What Does the Yield Curve Tell Us About Exchange Rate Predictability?*

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Abstract: This paper uses information contained in the cross-country yield curves to test the asset-pricing approach to exchange rate determination, which models the nominal exchange rate as the discounted present value of its expected future fundamentals. Research on the term structure of interest rates has long argued that the yield curve contains information about future economic activity such as GDP growth and inflation. Bringing this lesson to the international context, we extract the Nelson-Siegel (1987) factors of *relative* level, slope, and curvature from cross-country yield differences to proxy expected movements in future exchange rate fundamentals. Using monthly data between 1985-2005 for the United Kingdom, Canada, Japan and the US, we show that the yield curve factors indeed can explain and predict bilateral exchange rate movements and excess currency returns one month to two years ahead. Out-of-sample analysis also shows the yield curve factors to outperform a random walk in forecasting short-term exchange rate returns.

Keywords: Exchange Rate Forecasting, Term Structure of Interest Rates, Uncovered Interest Parity

JEL: E43, F31, G12, G15

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1. Introduction

Do the term structures of interest rates contain information about a country's exchange rate dynamics? This paper shows that the Nelson-Siegel factors extracted from two countries' relative yield curves can predict future exchange rate changes and excess currency returns 1 to 24 months ahead. When the home yield curve becomes steeper relative to the foreign one, over the subsequent months the home currency tends to depreciate and its excess return - currency returns net of interest differentials - decreases. When the domestic yield curve shifts up or its curvature increases relative to the foreign one, home currency will appreciate subsequently, though the response is not as robust. We also find that the relative factors together can forecast exchange rate out-of-sample one to two months ahead better than a random walk. Since the shape of the yield curve is known to reflect expected dynamics of future economic activity, our findings provide support for the asset pricing approach of exchange rate determination.

Decades of exchange rate studies have uncovered many well-known empirical puzzles, in essence failing to connect floating exchange rates to their theoretical macroeconomic determinants, or "fundamentals".[1] From a theoretical standpoint, the nominal exchange rate should be viewed as an asset price; however, the empirical validation of this view remains elusive. This asset approach is consistent with a range of structural models and relates the nominal exchange rate with the discounted present value of its expected future fundamentals, which include money supply, output, inflation and others. As measuring market expectations is difficult, additional assumptions, such as a linear driving process for the fundamentals, are typically imposed in order to relate the exchange rate to its currently observable fundamentals.[2]

[1] The handbook chapter by Frankel and Rose (1995) offers a comprehensive summary of the various difficulties confronting the exchange rate literature. Sarno (2005) is a more recent survey.
[2] See Engel and West (2005), Mark (1995), among many others.

The performance of the resulting exchange rate equations is infamously dismal, especially at short horizons such as less than a year or two.

This paper contends that market expectations may be more complicated than what econometricians can capture with the simple processes commonly assumed. As such, previous empirical failure may be the result of using inappropriate proxies for the market expectations of future fundamentals, rather than the failure of the models themselves. We propose an alternative method to test the asset approach by exploiting information contained in the shapes of the yield curves to capture market expectations. Research on the term structure of interest rates have long maintained that the yield curve contains information about expected future economic dynamics, such as monetary policy, output, and inflation, which are all relevant exchange rate fundamentals.[3] Extending this lesson to the international context, we extract three Nelson-Siegel (1987) factors - *relative* level, slope, and curvature - from the cross-country yield curve differences to summarize the expectation information contained in their yield curves.[4]

We look at three currency pairs over the period August 1985 to July 2005: the Canada dollar, the British pound, and the Japan yen relative to the US dollar.[5] Using monthly yield data, we extract the three Nelson-Siegel relative factors from the zero-coupon yield differences between the three countries from the US at maturities from one month to ten years. Our in-sample predictive regressions show that all three relative yield curve factors can help explain and predict bilateral exchange rate movements and excess currency returns one month to two years ahead, with the slope factor being the most robust across currencies. We find that a one-percent

[3] See Section 2.2 for details.
[4] The Nelson-Siegel factors are well-known for its empirical success over the past 20 years in providing a parsimonious summary for the price information for a large number of nominal bonds. See, for example Diebold, Piazzesi and Rudebusch (2005). Some proxy the yield curve by using only the term-spreads - the difference between the 10-year T-notes and the three-month T-bills, and the Nelson-Siegel framework is more comprehensive.
[5] We note that our results hold also for the other currency pair combinations in our sample that do not involve the US dollar. For ease of presentation, we only provide results relative to the US dollar in this paper. Other results are available upon request.

increase in the slope or level factors is associated with a 3-4% currency appreciation of the US dollar subsequently, with the magnitude of the effect declining over the horizon. The curvature factor has a much smaller effect of roughly one-to-one, and it is also the least robust. In our analyses, we pay special attention to address the inference bias inevitable in our small sample long-horizon regressions, which we discuss in more details in Section 3. In addition to in-sample predictive analysis, we conduct rolling out-of-sample forecasts to see how our model compares to the random walk model. Using the Clark and West (2006) test, we find that the relative factors model outperforms the random walk forecast for horizons one to two months ahead.[6]

Tying floating exchange rates to macroeconomic fundamentals has been a long standing struggle in international finance. Our results suggest that to the extent that the yield curve is shaped by market expectations about future macro fundamentals, exchange rate movements are not "disconnected" from fundamentals but relate to them via a present value asset pricing relation. Moreover, our results have straight-forward economic interpretations, and may offer some insight into the uncovered interest parity (UIP) puzzle.[7] We find that deviations from UIP, the currency risk premium, systematically react to the shape of the yield curves, or how the market perceives future interest rates, output, and other macro indicators. Our results on the slope factor, for example, have the following intuitive explanation. Since the flattening of the yield curve is typically considered as a signal for an economic slow-down or even a forthcoming recession, a flat domestic yield curve relative to the foreign one suggests that the expected future

[6] Since Meese and Rogoff (1983), the exchange rate forecast literature has repeatedly found the random walk model difficult to beat, especially at short horizons. See Frankel and Rose (1995) and Engel and West (2005). Due to our small sample size, we cannot obtain meaningful comparisons for long-horizon forecasts.

[7] UIP puzzle refers to the empirical regularity that when regressing exchange rate changes on the forward premium or interest differentials across countries, the slope coefficient tends to be negative instead of the theoretical prediction of unity. See Sec. 2 below for further details.

growth at home is relatively low.[8] In accordance with the present value relation, home currency depreciates as investors pull out, and ceteris paribus, appreciates back up over time towards its long-term equilibrium level. As the expected economic slowdown can induce higher perceived risk about the home currency, we find a significant drop in excess foreign currency returns, i.e. the risk premium, associated with the foreign currency. Noting that a rise in the short-term interest rate can flatten the slope of the yield curve, it is then easy to see, through the above mechanism, that the home currency may subsequently appreciate instead of depreciate according to UIP, if the risk premium adjustment is large enough.[9] Even though we do not explicitly model expectations and perceived risks, our results are in accordance with simple economic intuitions.

