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Abstract
We investigate the term structure of sovereign yield spreads for five advanced economies against the US and provide novel insights on the key drivers of the term structure. We show that the spread term structure dynamics are driven by three latent factors, which can be labeled as spread level, slope and curvature similar to common interpretations found in the yield curve literature. We further show that these estimated spread factors have predictive power for exchange rate changes and excess returns above the predictability of an uncovered interest rate parity approach. As the yield curve contains information about expected future economic conditions we conjecture that these yield spread factors reflect expected macroeconomic differentials which in turn drive exchange rates. Using the information content of yield spread curves may thus be promising to improve the forecasting accuracy of exchange rate models.

Key words: Sovereign Yield Spreads, Term Structure Modeling, Principal Component Analysis, Macroeconomic Fundamentals, Exchange Rate Forecasts

JEL: C58, E43, E44, F31

1 Introduction

Sovereign yield spreads denote the difference between two government yields of equal maturity. They are important variables for investment practitioners, risk management and policy makers as they reflect the relative economic position against other economies and are key input factors for exchange rate forecasts and carry trade strategies. Commonly used as proxies for the difference in interest rate levels between economies, they play a crucial role in one of the cornerstones of academic finance literature – the uncovered interest rate parity (UIRP) hypothesis.

The dynamic behavior of yield spreads, in particular the term structure, has however received little attention in previous research. The class of literature decomposing the credit-risk driven determinants of sovereign spreads for emerging economies usually focuses on selected long term maturities (Rocha and Garcia, 2005; Liu and Spencer, 2009; Hilscher and Nosbusch, 2010). The same holds for a recent stream of literature exploring the drivers of sovereign spreads within the Eurozone area (Bernoth and Erdogan, 2012; Maltritz, 2012; Eichler and Maltritz, 2013). The large number of studies testing the UIRP, see, e.g. McCallum (1994); Chinn and Meredith (2004); Backus et al. (2010) or Sarno (2005); Engel (2013) for recent surveys, usually apply spreads between short term interest rates, commonly known as the carry, and naturally disregard the dynamics of the entire spread term structure. These term structure dynamics may however be worth exploring as the information content of certain maturities is different.

We investigate the term structure of sovereign yield spreads and provide novel insights on the latent factors driving the term structure. We further show that these latent factors can predict exchange rate changes and excess returns up to 24 months ahead. We conclude that the spread factors proxy expected fundamental differentials in price levels, output and monetary policy.

For our analysis we investigate the term structure of yield spreads of six advanced economies (Australia, Canada, Switzerland, Japan, UK and the US) with highly liquid markets of bonds issued in their own, free floating currency and little to no credit or default risk. The spreads are calculated as the difference between end-of-months zero-bond yields of equal maturity and the term structure is constructed with 12 maturities ranging from three-months, six-months, 12-months and 24-months up to 120-months for the time period from January 1995 to December 2013. In line with previous research (Dungey et al., 2000; Boudoukh et al., 2005; Sarno et al., 2012) we calculate all spreads against US interest rates.[2] This leaves us with five datasets of sovereign spread curves - US-AU, US-CA, US-CH, US-JP and US-UK.

To identify the drivers of the sovereign spreads term structure we derive latent factors by

[2]We note that the results and conclusions presented in this paper also hold for other sovereign spread pair combinations.

means of a principal component analysis (PCA). This allows us to extract market expectations directly from the data. PCA is a common technique to describe dynamic term structure behaviour in a parsimonious manner and has been applied successfully on the term structure of interest rates (Barber and Copper, 2012), swap spreads (Cortes, 2006) or CDS spreads (Longstaff et al., 2012),just to name a few. Note that we apply the PCA directly on the yield spreads and , therefore, differ from the class of studies modeling the co-movement of government yields to derive common global factors (Driessen et al., 2003; Pérignon and Smith, 2007; Afonso and Martins, 2012; Juneja, 2012).

Our analysis of the yield spread term structure dynamics shows that the variation in the entire term structure can be explained through a relatively small number of three factors. For the considered economies, the three estimated factors explain approximately 99% of the entire variation in the term structure of spreads between US interest rates and yields in Australia, Canada, Japan, Switzerland and United Kingdom. Interestingly, similar to interpretations found in yield curve models (Litterman and Scheinkman, 1991; Leite et al., 2010), the identified latent factors can be labeled as spread level, spread slope and spread curvature. These findings are stable across all investigated sovereign spreads.

We further test the ability of these extracted latent spread factors to predict exchange rate changes and excess returns. The yield curve is well known to provide valuable information about future macroeconomic conditions in particular output, inflation and monetary policy, while expectation about cross-country differences in these fundamental factors also determine exchange rates. We thus suspect that the latent factors derived from the term structure of yield spreads – the cross-country differences between yield curves – may serve as a natural measure to the fundamental aspects of exchange rate determination.

Our in-sample predictive regression results confirm that the spread factors can explain and predict bilateral exchange rate movements and excess returns three month up to two years ahead. The predictive content seems to be highest for the '*safe haven currencies*' Swiss Franc and Japanese Yen as well as the Australian Dollar and to a lesser extent for the Canadian Dollar and the British Pound. We find that in particular the derived spread level and the spread slope factor are significant. The negative coefficients for both factors are also consistent with economic theory and findings in previous literature, in particular Chen and Tsang (2012, 2013) and Bui and Fisher (2015). Chen and Tsang (2012, 2013) find that cross-country Nelson-Siegel factors can predict future exchange rate changes and excess currency returns up to 24 months ahead. Bui and Fisher (2015) support their findings for the relative yield curves of the US and Australia.

We further find additional explanatory power for the extracted factors compared to the UIRP approach for most currencies and horizons. These results make intuitive sense when the exchange rate is understood as an asset price and relies more on long term expectations than on current fundamentals. Other than the UIRP approach - which only uses the information content up to a certain maturity - the spread factors take advantage of the information embodied in the entire spread term structure. The estimated latent spread factors can thus be interpreted as augmenting the single horizon UIRP relation with the information in spreads of additional maturities.

Overall, these results indicate that the obtained spread factors can be interpreted as an alternative set of latent fundamentals incorporating expected differences in observed macroeconomic fundamentals. This confirms the conclusions of Engel and West (2005), Bacchetta and van Wincoop (2013) and Balke et al. (2013) who find an important role of unobserved and expected fundamentals to explain exchange rate fluctuations. Considering the widespread forecasting failure of empirical exchange rate models based on observed macroeconomic fundamentals (Meese and Rogoff, 1983; Molodtsova and Papell, 2009; Rossi, 2013) the estimated spread factors may thus be helpful in future forecasting studies.

We contribute to the macro-finance literature in several dimensions. First, this is one of the first studies to thoroughly explore the dynamics of the entire term structure of yield spreads. Second, we provide key insights on latent key factors driving the term structure of sovereign spreads between advanced economies. Third, we show that the factors extracted from the term structure of sovereign spreads have predictive power for changes in the exchange rate and excess returns in line with economic intuition. We also illustrate that the extracted factors provide additional predictive information in comparison to the traditional UIRP approach.

The remainder of the paper is organized as follows: The subsequent section describes the relation between yield spread curves, macroeconomic fundamentals and exchange rates as found in previous literature. Section 3 reports descriptive statistics and investigates the dynamic behavior of the applied yield spread data. In Section 4 we estimate and interpret the latent yield spread factors, while Section 5 investigates the predictive ability of these factors for exchange rate changes and excess returns. Section 6 concludes and provides suggestions for future work in this area of research.

2 The relation between Yield Curves, Yield Spreads, Macroeconomic Fundamentals and Foreign Exchange Rates

2.1 Yield Curves and the Term Structure of Yield Spreads

The yield curve or the term structure of interest rates describes the relationship between yields and their time to maturity. Yield curves exist for numerous instruments and securities, theoretically for any interest bearing instrument that is available for different maturities. However, the term *yield curve* or *term structure of interest rates* in an academic sense is mainly used to describe the term structure of government bond yields which are commonly considered to reflect a benchmark for the level of interest rates in an economy.

The yield curve summarizes expectations about future paths of short interest rates ('Expectations Hypothesis') and perceived future uncertainty expressed in the term premiums. Consequently it also contains information about expected future economic conditions such as output, inflation and monetary policy (Ang et al., 2006; Rudebusch and Wu, 2008; Favero et al., 2012). The shape and movements of the yield curve have thus long been used to provide readings of market expectations and they are common indicators for central banks to receive timely feedback on their policy actions.

Research on the term structure of interest rates suggests that the variation in the term structure can be explained by a small number of underlying factors, see, e.g. Litterman and Scheinkman (1991) or more recently Bikbov and Chernov (2010). Typically, three factors already capture more than 99% of the variation in yields and are reflected in the entire term structure of interest rates and its dynamic behavior over time. They have an intuitive interpretation as level, slope and curvature related to the economically meaningful shift, rotation and butterfly moves of the yield curve, which describe how the yield curve changes in response to macroeconomic changes and monetary policy.

These yield curve factors also have the power to predict fluctuations in future economic conditions. Diebold et al. (2006) find that an increase in the US level factor raises capacity utilization, the US fund rate and inflation. Dewachter and Lyrio (2006) estimate an affine model for the yield curve with macroeconomic variables and suggest that the level factor reflects long run inflation expectations, the slope factor captures the business cycle, and the curvature represents the monetary stance of the central bank. Rudebusch and Wu (2007) also contend that the level factor incorporates long-term inflation expectations, and the slope factor captures the central bank's dual mandate of stabilizing the real economy and keeping inflation close to its target. They show that when the central bank tightens monetary policy, the slope factor rises, forecasting lower growth in the future.

The difference between two government yields of equal maturity – the '*sovereign yield spread*' or '*sovereign spread*' [3] - is also of particular importance to market participants and policy makers. Sovereign yield spreads reflect a government's creditworthiness and are heavily used by investment practitioners in exchange rate forecasting and carry trade strategies as these yield spreads reflect interest rate differentials which are key indicators

[3] Note that the academic literature uses various terms to denote the difference between government yields. Sovereign yield spreads are also commonly referred to as '*government bond spreads*' (Dungey et al., 2000), '*sovereign credit spreads*' (Oliveira et al., 2012; Sueppel, 2005), '*sovereign risk premia*' (Haugh et al., 2009) or '*relative yield curves*' (Chen and Tsang, 2013). We use the terms '*sovereign yield spreads*' and '*yield spreads*' or just '*spreads*' throughout the course of the analysis.

for expected exchange rate movements.
As sovereign spreads can be calculated for any maturity, they exhibit a term structure or spread curve of their own. This term structure of sovereign spreads naturally contains valuable long term information about expected cross-country differentials in the economic conditions reflected in the individual yield curves. These are the same macroeconomic differentials which play an important role in exchange rate determination.

