$p-value$	$MAPE$
C_1	0.77	-0.29	0.03									χ^2	
	(0.05)	(0.05)	(0.02)	FMB				2.39	2.46	-11.88	0.95		0.30
C_2	1.00	-0.11	0.07					(1.60)	(1.12)	(12.36)		(0.78)	
	(0.07)	(0.07)	(0.02)					[1.59]	[1.10]	[12.24]		[0.80]	
C_3	1.00	-0.17	-0.02										
	(0.04)	(0.05)	(0.02)									$HJ-dist$	
C_4	1.18	0.18	-0.01	GMM_1	0.03	0.41	-0.20	2.39	2.46	-11.88	0.95	0.593	0.30
	(0.05)	(0.05)	(0.01)		(0.82)	(0.89)	(0.50)	(1.68)	(1.13)	(12.41)			
C_5	1.06	0.39	-0.08	GMM_2	-0.01	0.28	-0.23	2.44	2.03	-12.29	0.94		0.30
	(0.06)	(0.06)	(0.03)		(0.85)	(0.98)	(0.53)	(1.65)	(1.11)	(12.95)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for the linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, sovereign credit risk (HML_{SC}) and s simple changes in Chicago Board Options Exchanges (CBOE) VIX index (ΔVIX) both as slope (country-specific) factors. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.8. Asset Pricing of Currency Carry Portfolios: $GDR + HML_{SC} + GVI$

All Countries with Transaction Costs													
	Factor Exposures				Factor Prices								
	β_{GDR}	β_{SC}	β_{GVI}		b_{GDR}	b_{SC}	b_{GVI}	λ_{GDR}	λ_{SC}	λ_{GVI}	R^2	$p-value$	$MAPE$
C_1	0.82	-0.29	3.29									χ^2	
	(0.04)	(0.05)	(0.91)	FMB				2.39	0.36	-0.38	0.98		0.16
C_2	0.97	-0.16	2.65					(1.60)	(1.17)	(0.44)		(0.94)	
	(0.06)	(0.07)	(1.57)					[1.57]	[1.16]	[0.40]		[0.93]	
C_3	1.02	-0.15	-0.23										
	(0.04)	(0.03)	(1.13)									$HJ-dist$	
C_4	1.17	0.18	-0.87	GMM_1	-0.71	-0.23	-36.34	2.39	0.36	-0.38	0.98	0.46	0.16
	(0.05)	(0.05)	(1.08)		(1.58)	(1.41)	(53.26)	(1.63)	(1.25)	(0.41)			
C_5	1.03	0.43	-4.84	GMM_2	-0.87	-0.44	-45.88	3.34	-0.17	-0.48	0.47		0.95
	(0.05)	(0.05)	(1.11)		(1.57)	(1.48)	(55.05)	(2.28)	(1.38)	(0.44)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for the linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, sovereign credit risk (HML_{SC}) and global FX volatility (innovation) risk (GVI) both as slope (country-specific) factors. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.9. Asset Pricing of Currency Carry Portfolios: $GDR + GSI + GVI$

All Countries with Transaction Costs													
	Factor Exposures			Factor Prices									
	β_{GDR}	β_{GSI}	β_{GVI}		b_{GDR}	b_{GSI}	b_{GVI}	λ_{GDR}	λ_{GSI}	λ_{GVI}	R^2	$p-value$	$MAPE$
C_1	0.89	0.32	4.06									χ^2	
	(0.06)	(0.38)	(1.36)	FMB				2.39	-0.61	-0.35	0.99		0.11
C_2	1.14	2.01	-0.14					(2.20)	(0.30)	(0.18)		(0.94)	
	(0.06)	(0.47)	(1.26)					[2.17]	[0.29]	[0.16]		[0.93]	
C_3	0.99	-0.74	1.76										
	(0.05)	(0.40)	(1.24)									$HJ-dist$	
C_4	1.07	-0.84	-0.22	GMM_1	-0.43	2.18	-35.97	2.39	-0.61	-0.32	0.99	0.51	0.11
	(0.05)	(0.40)	(1.23)		(0.47)	(3.18)	(12.33)	(1.69)	(0.33)	(0.12)			
C_5	0.89	-0.75	-5.46	GMM_2	-0.49	2.39	-38.34	2.16	-0.60	-0.36	0.96		0.23
	(0.06)	(0.82)	(2.01)		(0.59)	(2.85)	(14.73)	(1.88)	(0.26)	(0.13)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for the linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, innovations in global sovereign CDS spreads (GSI) and global FX volatility (innovation) risk (GVI) both as slope (country-specific) factors. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.10. Asset Pricing of Currency Carry Portfolios: $GDR + HML_{SC} + GLR$

All Countries with Transaction Costs													
	Factor Exposures			Factor Prices									
	β_{GDR}	β_{SC}	β_{GLR}		b_{GDR}	b_{SC}	b_{GLR}	λ_{GDR}	λ_{SC}	λ_{GLR}	R^2	$p-value$	$MAPE$
C_1	0.74	-0.33	10.14									χ^2	
	(0.05)	(0.05)	(7.08)	FMB				2.41	3.47	0.02	0.94		0.26
C_2	0.90	-0.19	1.89					(2.20)	(1.27)	(0.07)		(0.80)	
	(0.07)	(0.06)	(10.48)					[2.17]	[1.18]	[0.07]		[0.78]	
C_3	1.02	-0.15	-1.83										
	(0.04)	(0.03)	(11.25)									$HJ-dist$	
C_4	1.18	0.19	-13.79	GMM_1	0.41	0.87	87.39	2.41	3.47	0.02	0.94	0.69	0.26
	(0.04)	(0.05)	(7.25)		(0.33)	(0.32)	(293.65)	(1.77)	(1.16)	(0.06)			
C_5	1.16	0.47	3.59	GMM_2	0.41	0.73	88.82	2.51	2.89	0.02	0.93		0.34
	(0.08)	(0.05)	(8.30)		(0.30)	(0.22)	(288.46)	(1.85)	(0.84)	(0.06)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for the linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, sovereign credit risk (HML_{SC}) and global FX liquidity risk (GLR) measured by the aggregate level of relative bid-ask spreads, both as slope (country-specific) factors. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.11. Asset Pricing of Currency Carry Portfolios: $GDR + HML_{SC} + \Delta TED$