Finally, we note that our approach is consistent with previous research efforts using the term structure of the exchange rate forward premia to predict future spot exchange rate, such as Clarida and Taylor (1997) and Clarida et al (2003).[10] Yield differences relate to exchange rate forwards via the covered interest parity condition. However, given that the exchange rate forwards are only available up to a year or so, our yield curve approach can potentially capture a much a wider range of relevant market information by looking at yields all the way up to 10 years.

The rest of the paper is organized as follows. Section 2 discusses the relevant model and literature on the yield curve and nominal exchange rate modeling. Section 3 presents our data and empirical strategies. Our main results are shown in Section 4, and Section 5 covers additional robustness checks and discussions. Finally, Section 6 concludes.

[8] See the discussion in Section 2.2 below.
[9] A similar intuitive explanation can be made for the level factor as well (see Section 2.2 and Section 5.2).
[10] Clarida et al (2003) finds the term structure of forward premia contains useful information for forecasting future spot rates and proposes a regime-switching vector equilibrium correction model that out-performs a random walk.

2. The Exchange Rates and the Yield Curves

Both the exchange rate and the yield curve have decades of research behind them. Here we make no attempt to propose a comprehensive framework to jointly model the two. In fact, our conjecture is that market expectations are extremely difficult to capture appropriately in simple models, contributing to previous difficulties in fitting the exchange rate models empirically. We thus propose to sidestep it all together, and instead extract expectation information directly from the data. In this section, we first present the standard workhorse approach to modeling nominal exchange rate as an asset price. We then propose that progress in the yield curve literature, namely the empirical evidence that the yield curves embody information about expected future dynamics of key macroeconomic variables, can help improve upon the approach used in previous exchange rate studies. Next, we offer a brief presentation on the Nelson-Siegel yield curve factors as a parsimonious way to capture the information in the entire yield curve at each point in time, and present a short discussion on excess returns and risk premium.

2.1. The Present Value Model of Exchange Rate

The asset approach to exchange rate determination models the nominal exchange rate as the discounted present value of its expected future fundamentals, such as cross-country differences in monetary policy, output, and inflation. This present value relation can be derived from various exchange rate models that linearly relate log exchange rate, s_t, to its log fundamental determinants, f_t, and its expected future value $E_t s_{t+1}$.[11] For example, the workhorse monetary model first developed by Mussa (1976) - based on money market equilibrium, uncovered interest parity and purchasing power parity - can be expressed as:

[11] Standard textbook treatment can be found in Obstfeld and Rogoff (1996) Ch.8, or Mark (2001) Ch.3.

$$s_t = \gamma f_t + \psi E_t s_{t+1} \quad (1)$$

where $f_t = (m_t - m_t^*) - \phi(y_t - y_t^*)$, m is money stock, y is output, "*" denotes foreign variables, ϕ is the income elasticity of money demand, and γ and ψ are functions of the interest elasticity of money demand λ. Solving the above equation forward and imposing the appropriate transversality condition, nominal exchange rate then has the standard asset price expression, based on information at time t, I_t:

$$s_t = \lambda \sum_{j=1}^{\infty} \psi^j E_t(f_{t+j}|I_t) \quad (2)$$

This present-value expression serves as the starting point for many major contributions in the empirical exchange rate literature, such as Mark (1995), Engel and West (2005), and standard textbook treatments (Mark 2001, Obstfeld and Rogoff 1996). From equation (2), it is then common in the literature to assume that fundamentals to follow certain statistical processes, such as a driftless random walk or a linear process. One can then proceed to test this relationship either directly through a cointegration relation or an error-correction framework.[12]

Empirically, nominal exchange rate is best approximated by a unit root process, so we express equation (2) in a first-differenced form (ε is expectation error):

$$\Delta s_{t+1} = \lambda \sum_{j=1}^{\infty} \psi^j E_t(\Delta f_{t+j}|I_t) + \varepsilon_{t+1} \quad (3)$$

We next discuss how to use the information in the yield curves to proxy the expected discounted sum on the right-hand side of equation (3).[13]

2.2 The Yield Curve and the Nelson-Siegel Factors

The yield curve or the term structure of interest rates describes the relationship between yields and their time to maturity.[14] Traditional models of the yield curve posit that the shape of

[12] See Mark and Sul (2001) for example.

[13] Previous literature has attempted to use surveyed market expectations as an alternative, with limited success. See Frankel and Rose (1995)'s Handbook chapter and Sarno (2005) for more detailed discussions on the issues surrounding the use of surveyed expectation data.

the yield curve is determined by expected future paths of interest rates and perceived future uncertainty (the risk premia). While the traditional expectations hypothesis performs badly in empirical studies, research on the term structure of interest rates has convincingly demonstrated that the yield curve contains information about expected future economic activity, such as output and inflation.[15] Ang, Piazzesi and Wei (2006) estimate a VAR model for the US yield curve and GDP growth. By imposing non-arbitrage on the yields, they show that the yield curve predicts GDP growth both in and out of sample better than a simple unconstrained OLS for GDP growth on the slope. Hamilton and Kim (2002) decompose the term spread into expected future changed in short rates and term premium, and find that both components contribute to forecasting GDP growth. Mishkin (1990a and 1990b) shows that the yield curve predicts inflation, and Estrella (2005) provides a survey and an explanation on why the yield curve predicts output and inflation. These findings point out that the shape of the yield curve contains current market expectations about future macroeconomic variables that are the fundamentals of exchange rate. Taking this lesson to the international context, we propose to use the *difference* in the yield curves across countries to proxy expected movements in future exchange rate fundamentals f_t, the RHS of equation (3).

To summarize the shape of the yield curve succinctly, we utilize the Nelson-Siegel (1987) factor approach. Nelson and Siegel approximate the forward rate curve at a given time t with a Laguerre function that is the product between a polynomial and an exponential decay term. This forward rate is the solution with equal roots to the second order differential equation for spot rates. A parsimonious approximation of the yield curve can then be obtained by averaging over

[14] In our discussion as well as analyses, we consider only zero-coupon bonds to avoid the "coupon effect" (Caks 1977). We use the Treasuries to abstract away from default risks and liquidity concerns.
[15] Briefly, the expectations hypothesis says that a long yield of maturity m can be written as the average of the current one-period yield and the expected one-period yields for the coming $m-1$ periods, plus a term premium. See Thornton (2006) for a recent example on the empirical failure of the expectations hypothesis.

the forward rates, with the resulting function capable of capturing the relevant shapes of the empirically observed yield curves: monotonic, humped, or S-shaped. In addition, each of the factors also has a simple, intuitive interpretation as we discuss below. As our goal is to examine the *difference* in the yield curves between two countries, we fit the three Nelson-Siegel factors of the *relative* level (L_t^R), the relative slope (S_t^R), and the relative curvature (C_t^R), to the following:

$$i_t^m - i_t^{m*} = L_t^R + S_t^R\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + C_t^R\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) \quad (4)$$

where $i_t^m$and $i_t^{m*}$are continuously-compounded zero-coupon nominal yield on a m-month bond at home and abroad. The parameter λ controls the speed of exponential decay. The relative level factor L_t^R , with its loading of 1, has the same impact on all parts of the difference of the two yield curves: an increase in the relative level factor means the home yield curve is shifting up relative to the foreign one. The loading on the relative slope factor S_t^R starts at 1 when m= 0 and decreases to zero as maturity increases. The factor captures short-term movements that mainly affect yields on the short end of the curve. An increase in the relative slope factor means the home yield curve becomes flatter relative to the foreign one, holding the long ends of the yield curves fixed. The curvature factor C_t^R is a "medium" term factor, as its loading is zero at the beginning, increases and finally decays back to zero. It only affects the how curvy the relative yield curve is at the medium maturities. As with single country yield curves, these three *relative* factors capture most of the information in the yield curve differences (the average R-squared is about 0.99).