2.2 Yield Spreads, Exchange Rate Determination and Macroeconomic Fundamentals

The relation between differences in interest rates and exchange rates is traditionally expressed in the uncovered interest rate parity (UIRP) condition. Under the assumptions of risk neutral and rational market participants, the UIRP links expected exchange rate changes to interest rate differences over the same horizon:

$$\Delta s_{t+m} = i_t^{\tau} - i_t^{\tau *} + \rho_n, \qquad (1)$$

with Δs_{t+m} being the change in the logarithm of the nominal spot exchange rate (US currency price per unit of foreign currency) between time t and $t+m$, i_t^{τ} and $i_t^{\tau *}$ the monthly domestic and foreign interest rates of maturity τ with $\tau = m$ and ρ_n being the risk premium of holding foreign relative to home currency investments.[4]
This relationship naturally builds on interest rate differentials or sovereign spreads of a certain maturity. A τ-month spread accordingly only embodies information up to the time horizon until the underlying instruments mature. However, the exchange rate is commonly modeled as an asset price (Mark, 1995; Engel and West, 2005), where the nominal exchange rate is determined as the present value of the discounted sum of current and expected fundamentals based on the information set of agents in the economy that determine the exchange rate. Based on this approach the exchange rate not only relies on information up to a certain maturity but depends heavily on expected long term fundamentals. These may be reflected more accurately in the term structure of sovereign spreads, which also contains long term information about the expected cross-country differentials in macroeconomic fundamentals.

The term structure of sovereign spreads has the additional advantage that it captures market expectations of future macroeconomic conditions. Common exchange rate

[4]Empirically, this hypothesis has mostly been rejected (see, e.g., Sarno (2005) and Engel (2013) for recent surveys), most likely due to the presence of of time-varying risk premia and systematic expectation errors (Bekaert et al., 2007).

models[5] are usually based on the observable fundamental differentials between economies such as differences in growth, inflation, money supply and monetary policy. However, in a large body of empirical forecasting studies the random walk model has proven to be almost unbeatable by models with traditional economic predictors.[6]

This empirical failure may also be a result of using inappropriate proxies for the market expectations of future fundamentals rather than the failure of the models themselves. Engel and West (2005), for example, find that the exchange rate is not explained only by observable fundamentals. Balke et al. (2013) also show that it is difficult to obtain sharp inferences about the relative contribution of fundamentals using only data on observed fundamentals. Bacchetta and van Wincoop (2013) conclude that the reduced form relationship between exchange rates and fundamentals is driven not by the structural parameters themselves, but rather by expectations of these parameters. Properly measuring expectations thus becomes especially important in empirical testing. Factors summarizing the market expectations contained in the term structure of yield spreads may therefore serve as a natural measure to the fundamental aspects of exchange rate determination. Ang and Chen (2010) and Chen and Tsang (2013), for example, show that yield curve factors based on portfolio strategies and a Nelson-Siegel[7] model can explain foreign exchange rate returns.

These insights highlight two important points. First, the term structure of sovereign spreads is a highly relevant economic variable and it is crucial to understand the dynamics of sovereign spread curves. We will further investigate these dynamics in the subsequent sections. Second, the factors driving the term structure of sovereign spreads may be helpful to predict exchange rates as they summarize information about long term differences in macroeconomic fundamentals. We further explore this assertion in Section 5.

3 Yield Spread Data

3.1 Source and calculation

For our analysis of sovereign yield spreads we choose the five most advanced markets of government bonds issued in their own currency (US, UK, Japan, Canada and Switzerland). We also consider yields in Australia that have gained particular interest in the recent literature on carry-trades and foreign exchange risk premiums (Darvas, 2009; Chris-

[5]See Molodtsova and Papell (2009) for an overview of the most common exchange rate models based on observable macroeconomic fundamentals such as monetary and taylor rule models.

[6]Rossi (2013) provides an excellent overview of the empirical exchange rate forecasting literature since Meese and Rogoff (1983)'s seminal paper.

[7]The popular Nelson and Siegel (1987) model is a parsimonious, parametric factor model using flexible, smooth Laguerre functions to estimate the yield curve.

tiansen et al., 2011; Lustig et al., 2011; Sarno et al., 2012). The yield data is directly obtained from Bloomberg for the time period from January 1995 (the first availability of the time series) up to December 2013. Bloomberg yields have the advantage that they are consistently available for several economies.

The monthly sovereign yield spreads s_t^τ are calculated as the difference $i_t^\tau - i_t^{\tau *}$ between government bond zero yields of equal maturity τ at the end of each month. The term structure is constructed with 12 maturities ranging from three-months, six-months, 12-months and 24-months up to 120-months. Following the existing literature, all spreads are calculated against US yields. This leaves us with five datasets of sovereign spreads US-AU, US-CA, US-CH, US-JP and US-UK.[8]

3.2 Statistical Properties

We summarize selected statistical properties of all sovereign spread data sets in Table 1. Note that sovereign spreads can be either positive or negative depending on the respective yield being lower or higher than US yields. The negative mean US-Australian, US-British and US-Canadian sovereign yield spreads for example indicate that the respective yields have on average been higher than US yields. The opposite holds for Switzerland and Japan, where yields have been significantly lower than US yields throughout the sample period. It is also interesting to note, that calculated against US yields all average spread curves, indicated by the mean spreads of the different maturities, are upward sloping. This implies that for economies with yields mostly higher than US yields (Australia, UK and Canada) the average spread narrows with longer maturities while for economies with yields mostly lower than US yields (the two safe haven currencies Japan and Switzerland) the average spread widens with longer maturities. The mean spreads of different maturities also indicate that the slope of the average spread curve is relatively small.

The standard deviations point towards a difference in volatility between short-term and long-term maturities. The longer the maturity the lower is the standard deviation.For example, the shortest maturity (3-month) has a standard deviation as high as 2.16 for the US-Japanese spread and 1.66 for the US-Australian spread. In contrast, the 120-months spread for the same pairs of countries is characterized by a standard deviation of just 0.90 for US-Japan and 0.72 for US-Australia. The correlation coefficients reveal that the sovereign spreads of different maturities are highly correlated. As could be expected, correlation coefficients are highest for adjacent maturities. The correlation between the 3-months and 60-months spread ranges from 0.85 to 0.95 for example. Even the correlations between the 3-months and 120-months spreads are still as high as 0.8 for the US-JP

[8]The results and conclusions presented in this paper also hold for other sovereign spread pair combinations.

Maturity (months)	Mean	St Dev	Min	Max	Skew	Kurt	Corr(3)	Corr(12)	Corr(60)	Corr(120)
US-AU Spread										
3	-2.17	1.66	-5.50	0.94	0.11	1.96	1.00			
12	-2.02	1.66	-5.19	1.15	0.16	1.92	0.98	1.00		
60	-1.68	1.06	-3.89	0.47	0.11	1.99	0.94	0.98	1.00	
120	-1.33	0.72	-3.20	0.14	-0.36	2.61	0.67	0.74	0.81	1.00
US-CA Spread										
3	-0.24	0.98	-2.59	2.32	0.48	3.11	1.00			
12	-0.25	0.95	-2.43	2.34	0.38	2.85	0.97	1.00		
60	-0.31	0.61	-1.83	0.80	-0.22	2.52	0.92	0.96	1.00	
120	-0.22	0.58	-2.02	0.66	-1.07	3.78	0.46	0.49	0.62	1.00
US-CH Spread										
3	1.64	1.59	-1.09	4.52	0.18	1.44	1.00			
12	1.72	1.61	-1.03	4.66	0.19	1.42	0.98	1.00		
60	1.81	1.00	-0.13	4.09	0.28	2.09	0.95	0.98	1.00	
120	1.85	0.58	0.15	3.37	0.22	2.71	0.80	0.84	0.90	1.00
US-JP Spread										
3	2.63	2.16	-0.46	6.28	0.00	1.38	1.00			
12	2.83	2.17	0.01	6.75	-0.01	1.44	0.99	1.00		
60	3.00	1.40	0.36	5.77	-0.28	2.03	0.95	0.97	1.00	
120	2.91	0.90	0.76	4.79	-0.46	2.76	0.78	0.81	0.90	1.00
US-UK Spread										
3	-1.03	1.06	-3.40	0.89	-0.59	2.18	1.00			
12	-0.88	0.98	-3.23	0.65	-0.66	2.31	0.95	1.00		
60	-0.60	0.64	-2.47	0.88	-0.08	2.52	0.83	0.90	1.00	
120	-0.29	0.67	-2.39	1.39	-0.45	4.04	0.30	0.33	0.59	1.00

Table 1. Descriptive Statistics of sovereign yield spreads for the time period from 1995:01 - 2013:12. For each spread and selected maturities (3-months, 12-months, 60-months and 120-months) we report (from left to right) mean, standard deviation, minimum, maximum, skewness, kurtosis and correlations between the reported maturities.

spread with the exception being the US-UK spread with a relatively low correlation of 0.30.

Overall we find that the different yield spread curve data sets share some common characteristics:

- The short end of the spread curve is more volatile than the long end.
- Average spread curves are upward sloping
- The spreads of different maturities are highly correlated.

These properties are relatively similar to characteristics also commonly found in yield curve datasets, see, for example, Pooter et al. (2010) or Koopman and van der Wel (2011). However, yield curves usually exhibit a steeper and more concave sloping average curve and higher volatility at different maturities. Most importantly, yields are usually not negative.

3.3 Dynamic Behaviour

The aggregated descriptive statistics should also not hide the fact that spread curves may differ significantly from characteristic yield curves shapes. The plots of selected sovereign spread curves on given days in Figure 1 give an idea of the variety of different spread curves. Apparently they can take on a wide range of shapes through time, including upward and downward sloping, but other than yield curves, they are generally rather flat. This reflects the fact that in a highly connected global economy, advanced economies often face similar economic conditions and consequently often experience an upward or downward sloping yield curve at same time. Rather uncommon for yield curves, spread curves may also regularly contain several bumps.