All Countries with Transaction Costs													
	Factor Exposures			Factor Prices									
	β_{GDR}	β_{SC}	$\beta_{\Delta TED}$		b_{GDR}	b_{SC}	$b_{\Delta TED}$	λ_{GDR}	λ_{SC}	$\lambda_{\Delta TED}$	R^2	$p-value$	$MAPE$
C_1	0.73	-0.33	-0.03									χ^2	
	(0.05)	(0.05)	(0.23)	FMB				2.40	3.23	-0.33	0.93		0.30
C_2	0.90	-0.18	0.13					(2.19)	(1.65)	(3.34)		(0.74)	
	(0.08)	(0.07)	(0.14)					[2.17]	[1.54]	[3.30]		[0.75]	
C_3	1.03	-0.14	0.21										
	(0.04)	(0.02)	(0.18)									$HJ-dist$	
C_4	1.19	0.19	0.08	GMM_1	0.32	0.80	-0.46	2.40	3.23	-0.33	0.93	0.38	0.30
	(0.04)	(0.05)	(0.17)		(0.35)	(1.26)	(11.44)	(1.78)	(1.19)	(2.91)			
C_5	1.15	0.46	-0.38	GMM_2	0.32	0.73	0.40	2.34	2.78	-0.08	0.92		0.36
	(0.07)	(0.05)	(0.30)		(0.35)	(1.22)	(11.74)	(1.82)	(1.17)	(3.01)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for the linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor, sovereign credit risk (HML_{SC}) and changes in T-Bill Eurodollar (TED) Spreads Index (ΔTED) both as slope (country-specific) factors. The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ - dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.12. Asset Pricing of Currency Carry Portfolios: Peso Problem

	All Countries with Transaction Costs									
	Factor Exposures		Factor Prices							
	β_{GDR}	$\beta_{GSI_{W95}}$		b_{GDR}	$b_{GSI_{W95}}$	λ_{GDR}	$\lambda_{GSI_{W95}}$	R^2	$p-value$	$MAPE$
C_1	0.838	1.879							χ^2	
	(0.067)	(0.764)	FMB			2.408	-0.486	0.850		0.319
C_2	1.061	3.145				(2.186)	(0.192)		(0.831)	
	(0.098)	(0.780)				[2.174]	[0.187]		[0.799]	
C_3	1.059	0.556								
	(0.052)	(0.527)							$HJ-dist$	
C_4	1.084	-2.003	GMM_1	-0.390	-14.088	2.408	-0.486	0.850	0.788	0.504
	(0.055)	(0.520)		(0.401)	(6.691)	(1.731)	(1.23)			
C_5	0.959	-3.578	GMM_2	-0.097	-8.164	2.557	-0.336	0.892		0.377
	(0.075)	(0.931)		(0.317)	(4.375)	(1.744)	(1.24)			
	β_{GDR}	$\beta_{GSI_{W90}}$		b_{GDR}	$b_{GSI_{W90}}$	λ_{GDR}	$\lambda_{GSI_{W90}}$	R^2	$p-value$	$MAPE$
C_1	0.826	2.181							χ^2	
	(0.067)	(0.898)	FMB			2.404	-0.443	0.862		0.494
C_2	1.016	2.918				(2.186)	(0.172)		(0.839)	
	(0.100)	(1.020)				[2.174]	[0.161]		[0.810]	
C_3	1.067	0.984								
	(0.049)	(0.619)							$HJ-dist$	
C_4	1.100	-2.239	GMM_1	-0.376	-18.392	2.404	-0.443	0.862	0.788	0.494
	(0.052)	(0.738)		(0.378)	(7.964)	(1.826)	(0.156)			
C_5	0.991	-3.844	GMM_2	-0.098	-10.888	2.536	-0.301	0.783		0.513
	(0.076)	(1.074)		(0.278)	(5.138)	(1.780)	(0.114)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for comparison between two linear factor models (LFM) both based on position-unwinding risk (PUW) as the intercept (global) factor but differ in slope (country-specific) factor. The LFM in the top panel employs sovereign credit risk winsorized at 95% level ($HML_{SC_{W95}}$) and the LFM in the bottom panel adopts sovereign credit risk winsorized at 90% level ($HML_{SC_{W90}}$). The test assets are the transaction-cost adjusted excess returns of five currency carry portfolios from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.13. Markov Regime-switching Models of Currency Carry Portfolios: Estimates & Tests

	C_1	C_2	C_3	C_4	C_5
$\alpha(0)$	0.078***	0.089***	0.125***	0.111**	0.118***
$\alpha(1)$	0.039***	0.047***	0.054***	0.073***	0.061***
$\alpha(0) = \alpha(1)$	10.419***	17.907***	41.706***	0.413	14.659***
$\beta_{PUW}(0)$	-0.171***	-0.208***	-0.285***	-0.290***	-0.272***
$\beta_{PUW}(1)$	-0.091***	-0.108***	-0.123***	-0.159***	-0.129***
$\beta_{PUW}(0) = \beta_{PUW}(1)$	31.929***	25.418***	93.339***	2.258	27.942***
$\beta_{SC}(0)$	-1.068***	-0.297*	-0.954***	0.087	0.580***
$\beta_{SC}(1)$	-0.382***	-0.380***	-0.270***	0.094	0.187*
$\beta_{SC}(0) = \beta_{SC}(1)$	10.799***	0.093	5.311**	0.000	2.065
$p_{00} = 1 - p_{11}$	0.297	4.27243**	0.319	2.51	35.580***
Average Duration (Month):					
Regime 0	1.00	3.00	1.00	2.50	7.25
Regime 1	14.00	12.33	14.00	28.00	15.00
Linearity LR-test	7.391	21.325***	58.721***	46.856***	35.979***