In the recent macro-finance literature, the yield curve factors are given macroeconomic interpretations. Rudebusch and Wu (2008) argue 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. In a New Keynesian model,

Bekaert, Cho and Moreno (2006) show that the level factor is mainly moved by changes in the central bank's inflation target, and monetary policy shocks dominate the movements in the slope and curvature factors. Dewachter and Lyrio (2006) estimate an affine model for the yield curve with macroeconomic variables. They find that the level factor reflects agents' long run inflation expectation, the slope factor captures the business cycle, and the curvature represents the monetary stance of the central bank. Dewachter and Lyrio also show that their level factor is highly correlated with survey data on the long-run inflation expectations from the Survey of Professional Forecasters.

The macro-finance literature suggests an interpretation of the level factor: when the level factor increases, it is mostly explained by an increase in long-run expected inflation or the long-run inflation target of the central bank. While the macro-finance literature is ambiguous on the interpretation of the slope factor, we rely on the findings that the yield spread, which is highly correlated with the slope factor, is a powerful predictor of GDP growth and recessions.[16] Based on a probit model with US quarterly data from 1960 to 1995, Estrella and Mishkin (1996) conclude that: "the estimated probability of a recession four quarters ahead estimated from this model is 10 percent when the spread averages 0.76 percentage points over the quarter, 50 percent when the spread averages -0.82 percentage points, and 90 percent when the spread averages -2.40 percentage points." With the term spread's robust forecasting ability, we interpret the slope factor as follows: a higher slope factor (i.e. when the yield curve is flatter) signifies a higher probability of a downturn or recession. Since the research on the term structure does not offer a coherent story on the curvature factor, we do not emphasize the factor's role in our discussion.

[16] A non-exhaustive list of papers that show the predictive power of the yield curve include Estrella and Hardouvelis (1991), Plosser and Rouwenhorst (1994), Haubrich and Dombrosky (1996), Dueker (1997) and Dotsey (1998).

2.3. Excess Currency Returns and the Risk Premium

In addition to exchange rate changes, we also look at how excess returns respond to expectations about future macroeconomic dynamics. Excess returns from a foreign currency are the difference in the cross-country yields after adjusting for the relative currency movements:

$$rx_{t+m} = i_t^{m*} - i_t^m + \Delta s_{t+m} \qquad (5)$$

where the last term represents the percent appreciation of foreign currency.

Under the assumptions that on aggregate, foreign exchange market participants are risk neutral and have rational expectations, the efficient market condition for the foreign exchange market equates expected exchange rate changes to cross-country interest rate differences over the same horizon. This is the uncovered interest parity (UIP) condition. In *ex post* data, however, the UIP condition is systematically violated over a wide range of currency-interest rate pairs as well as frequencies. The leading explanations for this UIP puzzle point to either the presence of time-varying risk premia or systematic expectation errors.[17] We note that under the assumption of rational expectations, excess returns in equation (5) represents the risk premium associated with foreign currency holdings, ρ^F,in the risk-adjusted UIP relationship:

$$\text{UIP: } i_t^m = i_t^{m*} + \Delta s_{t+m} - \rho^F \qquad (6)$$

We will examine how the risk premium adjusts to market expectations about future relative macroeconomic dynamics.

[17] The peso problem of Rogoff (1980), among others, is also a common explanation. See Engel (1996) and Sarno (2005) for a survey and detailed discussion.

3. Empirical Methods

In this section, we describe the data we use, our regression specifications, as well as how we address the overlapping data problem in our regressions.

3.1. Data Description

Our sample consists of monthly data from August 1985 to July 2005 for the US, Canada, Japan, and the United Kingdom. We look at zero-coupon bond yields for maturities 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 48, 60 72, 84, 96, 108 and 120 months, where the yields are computed using the Fama-Bliss (1987) methodology.[18] For the rest of the paper, we treat the U.S. as the home country, and we measure exchange rate S as the U.S. dollar price per unit of the foreign currency.[19] A lower number means an appreciation of the home currency, the USD. For all horizons, we define exchange rate change as the annualized change of the log exchange rate s.

We fit the Nelson-Siegel (1987) yield curve as equation (4) above, which we put here again:

$$i_t^m - i_t^{m*} = L_t^R + S_t^R \left(\frac{1 - e^{-\lambda m}}{\lambda m} \right) + C_t^R \left(\frac{1 - e^{-\lambda m}}{\lambda m} - e^{-\lambda m} \right)$$

where i_t^m is the home nominal zero-coupon yield of maturity m, and i_t^{m*} is corresponding foreign yield.[20] We call the three factors L_t^R, S_t^R and C_t^R the *relative factors* for the two countries, and they summarize the differences in level, slope and curvature for the two yield curves. The

[18] We are extremely grateful to Vivian Yue for providing us the term structure data. For details on the data, please see Diebold, Li and Yue (2007).

[19] We note that the yields are reported on the second day on each month. We match the yield data at time t with the exchange rate of the last day of the previous month (2 days earlier). For example, our 3-month forecast would be to use the January 2nd information for the yield curves to predict March 31 exchange rate value relative to its level on Dec 31st the previous year.

[20] Unlike the typical application of the Nelson-Siegel yield curve, we fit the term structure of interest *differentials* for each country-pair on a *relative* level, a slope and a curvature factors in each period t. Alternatively, we can fit the Nelson-Siegel yield curve for each country first and then compute the difference of the three factors. We obtain slightly different results as there are missing yields for some maturities for one country but not the other, but the differences are very small and negligible.

parameter λ is fixed at 0.0609, as suggested by Nelson and Siegel. We use OLS to estimate the above equation for each period t, and as usual, the Nelson-Siegel curve gives really good fit and the R-squared is almost always above 0.99. The relative factors for each country versus the US are plotted with the log exchange rate in Figures 1-3, and their summary statistics are reported in the first half of Table 1. We note, in addition, that the augmented Dickey-Fuller test of Elliott et al (1996) reject the presence of a unit root in all of the relative factors, exchange rate changes, and excess return series.

The relative factors behave differently from the Nelson-Siegel factors in levels. The relative level factor has low persistence and small volatility. Unlike the Nelson-Siegel factors in levels it is difficult to visually distinguish the relative slope factor from the relative level factor. The relative curvature factor is noisy like the same factor in level. Correlation coefficients among the nine relative factors in the second half of Table 1 show us the following. First, factors across countries are positively correlated, especially for the level and slope factors. This is likely due to the presence of the U.S. yield curve in each of these country pairs.[21] Within each country the three factors are also correlated, but there is no consistent pattern.