In Figure 2 we plot the dynamics of spreads for short, medium and long maturities over the considered sample period. The difference in the level of the different spreads is obvious. The US-JP spread is usually the highest, while the US-Australian spread is usually the lowest. Nevertheless the different spreads move surprisingly coherent throughout time. All spreads decrease for example after the bursting of the dotcom bubble in 2001 when US yields dropped more in relative terms than other advanced economies' yields. In particular spreads for short-term but also for medium-term maturities exhibit a characteristic drop during earlier periods of the global financial crisis (GFC) in 2007-2008, when the US significantly reduced short term interest rates to nearly zero. Towards the end of the crisis we observe an upwards shift of spreads for Australia, Canada and the UK, since also these countries started to significantly reduce interest rates.

After the GFC, especially short term spreads exhibit a striking behavior. While prior to the crises there is a large temporal variation in the short term spreads, in its aftermath all

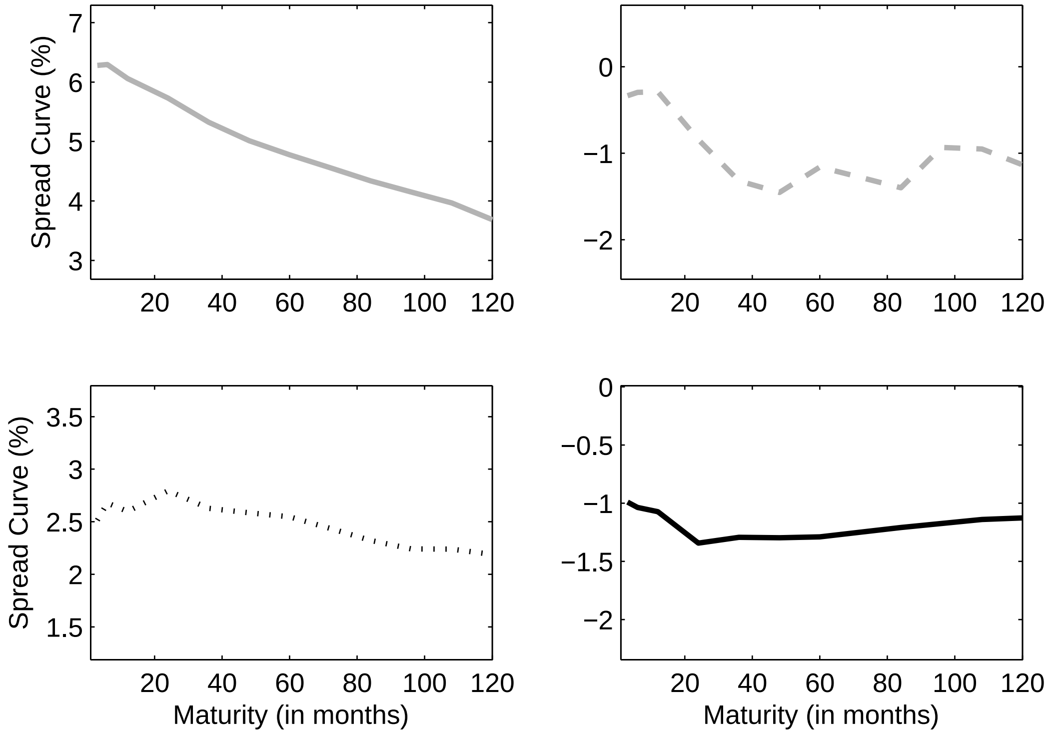

Figure 1. Representative sovereign spread curves for selected spreads and dates. The curves present the US-Japanese spread curve on 31 Aug 2000 (upper left panel), the US-British spread curve on 31 Dec 2008 (upper right panel), US-Swiss spread curve on 30 April 2010 (lower left panel) and the US-Australian spread curve on 31 Jan 2007 (lower right panel).

spreads - except the US-Australian - narrow and remain flat until the end of the sample period. This is obviously a direct consequence of the unprecedented expansive monetary policy of the major central banks. During the financial crisis the major central banks (except the Australian RBA, as Australia had been impacted less by the GFC) decreased their policy rate close to the zero bound and also directly intervened in the markets to bring yields down.[9] The central banks long term commitment to these policies and the rather dire economic prospects have led to a prolonged period of low and non-volatile short and medium yields in most advanced economies. This unique interest rate environment is naturally reflected in short and and less distinctively in medium term sovereign spreads as well.

Comparing short, medium and long term maturities, the difference in volatility mentioned above is clearly noticeable. While short spreads are quite volatile, long term spreads remain rather stable throughout the sample period as the underlying long term structural differences between economies do not change as quickly as short term economic fluctuations.

[9]The most prominent example is, of course, the controversial quantitative easing of the US Fed.

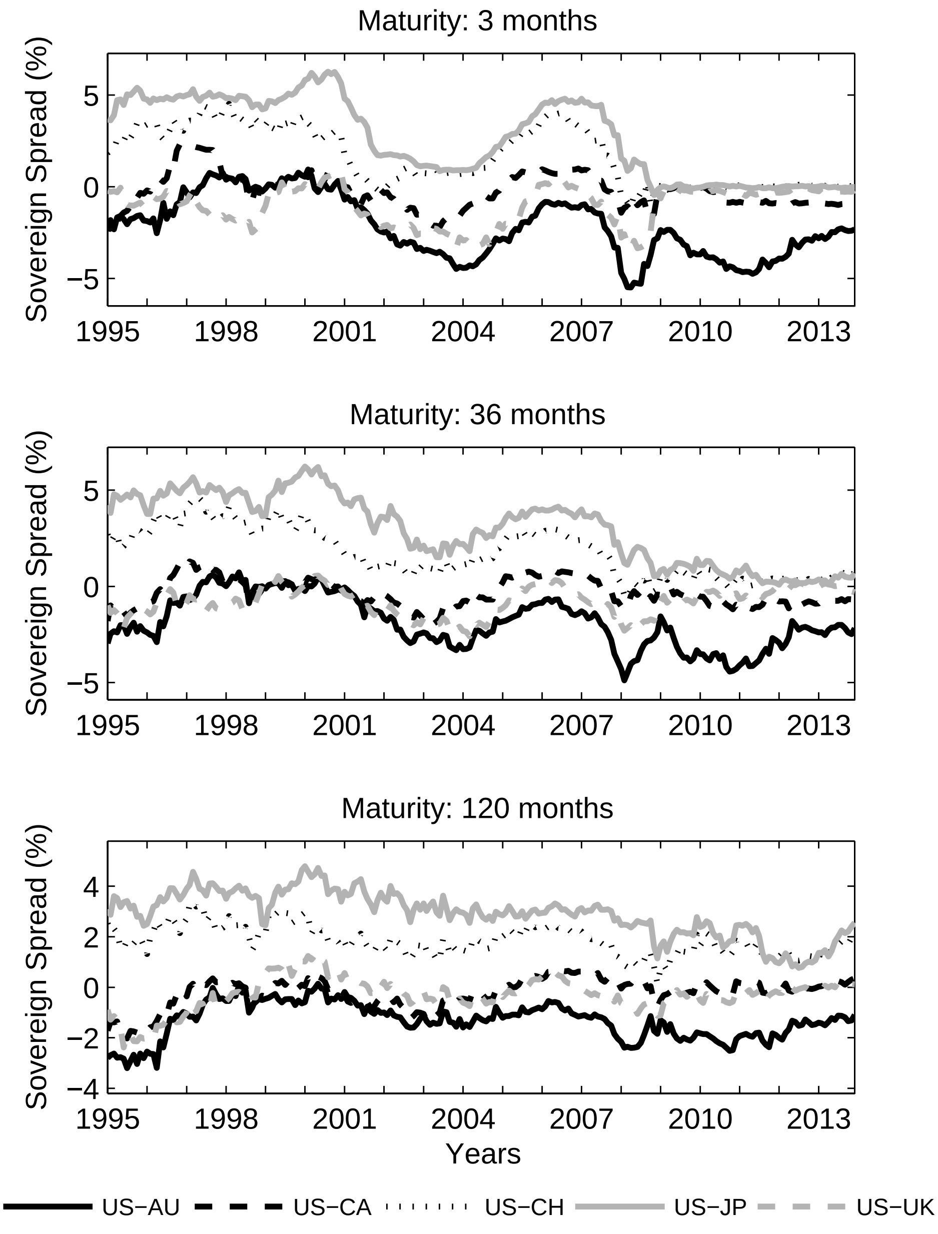

Figure 2. Sovereign spreads for selected short (3-month), medium (36-month) and long term (120-month) maturities. We plot US-Australian, US-Canadian, US-Swiss, US-Japanese and US-British sovereign yield spreads for the time period 1995:01 – 2013:12.

4 Latent Yield Spread Curve Factors

4.1 Estimating the Latent Factors

Our main objective is to identify and investigate the underlying factors driving the term structure of sovereign spreads. To derive these factors we conduct a principal component analysis (PCA). Principal component analysis is a statistical method that reduces the dimensionality of a data set by compressing the information it contains into a limited number of components or factors.[10] These factors thus summarize the main features of the original term structure of sovereign yield spreads in parsimonious form. PCA is a common approach applied to term structure dynamics (Longstaff et al., 2012; Blaskowitz and Herwartz, 2009; Barber and Copper, 2012) and works best with correlated time series (Duffee, 2011). It therefore seems a natural choice to reduce the dimensions of the highly correlated sovereign spreads. Practitioners may also benefit from the flexibility of factors that are not postulated a priori, but are rather derived from actual market data. Note that we apply PCA directly to the sovereign spreads and use standardized spreads with zero mean and unit variance.

To derive the orthogonal factors or principal components $F_{1,...,K}$ that can account for the variability in the term structure, assume S to be a TxN matrix of standardized sovereign spreads $s_{\tau,t}$, where T is the number of maturities and N is the number of observation dates. To extract loadings γ_K and factors F_K a PCA seeks an orthogonal KxT matrix Γ which yields a linear transformation

$$\Gamma S = \Phi, \tag{2}$$

where Φ is a KxN-dimensional matrix of latent factors F.

The matrix Γ is constructed using an eigenvector decomposition. Let Σ denote the TxT covariance matrix of S that can be decomposed as

$$\Sigma = \Gamma \Lambda \Gamma', \tag{3}$$

where the diagonal elements of $\Lambda = diag(\lambda_1, ..., \lambda_T)$ are the eigenvalues and the columns of Γ are the eigenvectors. Arranging the eigenvectors in decreasing order of the eigenvalues, the first K eigenvectors of Γ denote the factor loadings $[\gamma_1, ..., \gamma_K]$. Then the K latent factors $[F_1, ..., F_K]$ are defined by $F_{k,t} = \gamma_k' S_t$, where S_t is a T-dimensional vector of the term structure of sovereign yield spreads at time t. Given the wealth of literature detailing the use of PCA for examining term structure dynamics, we refer to Jolliffe (2002); Lardic et al. (2003) or Barber and Copper (2012) for further details.

