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

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Abstract: Since the term structure of interest rates embodies information about future economic activity, we extract *relative* Nelson-Siegel (1987) factors from cross-country yield curve differences to proxy expected movements in future exchange rate fundamentals. Using monthly data for the UK, Canada, Japan and the US, we show that the yield curve factors predict exchange rate movements and explain excess currency returns one month to two years ahead. Our results provide support for the asset-pricing formulation of exchange rate determination and offer an intuitive explanation to the uncovered interest parity puzzle by relating currency risk premiums to inflation and business cycle risks.

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

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Online Appendix is available at: http://faculty.washington.edu/yuchin/Papers/CT1OA.pdf.

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 domestic yield curve shifts down or becomes steeper by one percentage point relative to the foreign one, home currency can depreciate by 3-4 percent over subsequent months.[1] Its excess return - currency returns net of interest differentials – declines by even more. Since the Nelson-Siegel factors have well-known macroeconomic interpretations and capture expected dynamics of future economic activity, our findings provide support for the asset pricing approach of exchange rate determination, and imply that the currency risk premiums are driven by differential expectations about countries' future output and inflation, for example. Our results offer an intuitive explanation to the uncovered interest rate (UIP) puzzle.

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".[2] 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 to the discounted present value of its expected future fundamentals, which can include cross-country differences in money supply, output, and inflation, among 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.[3] The performance of

[1] When the curvature of the domestic yield curve increases relative to the foreign one, home currency will appreciate subsequently, though the response is not as robust.
[2] Frankel and Rose (1995) offers a comprehensive summary of the various difficulties confronting the empirical exchange rate literature. Sarno (2005) and Rogoff and Stavrakeva (2008) present more recent surveys.
[3] See Engel and West (2005) and Mark (1995), among many others.

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

This paper contends that market expectations may be more complicated than what econometricians can capture with the simple driving processes commonly assumed. As such, previous empirical failure may be the result of using inappropriate proxies for market expectations of future fundamentals, rather than the failure of the models themselves. We propose an alternative method to capture market expectations and test the asset approach by exploiting information contained in the shapes of the yield curves. Research on the term structure of interest rates has long maintained that the yield curve contains information about expected future economic dynamics, such as monetary policy, output, and inflation. Extending this lesson to the international context, we look at cross-country yield curve *differences*, and extract three Nelson-Siegel (1987) factors - *relative* level, slope, and curvature -to summarize the expectation information contained therein. The Nelson-Siegel representation has several advantages over the conventional no-arbitrage factor yield curve models. It is flexible enough to adapt to the changing shapes of the yield curve, and the model is parsimonious and easy to estimate. It is also more successful in describing the *dynamics* of the yield curve over time, which is important to our goal of relating the evolution of the yield curve to movements in the expected exchange rate fundamentals.[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] In addition, with a different dataset, we present corroborating results for a more recent period between January 1991 and May 2011. Using zero-coupon yield data, we fit the three Nelson-Siegel relative factors to the yield differences

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[4] The no-arbitrage models are often successful in fitting a cross-section of yields, but do not do as well in the dynamic setting (e.g. Duffee 2002). Diebold and Li (2006) show that by imposing an AR(1) structure on the factors, the Nelson-Siegel model has strong forecasting power for future yield curves. In addition, as discussed in Diebold, Rudebusch and Aruoba (2006), the Nelson-Siegel model avoids potential misspecification due to the presence of temporary arbitrage opportunities in the bonds market.

[5] We note that our results hold also for the other currency pair combinations in our sample. For ease of presentation, we only provide results relative to the US dollar in this paper.

between the three countries and the US at maturities ranging from three months to ten years. Our results show that all three relative yield curve factors can help predict bilateral exchange rate movements and explain excess currency returns one month to two years ahead, with the slope factor being the most robust across currencies. We find that a one-percentage point rise in the slope or level factors of one country relative to another produces an annualized 3-4% appreciation of its currency subsequently, with the magnitude of the effect declining over the horizon. The responses of excess currency returns tend to be even larger. Movements in the curvature factor have a much smaller effect on exchange rates of roughly one-to-one, and they are also the least robust. We pay special attention to addressing the inference bias inevitable in our small sample long-horizon regressions, which we discuss in more detail in Sec. 3.[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 regarding 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 straightforward economic interpretations, and offer insight into the uncovered interest parity puzzle: the empirical regularity that the currencies of high interest rate countries tend to appreciate subsequently, rather than depreciate according to the foreign exchange market efficient condition. In particular, we find that deviations from UIP – excess currency returns − systematically respond to the shape of the yield curves, which in turn capture market perception of future inflation, output, and other macro indicators.[7] Take, for example, our results showing that a flatter relative yield curve or an upward shift in its overall level predict subsequent home currency

[6] To complement results presented in the main text, we also conduct rolling out-of-sample forecasts to see how our yield curve model forecasts future exchange rate changes relative to the random walk forecasts and also forecasts based on interest differentials of a single maturity. Our model does not consistently outperform the two benchmarks considered. See Online Appendix for details.

[7] Deviations from UIP reflect both currency risk premium and expectation errors. For presentational simplicity we assume away systematic expectation errors here, though they are clearly present empirically and our analyses would carry through without making this assumption (See Froot and Frankel 1989 and Chen, Tsang, and Tsay 2010)

appreciation and a high home currency risk premium. Since the flattening of the yield curve is typically considered a signal for an economic slow-down or a forthcoming recession, a flat domestic yield curve relative to the foreign one suggests that the expected future growth at home is relatively low. In accordance with the present value relation, home currency faces depreciation pressure as investors pull out, and ceteris paribus, appreciates over time towards its long-term equilibrium value.[8] A similar explanation can also be applied to the case of a large level factor, which reflects high expected future inflation. Both of these scenarios can induce higher perceived risk associated with holding the domestic currency, as its payoff would be negatively correlated with the marginal utility of consumption. This explains our observed rise in excess home currency returns, i.e. the risk premium associated with domestic currency holding.

The above intuition has clear implications for the UIP puzzle. Since a rise in the short-term interest rate flattens the slope of the yield curve and/or raises its overall level, both would imply a risk-premium increase. The home currency may thus appreciate subsequently instead of depreciate according to UIP, if the risk premium adjustment is large enough. Even though we do not explicitly model expectations and perceived risks in this paper, our results are in accordance with simple economic intuitions. In fact, we show that by augmenting standard UIP regressions with longer-maturity rates, the UIP puzzle can disappear. This suggests the puzzle is related to an omitted risk premium term embodied in the rest of the yield curves.

Using data from the Survey of Professional Forecasters, we provide empirical support for the view that the U.S. yield curve factors are highly correlated, in the directions discussed above, with investors' reported expectations about future GDP growth and inflation in the U.S., as well as

[8] We note that this finding is contrary to the classic Dornbusch (1976) overshooting model, which predicts an immediate currency appreciation and subsequent depreciation in response to a higher interest rate. Our result is consistent with observations made in more recent papers, such as Eichenbaum and Evans (1995), Gourinchas and Tornell (2004) and Clarida and Waldman (2008).

with their reported levels of "anxiety" about an impending economic downturn.[9] Given their ability to capture market expectations, we conjecture the success of the yield curve factors in predicting exchange rates may also be attributable to their "real-time" nature. Molodtsova et al. (2008), for instance, estimate Taylor rules for Germany and the United States, and find strong evidence that higher inflation predicts exchange rate appreciation, using *real-time data* but not revised data. Finally, we note that our approach is consistent with previous research using the term structure of the exchange rate forward premia or the relative yield spreads to predict future spot exchange rate, such as Frankel (1979), 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 capture a much a wider range of relevant market information by looking at yields all the way up to 10 years or beyond.[11]

2. The Exchange Rates and the Yield Curves

Both the exchange rate and the yield curve rest atop decades of prodigious research. This paper makes no pretense of offering a comprehensive framework for jointly modeling the two, though we do believe this is a worthwhile endeavor.[12] 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

[9] We limit the analysis here to only the U.S. because comparable high-quality survey data are more difficult to obtain for the other countries. We explore the role of surveyed expectations more fully in Chen, Tsang, and Tsay (2010).