Finally, excess currency return is computed as:

$$rx_{t+m} = i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} \qquad (7)$$

where m is the horizon measured in months. As discussed above, it measures the annualized percent return from both interest differentials and currency appreciation, and represents the risk premium associated with holding foreign currency.

[21] Here we emphasize again that while we only present results based on the dollar-cross rates, our conclusions extend to non-dollar country pairs as well.

3.2 Estimation Specifications

To see if the relative factors predict exchange rate changes and excess currency returns in sample, we run the following two main regressions, each for horizons m = 3, 6, 12, 18, and 24, and also $m = 1$ for equation (8):[22]

$$\frac{1200(s_{t+m}-s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m} \quad (8)$$

$$rx_{t+m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + v_{t+m} \quad (9)$$

We note that for the UK, the relationship between the two dependent variables and the relative factors during the Exchange Rate Mechanism (ERM) crisis differs significantly from the rest of the sample.[23] So in our analysis we drop the period October 1990 – September 1992, which is when the crisis was in effect, from the regressions for the UK.

3.3 Overlapping Data Problem

It is well known that in longer horizon predictive analyses, one needs to address inference bias due to overlapping data. When the horizon for exchange rate change or excess currency return is more than 1 month, our LHS variable overlaps across observations, and u_{t+m} or v_{t+m} in equations (8) and (9) above will be a moving average process of order $m-1$. Statistics such as the standard errors will be biased. The typical solution to the problem is to use Newey-West standard errors. However, as shown in Ang and Bekaert (2006), the Newey-West adjustment suffers from serious size distortion (i.e. rejecting too often) when the sample size is small and the RHS variables are persistent. We address the problem with three alternative methods.

[22] The 1-month yield data is not available, so we do not have excess returns data to run equation (9).
[23] We run equations (2) and (3) on the constant and the relative factors and their interaction with an "ERM dummy", and find significant results on the interaction terms. Figure 3 also shows the large fluctuation in the UK exchange rate during that period.

Following Parker and Julliard (2005), we set up a Monte Carlo experiment under the null hypothesis that the exchange rate follows a random walk. First, we sample with replacement from the 1-month exchange rate returns and create a series (of size equal to our sample) of "white noise" under the null. Second, using this re-sampled 1-month exchange rate change series, we generate the 1, 3, 6, 12, 18, and 24 month-ahead exchange rate change as our LHS variables. Third, we regress these variables on the relative factors and keep the t-statistics. We repeat the three steps 2,000 times and use the critical values from the distributions of the t-statistics to do our inference. The setup for the excess currency return regression is similar except we use the actual yields in the second step to create the re-sampled excess returns. The rationale of the experiment is that, if exchange rate is truly unpredictable as a random walk, the Monte Carlo results will tell us the probability that the predictability we find is spurious.

The second method is suggested by Hansen and Tuypens (2004), who show through a series of simulations that one can obtain asymptotically correct standard errors by multiplying the OLS standard errors by the squared root of 2/3 times the length of the forecast horizon, $\sqrt{\frac{2}{3}m}$.

We find that the standard errors generated from the Monte Carlo experiment and the Hansen and Tuypens (2004) approach are similar and only lead to slight differences in the levels of statistical significance.

As a further robustness check, we constructed the rescaled t statistic suggested by Moon, Rubia and Valkanov (2004) (which is built on the results in Valkanov (2003)). They show that the rescaled t-statistic $t/\sqrt{m}$, where t is the typical OLS t statistic and m is the forecast horizon, is consistent even under a small sample size. Since the rescaled t-statistics is equivalent to multiply the OLS standard error by the factor $\sqrt{m}$, it is more conservative than the Hansen and

Tuypens (2004) approach and our Monte Carlo experiment results. To conserve space, we only report results using this most conservative method in this paper.

4. Main Results

Our main exchange rate predictive results based on equation (8) are presented in panel (a) in Tables 2-4, and the corresponding ones for excess returns, equation (9), are in panel (b). As a robustness check, we use the first month of each quarter and each half-year to construct a three-month and a six-month sample with no data overlap. We report the findings using the non-overlapping data in Tables 5 and 6. Below we discuss the results for each currency pairs.

Canada: the Canadian-USD results appear to be the weakest among the currency pairs we looked at, and our conjecture is that it is mainly due to the Canadian dollar's "commodity currency" status.[24] The relative factors do not seem to predict exchange rate movements beyond a quarter (panel (a) in Table 2), but they work better for excess returns (panel (b) in Table 2). The level and slope factors are statistically important in predicting excess returns up to a year, with quantitatively significant effect. For example, a 1% increase in the relative level factor predicts a more than 3% annualized drop in the excess return of Canadian dollar over the subsequent three months. Our results based on non-overlapping data reveal the same pattern: the three-month and six-month adjusted R^2-squares statistics for exchange rate change are only 0.029 and 0.02, while for excess returns they are 0.064 and 0.161, with all three factors contributing at times.

24 The Canadian dollar, along with Australian and New Zealand dollars, South African rand and so forth, are known to respond mainly to the world price of their primary commodity exports, of which their economies have a large dependency. See Chen and Rogoff (2003) for more discussion about the "commodity currencies".

Japan: The relative slope factor plays both a statistically and an economically strong role in predicting the yen-dollar movements. As shown in Table 3 panel (a), a 1% increase in the relative slope factor (i.e. the Japanese yield curve becomes steeper relative to the US one) predicts a 4% annualized depreciation of the yen over the next three months. In panel (b), the same 1% increase in the relative slope factor predicts a 6% drop in excess yen returns over the US dollar in the three-month horizon. We do not find large and statistically significant results for the other two relative factors. In Table 5, results based on non-overlapping data again tell us that the relative slope factor is a strong predictor for both exchange rate changes over the three-month and 6-month horizons Table 6 shows that the relative slope explains a substantial part of the future variations of the excess return as well, as evident by their R^2 statistics. We also note that while we only report results up to two years, the predictive power of the relative slope factor remains beyond two years for both exchange rate changes and excess returns.

United Kingdom: All the three factors predict exchange rate changes and excess returns, and all are both quantitatively and statistically significant. For example, a 1% increase in the relative level factor (i.e. the whole yield curve of the US shifts up by 1% relative to that of the UK) predicts almost 4% depreciation of the UK pound against the US dollar over the coming three months. The same increase in the relative level factor predicts an almost 5% drop in the excess sterling return over the next three months. The predictive power of the relative factors for excess return remains beyond the 24-month horizon (not shown). The non-overlapping results in Tables 5 and 6 confirm the relative factors' importance and the three-month and six-month adjusted R-squared for exchange rate change are 0.092 and 0.194, and for excess return are 0.131 and 0.274.