[10]Note that in the following we will use the terms factors and components interchangeable throughout the analysis.

4.2 Interpreting the Factors as Level, Slope and Curvature

Our methodological framework allows us to analyze and interpret the estimated latent factors. To start with, we present the shape of the loadings $\gamma_1, \gamma_2, \gamma_3$ on the three estimated latent factors as a function of maturity in Figure 3. The loadings are surprisingly

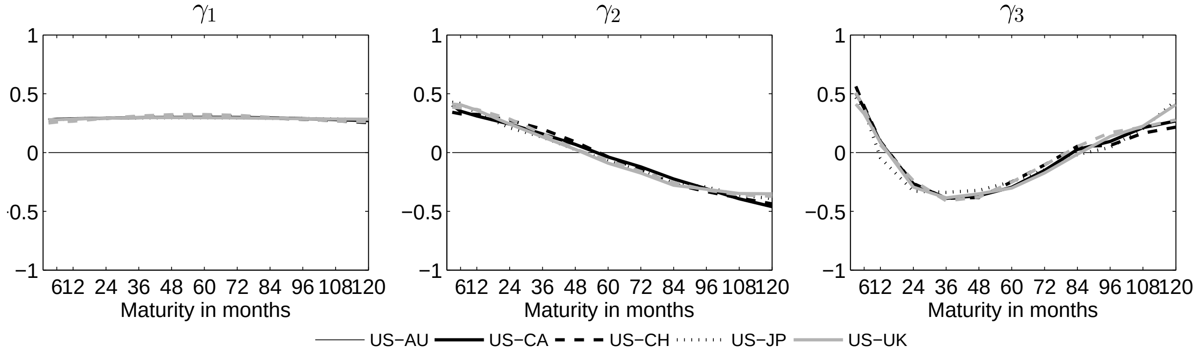

Figure 3. Loadings as a function of maturity for all spreads against US yields. We plot the loadings derived by the PCA for the first three factors for US-Australian, US-Canadian, US-Swiss, US-Japanese and US-British sovereign spreads. Note that principal components are not unique up to sign, i.e. multiplying a principal component by (-1) has no effect on the explanatory power of the component.

similar for all sovereign spreads against the US yields. Given the differences in sign and magnitude of the different spreads we would have expected different shapes in the loadings. For all spreads, the loading of the first factor is rather stable across all maturities, while loadings for the second and third loading factor change their signs for different maturities. Interestingly, the shape of the three factor loadings is quite similar to those found in other works where PCA has been applied the term structure of interest rates (Litterman and Scheinkman, 1991; Dai and Singleton, 2000; Afonso and Martins, 2012). The first loading is almost constant across all maturities and does not decay with longer maturities - hence the first component can be interpreted as a level factor. The loading is responsible for parallel shifts of the spread curve. The second loading has opposite signs at both ends of the spread term structure so it affects short-term and long-term spreads differently. Thus it can be interpreted as determining the slope of the spread curve. The third loading has equal signs at both ends of the maturity spectrum, but an opposite sign for medium-term maturities mainly affecting changes in the curvature of sovereign spreads. Therefore, the observed shape of the loadings allows us to interpret the components as spread level, slope and curvature factors. We verify this interpretation by investigating the relationship between the estimated factors and empirical spread level, slope and curvature. In line with the existing literature, see, e.g, Afonso and Martins (2012) or Diebold et al. (2006), we calculate the empirical spread level as the average of the longest (120-months), the shortest (3-months) and a medium-term maturity (we chose 36-months), the spread slope as the difference between the longest and shortest maturity and the spread curvature as twice the medium-term maturity minus the sum of the shortest and longest maturity. Figure 4 provides an illustrative plot of this relationship for the US-Canadian spread. For all three factor series the relation between the latent and empirical factors is visually apparent suggesting a close relationship between estimated factors and their empirical proxies. This also holds for all other investigated spread pairs. Table 2 summarizes the correlations between the empirical and estimated factor series for all spreads. The correlations are compellingly high especially for the first factor and confirm our interpretation that the three estimated latent factors correspond to level, slope and curvature of the yield spread curves.

	US-AU	US-CA	US-CH	US-JP	US-UK
F_1 / level	0.99	0.99	0.99	0.99	0.97
F_2 / slope	-0.71	-0.87	-0.57	-0.66	-0.94
F_3 / curv.	-0.76	-0.83	-0.69	-0.62	-0.96

Table 2. Correlation between the time series of the first three estimated factors (F_1, F_2, F_3) and the empirical level, slope and curvature for US-Australian, US-Canadian, US-Swiss, US-Japanese and US-British sovereign spreads over the time period 1995:01-2013:12.

These interpretations also make intuitive sense in regard to the shape of the spread curves and the percentage of the variation in yield spreads they explain. As spread curves are often rather flat, the slope factor plays a relatively smaller role than the level factor in explaining the variance. Interpreting the first factor as a level factor also helps to understand, why the first factors of the US-CA and especially the US-UK spread explain a relatively smaller fraction in the variance compared to the other spreads. As indicated, all datasets exhibit high correlation between the maturities - they are driven by the same '*level*' factor. For the US-UK spread and to a lesser extent for the US-CA spread, the correlation between the different maturities is also high, but less pronounced than for the other spread datasets. The correlation between the 3-months and 120-months US-UK spread, for example, is only 0.3. Thus, a level factor explains less variance for the spreads between US and UK yields than for the other spreads.

Overall, the conducted analysis suggests that the dynamics of the entire term structure for sovereign spreads can be decomposed by using a small number of three latent factors. Further, the three factors can be suitably labelled as spread '*level* (F_L)', '*slope* (F_S)' and '*curvature* (F_C)' and are highly correlated with empirical measures of the factors. Our results are robust across sovereign spreads between advanced economies, namely spreads between the US and Australia, Canada, Japan, Switzerland and United Kingdom sovereign yields.

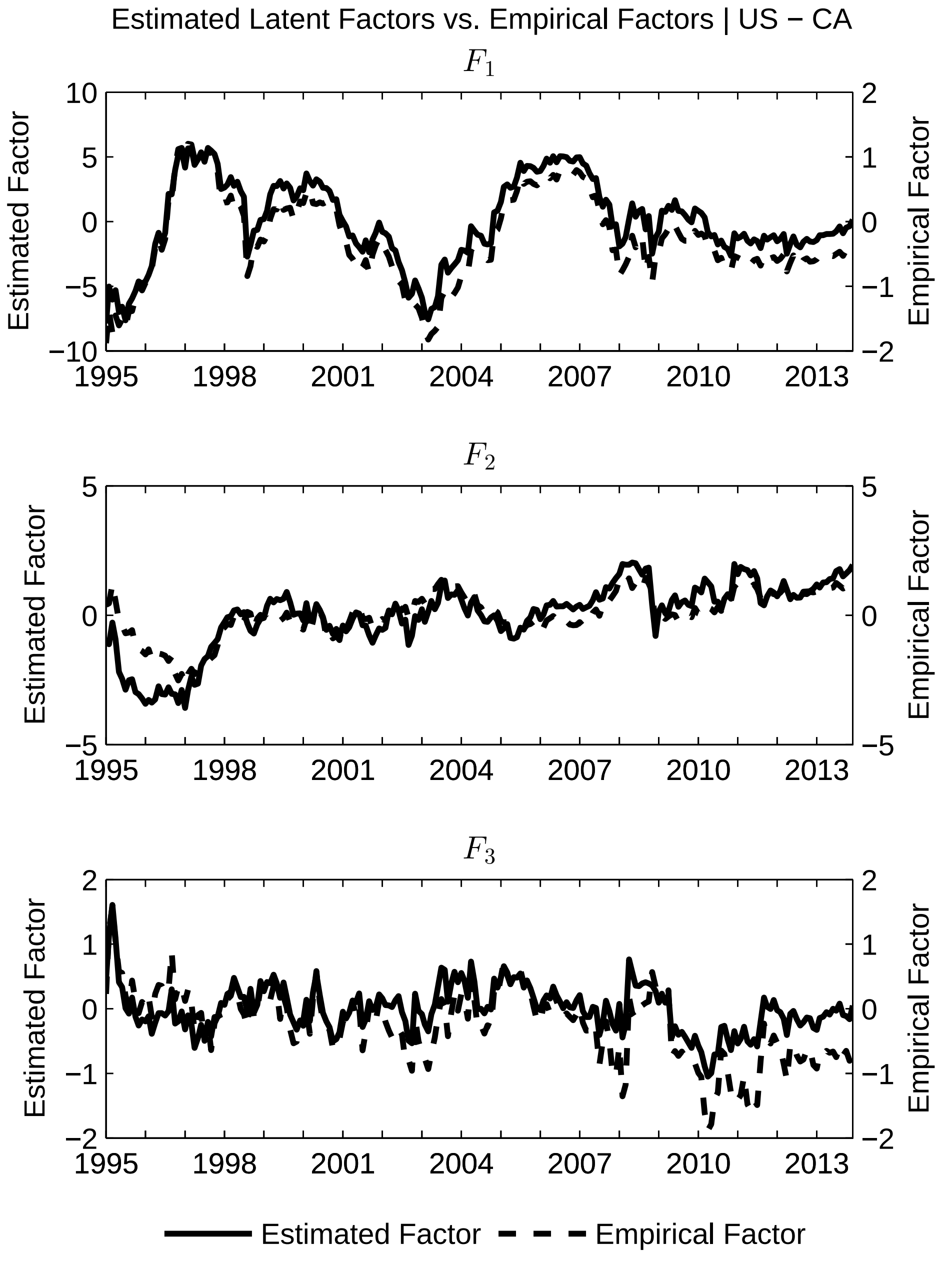

Figure 4. Time series of the first three estimated latent factors (F_1, F_2, F_3 —) against the empirical level, slope and curvature (- - -) for US-Canadian sovereign spreads. In line with existing literature, we calculate the empirical level as the average of the longest (120-months), the shortest (3-months) and a medium-term maturity (we chose 36-months); the empirical slope as the difference between the longest and shortest maturity and the curvature as twice the medium-term maturity minus the sum of the shortest and longest maturity. Note that the second and third factors are negatively correlated, thus the estimated factor series have been multiplied with (-1) for illustrative purposes..

4.3 Factor Dynamics

Applying PCA allows for a data-driven selection of the K most important latent factors. Table 3 displays the variance explained by the first three principal components extracted by the applied PCA.