This table reports the parameter estimates of five currency carry portfolios (monthly excess returns) with Newey and West (1987) HAC standard errors. Asterisks refer to the level of statistical significance of the estimated coefficients, '*' 10%, '**' 5%, and '***' 1%. Regime 0 is high volatility state and Regime 1 is low volatility state. The Wald statistics computed by asymptotic covariance matrix for testing identical parameters and systematically alternating regimes (opposite to arbitrarily switching between two regimes) in terms of smoothed transition probabilities, average duration of each regime (month), and the linearity LR-tests are also reported. However, owing to the issue of non-standard asymptotic χ^2 distribution, the validity of the LR-statistic for linearity test is questioned (Teräsvirta, 2006). The sample period is from September 2005 to January 2013.

Table A.14. Currency Portfolios Sorted on Betas with HML_{SC}

All Countries without Transaction Costs							
Portfolios	L	LM	M	UM	H	Avg.	H/L
Mean (%)	1.71	2.15	2.26	3.24	4.07	2.69	2.36
Median (%)	2.91	4.73	4.53	4.91	7.48	5.38	3.51
Std.Dev. (%)	9.33	10.57	7.27	5.20	10.64	8.60	9.42
Skewness	-0.07	-0.26	-0.34	-0.25	-0.41	-0.27	-0.22
Kurtosis	0.03	0.26	0.35	0.15	0.49	0.26	0.60
Sharpe Ratio	0.18	0.20	0.31	0.62	0.38	0.34	0.25
$f - s$ (%)	-0.77	0.69	1.49	4.30	5.05	2.15	5.82

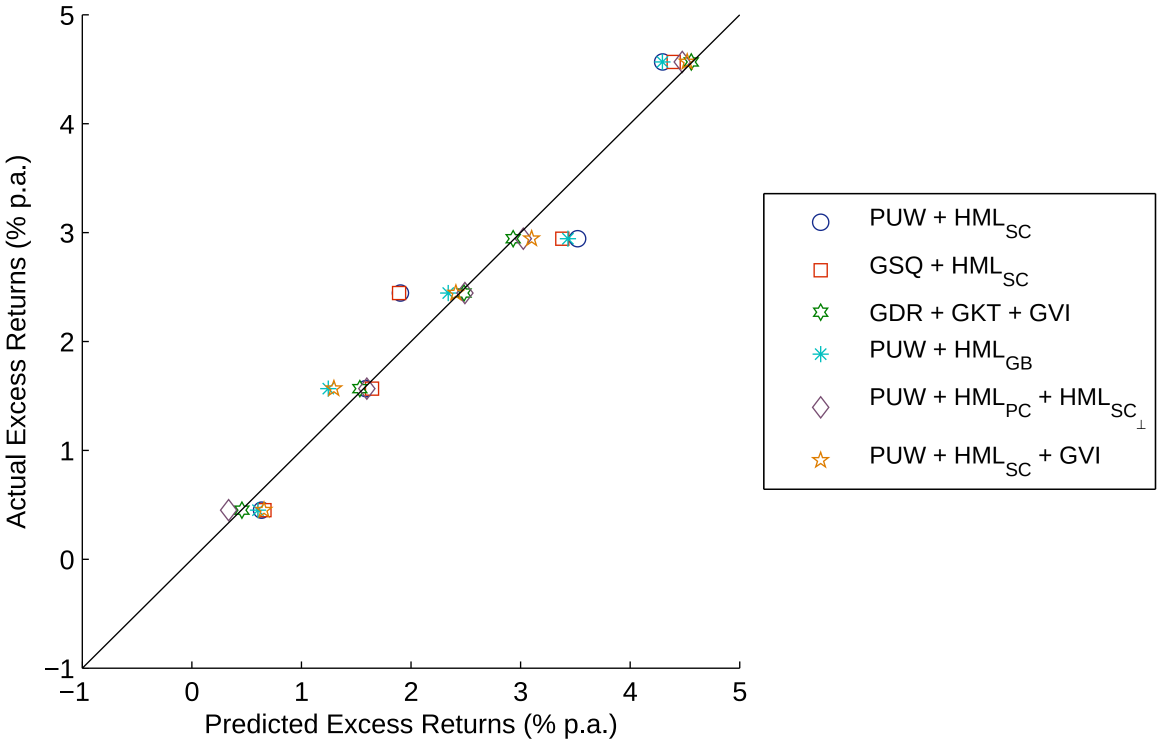
This table reports descriptive statistics of the excess returns of currency portfolios sorted on individual currencies' average β_{SC}, which are the risk exposures to HML_{SC} (sovereign credit factor), from September 2005 to January 2013. The rolling window of 60 months is chosen to obtain stable estimations of β_{SC} with very low volatility. The rank of individual currencies' risk exposures is relatively persistent to the sorting over the sample period, hence the portfolios do not need to be rebalanced during the whole sample period. The 20% currencies with the lowest β_{SC} are allocated to Portfolio 'L' (Low), and the next 20% to Portfolio 'LM' (Lower Medium), Portfolio 'M' (Medium), Portfolio 'UM' (Upper Medium) and so on to Portfolio 'H' (High) which contains the highest 20% β_{SC}. 'Avg.', and 'H/L' denotes the average excess returns of five portfolios, and difference in the excess returns between Portfolio 'H' and the Portfolio 'L' respectively. All excess returns are monthly in USD with daily availability and adjusted for transaction costs (bid-ask spreads). The mean, median, standard deviation and higher moments are annualized and in percentage. Skewness and kurtosis are in excess terms. The last row ($f - s$) shows the average annualized forward discounts of five portfolios in percentage.