[10] Frankel (1979) incorporates long term interest rates, proxying for long term inflation, in exchange rate models. Clarida et al. (2003) finds the term structure of forward premia can forecast future spot rates. See also Boudoukh, Richardson, and Whitelaw (2005) and de los Rios (2009).

[11] Our Nelson-Siegel framework is also more comprehensive than using only the term spreads (for example, the difference between 10-year Treasury notes and 3-month Treasury bills).

[12] Bekaert, Wei and Xing (2007) and Wu (2007) are recent examples that attempt to jointly analyze the uncovered interest parity and the expectation hypothesis of the term structure of interest rates. On the finance side, recent efforts using arbitrage-free affine or quadratic factor models have also shown success in connecting the term structure with the dynamics of exchange rates (see Inci and Lu (2004) and references therein.) In contrast to these papers, our work here emphasizes the macroeconomic connections between the yield curves and the exchange rates, through the use of the Nelson-Siegel factors. Chen and Tsang (2009) present a macro-finance model of the exchange rate.

the yield curve literature, namely the empirical evidence that yield curves embody information about expected future dynamics of key macroeconomic variables, can help improve upon the approach used in previous exchange rate estimations. Next, we offer a brief presentation of the Nelson-Siegel yield curve factors as a parsimonious way to capture the information in the entire yield curve while having well-established connection with macroeconomic variables. Lastly, we present a short discussion on excess returns and risk premium, connecting our findings to the UIP literature.

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 $E_t s_{t+1}$. The first classical example is the workhorse monetary model first developed by Mussa (1976) and explored extensively in subsequent papers. Based on money-market equilibrium, uncovered interest parity and purchasing power parity, the monetary model can be expressed as:

$$s_t = \gamma f_t + \psi E_t s_{t+1} \tag{1}$$

where $f_t = (m_t - m_t^*) - \phi(y_t - y_t^*)$, m is money stock, y is output, "*" denotes foreign variables, and ϕ, γ, ψ (as well as λ below) are parameters related to the income and interest elasticities of money demand. Variations of the monetary model that capture price rigidities and short-term liquidity effects expand the set of fundamentals to: $f_t^M = (m_t - m_t^*) - \beta_y(y_t - y_t^*) - \beta_i(i_t - i_t^*) + \beta_\pi(\pi_t - \pi_t^*)$, as in Frankel (1979). Solving eq. (1) forward and imposing the appropriate transversality condition, nominal exchange rate has the standard asset price expression, based on information I_t at time t:

$$s_t = \lambda \sum_{j=0}^{\infty} \psi^j E_t(f_{t+j}|I_t) \tag{2}$$

This present-value expression, with alternative sets of model-dependent fundamentals, serves as the starting point for standard textbook treatments and for many major contributions to the empirical exchange rate literature (e.g. Mark 1995; Engel and West 2005).

Several recent papers emphasize the importance of monetary policy rules, especially the Taylor rule, in modeling exchange rates.[13] The Taylor rule model assumes that the monetary policy instruments, the home interest rate i_t and the foreign rate i_t^*, are set as follows:

$$i_t = \mu_t + \beta_y y_t^{gap} + \beta_\pi \pi_t^e$$

$$i_t^* = \mu_t{}^* + \beta_y y_t^{*,gap} + \beta_\pi \pi_t^{*,e} - \delta q_t \quad (3)$$

where y_t^{gap} is the output gap, π_t^e is the expected inflation, $\beta_y, \beta_\pi, \delta > 0$, and μ_t contains the inflation and output targets, the equilibrium real interest rate, and other omitted terms. The foreign corresponding variables are denoted with a "*", and following the literature, we assume the foreign central bank to explicitly target the real exchange rate or purchasing power parity $q_t = s_t - p_t + p_t^*$ in addition, with p denoting the overall price level.[14] The efficient market condition for the foreign exchange markets, under rational expectations, equates cross border interest differentials $i_t - i_t^*$ with the expected rate of home currency depreciation, adjusted for the risk premium associated with home currency holdings, ρ^H:

$$i_t - i_t^* = E_t \Delta s_{t+1} + \rho_t^H \quad (4)$$

Combining eqs. (3) and (4) and letting $v_t = \mu_t - \mu_t{}^*$, we have:

$$\beta_y (y_t^{gap} - y_t^{*,gap}) + \beta_\pi (\pi_t^e - \pi_t^{*,e}) + \delta (s_t - p_t + p_t^*) + v_t = E_t \Delta s_{t+1} + \rho_t^H \quad (5)$$

Solving for s_t and re-arranging terms, we arrive at an expression equivalent to eq. (1) above, with a different set of fundamentals f_t^{TR1}:

$$s_t = \frac{\delta}{1+\delta}(p_t - p_t^*) - \frac{1}{1+\delta}\{\beta_y (y_t^{gap} - y_t^{*,gap}) + \beta_\pi (\pi_t^e - \pi_t^{*,e}) - \rho_t^H + v_t\} + \frac{1}{1+\delta} E_t s_{t+1} \quad (6)$$

[13] See Engel and West (2005), Molodtsova and Papell (2008), and Wang and Wu (2009) as examples.

[14] For notation simplicity, we assume the home and foreign central banks to have the same weights β_y and β_π.

Here $f_t^{TR1} = \{(p_t - p_t^*), (y_t^{gap} - y_t^{*,gap}),\ (\pi_t^e - \pi_t^{*,e}),\ \rho_t^H\}$. (As pointed out in Engel and West (2005), eq. (6) can be re-expressed in the same general form as eq. (1) but with yet a different set of fundamentals f_t^{TR2}:

$$s_t = \delta(i_t - i_t^*) + \delta(p_t - p_t^*) - \beta_y(y_t^{gap} - y_t^{*,gap}) - \beta_\pi(\pi_t^e - \pi_t^{*,e}) + (1-\delta)\rho_t^H - \nu_t + (1-\delta)E_t s_{t+1} \quad (7)$$

with $f_t^{TR2} = \{(i_t - i_t^*), (p_t - p_t^*), (y_t^{gap} - y_t^{*,gap}), (\pi_t^e - \pi_t^{*,e}),\ \rho_t^H\}$.

Both eqs. (6) and (7) can be solved forward, leading to the asset pricing eq. (2) above with a different set of fundamentals f_t^{TR1} or f_t^{TR2}.

The above shows that various structural exchange rate models, classical or Taylor rule-based, can deliver the net present value equation where exchange rate is determined by expected future values of cross-country output, inflation, and interest rates. As shown in the next section, these are exactly the macroeconomic indicators for which the yield curves appear to embody information.