	US-AU	US-CA	US-CH	US-JP	US-UK
F_1	91.8	84.2	94.3	93.4	77.5
F_2	7.1	13.9	4.6	6.0	19.9
F_3	0.7	1.1	0.6	0.4	1.7
Total	99.6	99.2	99.5	99.8	99.1

Table 3. Explained variance of first three principal components (F_1, F_2, F_3) in percent extracted by principal component analysis (PCA) for US-Australian, US-Canadian, US-Swiss, US-Japanese and US-British sovereign yield spread curves over the time period 1995:01 – 2013:12.

For all spreads the three leading principal components already account for about 99% of the variance in the term structure, with the first principal component playing the most dominant role. The first factor already explains more than 90% of the variance for three out of the five spreads. For US-UK and US-CA sovereign spreads the explanatory power of the first component is slightly lower, but still explains 84.2%, respectively 77.5%, of the variance. The second factor explains a further 4.6% up to 19.9% and the third factor an additional 0.4% to 1.7%. Including the first two factors is an obvious choice. Note that we decided to also include the third factor, as this allows us to interpret the factors in line with common yield curve models in the subsequent sections.

We plot the time series of the first three estimated factors F_1, F_2, F_3 in Figure 5. It is observable that the three factors behave quite differently.[11] The first factor is the most volatile and seems to be relatively persistent. It also seems to mirror the dynamic behavior of the yield spreads relatively closely. Most prominent is the characteristic drop at the beginning of the GFC. The second factor is relatively noisy. It also exhibits a distinctive spike towards the end of the GFC. The third factor is the least volatile and also relatively small in magnitude. Comparing the factors of the different spread pairs, it is also interesting to note that the respective time series of the different spreads move together relatively closely through time. This holds especially for the first factor.

[11] Note that, as the PCA extracts orthogonal factors the correlation between the first, second and third factor is zero. All factor series have a zero mean.

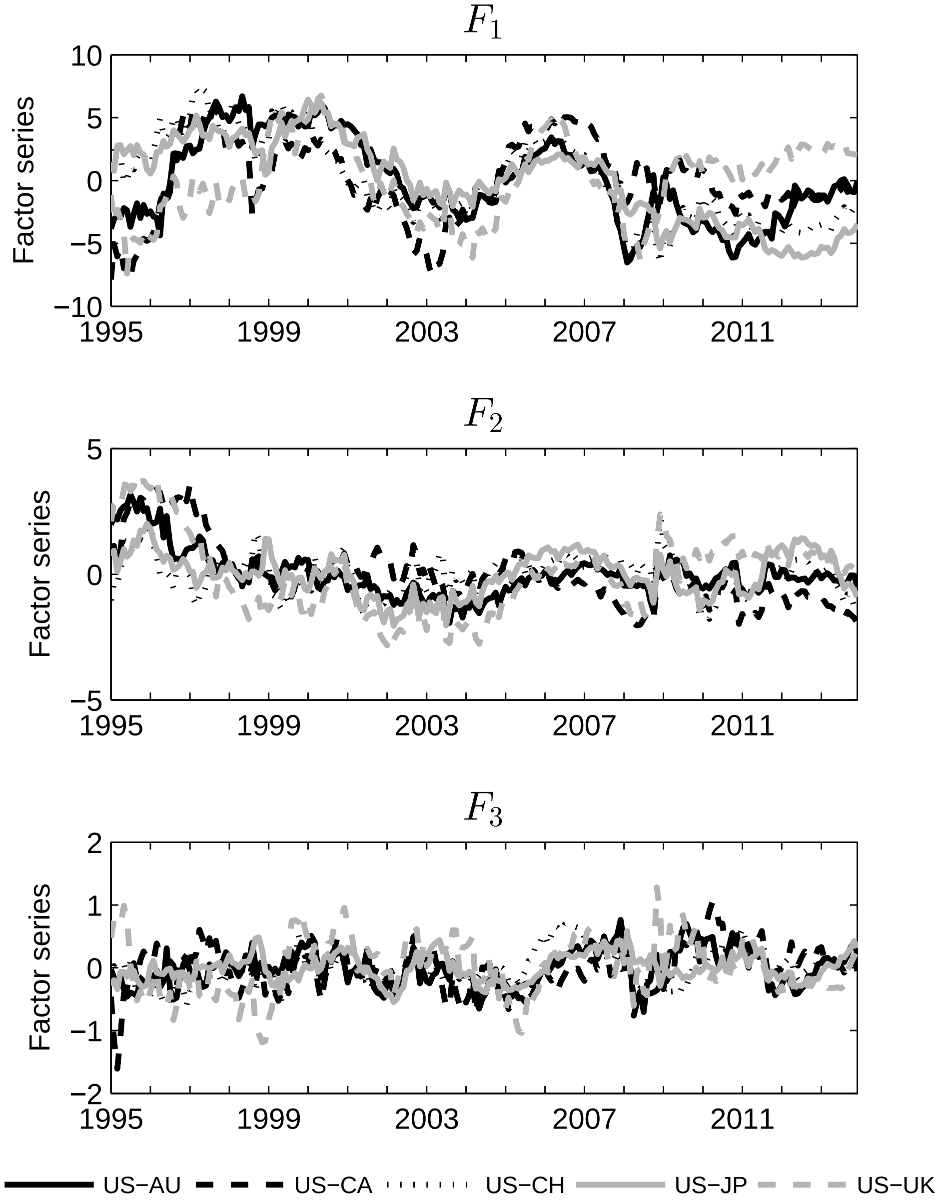

Figure 5. Time series of first three Factors (F_1, F_2, F_3) estimated by the principal component analysis (PCA) for US-Australian, US-Canadian, US-Swiss, US-Japanese and US-British sovereign yield spread curves over the time period 1995:01 – 2013:12.

5 Exchange Rate Predictability

5.1 Rationale and previous findings

Section 2 concluded that the latent factors estimated from the term structure of yield spreads may serve as natural measures of exchange rate determination. The yield spread curve contains information about the expected cross-country differentials in economic fundamentals that are known to drive exchange rates. As the latent spread factors summarize this information they may also possess predictive power for the expected path of exchange rates.

Previous literature has produced some encouraging results. Clarida et al. (2003) provide evidence that the term structure of forward premia contains valuable information for forecasting future spot exchange rates using a regime-switching vector equilibrium correction model. Bekaert et al. (2007) advocate that risk factors driving the premiums in the term structure of interest rates may drive the risk premiums in currency returns. Ang and Chen (2010) use the domestic empirical level and slope factors of the term structure together with interest rate volatility to predict FX rate returns in a cross sectional setting based on portfolio strategies. They find a economically and statistically significant ability of changes in interest rates and slopes of the yield curve to predict foreign exchange returns, above the predictability of carry. Chen and Tsang (2013) examine the predictive power for exchange rate changes and excess returns using cross-country yield curve factors constructed with the parametric Nelson-Siegel Model. They find that Nelson-Siegel factors extracted from two countries' relative yield curves can predict future exchange rate changes and excess currency returns one up to 24 months ahead. Bui and Fisher (2015) confirm their findings for the relative yield curves of the US and Australia.

These results also indicate that the macroeconomic information contained in the latent spread factors may be useful in exchange rate determination. To verify this assumption, in the following we examine the ability of the extracted yield spread factors to capture the variation in exchange rate changes and excess returns more thoroughly.

5.2 Exchange Rate Data

For the analysis we retrieve the AUD, CAD, CHF, JPY and GBP exchange rates against the USD from Bloomberg and match the end of the month exchange rates with the corresponding end of the month sovereign yield spreads. We consider the US as the home country thus the exchange rate is measured as the US Dollar price per unit of foreign currency. Therefore, a rise in the exchange rate represents a depreciation of the USD and a lower value an appreciation of the USD.

Figure 6 plots the time series of the log exchange rates. The majority of the exchange rates are relatively erratic and volatile with only the Japanese Yen and the British Pound being relatively stable throughout the entire time period and mainly fluctuating around a long-term equilibrium value. The bursting of the dotcom bubble in 2001 does not seem to be clearly reflected, but all currencies except the Japanese Yen experience a characteristic depreciation against the US Dollar at the beginning of the GFC in 2007. This is followed by a quick and sharp recovery.

The exchange rate change Δs_{t+m} for horizon m is defined as the annualized change of

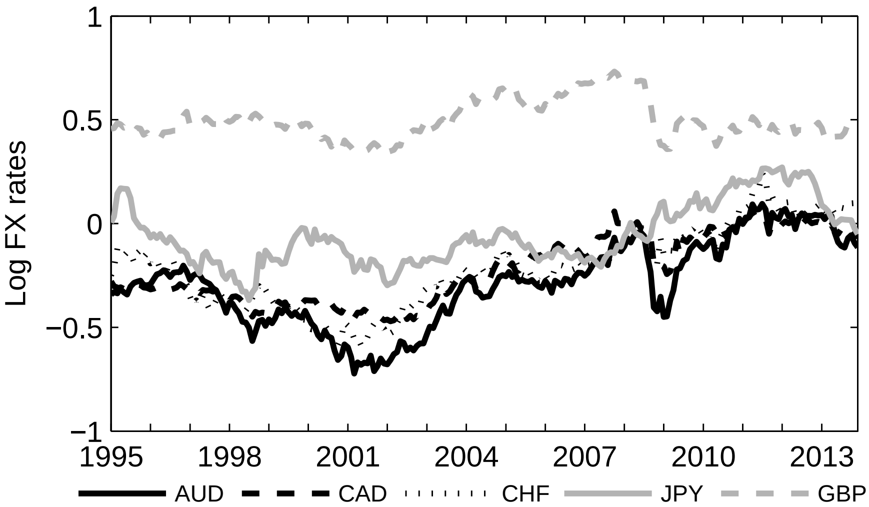

Figure 6. Time Series of log exchange rates for AUD, CAD, CHF, 100xJPY and the GBP against the USD for the time period from 2005:01 - 2013:12. The exchange rate is measured as the US Dollar price per unit of foreign currency. Thus an increase in the exchange rate represents an depreciation of the USD.

the log exchange rate s. Excess returns xs_{t+m} are calculated by adjusting the exchange rate change of horizon m with the corresponding yield spread of equal maturity τ, see, e.g., Christensen et al. (2011):

$$xs_{t+m} = \Delta s_{t+m} + i_t^{\tau *} - i_t^{\tau}, \tag{4}$$

where $m = \tau$.