Table A.15. Currency Portfolios Doubly Sorted on Betas with HML_{SC} & Betas with PUW

All Countries without Transaction Costs											
β_{SC}	Bottom			Mezzanine			Top				
β_{PUW}	Low	Medium	High	Low	Medium	High	Low	Medium	High	Avg.	H/L
Mean (%)	0.99	1.42	2.18	1.81	2.57	3.68	2.91	2.79	5.13	2.61	4.14
Median (%)	2.69	3.31	6.74	2.21	4.76	6.97	4.90	7.17	8.18	5.21	6.45
Std.Dev. (%)	6.53	10.85	13.05	3.17	9.09	13.86	5.49	11.35	11.85	9.47	10.83
Skewness	-0.03	-0.05	-0.23	-0.13	-0.41	-0.27	-0.20	-0.32	-0.44	-0.23	-0.37
Kurtosis	0.07	0.10	0.18	0.12	0.50	0.25	0.09	0.29	0.57	0.24	0.39
Sharpe Ratio	0.15	0.13	0.17	0.57	0.28	0.27	0.53	0.25	0.43	0.31	0.38
$f - s$ (%)	-0.61	-0.22	0.46	2.32	2.39	3.96	2.06	3.95	5.95	2.24	6.57

This table reports descriptive statistics of the excess returns of currency portfolios sorted on both individual currencies' average β_{SC} and average β_{PUW}, which are the risk exposures to HML_{SC} (sovereign credit factor) and to PUW (position-unwinding likelihood indicator) respectively, from September 2005 to January 2013. The rolling window of 60 months is chosen to obtain stable estimations of β_{SC} and β_{PUW} with very low volatility. The rank of individual currencies' risk exposures is relatively persistent to the sorting over the sample period, hence the portfolios do not need to be rebalanced during the whole sample period. The portfolios are doubly sorted on bottom 30%, mezzanine 40%, and top 30% basis. 'Avg.' denotes the average excess returns of nine portfolios, and 'H/L' is difference in the excess returns between the portfolio that consists of the top 30% currencies in both β_{SC} and β_{PUW} and the portfolio that consists of the bottom 30% currencies in both β_{SC} and β_{PUW}. All excess returns are monthly in USD with daily availability and adjusted for transaction costs (bid-ask spreads). The mean, median, standard deviation and higher moments are annualized and in percentage. Skewness and kurtosis are in excess terms. The last row ($f - s$) shows the average annualized forward discounts of five portfolios in percentage.

Figure A.5. Cross Sectional Goodness of Fit: Currency Carry Portfolios



This figure shows the cross-sectional predictive power of position-unwinding risk and sovereign credit risk on five currency carry portfolios. The excess returns are in percentage per annum.

Table A.16. Asset Pricing of Currency Momentum & Volatility Risk Premium Portfolios

All Countries with Transaction Costs										
Factor Exposures			Factor Prices							
	β_{GDR}	β_{SC}		b_{GDR}	b_{SC}	λ_{GDR}	λ_{SC}	R^2	$p-value$	$MAPE$
$P_{1,MMT}$	1.128	0.090							χ^2	
	(0.085)	(0.071)	FMB			2.368	-13.496	0.651		0.421
$P_{2,MMT}$	1.188	0.058				(2.160)	(5.234)		(0.727)	
	(0.143)	(0.078)				[2.174]	[5.686]		[0.714]	
$P_{3,MMT}$	0.912	0.042								
	(0.036)	(0.072)							$HJ-dist$	
$P_{4,MMT}$	0.856	-0.060	GMM_1	0.122	-3.953	2.368	-13.496	0.651	0.381	0.421
	(0.055)	(0.038)		(0.161)	(1.681)	(1.390)	(5.709)			
$P_{5,MMT}$	0.885	-0.125	GMM_2	0.078	-4.253	2.074	-14.502	0.550		0.544
	(0.126)	(0.100)		(0.183)	(1.705)	(1.632)	(5.794)			
	β_{GDR}	β_{SC}		b_{GDR}	b_{SC}	λ_{GDR}	λ_{SC}	R^2	$p-value$	$MAPE$
$P_{1,VRP}$	0.892	0.508							χ^2	
	(0.155)	(0.108)	FMB			2.295	5.198	0.820		0.554
$P_{2,VRP}$	0.970	-0.004				(2.195)	(2.465)		(0.865)	
	(0.048)	(0.059)				[2.179]	[2.571]		[0.846]	
$P_{3,VRP}$	1.105	-0.102								
	(0.048)	(0.067)							$HJ-dist$	
$P_{4,VRP}$	1.231	-0.312	GMM_1	0.312	1.557	2.295	5.198	0.820	0.763	0.554
	(0.137)	(0.070)		(0.212)	(0.675)	(1.810)	(2.267)			
$P_{5,VRP}$	1.263	-0.188	GMM_2	0.271	1.579	1.3914	5.287	0.725		0.652
	(0.058)	(0.067)		(0.234)	(0.700)	(1.979)	(2.342)			

This table reports time-series factor exposures (β), and cross-sectional factor loadings (b) and factor prices (λ) for comparison between two tested assets in a linear factor model (LFM) based on Lustig, Roussanov, and Verdelhan's (2011) dollar risk (GDR) as the intercept (global) factor and Huang and MacDonald's (2013) sovereign credit risk (HML_{SC}) as the slope (country-specific) factor. The test assets are the transaction-cost adjusted excess returns of five currency momentum portfolios (top panel), and five currency volatility risk premium portfolios (bottom panel) respectively, from September 2005 to January 2013. The coefficient estimates of Stochastic Discount Factor (SDF) parameters b and λ are obtained by Fama-MacBeth (FMB) without a constant in the second-stage regressions (Fama and MacBeth, 1973), and by fist-stage (GMM_1) and iterated (GMM_2) Generalized Method of Moments procedures. Newey-West VARHAC standard errors (Newey and West, 1987) with optimal lag selection (Andrews, 1991) and corresponding p-value of χ^2 statistic (for testing the null hypothesis that the cross-sectional pricing errors are jointly equal to zero) are in the parentheses. The Shanken-adjusted standard errors (Shanken, 1992) and corresponding p-value of χ^2 statistic are in the brackets. The cross-sectional R^2, the simulation-based p-value of Hansen-Jagannathan distance (Hansen and Jagannathan, 1997) for testing whether it is equal to zero ($HJ-dist$), and Mean Absolute Pricing Error ($MAPE$) are also reported.