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

$$\Delta s_{t+1} = \lambda \sum_{j=1}^{\infty} \psi^j E_t(\Delta f_{t+j} | I_t) + \varepsilon_{t+1} \quad (8)$$

From here on, we deviate from the common approach in the literature which imposes additional assumptions on the statistical processes driving the fundamentals. Instead, we use the information in the yield curves to proxy the expected discounted sum on the right-hand side of eq. (8).[15]

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. Traditional models of the yield curve posit that its shape is determined by expected future paths of interest rates and perceived future uncertainty (the risk premia). While the classic expectations hypothesis is rejected frequently, research on the term

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[15] Previous literature has attempted to use surveyed market expectations as an alternative. See Frankel and Rose (1995), Sarno (2005), and Chen, Tsang, and Tsay (2010) for more discussions.

structure of interest rates has convincingly demonstrated that the yield curve contains information about expected future economic conditions, such as output growth and inflation.[16] Below we give a brief summary of the Nelson-Siegel (1987) framework for characterizing the shape of the yield curve, and motivate our use of the *relative* factors. We then summarize findings of the macro-finance literature regarding the factors' predictive content.

The Nelson-Siegel (1987) factors offer a succinct approach to characterize the shape of the yield curve in the following form: [17]

$$i_t^m = L_t + S_t\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + C_t\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) \quad (9)$$

where i_t^m is the continuously-compounded zero-coupon nominal yield on an *m*-month bond, and parameter λ controls the speed of exponential decay[18] The three factors, L_t, S_t and C_t typically capture most of the information in a yield curve, with R^2 usually close to 0.99.

2.3. The Yield Curve-Macro Linkage

There is a long history of using the term structure to predict output and inflation.[19] Mishkin (1990a and 1990b) shows that the yield curve predicts inflation, and that movements in the longer end of the yield curve are mainly explained by changes in expected inflation. Barr and Campbell (1997) use data from the UK index-linked bonds market and show that long-term expected inflation explains almost 80% of the movement in long yields. Estrella and Mishkin (1996) show that the term spread is correlated with the probability of a recession, and Hamilton and Kim (2002) find that it can forecast GDP growth.

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[16] The expectations hypothesis expresses a long yield of maturity m as the average of the current one-period yield and the expected one-period yields for the upcoming $m-1$ periods, plus a term premium. See Thornton (2006).

[17] Nelson-Siegel (1987) derive the factors by approximating the forward rate curve at a given time with a Laguerre function that is the product of a polynomial and an exponential decay term. This forward rate is the (equal-root) solution to the second order differential equation for the spot rates. A parsimonious approximation of the yield curve can then be obtained by averaging over the forward rates. The resulting function capable of capturing the relevant shapes of the empirically observed yield curves: monotonic, humped, or S-shaped.

[18] We use zero-coupon bonds to avoid the coupon effect and the Treasuries to abstract away from default risks and liquidity concerns. Parameter λ is set to 0.0609 as is standard in the literature

[19] See Estrella (2005) for a survey and explanations for why the yield curve predicts output and inflation.

The more recent macro-finance literature connects the observation that the short rate is a monetary policy instrument with the idea that yields of all maturities are risk-adjusted averages of expected short rates. This more structural approach offers deeper insight into the relationship between the yield curve factors and macroeconomic dynamics.[20] Ang, Piazzesi and Wei (2006) find that the term spread (the slope factor) and the short rate (the sum of level and slope factors) outperform a simple AR(1) model in forecasting GDP growth 4 to 12 quarters ahead. Using a New Keynesian model, Bekaert, Cho and Moreno (2010) demonstrate 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. Last but not least, Rudebusch and Wu (2007, 2008) 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 provide macroeconomic underpinnings for the factors, and show that when agents perceive an increase in the long-run inflation target, the level factor will rise and the whole yield curve will shift up. The slope factor is modeled via a Taylor-rule, reacting to the output gap y_t^{gap} and inflation π_t. When the central bank tightens monetary policy, the slope factor rises, forecasting lower growth in the future.[21] To capture the arguments in the vast literature above, we provide a simple illustrative example of how the level and slope factors incorporate expectations of future inflation and output dynamics in the Appendix A1.

Noting that the exchange rate fundamentals (f_t^M, f_t^{TR1}, or f_t^{TR2}) discussed in Section 2.1 are in cross country *differences*, we propose to measure the discounted present value on the right-hand side

[20] See Diebold, Piazzesi and Rudebusch (2005) for a short survey.
[21] The literature does not provide a clear interpretation of the curvature factor, so we do not emphasize its macro linkage.

of eq. (8) with the cross country *differences* in their yield curves. Assuming symmetry and exploiting the linearity in the factor-loadings in eq. (9), we fit three Nelson-Siegel factors of the *relative* level (L_t^R), the relative slope (S_t^R), and the relative curvature (C_t^R), as follows:

$$i_t^m - i_t^{m*} = L_t^R + S_t^R\left(\frac{1-e^{-\lambda m}}{\lambda m}\right) + C_t^R\left(\frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}\right) + \epsilon_t^m \tag{10}$$

where ϵ_t^m is fitting error. The relative factors, L_t^R, S_t^R, and C_t^R, serve as a proxy for expected future fundamentals in our exchange rate regressions. (We note that i_t^m is defined as the US or home yield, so the relative factors are defined from the perspective of the US relative to the other countries.)

2.4 Excess Currency Returns and the Risk Premium

To gain further insight into the UIP puzzle, we examine how excess returns respond to expectations about future macroeconomic dynamics. Excess return, defined here for the foreign currency, is the difference in the cross-country yields adjusting for the relative currency movements:

$$rx_{t+m} = i_t^{m*} - i_t^m + \Delta s_{t+m} \tag{11}$$

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

As discussed earlier, 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 UIP condition. In *ex post* data, however, UIP 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.[22] We note that under the assumption of rational expectations, excess returns in eq. (11) represents the risk premium associated with foreign currency holdings, ρ^F, as expressed below:

[22] The peso problem is also a common explanation. See Engel (1996) and Sarno (2005) for surveys.

$$\Delta s_{t+m} - (i_t^m - i_t^{m*}) = \rho_{t+m}^F + \varepsilon_{t+m} = rx_{t+m} \quad (12)$$

where ε_{t+m} represents expectation error and would be white noise under rational expectations.[23] We examine how the risk premium adjusts to market expectations about future relative macroeconomic dynamics, as captured by the relative factors.

3. Data and Estimation Strategies

3.1. Data Description

Our main sample consists of monthly data from August 1985 to July 2005 for the US, Canada, Japan, and the United Kingdom of the following series:

- 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. The data set is from Diebold, Li and Yue (2007), and we use three-month Treasury bills from Global Financial Data to fill in some of the missing observations.
- Exchange rate measured as the U.S. dollar price per unit of the foreign currency.[24] 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.

To supplement our main results and to see whether our findings are robust over the financial crisis of 2008, we also use data covering January 1991-May 2011, which we obtain from the Bank of Canada, Bank of England, and the Federal Reserve Economic Data (we do not have data on Japan.)