Overall, we see that for all three currency pairs, the relative yield curve factors can play a quantitatively and statistically significant role in explaining future exchange rate movements, from one month ahead to sometimes beyond two years. We note another interesting pattern that is consistent across the currency pairs. The effect of the factors, as captured by the size of the regression coefficients, tends to approach zero as forecast horizon increases. This may reflect that current information and expectations have less effect on actual exchange rate realization farther into the future, but the imprecision in the estimates and the likely bias from the noise in longer-horizon data prevent any conclusive statement.

5. Robustness Tests and Discussions

5.1 Out-Sample Forecasting Results

We next look at the out-of-sample forecasting performance of the relative yield curve factors, compared to that of a random walk. We use a rolling window with a size of five years and construct out-of-sample forecasts for one, two, and three months ahead and for each forecast we calculate the squared prediction error. The first regression uses the first 60 + m observations (as our LHS variable is m ahead), and then make forecast for exchange rate change from 60+m to 60+2m. The second regression moves forward over time by one period, and so on. At the end of the rolling process, we calculate the mean squared forecast error (MSFE) for our model, and compare it with MSFE produced by a drift-less random walk. Table 7 reports the *t*-statistics of the comparison based on the Clark-West (2006) predictability test, which accounts for the upward shift of MSFE in our model.

For all three currency pairs, the null of equal predictability (i.e. our model) is rejected at the one-month horizon, and some also at the two-month horizon. Due to the small sample size, we do not learn much from forecasts of longer horizons, as the sampling variance is too large for us to reject the random walk model.

5.2 Interpretation and Discussion

This section provides an intuitive interpretation of our findings. We emphasize once more that since the goal of this paper is to sidestep explicit modeling of market expectations, including perceived risks, our results do not constitute an explicit test for any specific model. Nevertheless, our positive results have simple and intuitive economic interpretations, as follows. As discussed in Section 2.2, the yield curve literature tells us is that when a country's yield curve is flatter or its level higher, the market expects forthcoming economic downturn to be more likely or higher inflation. Our results show that under these scenarios, its currency becomes less desirable and depreciates according to the present value relation, and subsequently appreciates back towards it longer-run term equilibrium level. The declining effect of the yield curve information on exchange rate changes further into the horizon suggests that movements in market expectations tend to be transitory.

Under rational expectations, excess foreign currency return is the risk premium associated with holding foreign currency. Our result shows that this risk premium, ρ^F, responds strongly to the relative yield curve factors. When market expectation points to more output decline (flat relative slope) or higher future inflation (high relative level) in the foreign country, we see a correspondingly rise in ρ^F. [25] This finding provides an insight into the uncovered

[25] In the notation of equation (9), this means either S^R or L^R is low, and excess return, or ρ^F is high.

interest rate parity puzzle. Consider an increase in the foreign short-term interest rate i^*. Crudely speaking, its impact on the shape of the foreign yield curve can either be flattening it (if the long rates do not respond), or raising the whole curve (if the longer maturity rates go up as well.)[26] Assuming the home yield curve stays fixed, this corresponds to the scenario we just discussed, and ρ^F should rise. It is then easy to see from equation (6), that if the rise in ρ^F is large enough, the exchange rate term, Δs_{t+m}, can indeed turn positive, i.e. foreign currency appreciates in response to a rise in foreign interest rate.

Our results are also consistent with Meredith and Chinn's (1998) finding that the UIP holds better at longer-horizon (five and ten years). As noted in Section 4, the relative factors, embodying time t expectations about future economic dynamics, have a declining impact on the risk premium at more distant horizons. This suggests that the expectation and perceived risk at time t for horizons further into the future tend to be smaller or more neutral. As such, the exchange rate responds are less affected by risk and are more in line with basic fundamentals such as the interest differentials. Consequently, the UIP condition holds better.

Even though we offer no rigorous proof, the above interpretation offers a potential answer to the concern raised in Sarno (2005): While defining the risk premium as excess return "would allow us to study some of the properties of the risk premium by examining its projection on available information, there is no reason to expect that this implicitly defined risk premium will behave in a manner consistent with our economic intuition."

26 In other words, the short rate differences and the relative factors should be positively correlated, as we observe in the data. We also find the correlation declining with yields of longer maturity.

6. Conclusion

We find that the Nelson-Siegel factors extracted from the relative the yield curves between two countries are both statistically and economically significant in explaining future exchange rate movements and in addition, excess currency returns. This result supports the view that exchange rate movements are systematically related to expected future fundamentals, via a present value relationship, as in the asset approach to exchange rate determination. Our approach addresses the Meese-Rogoff (1983) forecast puzzle by outperforming the random walk in short-horizon out-of-sample forecasts. Our findings also support an intuitive explanation for the failure of the short-horizon UIP puzzle.

One may contend that we have merely transported the exchange rate puzzles to the yield curve side, since we did not explicitly justified the behavior and shape of the yield curves. Indeed we do not propose any structural modeling of the expectation formation process or have an explanation for the empirical failing of the expectation hypothesis. Our view is that market expectations of future variables in different time horizons may be too complicated to be captured by simple models, theoretical or empirical. Given the term structure of interest rates has been found to embody such market expectations, the present value approach to exchange rate determination can thus be tested without having to impose either structural or statistical assumptions on the expectation formation process. Our findings support this approach: the difference between two country's yield curves can predict the relative value of their currencies.

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Table 1: Summary Statistics and Correlations of the Relative Factors

(a) Summary Statistics

	Relative Level L^R			Relative Slope S^R			Relative Curvature C^R		
	Canada	Japan	UK	Canada	Japan	UK	Canada	Japan	UK
Mean	-0.567	3.168	-0.146	-0.633	-0.835	-1.765	-0.827	1.115	-1.430
Median	-0.592	3.166	-0.481	-0.516	-0.988	-2.323	-0.686	1.093	-0.855
Max	2.024	5.725	3.910	6.463	3.594	7.576	8.641	8.585	16.073
Min	-3.094	1.203	-4.620	-5.398	-5.419	-6.780	-13.889	-7.313	-24.945
SD	0.941	0.902	1.845	1.926	1.990	2.571	3.039	2.736	7.048
Skewness	0.204	0.151	0.219	0.383	0.025	0.997	-0.454	-0.139	-0.968
Kurtosis	3.029	2.538	2.592	3.323	2.119	4.294	6.437	2.596	5.304

(b) Correlations between relative Factors

	L^R - Can	L^R - Jap	L^R - UK	S^R - Can	S^R - Jap	S^R - UK	C^R - Can	C^R - Jap	C^R - UK
L^R - Can	1.000								
L^R - Jap	0.576	1.000							
L^R - UK	0.629	0.517	1.000						
S^R - Can	-0.030	-0.044	0.265	1.000					
S^R - Jap	0.082	-0.058	0.206	0.616	1.000				
S^R - UK	-0.095	-0.047	0.168	0.654	0.658	1.000			
C^R - Can	-0.515	-0.060	-0.036	-0.131	0.000	0.142	1.000		
C^R - Jap	-0.091	-0.177	0.054	0.360	0.482	0.405	0.318	1.000	
C^R - UK	-0.316	-0.142	-0.770	-0.236	-0.205	-0.339	0.035	0.063	1.000