5.3 Estimation Specifications

To test the predictive ability of the latent yield spread factors we regress exchange rate changes and excess returns on the extracted factors for horizons $m = 3, 6, 12, 24$ months:

$$\Delta s_{t+m} = \alpha_m^{\Delta s} + \beta_{m,L}^{\Delta s} F_{L,t} + \beta_{m,S}^{\Delta s} F_{S,t} + \beta_{m,C}^{\Delta s} F_{C,t} + u_{t+m}; \tag{5}$$

$$xs_{t+m} = \alpha_m^{xs} + \beta_{m,L}^{xs} F_{L,t} + \beta_{m,S}^{xs} F_{S,t} + \beta_{m,C}^{xs} F_{C,t} + v_{t+m}. \tag{6}$$

F_L, F_S, and F_C are the three latent spread factors extracted from the PCA above.[12] The predictive ability is evaluated by estimating $\beta^{\Delta s}_{m,[L,S,C]}$ and $\beta^{xs}_{m,[L,S,C]}$ over the entire sample. If the yield spread factors contain relevant information, the coefficients should be different from zero.

Regressions using longer time horizons need to address an inference bias due to overlapping observations (Harri and Brorsen, 2009). Since the horizon m for exchange rate changes and excess returns is longer than the frequency of data (one month in this case), the left hand side variable overlaps across observations and the error terms u_{t+m} and v_{t+m} will be a moving average processes of order $m-1$. In this case OLS parameter estimates would be inefficient and hypothesis tests are biased (Hansen and Hodrick, 1980). One way to deal with this problem is to only use non-overlapping observations. This would eliminate the autocorrelation problem but it is obviously highly inefficient as it reduces the number of observations dramatically and dismisses valuable information. Another and more efficient approach is to account for the moving average error term in hypothesis testing. Thus, we use Heteroskedasticity and Autocovariance Consistent (HAC) estimators developed by Newey and West (1987) for OLS estimation.[13]

It is well known that the global financial crisis (GFC) in 2007-2009 has caused major eruptions in bond and interest rate markets. Bianchetti (2010) for example find that standard curve no-arbitrage relations are no longer valid. Steeley (2014) describes the impact of the GFC and its aftermath for interest rate term structure forecasting models. Bui and Fisher (2015) report a different relationship between relative yield curves and the USD/AUD exchange rate before and after the crisis. Thus, we first run equations (5) and (6) with the latent spread factors and their interaction with a GFC dummy (2007:08 to 2009:05)[14] and find significant results on the interaction terms for most of the spread pairs and horizons.[15] We conclude that the crisis period differs significantly from the rest of the sample and drop the time period from 2007:08 to 2009:05 for the regressions.

5.4 Regression Results

Based on economic intuition and the results found in previous research, see, in particular Chen and Tsang (2013), we expect the coefficients on spread level and slope factors to be negative.[16] The yield curve literature suggests that the level factor can be seen as

[12] We note that the null of a unit root is generally rejected for exchange rate changes, excess returns and factor time series.

[13] Following Schwert (2002)'s method, we determine the number of lags of the residual autocorrelations as 12.

[14] Guidolin and Tam (2013) provide an extensive overview of the crisis dating literature and provide a conservative consensus dating centered around August 2007 - May 2009.

[15] Results for these regressions are reported in the Appendix.

[16] The literature has not provided a clear interpretation of the curvature factor yet thus we have no specific expectations in terms of sign and magnitude of its coefficients.

a long-run inflation expectation factor while the slope factor reflects business cycle and output growth dynamics. A higher yield curve level in a country thus indicates that the market expects rising inflation and a flat yield curve points to the market expecting a forthcoming economic downturn. In these situations, a countries' currency may be less desirable and will potentially face depreciation pressure. As Bui and Fisher (2015) describe, the currency will appreciate and recover toward its long-run equilibrium value. An increase in the yield spread level or slope factor (the home yield curve shifts up or the foreign yield curve becomes steeper)[17] thus indicates a decrease in the nominal exchange rate equivalent to an appreciation of the USD or depreciation of the foreign currency.
A similar logic applies to the spread level and slope factor coefficients in the excess return regressions. As noted above, excess foreign currency returns can be considered as the risk premium associated with holding a currency. An increase in the yield spread level and slope factors indicates higher expected foreign growth and lower expected foreign inflation. Thus, investors may demand smaller risk premia for holding the foreign currency.
The results of the predictive regressions are presented in Tables 4 – 8. Indeed, we find

US-Australian Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-1.82*****	**-1.71*****	**-1.52*****	**-0.84****	**-2.28*****	**-2.19*****	**-2.00*****	**-1.27*****
	(-2.94)	(-3.03)	(-3.02)	(-2.17)	(-3.69)	(-3.88)	(-3.95)	(-3.28)
F_S	-2.23	-2.21	**-2.86***	**-3.63*****	**-2.90***	**-2.81***	**-3.38****	**-3.99*****
	(-1.35)	(-1.41)	(-1.75)	(-2.66)	(-1.76)	(-1.78)	(-2.05)	(-2.90)
F_C	-3.23	-3.04	-1.80	-1.69	-4.10	-3.66	-1.89	-1.33
	(-0.48)	(-0.68)	(-0.40)	(-0.39)	(-0.61)	(-0.81)	(-0.42)	(-0.30)
nob	200	194	182	158	200	194	182	158
adj R^2	0.08	0.17	0.26	0.29	0.13	0.25	0.37	0.40

Table 4. Results of regressing the latent US-AU spread factors F_L, F_S, F_C on USD/AUD exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. *Nob* denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant. The time period from 2007:08 to 2009:05 (GFC) has been dropped from the sample.

negative negative coefficients on the yield spread level and slope factors for nearly all investigated horizons and currencies. For example, a 1% increase in the US-Australian yield spread level factor (i.e. the whole yield curve of the US/Australia shifts up/down by 1% relative to the Australian/US yield curve) predicts a 1.82% annualized depreciation of the Australian Dollar against the US Dollar and a 2.23% annualized drop in the excess return in the next quarter. Likewise, an 1% increase in the US-Swiss yield spread slope factor (i.e. the Swiss/US yield curve becomes steeper/flatter relative to the US/Swiss one) predicts a 5.16% annualized depreciation of the Swiss Franc over the next 12 months. The same 1% increase in the relative slope factor predicts an 5.84% drop in Franc excess returns for the next year.

[17]Note the negative correlation between empirical and estimated slope factor.

US-Canadian Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	-0.60	-0.63	**-0.67****	**-0.63****	**-0.87****	**-0.90****	**-0.94*****	**-0.88*****
	(-1.37)	(-1.57)	(-2.12)	(-2.44)	(-1.98)	(-2.27)	(-2.98)	(-3.36)
F_S	-0.40	-0.38	-0.87	**-1.12***	-0.73	-0.71	**-1.19****	**-1.36****
	(-0.55)	(-0.58)	(-1.58)	(-1.86)	(-1.01)	(-1.08)	(-2.15)	(-2.24)
F_C	-1.72	-2.58	-2.79	-1.81	-2.27	-2.97	-2.89	-1.57
	(-0.73)	(-1.10)	(-1.12)	(-1.10)	(-0.95)	(-1.27)	(-1.16)	(-0.95)
nob	200	194	182	158	200	194	182	158
adj R^2	0.01	0.06	0.20	0.30	0.04	0.12	0.32	0.43

Table 5. Results of regressing the latent US-CA spread factors F_L, F_S, F_C on USD/CAD exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. Nob denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant. The time period from 2007:08 to 2009:05 (GFC) has been dropped from the sample.

US-Swiss Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-1.21***	**-1.18***	**-1.20****	**-1.18*****	**-1.64*****	**-1.64*****	**-1.67*****	**-1.60*****
	(-1.93)	(-1.94)	(-2.35)	(-4.02)	(-2.63)	(-2.69)	(-3.23)	(-5.42)
F_S	**-5.16*****	**-4.91*****	**-4.67*****	**-4.11*****	**-5.84*****	**-5.58*****	**-5.20*****	**-4.41*****
	(-2.59)	(-3.50)	(-3.19)	(-3.79)	(-2.94)	(-3.99)	(-3.51)	(-4.03)
F_C	3.91	5.60	2.62	-4.64	3.18	5.01	2.63	-4.23
	(0.58)	(0.97)	(0.41)	(-0.99)	(0.47)	(0.87)	(0.41)	(-0.89)
nob	200	194	182	158	200	194	182	158
adj R^2	0.07	0.15	0.28	0.42	0.11	0.22	0.39	0.53

Table 6. Results of regressing the latent US-CH spread factors F_L, F_S, F_C on USD/CHF exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. Nob denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant. The time period from 2007:08 to 2009:05 (GFC) has been dropped from the sample.

There is no clear pattern for the sign and magnitude of the curvature factor and its coefficients are often insignificant, hence it does not seem to play an important role. Omitting the spread curvature factor from the regressions (results are not reported here) confirms that the additional explanatory power of including the third factor is rather limited. This is not entirely surprising, as it also only explains a relatively small amount of the variation in the term structure of yield spreads and has not been previously linked to economic variables.

We obtain differing results with regards to the significance of the coefficients for the different currencies. The latent yield spread factors seem to work well for the safe haven currencies Swiss Franc and Japanese Yen.[18] For the Swiss Franc both spread level as well as spread slope factor are statistically significant in predicting exchange rate changes and excess returns for 3 to 24 months. For the Japanese Yen the slope factor seems to play

[18]Amongst others Ranaldo and Soderlind (2010) find that the Swiss franc and to a smaller extent the Japanese yen have significant safe-haven characteristics.

US-Japanese Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	-0.05	-0.16	-0.20	0.16	-0.65	-0.78	-0.82	-0.42
	(-0.09)	(-0.28)	(-0.39)	(0.31)	(-1.02)	(-1.33)	(-1.61)	(-0.82)
F_S	**-8.01*** **	**-8.07*** **	**-6.96*** **	**-5.19*** **	**-8.89*** **	**-8.96*** **	**-7.74*** **	**-5.68*** **
	(-5.32)	(-5.90)	(-5.87)	(-5.49)	(-5.88)	(-6.57)	(-6.53)	(-5.98)
F_C	2.24	5.95	9.58	5.07	1.32	5.24	9.42	5.63
	(0.23)	(0.88)	(1.56)	(1.09)	(0.14)	(0.77)	(1.54)	(1.21)
nob	200	194	182	158	200	194	182	158
adj R^2	0.08	0.19	0.34	0.30	0.11	0.24	0.42	0.39

Table 7. Results of regressing the latent US-JP spread factors F_L, F_S, F_C on USD/JPY exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. Nob denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant. The time period from 2007:08 to 2009:05 (GFC) has been dropped from the sample.