We estimate eq. (10) by OLS period-by-period, to obtain times series of the relative Nelson-Siegel factors, L_t^R, S_t^R and C_t^R, for Canada, Japan, and the UK, relative to the US. We plot the relative

[23] If we relax the assumption of rational expectations, ρ^F would then represent both risk premium and expectation errors.
[24] The yields are reported for the second day of 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).

factors with the log exchange rates in Figures 1-3, and report their summary statistics in the first half of Table 1.[25]

The relative factors behave somewhat differently from the typical single-country Nelson-Siegel factors, as to be expected. The relative level factor has low persistence and small volatility. Unlike the single-country slope factor which is typically very noisy, it is difficult to visually distinguish the relative slope factor from the relative level factor. The relative curvature factor is the most volatile, as with the single-country curvature. There are also some noticeable differences across countries in their coefficients of variation (SD/mean). For example, Japan's relative level has a much higher mean and is also much less varied, whereas the UK has a very volatile curvature factor. Correlation coefficients among the nine relative factors are reported in the second half of Table 1. We note that 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.[26] Within each country, the three factors are also correlated, but there is no consistent pattern.

Finally, excess currency return is computed as:

$$rx_{t+m} = i_t^{m*} - i_t^m + \frac{1200(s_{t+m} - s_t)}{m} \tag{13}$$

where m is the horizon measured in months. As discussed above, this measures the annualized percentage return from both interest differentials and currency appreciation, and represents the risk premium associated with holding foreign currency (under the assumption of no systematic expectation errors, as discussed earlier).

3.2. Yield Curve Factors and Surveyed Expectations

Section 2 summarized prior research showing the term structure factors as a robust and power predictor for future macroeconomic dynamics. We conduct some simple tests here using our

[25] We note that the augmented Dickey-Fuller test of Elliott et al. (1996) rejects the presence of a unit root in all of the relative factors, exchange rate changes, and excess return series.
[26] We note again that our conclusions extend to non-dollar country pairs as well.

U.S. yield curve data and the Survey of Professional Forecasters (SPF), which contains forecasts on a wide range of economic indicators for the U.S. from a large group of private-sector and institutional economists.[27] We take the mean forecasts for real GDP growth and CPI inflation for horizons from 1 to 4 quarters ahead, and correlate them with the current yield curve factors. We also check the correspondence of the "Anxious Index" - a measure of the market's perceived probability of real GDP decline k quarters later - with the current slope factor. Using data from 1985Q3 to 2005Q2, we run the following three sets of regression, in accordance with the discussion in Section 2.2 and Appendix A1, regarding the information embodied in the slope and level factors S_t and L_t:[28]

$$E_t\Delta y_{t+m} = \alpha_{Sm} + \beta_{Sm}S_t + \beta_{ym}\Delta y_t + u_{Smt} \quad (14)$$

$$A_{t+m} = \gamma_{Sm} + \delta_{Sm}S_t + \delta_{ym}\Delta y_t + v_{Smt} \quad (15)$$

$$E_t\pi_{t+m} = \alpha_{Lm} + \beta_{Lm}L_t + \beta_{\pi m}\pi_t + u_{Lmt} \quad \text{for m= 3, 6, 9, and 12} \quad (16)$$

Here $E\Delta y_{t+m}$ denotes real GDP growth forecast, $E\pi_{t+m}$ CPI denotes inflation forecast, and A_{t+m} is the Anxious Index for horizon m-months ahead. The first two regressions test whether the current slope reflects expected real GDP dynamics, and the third regression checks whether the level factor is correlated with expected future inflation. Since our main argument is that the factors can capture market expectations about the dynamics of future fundamentals *beyond* the currently observed fundamentals, we include them as additional regressors.

Table 2 shows that indeed, a larger slope factor (flatter slope) corresponds to lower expected output 3 quarters to a year ahead, as well as higher perceived probability of an economic downturn over the six-month to one-year horizons. A larger level factor consistently maps to higher expected inflation across all future horizons. These results are robust to the inclusion of the current fundamentals as well (results available upon request).

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[27] We note that comparably reliable surveyed expectation data are difficult to obtain for the other countries in our paper, hence this section looks at the U.S. only.
[28] Additional results using all three factors are in Online Appendix.

3.3 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 eq. (17):[29]

$$\frac{1200(s_{t+m}-s_t)}{m} = \beta_{m,0} + \beta_{m,1}L_t^R + \beta_{m,2}S_t^R + \beta_{m,3}C_t^R + u_{t+m} \tag{17}$$

$$rx_{t+m} = \gamma_{m,0} + \gamma_{m,1}L_t^R + \gamma_{m,2}S_t^R + \gamma_{m,3}C_t^R + v_{t+m} \tag{18}$$

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.[30] 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.

It is well known that longer horizon predictive analyses are prone to inference bias from using 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 eqs. (17) and (18) above will be a moving average process of order $m-1$. Statistics such as the standard errors will be biased. One common solution is to use Newey-West standard errors. However, the Newey-West adjustment suffers from serious size distortion (i.e. rejecting too often) when the sample size is small and the regressors are persistent. We address the problem using two alternative methods. The first method uses critical values constructed from Monte Carlo simulations (discussed in the Online Appendix). For the rest of the paper, we correct the long-horizon bias using the re-scaled t statistic suggested by Moon, Rubia and Valkanov (2004) and Valkanov (2003), as it delivers more conservative inferences than the Monte Carlo results. As discussed in Appendix A1, Moon et al (2004) propose to re-scale standard t-statistics by $1/\sqrt{m}$ and show that this re-scaled t statistic is

[29] Since 1-month yield data is not available, we do not have excess returns data to run eq. (18).
[30] We run eqs. (17) and (18) with the relative factors and their interaction with an "ERM dummy", and find significant results on the interaction terms. Figure 1C also shows the large jumps in the UK pound during this period.

approximately standard normal, provided that the regressor x_t is highly persistent. When the regressor is not a near-integrated process, however, the adjusted t-statistic tends to under-reject the null. Since the unit root null is rejected for most of our factors, we note that the predictive power of the factors may actually be stronger than implied by the results we present below in Tables 3-5.[31]

4. Main Results

4.1. Predictive Regressions

Our main exchange rate predictive results based on eq. (17) are presented in panel (a) of Tables 3-5, with the corresponding results for excess returns eq. (18) 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 Table 6 panels (a) and (b). Below we discuss the results for each currency pair.

Canada: The relative factors do not seem to predict exchange rate movements beyond six months (panel (a) in Tables 3 and 6), but they work better for excess returns (panel (b) in Tables 3 and 6). The level and slope factors are statistically important in predicting excess returns up to a year, with quantitatively significant effect. For example, a one percentage point increase in the relative level factor (e.g. a lower expected inflation in Canada) predicts more than a 4% annualized drop in the excess return of Canadian dollar over the subsequent three months. Results based on non-overlapping data reveal the same pattern: the three-month and six-month adjusted R^2 statistics for exchange rate change are only 0.03 and 0.01, while for excess returns they are 0.11 and 0.16, with all three factors contributing at times. We note that the Canadian-US results appear to be the

[31] We note that even though our estimations involve first running the Nelson-Siegel regressions, Pagan (1984)'s "estimated regressors" issue does not apply here. We are not trying to make inference on any true latent factors that are unobservable. Rather, the Nelson-Siegel factors we extract are merely used to summarize information in the yield curves, so whatever level, slope, or curvature we obtain from the first stage are precisely the ones we want. Moreover, Chen and Tsang (2009) use a (one-step) state-space model to estimate the joint dynamics among yield curve factors and exchange rates; they found similar results as the two-step approach.

weakest among the currency pairs we examined, with the predictability dissipating quickly after 6 months. Our conjecture is that this is mainly due to the Canadian dollar's "commodity currency" status, as discussed previously in the literature.[32]

Japan: The relative slope factor plays both a statistically and an economically strong role in predicting the yen-dollar movements. As shown in Table 4 panel (a), a one-percentage-point increase in the relative slope factor (i.e. the Japanese yield curve becomes steeper relative to the US one, e.g. reflecting stronger Japanese growth prospect) predicts a 3.6% annualized depreciation of the yen over the next three months. In panel (b), the same 1% increase in the relative slope factor predicts a 4.5% drop in excess yen returns over the US dollar in the three-month horizon. The same pattern can be observed over horizons up to two years. These results make intuitive sense; during periods in which the Japanese relative growth prospect is high (compared to the sample average), the yen should be strong and investors would demand less risk premium for holding yen. Subsequently, the yen depreciates towards its equilibrium value (sample average). Interestingly, we do not find statistically significant results for the other two relative factors.