Table 2: Predicting the Canadian-US Exchange Rate and Excess Returns

(a) Exchange Rate $\frac{1200(s_{t+m}-s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m}$

	m=1	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-3.542*	-2.789*	-1.789	-1.540	-1.249	-0.720
$t/\sqrt{m}$	-1.928	-1.832	-1.184	-0.966	-0.722	-0.377
$\mathbf{S^R}$	-0.731	-0.575	-0.517	-0.458	-0.367	-0.244
$t/\sqrt{m}$	-0.944	-0.898	-0.812	-0.685	-0.506	-0.306
$\mathbf{C^R}$	-0.945*	-0.867*	-0.643	-0.496	-0.461	-0.349
$t/\sqrt{m}$	-1.652	-1.834	-1.360	-0.995	-0.850	-0.584
N. obs.	239	237	234	228	222	216

(b) Excess Return $i_t^{m*} - i_t^m + \frac{1200(s_{t+m}-s_t)}{m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + v_{t+m}$

	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-3.206*	-2.550*	-2.585	-2.305	-1.721
$t/\sqrt{m}$	-1.817	-1.660	-1.611	-1.339	-0.908
$\mathbf{S^R}$	-1.437*	-1.333*	-1.174*	-0.963	-0.753
$t/\sqrt{m}$	-1.845	-2.038	-1.746	-1.335	-0.949
$\mathbf{C^R}$	-0.828	-0.744	-0.739	-0.771	-0.633
$t/\sqrt{m}$	-1.448	-1.550	-1.472	-1.431	-1.068
N. obs.	172	224	228	222	216

Note: Exchange rate *s* is log(USD/CAD). The row $t/\sqrt{m}$ reports the re-scaled t-statistics for the estimates (see text for details). Estimates for the constant term are omitted, and * indicates significance level of 10% or below.

Table 3: Predicting the Japanese-US Exchange Rate and Excess Returns

(a) Exchange Rate $\frac{1200(s_{t+m}-s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m}$

	m=1	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-2.606	-1.424	-0.871	-2.155	-1.504	-1.504
$t/\sqrt{m}$	-0.705	-0.467	-0.293	-0.866	-0.590	-0.617
$\mathbf{S^R}$	-4.093*	-4.061*	-3.950*	-3.176*	-2.321*	-2.321*
$t/\sqrt{m}$	-2.173	-2.605	-2.607	-2.506	-1.778	-1.852
$\mathbf{C^R}$	0.535	0.890	0.566	-0.096	-0.565	-0.565
$t/\sqrt{m}$	0.385	0.771	0.504	-0.102	-0.585	-0.609
N. obs.	239	237	234	228	222	216

(b) Excess Return $i_t^{m*} - i_t^m + \frac{1200(s_{t+m}-s_t)}{m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + v_{t+m}$

	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-2.187	-2.233	-3.151	-3.223	-2.521
$t/\sqrt{m}$	-0.656	-0.752	-1.265	-1.262	-1.031
$\mathbf{S^R}$	-5.787*	-4.967*	-3.899*	-3.160*	-2.846*
$t/\sqrt{m}$	-3.431	-3.281	-3.076	-2.411	-2.260
$\mathbf{C^R}$	1.023	0.463	-0.327	-0.762	-0.852
$t/\sqrt{m}$	0.802	0.409	-0.347	-0.788	-0.915
N. obs.	153	228	228	222	216

Note: Exchange rate *s* is log(USD/JPY). The row $t/\sqrt{m}$ reports the re-scaled t-statistics for the estimates (see text for details). Estimates for the constant term are omitted, and * indicates significance level of 10% or below.

Table 4: Predicting the UK-US Exchange Rate and Excess Returns

(a) Exchange Rate $\frac{1200(s_{t+m}-s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m}$

	m=1	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-3.101	-3.929*	-3.104*	-2.593*	-2.028	-1.512
$t/\sqrt{m}$	-1.332	-2.293	-2.031	-1.791	-1.410	-1.094
$\mathbf{S^R}$	-1.836	-2.354*	-1.965*	-1.353*	-1.097	-0.806
$t/\sqrt{m}$	-1.519	-2.629	-2.431	-1.751	-1.435	-1.097
$\mathbf{C^R}$	-0.751	-1.125*	-1.006*	-0.796*	-0.607	-0.395
$t/\sqrt{m}$	-1.129	-2.296	-2.282	-1.900	-1.445	-0.983
N. obs.	215	213	210	204	198	192

(b) Excess Return $i_t^{m*} - i_t^m + \frac{1200(s_{t+m}-s_t)}{m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + v_{t+m}$

	m=3	m=6	m=12	m=18	m=24
$\mathbf{L^R}$	-4.858*	-4.451*	-3.718*	-3.086*	-2.534*
$t/\sqrt{m}$	-1.959	-2.446	-2.507	-2.134	-1.821
$\mathbf{S^R}$	-3.772*	-2.824*	-2.138*	-1.727*	-1.397*
$t/\sqrt{m}$	-1.926	-2.377	-2.530	-2.249	-1.888
$\mathbf{C^R}$	-0.939	-1.229*	-1.039*	-0.906*	-0.718*
$t/\sqrt{m}$	-0.994	-2.135	-2.363	-2.157	-1.766
N. obs.	108	159	195	198	192

Note: Exchange rate *s* is log(USD/GBP). The row $t/\sqrt{m}$ reports the re-scaled *t*-statistics for the estimates (see text for details). Estimates for the constant term are omitted, and * indicates significance level of 10% or below.

Table 5: Exchange Rate Regressions with Non-Overlapping Data

	m=3	m=6	m=3	m=6	m=3	m=6
	Canada		Japan		UK	
L^R	-3.220*	-1.702	-2.153	0.060	-4.666*	-2.669*
	(1.357)	(1.393)	(2.982)	(2.975)	(1.890)	(1.176)
S^R	-0.550	-0.642	-3.494*	-4.226*	-2.308*	-2.080*
	(0.521)	(0.425)	(1.693)	(1.816)	(0.943)	(0.674)
C^R	-0.794*	-0.791*	0.503	1.024	-1.240*	-0.831*
	(0.443)	(0.442)	(1.258)	(1.255)	(0.563)	(0.325)
N. obs.	79	39	79	39	71	35
Adj. R^2	0.029	0.020	0.029	0.067	0.092	0.194

Table 6: Excess Currency Return Regressions with Non-Overlapping Data

	m=3	m=6	m=3	m=6	m=3	m=6
	Canada		Japan		UK	
L^R	-2.725	-2.655	-1.450	-0.932	-7.165*	-3.756*
	(1.445)	(1.393)	(3.297)	(2.971)	(3.593)	(1.505)
S^R	-1.561*	-1.503*	-6.893*	-5.049*	-3.477	-3.222*
	(0.587)	(0.430)	(1.430)	(1.808)	(2.226)	(1.029)
C^R	-0.765	-0.916*	1.613	0.867	-2.576	-0.869
	(0.472)	(0.443)	(1.567)	(1.249)	(1.552)	(0.588)
N. obs.	58	39	33	39	35	28
Adj. R^2	0.064	0.161	0.289	0.135	0.131	0.274