Table A.17. Linear & Nonlinear Granger Causality Tests for Impulsive Country-specific Risk

	Linear	Nonlinear
HML_{SC} does not Granger cause HML_{FB}	0.01	0.02
HML_{FB} does not Granger cause HML_{SC}	0.37	0.03
HML_{SC} does not Granger cause GVI	0.03	0.04
GVI does not Granger cause HML_{SC}	0.63	0.73
HML_{SC} does not Granger cause ΔVIX	0.04	0.07
ΔVIX does not Granger cause HML_{SC}	0.92	0.41
HML_{SC} does not Granger cause ΔTED	0.00	0.03
ΔTED does not Granger cause HML_{SC}	0.29	0.05
HML_{SC} does not Granger cause GLR	0.25	0.07
GLR does not Granger cause HML_{SC}	0.44	0.10
HML_{SC} does not Granger cause HML_{GB}	0.03	0.05
HML_{GB} does not Granger cause HML_{SC}	0.65	0.12
HML_{SC} does not Granger cause HML_{EM}	0.05	0.22
HML_{EM} does not Granger cause HML_{SC}	0.70	0.19

This table reports the $p - values$ of linear and nonlinear Granger causality tests (see Hiemstra and Jones, 1994; Diks and Panchenko, 2006 for details) for the impulsive country-specific risk. The first column lists the null hypotheses to be tested. Due to the limited sample size, Akaike's Final Prediction Error (also as known as AIC) is chosen as the lag-length selection procedure rather than Schwarz (Bayesian) Information Criterion (SIC) or Hannan-Quinn Information Criterion (see Anderson, 2004 for details). The bandwidth of 1.50 is chosen according to the sample size. The sample period is from September 2005 to January 2013.

Table A.18. Linear & Nonlinear Granger Causality Tests for Global Contagion

	Linear	Nonlinear		Linear	Nonlinear
HML_{SC} does not Granger cause GDR	0.08	0.06	HML_{FB} does not Granger cause GDR	0.02	0.13
GDR does not Granger cause HML_{SC}	0.43	0.41	GDR does not Granger cause HML_{FB}	0.54	0.27
GVI does not Granger cause GDR	0.36	0.05	ΔVIX does not Granger cause GDR	0.00	0.04
GDR does not Granger cause GVI	0.64	0.10	GDR does not Granger cause ΔVIX	0.35	0.11
GLR does not Granger cause GDR	0.85	0.69	ΔTED does not Granger cause GDR	0.00	0.54
GDR does not Granger cause GLR	0.05	0.38	GDR does not Granger cause ΔTED	0.03	0.75
HML_{SC} does not Granger cause PUW	0.27	0.30	HML_{FB} does not Granger cause PUW	0.09	0.51
PUW does not Granger cause HML_{SC}	0.40	0.65	PUW does not Granger cause HML_{FB}	0.99	0.51
GVI does not Granger cause PUW	0.23	0.78	ΔVIX does not Granger cause PUW	0.04	0.53
PUW does not Granger cause GVI	0.29	0.06	PUW does not Granger cause ΔVIX	0.69	0.07
GLR does not Granger cause PUW	0.65	0.12	ΔTED does not Granger cause PUW	0.18	0.56
PUW does not Granger cause GLR	0.07	0.23	PUW does not Granger cause ΔTED	0.05	0.24
HML_{SC} does not Granger cause GSQ	0.24	0.06	HML_{FB} does not Granger cause GSQ	0.04	0.06
GSQ does not Granger cause HML_{SC}	0.22	0.14	GSQ does not Granger cause HML_{FB}	0.27	0.16
GVI does not Granger cause GSQ	0.46	0.68	ΔVIX does not Granger cause GSQ	0.03	0.02
GSQ does not Granger cause GVI	0.06	0.07	GSQ does not Granger cause ΔVIX	0.13	0.08
GLR does not Granger cause GSQ	0.86	0.22	ΔTED does not Granger cause GSQ	0.17	0.43
GSQ does not Granger cause GLR	0.34	0.28	GSQ does not Granger cause ΔTED	0.22	0.50