United Kingdom: Table 5 shows that all three Nelson-Siegel factors predict exchange rate changes and ex-post excess returns with quantitatively and statistically significant impact. A one percentage-point increase in the relative level factor (i.e. the whole yield curve of the US shifts up by one percentage point relative to that of the UK) predicts a 4% depreciation of the pound against the dollar and a 5% drop in the excess sterling return over the subsequent quarter. The explanatory power of the relative factors for ex-post excess return in fact extends beyond two years (not shown). The non-overlapping results in Table 6 confirm the relative factors' importance. The three-month and six-month adjusted R-squares statistics for exchange rate change are 0.11 and 0.12, and for

[32] The Canadian dollar is known to respond chiefly to the world price of their primary commodity exports (see Chen and Rogoff (2003) for further discussion on "commodity currencies".) In addition, Krippner (2006) found that the failure of the UIP in CAD/USD rate is associated with the cyclical component of their interest rates.

excess return are 0.16 and 0.27. We note that these are high numbers; they contrast sharply with the view that exchange rates are "disconnected" from macro-fundamentals.

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 over future intervals ranging from one month to two years. We also observe a consistent pattern across currency pairs: the effects of the factors, as captured by the size of the regression coefficients, tend to approach zero as forecast horizon increases. We view this as an indication that current information and expectations have a declining effect on the actual exchange rate realization farther into the future; however, imprecision in the estimates and likely bias from noise in longer-horizon data prevent any conclusive statement. (Note: we present parallel results based on more recent data covering Jan 1991- May 2011 in the Online Appendix.)

4.2. Comparison with Interest Differential Regressions

Given our positive results above, a natural question is how our factor model – using information contained in the full yield curves – compares to specifications using interest differentials of only one (e.g UIP) or two maturities (e.g. Frankel 1979). Below we present the discussion using the UIP regression as an example, though the logic applies to other cases as well.

The UIP puzzle originates from observing a negative and often significantly estimated coefficient β in the following regression setup, for m in the one year range:

$$\Delta s_{t+m} = \alpha + \beta(i_t^m - i_t^{m*}) + \varepsilon_{t+m} \tag{19}$$

While it implies that exchange rate change is predictable by interest rate differentials, we note that this in-sample predictability is consistent with "exchange rate disconnect" or Meese-Rogoff (1983) random walk results, as the explanatory power of interest differences is typically extremely small.[33] How does our Nelson-Siegel factor approach relate to the UIP regression above? Intuitively, our yield curve approach augments the m-period UIP regression with yield differences of all other maturities. As one can imagine the estimation problem associated with having many highly collinear regressors, the NS factors serve as a parsimonious way to reduce dimension, with the additional benefit of having well-established macroeconomic interpretations.

Mathematically, it is also easy to see that eq. (19) is a constrained version of our factor model eq. (17). Substituting the formula for the relative Nelson-Siegel yield curve, eq. (10) into eq. (19) and re-arranging terms, the UIP regression takes the following form:

$$\Delta s_{t+m} = \alpha + \beta L_t^R + \beta\left(\frac{1-\exp(-\lambda m)}{\lambda m}\right) S_t^R + \beta\left(\frac{1-\exp(-\lambda m)}{\lambda m} - \exp(-\lambda m)\right) C_t^R + \epsilon_{t+m} \qquad (20)$$

This shows that the UIP regression is a constrained version of our model eq. (17), with the following two horizon (m)-dependent restrictions:

$$\frac{\beta_{2,m}}{\beta_{1.m}} = \left(\frac{1-\exp(-\lambda m)}{\lambda m}\right),\ \frac{\beta_{3,m}}{\beta_{1,m}} = \left(\frac{1-\exp(-\lambda m)}{\lambda m} - \exp(-\lambda m)\right) \qquad (21)$$

Since our model encompasses the UIP regression, we can formally test whether these restrictions are supported in the data, and whether the flexibility offered by the factor models is useful. We will discuss this more fully over the next two sections, but first report in Table 7(a) adjusted-R^2 comparisons between the two models using the full sample period. We see that in terms of in-sample fit, the factors offer marginal improvements of between 0.01 to 0.07.

[33] Fama (1984) reports an average R^2 of 0.01 for monthly data; see also Chinn (2006) and Chinn and Meredith (2004).

4.3. Model Comparisons over Sub-Samples

To supplement the above results, we further compare the factor model and the interest differential model over sub-sample periods using a rolling window of five years. This exercise is motivated by the common finding in the literature that the additional predictive or forecast content in the more general specifications can be episodic (see e.g. Stock and Watson 2008). That is, there are periods where the additional information in the more comprehensive models offers significant explanatory power, but in other times, these models perform similarly to the more restricted specifications. We illustrate this point by looking at three sets of tests using a rolling-five year window over the full sample period. First, we test for the validity of the restrictions the interest-differential model imposed on the Nelson-Siegel factors, as derived in eq. (21) above, for m = 3, 6, and 12 months; results are plotted in Figures 2A-2C. The 10%-critical value is generated by Monte Carlo simulations to account for small sample bias and autocorrelations in the data (see Appendix A3). In all cases, we see clearly that the F-tests indicate rejections of the UIP restrictions in favor of the factor model (when the F-statistic is above the 10% critical value). For example, the 1990's seem to be a period in which that the factor model is favored in Canada.

Next, we plot and compare the recursively constructed adjusted-R^2s for the interest differential model and for the more general factor model, again using a five-year rolling window.[34] Figure 3B shows that for Japan, the interest-differential model has a better fit, though the differences are small. This result may be related to the our earlier findings that only the slope factors are found to be significant for Japan, suggesting that the flexibility of the Nelson-Siegel curve offers little value (but add estimation costs). For Canada and the UK (Figures 3A and 3C), on the other

[34] To adjust for bias due to overlapping observations, the adjusted-R^2 are constructed using Monte Carlo simulations (see Appendix A3.)

hand, we see sub-periods where the Nelson-Siegel factor model provides large improvements over the single-maturity interest differential model.

5. Discussion

5.1. Interpretations

While we do not explicit test for any specific macroeconomic models discussed in Section 2.1, our positive results nevertheless have intuitive economic interpretations, as follows. As discussed in Section 2.2, the yield curve literature shows that when a country's yield curve is flat or its level high, the market expects a forthcoming economic downturn or rising inflation in that country, respectively. Keeping everything else equal, our results show that under these scenarios, its currency is less desirable and faces depreciation pressure, in accordance with the present value relation eq. (8). Subsequently, its currency will appreciate and recover towards its long-run equilibrium level. Our finding that there is a declining impact of yield curve information on currency movements farther into the horizon supports this view and suggests that movements in market expectations tend to be transitory.