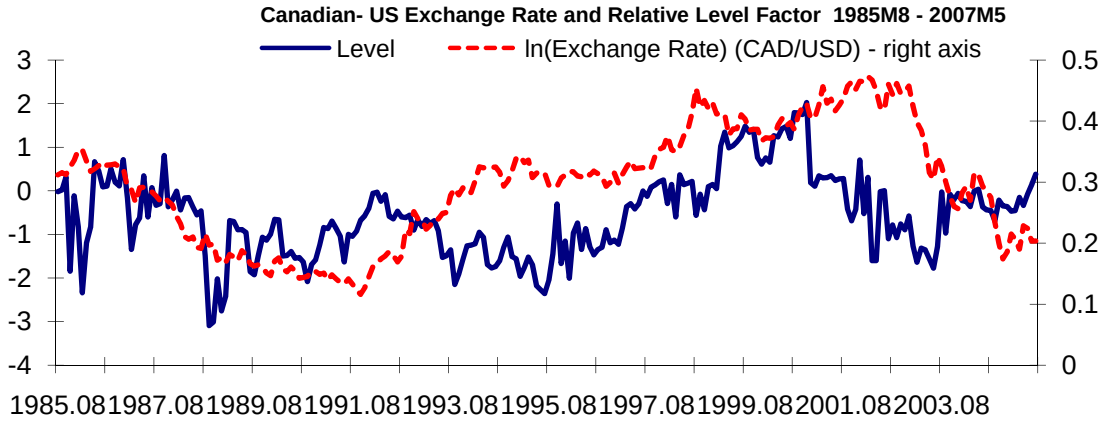
Note to Tables 8 and 9: Newey-West standard errors are reported in the parentheses. * indicates significance level of 10% or below. We use the first month of a quarter and the first month of every half-year to construct non-overlapping samples. Observations during the ERM period are dropped for the UK.

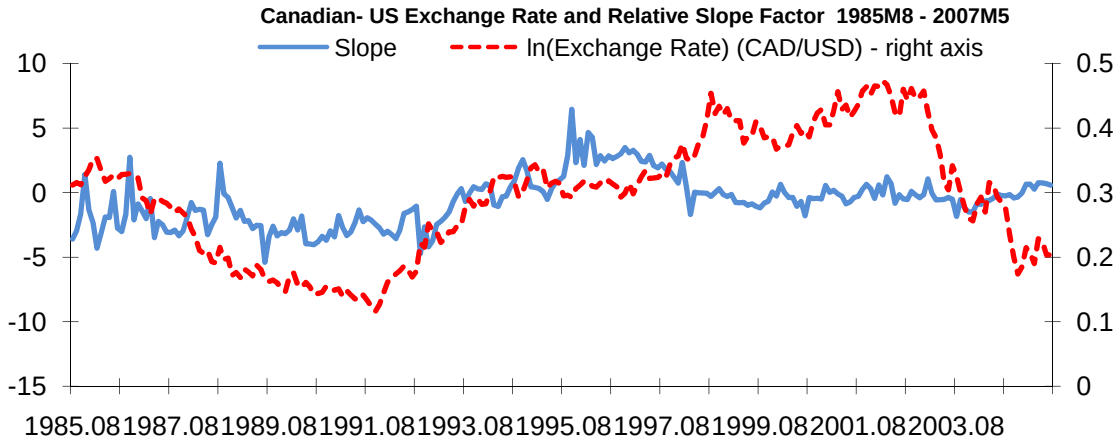
Table 7: Clark-West (2006) Output-of-Sample Test Statistics

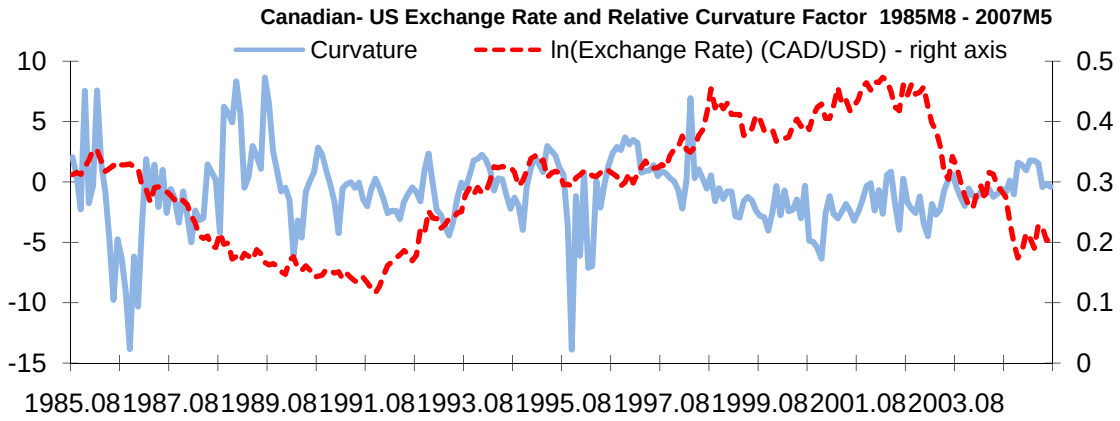
Horizon	Canada	Japan	UK
m=1	3.860*	2.517*	3.274*
m=2	2.002*	1.475	1.719*
m=3	1.367	1.240	1.128

Note: * indicates significance level of 10% or below. See Clark and West (2006) for details of the testing procedure.