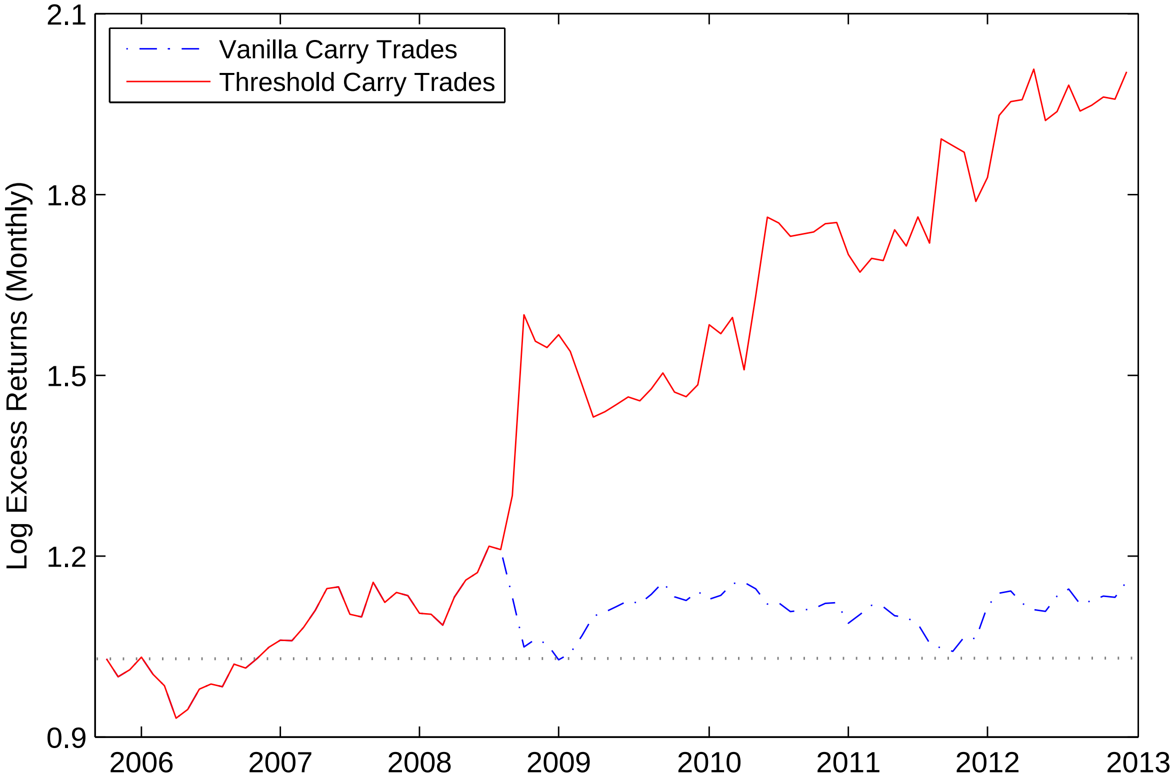
This table reports the $p - values$ of linear and nonlinear Granger causality tests (see Hiemstra and Jones, 1994; Diks and Panchenko, 2006 for details) for global contagion. The first column lists the null hypotheses to be tested. Due to the limited sample size, Akaike's Final Prediction Error (also as known as AIC) is chosen as the lag-length selection procedure rather than Schwarz (Bayesian) Information Criterion (SIC) or Hannan-Quinn Information Criterion (see Anderson, 2004 for details). The bandwidth of 1.50 is chosen according to the sample size. The sample period is from September 2005 to January 2013.

Table A.19. Smooth Transition Models of Currency Carry Portfolios: Estimates & Tests

	C_1	C_2	C_3	C_4	C_5
β_{FB}	-0.426***	-0.177***	-0.065***	0.120***	0.572***
$\alpha(0)$	-0.002***	-0.001	0.001	0.044***	-0.001
$\beta_{GDR}(0)$	0.984***	1.066***	0.967***	0.118	0.989***
$\alpha(1)$	0.003***	0.005	0.003	-0.044***	0.003*
$\beta_{GDR}(1)$	-0.050	-0.196	0.243***	1.011***	-0.070
γ	27.0	138.0	99.0	149.0	26.0
c	0.462	0.751	0.721	0.719	0.462
Nonlinearity LM-test	1.75	0.424	2.21*	0.433	1.780

This table reports the parameter estimates of five currency carry portfolios (monthly excess returns) with Teräsvirta (1998) standard errors scaling procedure. Regime 0 denotes linear regime and Regime 1 the nonlinear regime. Both the constant term (α) and dollar risk (GDR) enter the model nonlinearly, forward bias risk (HML_{FB}) enters the linear part of the STR model only. Position-unwinding likelihood indicator (PUW) is the transition variable (ν_t). γ_j, and c_j denotes the slope parameter that determines the smoothness of the transition function $\omega(\cdot)$, and the threshold level, respectively. Asterisks refer to the level of statistical significance of the estimated coefficients (not for γ and c), '*' 10%, '**' 5%, and '***' 1%. $LM-test$ for examining the null hypothesis of no remaining nonlinearity (Eitrheim and Teräsvirta, 1996) is employed. The in-sample period is from September 2005 to September 2009.

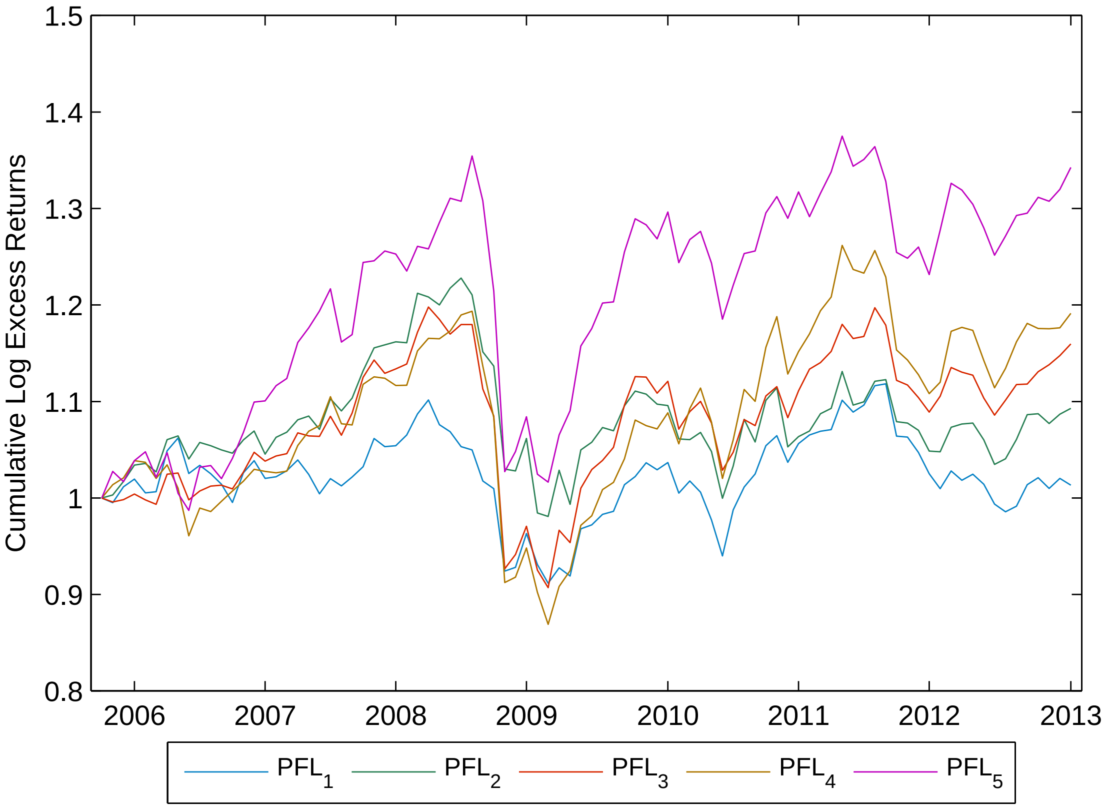
Figure A.6. Cumulative Excess Returns of the Alternative Currency Carry Portfolio: Threshold Trading on *PUW*