Assuming away systematic market expectation errors, excess foreign currency return can be considered the risk premium associated with holding this currency (see eq. 12). Our results show that the currency risk premium, ρ^F, correlates strongly with the relative yield curve factors. When market expectations point to more output decline (flat relative slope) or higher future inflation (high relative level) in a foreign country, we see a correspondingly high foreign currency risk premium.[35] This pattern makes intuitive sense. For example, consider the case of a high relative level factor abroad, signaling a higher expected inflation there. During periods when inflation is high, the purchasing power of nominal currency declines, and its relative value (exchange rate) weakens

[35] In the notation of eq. (18), this means when either S^R or L^R is low, excess return or ρ^F is high.

according to the present value model. This means both the real and relative returns of foreign currency are low. To the extent that inflation and consumption growth are negatively correlated (as documented in the literature), we see a negative covariance between foreign currency returns and the marginal utility of consumption.[36] Foreign currency is thus risky – a bad hedge for inflation risk – so ρ^F is high. A similar argument can be made about the slope factor, which reflects business cycle or output growth dynamics. When the relative slope is flatter abroad, agents expect low output there and a weaker foreign currency. The low payoff from the foreign currency in states of nature in which output and consumption are low (marginal utility high) makes it a bad hedge and a risky asset, which must offer a risk premium. While our paper does not formally prove any structural mechanism, our robust results are in line with basic economic intuition.

5.2. An Explanation of the UIP Puzzle

Our finding that the risk premium increases with a higher level factor or a flatter slope also offers a viable explanation to the UIP puzzle. In the context of eq. (12), resolving the UIP puzzle means explaining why a rise in i_t^{m*} or a drop in i_t^m can lead to an increase in Δs_{t+m} (for small m). Let us consider the scenario of an increase in the foreign short-term interest rate i^*. Crudely speaking, its impact on the shape of the foreign yield curve would entail either flattening it (if the long rates do not respond), or raising the whole curve (if the longer maturity rates go up as well).[37] Assuming the home yield curve stays fixed, this corresponds to the scenario we discussed above and ρ^F should rise. It is then easy to see from eq. (12) that if the rise in ρ^F is large enough, Δs_{t+m} can indeed turn positive, i.e. foreign currency appreciates in response to a rise in foreign interest rate.

[36] Piazzesi and Schneider (2006) use post-war US data and find inflation to be negatively correlated with current, past, and future consumption growth. Inflation risk therefore explains the positive (yield) term premia.
[37] This also implies that the short rate differences and the relative factors should be positively correlated, which we do observe in our data. We also find the correlation to be declining with yields of longer maturity.

From an econometric perspective, this result points to an omitted-variable bias problem in the original UIP regression. By omitting the risk premium term ρ^F that is negatively correlated with $(i_t^m - i_t^{m*})$, the estimated coefficient for the interest differential term would be biased downward from 1, and possibly turn negative, resulting in the UIP puzzle. Indeed, we report in Table 7(b) the UIP coefficient estimates for horizons 3, 6, and 9 months, both with and without the inclusion of two additional regressors – the one- and the five-year yield differentials – which we use to proxy ρ^F.[38] We observe a consistent pattern here. The slope coefficients β are all significantly negative under the original "UIP" specification, confirming the puzzle. Once the omitted risk term (long bond yield differential) is included, these coefficients all either turn positive or become insignificantly different from zero.

From a practical standpoint, our finding suggests that to predict currency return over a short period, one can do better than looking at just the interest differentials of the corresponding maturity (UIP). By looking at the rest of the yield curves of the two countries, one can obtain additional information on the relative risk market participants perceive regarding the two currencies. If the country with the higher short rate has lower long-maturity yields relative to the yields of the other country, its currency would tend to appreciate subsequently as the market prices in a large risk premium to compensate for the unfavorable economic conditions anticipated for this country. Our results are also consistent with the longer-horizon UIP literature, where e.g. Chinn and Meredith (2004) find that the UIP holds better over horizons of five to ten years. We observe that the relative factors, embodying current expectations about future economic dynamics, have a *declining* impact on ex-post risk premia over longer horizons. This suggests that expectations and risk perceived at time t for horizons further into the future tend to more neutral. As such, the long-

[38] As explained in Section 4.2, the yield factors encompass any single maturity interest rate, so including the factors in the regression would lead to perfect colinearity. We thus use only a long-yield difference to proxy the omitted risk.

horizon exchange rate movements are less affected by risk premium and should be more in line with basic fundamentals such as the UIP interest differentials.

6. Conclusion

We find that the Nelson-Siegel factors extracted from the relative yield curves between two countries can explain future exchange rate movements and excess currency returns. Unlike the "exchange rate disconnect" conclusion that dominates previous literature, our results provide support for the view that exchange rate movements are systematically related to expected future macroeconomic fundamentals in accordance with theoretical models that imply a present value relationship. The main insight here is that since market expectations may be too complicated to be captured by simple statistical models, we should look for such information in the data. Given that the term structure of interest rates has been found to embody market expectations on future macro dynamics, the present value exchange rate models 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 countries' yield curves can predict the relative value of their currencies and risk premiums. Our results also, as a natural consequence, offer a simple and intuitive explanation for the UIP puzzle.

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Appendix [1]

A1. Relating Level and Slope to Expected Inflation and Output Dynamics

This section provides a simple illustrative example to show how the level and slope factors incorporate expectations regarding future inflation and output dynamics. Assume that short-term rate i_t is determined by the following monetary policy:

$$i_t = \rho + \pi_t^* + \phi_\pi(\pi_t - \pi_t^*) + \phi_y \tilde{y}_t + \phi_X X_t + u_t \tag{A1}$$

where ρ is the constant long-run real rate, and the vector X_t contains variables to which the central bank reacts other than inflation π_t and output gap $\tilde{y}_t$. X_t has a long-run value of zero. Following Ireland (2007), we assume the long-run inflation target π_t^* to evolve exogenously as a random walk. The above policy rule ensures that in the long run, $i_{LR} = \rho + \pi_{LR}^*$.

Next, we express the yield of maturity m as:

$$i_t^{(m)} = \frac{1}{m}\sum_{i=1}^{m-1} E_t\{i_{t+i}\} + \theta_t^{(m)} \tag{A2}$$

This expression can be motivated by either the Expectations Hypothesis (footnote 13) or the canonical no-arbitrage affine model of term structure.[2] Substituting the monetary rule (10) into (11), we have:

$$i_t^{(m)} = \frac{1}{m}\sum_{i=1}^{m-1} E_t\{\rho + \pi_{t+i}^* + \phi_\pi(\pi_{t+i} - \pi_{t+i}^*) + \phi_y \tilde{y}_{t+i} + \phi_X X_{t+i} + u_{t+i}\} + \theta_t^{(m)} \tag{A2}$$

From (9), we see that the level factor is the infinite maturity yield. By taking the limit as m goes to infinity in (12):

$$L_t = i_t^{(\infty)} \propto \rho + \pi_t^* + u_t + \theta_t^{(\infty)} \tag{A4}$$

This expression relates the level factor to the long-run inflation target. Expressing the slope factor as the difference between the short term yield and the level factor:

$$S_t = i_t - i_t^{(\infty)} = \phi_\pi(\pi_t - \pi_t^*) + \phi_y \tilde{y}_t + \phi_X X_t - \theta_t^{(\infty)} \tag{A5}$$

[1] Additional results are reported in an Online Appendix, which is available at: http://faculty.washington.edu/yuchin/Papers/CT1OA.pdf and https://filebox.vt.edu/users/byront/CT1OA.pdf

[2] In affine models, $\theta_t^{(m)}$ is determined by the risk specification; the Expectation Hypothesis treats it as exogenous.

we relate it to the inflation gap, and the output gap.