US-British Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	-0.50	-0.49	-0.61	**-0.57** **	-0.76	**-0.76***	**-0.88** **	**-0.82*** **
	(-1.03)	(-1.08)	(-1.50)	(-2.00)	(-1.57)	(-1.68)	(-2.16)	(-2.87)
F_S	-0.82	-0.75	-0.42	-0.38	-1.22	-1.15	-0.79	-0.62
	(-0.97)	(-0.93)	(-0.64)	(-0.70)	(-1.46)	(-1.43)	(-1.18)	(-1.13)
F_C	-0.11	-1.44	-1.33	0.92	-0.67	-1.82	-1.35	1.12
	(-0.03)	(-0.48)	(-0.69)	(0.52)	(-0.21)	(-0.61)	(-0.70)	(0.64)
nob	200	194	182	158	200	194	182	158
adj R^2	0.01	0.03	0.09	0.14	0.03	0.08	0.18	0.26

Table 8. Results of regressing the latent US-UK spread factors F_L, F_S, F_C on USD/GBP exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. Nob denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant. The time period from 2007:08 to 2009:05 (GFC) has been dropped from the sample.

the most dominant role.

We also find equally promising results for the Australian Dollar. The US-AU spread level factor has significant explanatory power for foreign exchange rate changes and excess returns across all horizons while the US-AU spread slope factor is mostly significant for long horizons.

In case of the Canadian Dollar we find significant results only for longer horizons. We assume that these results are mainly due to the Canadian Dollar's commodity currency status, as characterized by Chen and Rogoff (2003). The currency responds mainly to the world price of the country's primary commodity exports and thus appears to be dominated by factors that are not directly related to its macro economic fundamentals in the short term. Krippner (2006) also found that the USD/CAD exchange rate is rather unrelated to the difference in interest rates due to the cyclical component of Canadian interest rates.

The results for the British Pound appear to be the weakest among all currency pairs. We find no consistent predictive power in any of the yield curve factors for the GBP. As the low correlation between distant maturities found in Section 3 indicated, the US-UK spread term structure seems to be somewhat disconnected. Thus the different yield spread maturities are presumably not driven by common factors related to fundamentals and exchange rates to the same extent as the other currencies are.

For all currencies, the explanatory power indicated by the adjusted coefficient of determination increases with lengthening horizon. Thus, in the longer term exchange rate changes seem to be less affected by risk and more affected by the fundamental differentials incorporated in the yield spreads. This also agrees with previous findings that the relation between differences in interest rates and exchange rates seems to work better for longer horizons (Chinn and Meredith, 2004; Rossi, 2013).

Overall, the in-sample predictive regression results show that the extracted yield spread factors can help to explain and predict bilateral exchange rate movements and excess currency returns three month to two years ahead. Most dominant are the spread level and slope factor, while the spread curvature factor seems to have no consistent explanatory power. The negative signs of the coefficients for level and slope factor are consistent with economic theory and previous findings. These results provide strong evidence for the linkage between the term structure of yield spreads, macroeconomic fundamentals and exchange rates.

5.5 Comparison with the UIRP

Based on the insights described in Section 2, one way to understand the estimated latent spread factors in relation to exchange rate changes is to interpret them as augmenting the traditional m-horizon UIRP approach with the information in spreads of additional maturities. Both, latent spread factors and UIRP, relate differences in interest rates between economies to changes in exchange rates. However, while the UIRP relation only uses the information content up to a certain maturity, the latent spread factors summarize the information embodied in the entire spread term structure.

To formally test whether the latent spread factors provide additional, valuable information for predicting exchange rate changes, we apply a Likelihood-Ratio (LR) test between the traditional UIRP regression model

$$\Delta s_{t+m} = \alpha^{\Delta s}_{m,UIP} + \beta^{\Delta s}_{m,UIP}(i^m_t - i^{m*}_t) + \epsilon_{t+m} \tag{7}$$

based on the UIRP relation in equation (1) and an extended UIP regression model which also includes the three latent spread factors F_L, F_S, and F_C

$$\Delta s_{t+m} = \alpha^{\Delta s}_{m,UIP} + \beta^{\Delta s}_{m,UIP}(i^m_t - i^{m*}_t) + \beta^{\Delta s}_{m,L} F_{L,t} + \beta^{\Delta s}_{m,S} F_{S,t} + \beta^{\Delta s}_{m,C} F_{C,t} + \epsilon_{t+m}. \tag{8}$$

The LR test is commonly used to evaluate the difference between two nested models, e.g. when the simpler model is a special case of the more complex model. It is based on a comparison of the maximum likelihood of the two models.[19] If L_{UIP} is the likelihood of the simple UIRP model in equation (7) and L_{UIPext} is the likelihood of the more complex model in equation (8) the LR test statistic (LRT) is calculated as

$$LRT = -2\,log\,\frac{L_{UIP}}{L_{UIPext}}. \tag{9}$$

Asymptotically, the test statistic follows a chi-square distribution, with the degrees of freedom equal to the difference in the number of parameters between the two models.
We present the results of the LR test in table 9. The LRT-values and p-values indicate that using the information of the entire yield spread term structure summarized in the latent spread factors clearly provides additional explanatory power to the UIRP regression. We find significant LR test statistics, often at the 1% level of significance, for nearly all currencies and horizons except for the British Pound. Not surprisingly, we find the strongest results for the two safe haven currencies Swiss Franc and Japanese Yen.
These results make intuitive sense when the exchange rate is understood as an asset price.

	LR Test Statistic			
	Horizon			
Spread	3	6	12	24
US-AU	**7.00***	0.57	**26.50*****	**51.53*****
US-CA	0.26	2.26	**6.85***	**21.36*****
US-CH	**12.99*****	**24.94*****	**41.34*****	**61.52*****
US-JP	**21.59*****	**42.69*****	**70.55*****	**64.48*****
US-UK	2.50	**9.87****	**7.46***	1.12
nob	198	192	180	156

Table 9. Results of a Likelihood Ratio (LR) test between the simple UIRP model based on equation (7) and raand extended UIRP model also including the three latent spread factors F_L, F_S, F_C in equation (8). We present the LR test statistics and p-values for all considered sovereign spread pairs and horizons m=3,m=6,m=12,m=24. A p-value less than the significance level implies that the extended model is better than the simpler model. *,** , *** indicate superiority on a 10%, 5%, 1% level..

A 24 month yield only embodies information for the next two years until the underlying instrument matures. However the exchange rate as an asset price is determined to a large extent by the expected long term future values of the fundamentals. While these can obviously not be reflected in a short or medium term yield, they are reflected in the yield spread factors which summarize the information embodied in the entire term structure up to 120 months.

[19]Adding additional parameters will always result in a higher likelihood score. However, the LR test provides an objective criterion whether the difference in likelihood scores among the two models is statistically significant considering the loss of degrees of freedom for the more complex model.

6 Conclusion

This paper provides a novel analysis of the term structure of sovereign yield spreads. We focus on the yield spreads of advanced economies with highly liquid markets of bonds issued in their own currency, little to no credit or default risk and free floating exchange rates (Australia, Canada, Switzerland, Japan, UK and US). Using a monthly frequency, we calculate all spreads against the US for the time period from January 1995 to December 2013.

Our main objective is to derive the latent factors driving the term structure of sovereign yield spreads. We apply a principal component analysis on each of the five sovereign spread data sets. Our analysis shows that the term structure of all sovereign spreads is driven by similar factors and the first three estimated factors are sufficient to explain more than 99% of the variation in the entire spread term structure. Interestingly, the identified factors show a very similar shape to those reported in studies analysing the term structure of interest rates, see, e.g., Litterman and Scheinkman (1991); Bikbov and Chernov (2010), and can be labeled as spread level, spread slope and spread curvature.

We further find that the extracted yield spread factors can explain and predict bilateral exchange rate movements and excess returns three month to two years ahead. Most dominant are the spread level and spread slope factor. The negative signs of the predictive regression coefficients on these factors indicate that an increase in the yield spread level or spread slope factor, i.e. when the foreign yield curve shifts down or becomes steeper relative to the US, predicts a depreciation and smaller excess returns of the foreign currency against the US Dollar. This is consistent with economic intuition and findings in the previous literature (Chen and Tsang, 2013; Bui and Fisher, 2015).

Exchange rate models are traditionally based on macroeconomic fundamentals such as differences in price levels, output and monetary policy (Engel and West, 2005; Molodtsova and Papell, 2009). The estimated factors naturally summarize information about the same fundamentals reflected in the term structure of sovereign yield spreads. We thus conclude that the latent factors derived from the term structure of yield spreads seem to proxy fundamental aspects of exchange rate determination.

When we test the additional explanatory power of the estimated spread factors in comparison to the traditional UIRP approach, we find significant results for most currencies and horizons. We thus conclude that using the information of the entire spread curve summarized in the spread factors clearly adds valuable information. This finding seems to be strongest for the safe haven currencies Swiss Franc and Japanese Yen.

Our findings make intuitive sense when the exchange rate is understood as an asset price. Within the present value framework exchange rates rely more on future than on current fundamentals. In other words, the exchange rate as an asset price is determined to a large extent by the long term expected values of fundamentals. While the UIP relation only reflects information up to a limited horizon, these long term fundamentals are reflected in the yield spread factors which summarize the information of the entire term structure up to 120 months ahead. Thus, the term structure of yield spreads may provide more accurate information for expected fundamentals.

Our findings have several important implications for future studies in this area. To start with, our results highlight the importance of the term structure of yield spreads as a factor containing valuable macro-financial information. While the spread between certain maturities is subject to the enormous body of UIRP-literature, the term structure of spreads has been widely neglected so far. We have identified and successfully labeled the latent driving forces of the spread term structure, but more research is required to fully understand the fundamental information it contains. Furthermore, we provide additional evidence of the link between interest rates, macroeconomic fundamentals and exchange rates and confirm the view, that the exchange rate can be modeled as an asset price. Considering the widespread forecasting failure of empirical exchange rate models based on observable macroeconomic fundamentals (Meese and Rogoff, 1983; Rossi, 2013), the estimated latent spread factors may be particularly helpful in future forecasting studies. Recent results point out that this empirical failure may also be a result of using inappropriate proxies for the market expectations of future fundamentals rather than the failure of the models themselves (Bacchetta and van Wincoop, 2013; Balke et al., 2013). Including the fundamental information embodied in the latent factors of sovereign yield spreads may thus be a promising approach to improve the forecasting accuracy.