Figure 1: The Canadian-US Exchange Rate and Relative Factors

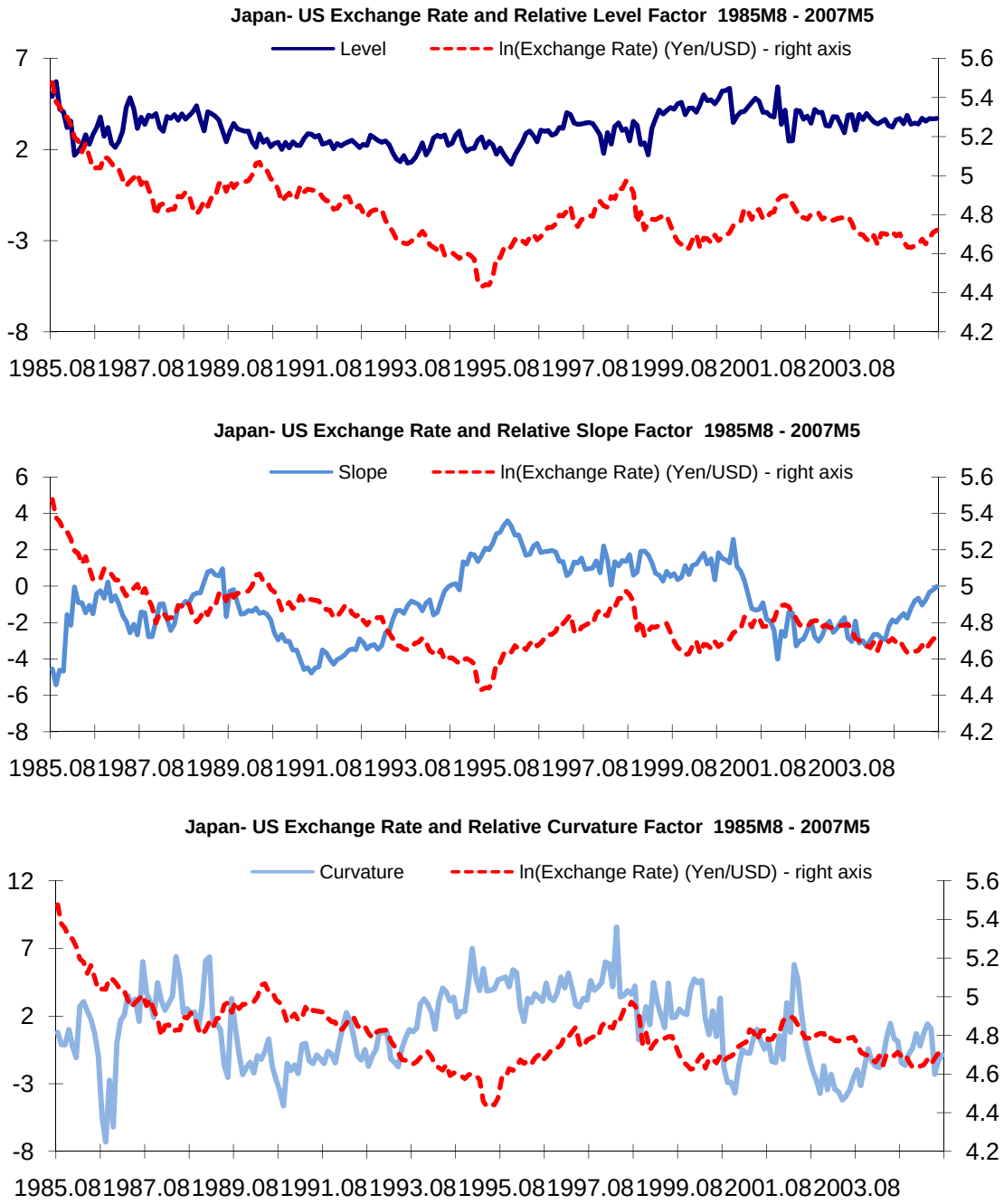






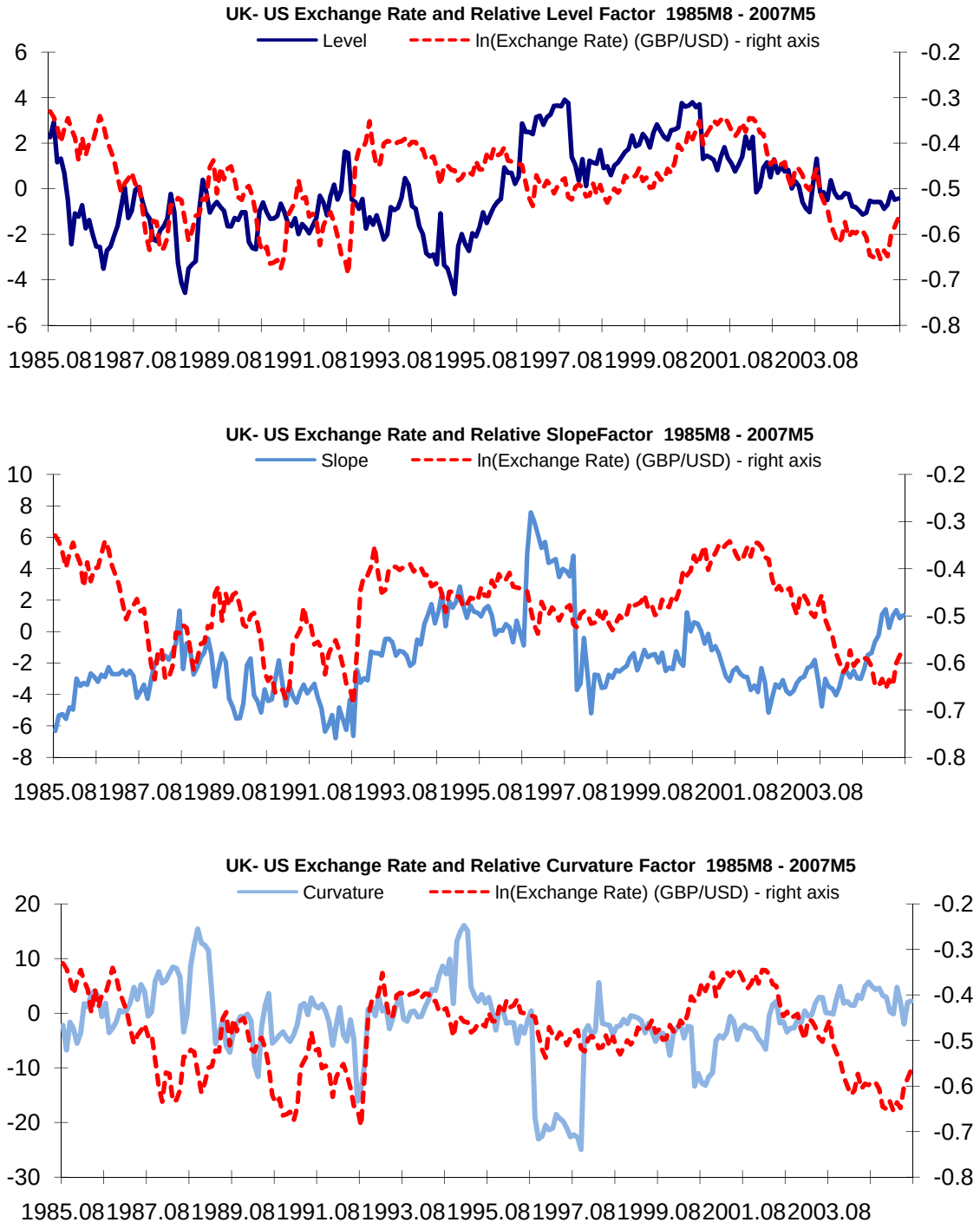
Note: The relative term structure factors are calculated by the following procedure: in each period, we subtract the yields of the country from those of the US with matching maturities. We then fit the Nelson-Siegel yield curve on the yield differences to obtain the level, slope and curvature factors for that period.

Figure 2: The Japan-US Exchange Rate and Relative Factors



Note: The relative term structure factors are calculated by the following procedure: in each period, we subtract the yields of the country from those of the US with matching maturities. We then fit the Nelson-Siegel yield curve on the yield differences to obtain the level, slope and curvature factors for that period.

Figure 3: The UK-US Exchange Rate and Relative Factors



Note: The term structure factors for each country are calculated by the following procedure: in each period, we subtract the yields of each country from those of the US, matching the maturities. We then fit the Nelson-Siegel yield curve on the yield differences and obtain the level, slope and curvature factors for that period.