We further note that as an identity:

$$i_t = L_t + S_t \tag{A6}$$

This implies that the short-term interest rate, the policy instrument, can be decomposed into two components: a secular component which reflects changes in the inflation target, and a cyclical component which reflects the short term deviations from targets.

A2. Rescaled T-statistics of Moon et al (2004) and Valkanov (2003)

Consider the standard returns regression setup proposed in Campbell and Shiller (1988) and Nelson and Kim (1993):

$$r_{t,t+1} = \alpha + \beta x_t + u_{t+1}$$
$$x_t = \rho x_{t-1} + \epsilon_t \tag{A7}$$

where $r_{t,t+1}$ is the 1-period return between time t and $t+1$, ρ is close to unity, and u_t , ϵ_t are independent and identically distributed over time with a possibly non-zero covariance.[3] The null hypothesis is that $r_{t,t+1}$ is not predictable by x_t, i.e. $H_0\colon \beta = 0$. The long-horizon predictive regression for horizon m ahead is as follows:

$$R_{t,t+m} = \alpha_m + \beta_m x_t + u_{m,t+1} \tag{A8}$$

where the long-horizon return between t and $t+m$ is constructed from one-period returns: $R_{t,t+m} = \sum_{j=0}^{m-1} r_{t+j,t+j+1}$, and overlaps across observations. Given a fixed sample size T, we see that the larger the m, the more serious is the degree of data overlap, which can significantly influence the properties and the limiting distributions of the inference statistics. Specifically, Moon, Rubia and Valkanov show that the OLS t-statistic for $\hat{\beta}_m$ diverges as horizon m increases, even under the null hypothesis of no predictability. Put it differently, we tend to observe a larger bias towards predictability for a

[3] The analysis can be extended to a multivariate framework. For notation simplicity, we let x_t be a scalar.

higher m. The authors demonstrate that the re-scaled t-statistic $t/\sqrt{m}$ has a well-defined limiting distribution. Based on Monte Carlo experiments, they show that the re-scaled t statistic is approximately standard normal, provided that the regressor x_t is highly persistent and the correlation between the two shocks u_t and ϵ_t is not too high. When the regressor is not a near-integrated process, the adjusted t-statistic tends to under-reject the null. Since the unit root null is rejected for most of our factors, the predictive power of the factors may actually be stronger than implied by the results we present below in Tables 3-5.

A3. Monte Carlo Experiments

This section describes how we construct the test statistics and critical values used in Figure 2 and Figure 3. Our goal is to test whether the restrictions (21) are rejected (i.e. the interest-differential model is rejected) when we estimate the factor model using a rolling window. Since the sample is small and the factors are persistent, we cannot rely on the conventional critical values for the F-test. We therefore calculate the critical values through a Monte Carlo experiment, with a setting similar to that in Mark (1995).

For each country and for $m = 3, 12, 24$, we generate artificial data as follows:

1) Regress 1-month exchange rate change on a constant, keep the standard error of regression as $\hat{\sigma}$.

2) Generate a vector of error terms ϵ_t from $N(0, \hat{\sigma})$, and then create $\epsilon_t^m = (\epsilon_{t+m-1} + \cdots + \epsilon_m)/m$. All have the same length as in the actual data.

3) Regress actual m-month exchange rate change on the corresponding *actual* interest differential, keep the coefficient estimates as $\hat{\alpha}^m, \hat{\beta}^m$.

4) Generate artificial data by using the *actual* interest differential $i_t^m - i_t^{m*}$:

$$\frac{1200(s_{t+m} - s_t)}{m} = \hat{\alpha}^m + \hat{\beta}^m(i_t^m - i_t^{m*}) + \epsilon_t^m \qquad \text{(A9)}$$

That is, the data generating process, or the true model, is the UIP regression.

5) Next, regress the artificial exchange rate series $\frac{1200(s_{t+m}-s_t)}{m}$ on the *actual* relative level, slope and curvature factors, using a 5-year rolling window.

6) For each regression, keep the F-statistic for the test that the UIP restrictions discussed above are correct.

7) Repeat step 2) to step 6) 500 times.

The above experiment tells us, when the interest differential model is the true DGP, how often we wrongly reject it in favor of the factors model due to the overlapping LHS variable, small sample, persistence of the factors, or other problems. We use the 90% percentile of the 500 artificial F-statistics as the critical value for the F-test using the actual data. Under our setting, the critical value is allowed to vary over time.

For Figure 3, the setting for the Monte Carlo experiment is the same except that steps 3) and 4) are replaced by:

3') Regress actual m-month exchange rate change on a constant, keep the coefficient estimates as $\hat{\alpha}$.

4') Generate artificial data by the following equation:

$$\frac{1200(s_{t+m}-s_t)}{m} = \hat{\alpha}^m + \epsilon_t^m \tag{A10}$$

The above experiment tells us, when the random walk is the true DGP, how often we wrongly obtain R-square above 0 due to the overlapping LHS variable, small sample, persistence of the factors, or other problems. We plot the average of the 500 artificial R-square in Figure 3 to compare with the actual R-square.

Tables

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	-0.599	3.179	-0.395	-0.678	-0.826	-2.273	-0.611	1.055	0.417
Median	-0.598	3.208	-0.591	-0.515	-1.017	-2.446	-0.740	1.014	-0.260
Max	2.000	6.279	3.110	4.406	3.567	2.946	10.589	11.138	14.938
Min	-3.076	1.225	-4.560	-5.306	-4.997	-7.097	-7.205	-5.821	-11.563
SD	0.969	0.947	1.604	1.827	1.955	1.933	2.561	2.754	4.476
Skewness	0.215	0.224	0.032	0.207	0.063	0.159	0.771	0.108	0.809
Kurtosis	2.906	2.663	2.412	2.752	2.116	2.784	5.660	2.721	4.264

(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	0.588	1.000							
L^R - UK	0.714	0.566	1.000						
S^R - Can	-0.080	-0.021	0.223	1.000					
S^R - Jap	0.046	-0.070	0.149	0.624	1.000				
S^R - UK	-0.180	-0.153	-0.225	0.639	0.664	1.000			
C^R - Can	-0.586	-0.159	-0.261	0.079	0.113	0.084	1.000		
C^R - Jap	-0.110	-0.265	-0.069	0.399	0.559	0.509	0.330	1.000	
C^R - UK	-0.412	-0.122	-0.689	-0.027	-0.027	0.339	0.361	0.255	1.000