This figure shows the cumulative excess returns of an alternative carry trade strategy that is immunized from currency crashes, in comparison of the traditional long-short strategy. It trades on the threshold level of position-unwinding risk that investing in the highest interest-rate currencies funded by the lowest interest-rate currencies during the tranquil period and reverse the positions once the threshold level of position-unwinding likelihood indicator is reached. The out-of-sample period is from October 2009 to January 2013.

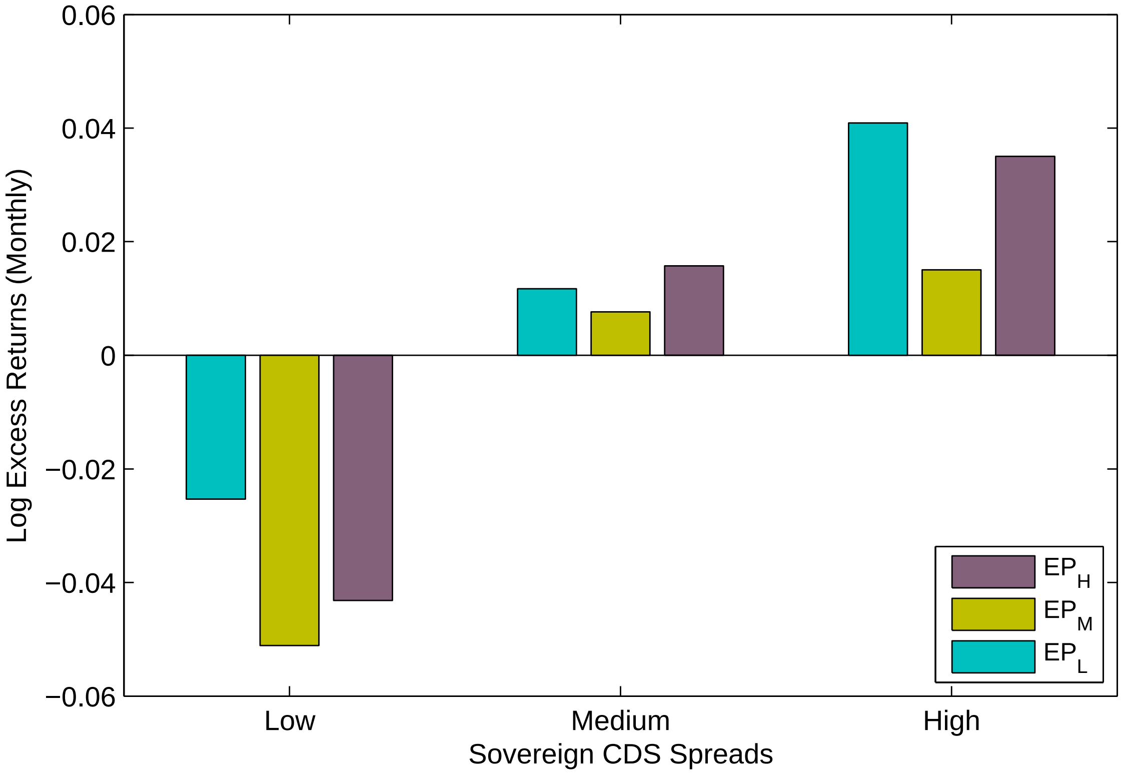
Appendix B.

Figure B.1. Cumulative Excess Returns of Currency Carry Portfolios Sorted on Forward Discounts



This figure shows the cumulative excess returns of currency carry portfolios sorted on forward discounts and in long positions from September 2005 to January 2013. PFL_1, PFL_2, and PFL_3, PFL_4, and PFL_5 denotes the currency carry portfolios with lowest, lower medium, medium, higher medium, and highest forward discounts, respectively.

Figure B.2. Currency Portfolios Doubly Sorted on Sovereign CDS Spreads and Equity Premia



This figure shows the average monthly excess returns of nine currency portfolios (the vertical axis) that are sorted on both sovereign CDS spreads and equity premia over U.S. market from September 2005 to January 2013. EP_L, EP_M, and EP_H denotes the low, medium, and high equity-premium currency portfolios, respectively. The horizontal axis represents the level of sovereign CDS spreads of currency portfolios in ascending order.