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Appendix

A Regression Results with interaction terms

US-Australian Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-1.84*** **	**-1.73*** **	**-1.48*** **	**-0.75***	**-2.29*** **	**-2.21*** **	**-1.96*** **	**-1.18*** **
	(-2.84)	(-2.86)	(-2.61)	(-1.74)	(-3.56)	(-3.64)	(-3.44)	(-2.75)
F_S	-2.20	-2.09	**-2.65***	**-3.83*** **	**-2.86***	**-2.68***	**-3.17** **	**-4.18*** **
	(-1.37)	(-1.41)	(-1.69)	(-2.81)	(-1.79)	(-1.81)	(-2.00)	(-3.06)
F_C	-1.50	-0.55	2.39	-2.88	-2.37	-1.17	2.28	-2.50
	(-0.23)	(-0.11)	(0.45)	(-0.69)	(-0.37)	(-0.24)	(0.43)	(-0.59)
F_L x GFCd	**5.33*** **	**7.03*** **	**5.61*** **	0.71	**5.30*** **	**7.03*** **	**5.65*** **	0.71
	(2.71)	(5.30)	(3.80)	(0.81)	(2.70)	(5.31)	(3.83)	(0.81)
F_S x GFCd	**25.48*** **	**18.64** **	7.28	6.51	**25.44*** **	**18.69** **	7.32	6.42
	(4.40)	(2.01)	(0.76)	(1.12)	(4.37)	(2.02)	(0.76)	(1.12)
F_C x GFCd	**62.91*** **	**59.29*** **	**-15.64***	5.50	**63.07*** **	**59.17*** **	**-15.76***	5.55
	(3.36)	(6.01)	(-1.66)	(1.14)	(3.37)	(5.99)	(-1.67)	(1.15)
nob	225	222	216	204	225	222	216	204
adj R^2	0.20	0.38	0.27	0.21	0.22	0.40	0.32	0.30

Table 10. Results of regressing the latent US-AU spread factors F_L, F_S, F_C and their interactions with a GFC dummy (from 2007:08-2009:05) on USD/AUD exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. *Nob* denotes number of observations, m denotes theforecasting horizon in months. We omit the estimates of the constant.

US-Canadian Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-0.51**	**-0.42**	**-0.39**	**-0.51***	**-0.78***	**-0.70**	**-0.66***	**-0.75*** **
	(-1.15)	(-0.96)	(-1.07)	(-1.94)	(-1.76)	(-1.59)	(-1.81)	(-2.86)
F_S	-0.65	-0.70	**-1.18***	**-1.22** **	**-0.98**	**-1.02**	**-1.50** **	**-1.45** **
	(-0.81)	(-0.92)	(-1.96)	(-2.06)	(-1.22)	(-1.34)	(-2.48)	(-2.44)
F_C	-1.14	-2.26	-3.01	-2.55	-1.68	-2.65	-3.10	-2.31
	(-0.46)	(-1.06)	(-1.36)	(-1.37)	(-0.68)	(-1.24)	(-1.41)	(-1.23)
F_L x GFCd	**2.79**	**-2.10**	**1.18**	-0.14	**2.78**	**-2.11**	**1.21**	-0.10
	(0.62)	(-0.85)	(0.93)	(-0.15)	(0.61)	(-0.85)	(0.96)	(-0.11)
F_S x GFCd	**10.43*** **	**11.88*** **	11.18***	3.51***	**10.39*** **	**11.89*** **	11.25***	3.53***
	(3.75)	(6.67)	(6.34)	(3.68)	(3.74)	(6.68)	(6.39)	(3.67)
F_C x GFCd	**21.85** **	**15.97**	**-17.47*** **	-4.57	**21.84** **	**16.01**	**-17.47*** **	-4.67
	(2.32)	(1.58)	(-3.93)	(-1.57)	(2.32)	(1.59)	(-3.95)	(-1.60)
nob	225	222	216	204	225	222	216	204
adj R^2	0.10	0.22	0.31	0.23	0.11	0.24	0.35	0.33

Table 11. Results of regressing the latent US-CA spread factors F_L, F_S, F_C and their interactions with a GFC dummy (from 2007:08-2009:05) on USD/CAD exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. *Nob* denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant.

US-Swiss Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-1.22***	**-1.19***	**-1.12****	**-0.85****	**-1.66*****	**-1.65*****	**-1.59*****	**-1.27*****
	(-1.92)	(-1.93)	(-2.14)	(-2.14)	(-2.61)	(-2.68)	(-2.99)	(-3.17)
F_S	-4.89**	-4.44***	**-3.87****	**-3.08****	**-5.57*****	**-5.12*****	**-4.40*****	**-3.37****
	(-2.43)	(-3.07)	(-2.33)	(-2.37)	(-2.78)	(-3.54)	(-2.61)	(-2.58)
F_C	4.79	7.22	7.50	5.27	4.05	6.64	7.56	5.74
	(0.73)	(1.35)	(1.31)	(1.14)	(0.62)	(1.25)	(1.31)	(1.23)
F_L x GFCd	**0.78**	**2.19**	**1.86**	0.72	**0.74**	**2.20**	**1.94**	0.73
	(0.61)	(1.45)	(1.31)	(0.87)	(0.58)	(1.46)	(1.39)	(0.87)
F_S x GFCd	**14.53****	**19.31*****	8.91***	6.99***	**14.48****	**19.33*****	9.06***	6.98***
	(2.53)	(2.85)	(3.36)	(2.87)	(2.51)	(2.86)	(3.47)	(2.85)
F_C x GFCd	**41.36****	**18.63**	**-2.73**	-3.72	**41.66****	**18.50**	**-3.20**	-3.71
	(2.14)	(1.38)	(-0.25)	(-0.57)	(2.16)	(1.37)	(-0.29)	(-0.57)
nob	225	222	216	204	225	222	216	204
adj R^2	0.08	0.16	0.23	0.28	0.11	0.22	0.32	0.40

Table 12. Results of regressing the latent US-CH spread factors F_L, F_S, F_C and their interactions with a GFC dummy (from 2007:08-2009:05) on USD/CHF exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. *Nob* denotes number of observations, *m* denotes the forecasting horizon in months. We omit the estimates of the constant.

US-Japanese Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-0.03**	**-0.14**	**-0.16**	**0.12**	**-0.63**	**-0.76**	**-0.78**	**-0.46**
	(-0.05)	(-0.24)	(-0.30)	(0.20)	(-0.97)	(-1.26)	(-1.42)	(-0.75)
F_S	-7.72***	-7.57***	**-5.97*****	**-3.23****	**-8.61*****	**-8.47*****	**-6.75*****	**-3.71****
	(-5.02)	(-5.41)	(-4.52)	(-2.20)	(-5.57)	(-6.06)	(-5.11)	(-2.52)
F_C	5.41	10.81	15.62**	11.02**	4.48	10.10	15.47**	11.62**
	(0.56)	(1.42)	(2.28)	(1.96)	(0.47)	(1.32)	(2.26)	(2.06)
F_L x GFCd	**-0.27**	**-1.77**	**-1.70****	-2.19**	**-0.30**	**-1.76**	**-1.67****	-2.18**
	(-0.16)	(-1.59)	(-2.51)	(-2.49)	(-0.18)	(-1.59)	(-2.47)	(-2.46)
F_S x GFCd	**-7.32**	**8.83**	5.96*	4.45	**-7.47**	**8.86**	6.09*	4.50
	(-0.49)	(1.19)	(1.71)	(1.32)	(-0.50)	(1.20)	(1.77)	(1.33)
F_C x GFCd	**44.66****	**15.35**	**14.01**	10.65	**44.78****	**15.23**	**13.92**	10.69
	(2.54)	(1.14)	(1.48)	(1.40)	(2.54)	(1.13)	(1.47)	(1.40)
nob	225	222	216	204	225	222	216	204
adj R^2	0.09	0.17	0.33	0.23	0.12	0.22	0.40	0.33

Table 13. Results of regressing the latent US-JP spread factors F_L, F_S, F_C and their interactions with a GFC dummy (from 2007:08-2009:05) on USD/JPY exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. *Nob* denotes number of observations, *m* denotes the forecasting horizon in months. We omit the estimates of the constant.

US-British Spread

	FX Rate Change (Δs_{t+m}) Regression				Excess Return (xs_{t+m}) Regression			
	m=3	m=6	m=12	m=24	m=3	m=6	m=12	m=24
F_L	**-0.51**	**-0.49**	**-0.55**	**-0.42**	**-0.77**	**-0.76**	**-0.82***	**-0.66****
	(-1.05)	(-1.06)	(-1.30)	(-1.38)	(-1.58)	(-1.65)	(-1.92)	(-2.19)
F_S	-0.81	-0.73	**-0.39**	**-0.47**	**-1.21**	**-1.13**	**-0.75**	**-0.71**
	(-0.96)	(-0.90)	(-0.57)	(-0.77)	(-1.45)	(-1.39)	(-1.09)	(-1.16)
F_C	0.10	-1.17	-1.00	-1.08	-0.46	-1.55	-1.04	-0.87
	(0.03)	(-0.38)	(-0.54)	(-0.47)	(-0.14)	(-0.51)	(-0.56)	(-0.38)
F_L x GFCd	**6.05*****	**4.99*****	**3.47*****	2.23***	**6.02*****	**4.98*****	**3.51*****	2.25***
	(3.12)	(4.91)	(4.17)	(5.34)	(3.10)	(4.90)	(4.21)	(5.37)
F_S x GFCd	**9.57****	**12.45*****	7.63***	3.64***	**9.58****	**12.47*****	7.62***	3.58***
	(2.40)	(4.32)	(4.23)	(5.39)	(2.41)	(4.32)	(4.25)	(5.29)
F_C x GFCd	**3.55**	**11.28**	**-4.68**	0.13	**3.71**	**11.21**	**-4.86**	0.15
	(0.34)	(1.40)	(-0.82)	(0.05)	(0.36)	(1.39)	(-0.86)	(0.06)
nob	225	222	216	204	225	222	216	204
adj R^2	0.23	0.47	0.39	0.26	0.22	0.46	0.39	0.27

Table 14. Results of regressing the latent US-UK spread factors F_L, F_S, F_C and their interactions with a GFC dummy (from 2007:08-2009:05) on USD/GBP exchange rate changes Δs_{t+m} (equation (5) and excess returns xs_{t+m} (eq. 6) over the sample period 1995:01 - 2013:12. Newey-West robust t-statistics are reported in paranthesis. *,** , *** indicate significace of the coefficients on a 10%, 5%, 1% level. Nob denotes number of observations, m denotes the forecasting horizon in months. We omit the estimates of the constant.