Table B.1. Principal Component Analysis of Asset Excess Returns

	Currency Carry Portfolios					
	C_1	C_2	C_3	C_4	C_5	Variance (%)
PC_1	0.876	0.946	0.959	0.952	0.904	86.120
PC_2	0.442	0.143	-0.043	-0.157	-0.368	7.552
Total						93.672
	Government Bond Portfolios					
	B_1	B_2	B_3	B_4	B_5	Variance (%)
PC_1	0.741	0.932	0.951	0.919	0.831	77.120
PC_2	0.635	0.111	0.049	-0.252	-0.469	14.035
Total						91.155
	Equity Momentum Portfolios					
	E_1	E_2	E_3	E_4	E_5	Variance (%)
PC_1	0.956	0.976	0.977	0.974	0.958	93.730
PC_2	0.259	0.066	-0.015	-0.067	0-.242	2.699
Total						96.429

This table reports the principal component coefficients of currency carry, government bonds, equity momentum portfolios. PC_1, PC_2 denotes the first principal component, and the second principal component, respectively. The last column shows the share of the total variance (in %) explained by each common factor. The last row provides the cumulative share of the total variance (in %) explained by the first two common factors. The sample period is from September 2005 to January 2013.

Table B.2. Descriptive Statistics of Government Bond Portfolios

All Countries without Transaction Costs							
Portfolios	B_1	B_2	B_3	B_4	B_5	Avg.	H/L
Mean (%)	3.87	3.93	5.50	5.75	7.62	5.34	3.76
Median (%)	3.55	7.53	8.82	10.14	10.54	8.12	7.05
Std.Dev. (%)	6.30	8.45	8.28	12.57	16.72	10.46	15.54
Skewness	0.07	-0.20	-0.13	-0.37	-0.27	-0.18	-0.36
Kurtosis	0.02	0.19	0.14	0.38	0.53	0.25	0.60
Sharpe Ratio	0.61	0.47	0.70	0.44	0.46	0.53	0.24
AC(1)	-0.09	-0.18	-0.09	-0.01	0.04	-0.06	0.08

This table reports descriptive statistics of the excess returns in USD of government bond (total return) indices portfolios with 5-year maturity sorted on 1-month lagged redemption yield. The 20% equity indices with the lowest lagged redemption yields are allocated to Portfolio B_1, and the next 20% to Portfolio B_2, and so on to Portfolio B_5 which contains the highest 20% lagged redemption yields. The portfolios are rebalanced simultaneously with the the currency portfolios, hence the excess returns have the same duration. 'Avg.', and 'H/L' denotes the average excess returns of five portfolios, and difference in the excess returns between Portfolio B_5 and Portfolio B_1 respectively. All excess returns are monthly and unadjusted for transaction costs with the sample period from September 2005 to January 2013 with daily availability. The mean, median, standard deviation and higher moments are annualized (so is the Sharpe Ratio) and in percentage. Skewness and kurtosis are in excess terms. AC(1) is the first order autocorrelation coefficient of the monthly excess returns in monthly frequency.

Table B.3. Descriptive Statistics of Equity Momentum Portfolios

All Countries without Transaction Costs							
Portfolios	E_1	E_2	E_3	E_4	E_5	Avg.	H/L
Mean (%)	1.33	1.59	2.98	4.44	4.74	3.01	3.41
Median (%)	9.80	14.85	15.68	15.60	16.99	14.58	5.03
Std.Dev. (%)	25.62	25.60	26.06	26.52	30.88	26.94	15.27
Skewness	-0.28	-0.40	-0.46	-0.47	-0.46	-0.04	-0.17
Kurtosis	0.25	0.45	0.63	0.67	0.67	0.53	0.33
Sharpe Ratio	0.05	0.06	0.11	0.17	0.15	0.11	0.22
AC(1)	0.10	0.22	0.20	0.20	0.19	0.20	-0.18

This table reports descriptive statistics of the excess returns in USD of equity momentum portfolios sorted on 1-month lagged equity-index excess returns. The 20% equity indices with the lowest lagged excess returns are allocated to Portfolio E_1, and the next 20% to Portfolio E_2, and so on to Portfolio E_5 which contains the highest 20% lagged excess returns. The portfolios are rebalanced simultaneously with the the currency portfolios, hence the excess returns have the same duration. 'Avg.', and 'H/L' denotes the average excess returns of five portfolios, and difference in the excess returns between Portfolio E_5 and Portfolio E_1 respectively. All excess returns are monthly and unadjusted for transaction costs with the sample period from September 2005 to January 2013 with daily availability. The mean, median, standard deviation and higher moments are annualized (so is the Sharpe Ratio) and in percentage. Skewness and kurtosis are in excess terms. AC(1) is the first order autocorrelation coefficient of the monthly excess returns in monthly frequency.

Table B.4. Correlations between Risk Factors and Principal Components

	Currency		Bond		Equity	
	PC_1	PC_2	PC_1	PC_2	PC_1	PC_2
GDR	0.999	0.047	0.915	0.205	0.837	0.047
PUW	-0.750	-0.243	-0.396	-0.196	-0.485	-0.184
GSQ	-0.837	-0.019	-0.785	-0.146	-0.697	-0.003
GKT	0.158	0.041	0.127	0.080	0.123	-0.118
HML_{FB}	0.390	0.904	0.156	0.820	0.566	-0.088
HML_{SC}	-0.082	0.712	-0.106	0.697	0.287	0.038
GSI	-0.722	-0.310	-0.443	-0.310	-0.630	-0.211
HML_{GB}	0.693	0.551	0.561	0.752	0.829	0.005
HML_{EM}	0.329	0.203	0.307	0.128	0.340	0.925
GVI	-0.629	-0.369	-0.443	-0.369	-0.582	0.065
ΔVIX	-0.541	-0.431	-0.374	-0.475	-0.703	-0.122
GLR	-0.268	-0.178	-0.205	-0.218	-0.299	0.048
ΔTED	-0.084	-0.176	-0.092	-0.115	-0.201	-0.087

This table reports the correlations between risk factors and the principal components of currency carry, government bonds, equity momentum portfolios. PC_1, PC_2 denotes the first principal component, and the second principal component, respectively. The sample period is from September 2005 to January 2013.