Table 2: Surveyed Forecasts and Yield Curve Factors

a) $E_t \Delta y_{t+m} = \alpha_{Sm} + \beta_{Sm} S_t + u_{Smt}$

	m=3	m=6	m=9	m=12
β_{Sm}	0.016	-0.073	-0.083*	-0.192*
	(0.065)	(0.048)	(0.034)	(0.038)
N. obs.	80	80	80	80
Adj. R^2	-0.012	0.017	0.059	0.235

b) $A_{t+m} = \gamma_{Sm} + \delta_{Sm} S_t + v_{Smt}$

	m=3	m=6	m=9	m=12
δ_{Sm}	-0.352	1.078*	1.830*	1.950*
	(0.857)	(0.526)	(0.335)	(0.344)
N. obs.	80	80	80	80
Adj. R^2	-0.011	0.039	0.267	0.283

c) $E_t \pi_{t+m} = \alpha_{Lm} + \beta_{Lm} L_t + u_{Lmt}$

	m=3	m=6	m=9	m=12
β_{Lm}	0.458*	0.462*	0.468*	0.482*
	(0.044)	(0.039)	(0.037)	(0.037)
N. obs.	80	80	80	80
Adj. R^2	0.579	0.638	0.663	0.684

Note: * indicates significance level of 10% or below. We use quarterly data from the Survey of Professional Forecasters maintained by the Federal Reserve Bank of Philadelphia. The factors are quarterly average of the monthly data (though we obtain similar results when we use the first month of each quarter instead).

Table 3: 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
L^R	-3.740*	-2.991*	-1.957	-1.646	-1.418	-0.915
$t/\sqrt{m}$	-2.517	-1.924	-1.264	-1.008	-0.802	-0.471
S^R	-0.657	-0.518	-0.470	-0.427	-0.302	-0.161
$t/\sqrt{m}$	-1.361	-0.775	-0.709	-0.613	-0.402	-0.195
C^R	-1.041*	-0.923	-0.692	-0.524	-0.564	-0.492
$t/\sqrt{m}$	-1.952	-1.576	-1.183	-0.849	-0.844	-0.671
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
L^R	-4.157*	-2.597*	-2.646	-2.493	-1.933
$t/\sqrt{m}$	-2.651	-1.657	-1.611	-1.419	-1.002
S^R	-1.326*	-1.323*	-1.158*	-0.892	-0.665
$t/\sqrt{m}$	-1.946	-1.956	-1.652	-1.193	-0.813
C^R	-1.096*	-0.754	-0.750	-0.884	-0.784
$t/\sqrt{m}$	-1.805	-1.279	-1.207	-1.332	-1.078
N. obs.	233	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 4: 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
L^R	-1.750	-0.611	-0.263	-1.792	-2.030	-1.429
$t/\sqrt{m}$	-0.566	-0.203	-0.090	-0.731	-0.815	-0.602
S^R	-3.417*	-3.556*	-3.641*	-2.984*	-2.401*	-2.193
$t/\sqrt{m}$	-1.921	-2.089	-2.199	-2.152	-1.690	-1.614
C^R	-0.273	0.253	0.154	-0.352	-0.676	-0.704
$t/\sqrt{m}$	-0.227	0.202	0.126	-0.344	-0.647	-0.707
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
L^R	-1.545	-1.470	-2.767	-3.045	-2.453
$t/\sqrt{m}$	-0.509	-0.502	-1.127	-1.220	-1.031
S^R	-4.519*	-4.631*	-3.713*	-3.001*	-2.715*
$t/\sqrt{m}$	-2.609	-2.768	-2.672	-2.108	-1.993
C^R	0.314	0.016	-0.582	-0.949	-0.992
$t/\sqrt{m}$	0.242	0.013	-0.567	-0.907	-0.992
N. obs.	233	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 5: 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**
L^R	-2.970*	-4.037*	-3.210*	-2.664*	-2.129	-1.585
$t/\sqrt{m}$	-1.761	-2.382	-2.119	-1.853	-1.489	-1.142
S^R	-2.509*	-2.341*	-1.752*	-1.170	-0.943	-0.777
$t/\sqrt{m}$	-2.037	-2.080	-1.746	-1.236	-0.999	-0.840
C^R	-0.504	-1.221*	-1.164*	-0.934*	-0.743	-0.451
$t/\sqrt{m}$	-0.745	-1.962	-2.061	-1.692	-1.327	-0.820
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**
L^R	-4.991*	-4.450*	-3.814*	-3.197*	-2.595*
$t/\sqrt{m}$	-2.940	-2.451	-2.586	-2.222	-1.867
S^R	-3.219*	-2.860*	-2.014*	-1.590*	-1.359
$t/\sqrt{m}$	-2.861	-2.178	-2.051	-1.675	-1.467
C^R	-1.247*	-1.207*	-1.143*	-1.038*	-0.779
$t/\sqrt{m}$	-1.965	-1.804	-2.041	-1.841	-1.416
N. obs.	209	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 6(a): Exchange Rate Regressions with Non-Overlapping Data

	m=3	m=6	m=3	m=6	m=3	m=6
	Canada		Japan		UK	
L^R	-3.422*	-1.734	-1.651	0.786	-5.213*	-3.054*
	(1.417)	(1.431)	(2.926)	(2.968)	(1.865)	(1.115)
S^R	-0.499	-0.705*	-2.612	-2.677	-1.660	-1.775*
	(0.521)	(0.415)	(1.740)	(1.948)	(1.160)	(0.762)
C^R	-0.956*	-0.739	-0.499	-0.457	-1.773*	-1.109*
	(0.530)	(0.450)	(1.363)	(1.517)	(0.734)	(0.448)
N. obs.	79	39	79	39	71	35
Adj. R^2	0.031	0.009	0.017	0.037	0.108	0.200

Table 6(b): 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	-4.590*	-2.647*	-2.722	-0.175	-6.153*	-3.914*
	(1.406)	(1.416)	(2.918)	(2.978)	(1.869)	(1.410)
S^R	-1.362*	-1.547*	-3.512*	-3.510*	-2.424*	-3.223*
	(0.512)	(0.417)	(1.737)	(1.951)	(1.128)	(1.048)
C^R	-1.117*	-0.846*	-0.578	-0.604	-1.904*	-0.899*
	(0.533)	(0.442)	(1.359)	(1.524)	(0.730)	(0.588)
N. obs.	79	39	79	39	71	28
Adj. R^2	0.105	0.157	0.057	0.102	0.162	0.271

Note: 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: Nelson-Siegel Factors and the UIP Regressions

7(a) Full In-Sample Fit Comparison in Adjusted R^2

$$Factors:\ \Delta s_{t+m} = \beta_0 + \beta_1 L_t^R + \beta_2 S_t^R + \beta_3 C_t^R + u_{t+m}$$
$$UIP: \Delta s_{t+m} = \alpha + \beta(i_t^m - i_t^{m*}) + \varepsilon_{t+m}$$

	m=3		m=6		m=9	
	Factors	**UIP**	**Factors**	**UIP**	**Factors**	**UIP**
Canada	0.03	0.00	0.04	0.02	0.06	0.03
N. obs.*	172		224		229	
Japan	0.13	0.11	0.17	0.14	0.26	0.24
N. obs.	153		228		230	
UK	0.08	0.07	0.17	0.11	0.23	0.16
N. obs.	108		159		187	

Note: Due to the missing observations in short maturity yields, the sample for the factor model is adjusted to match that of the UIP regressions.

7(b) Controlling for Risks: Adding Long Rates in the UIP Regression

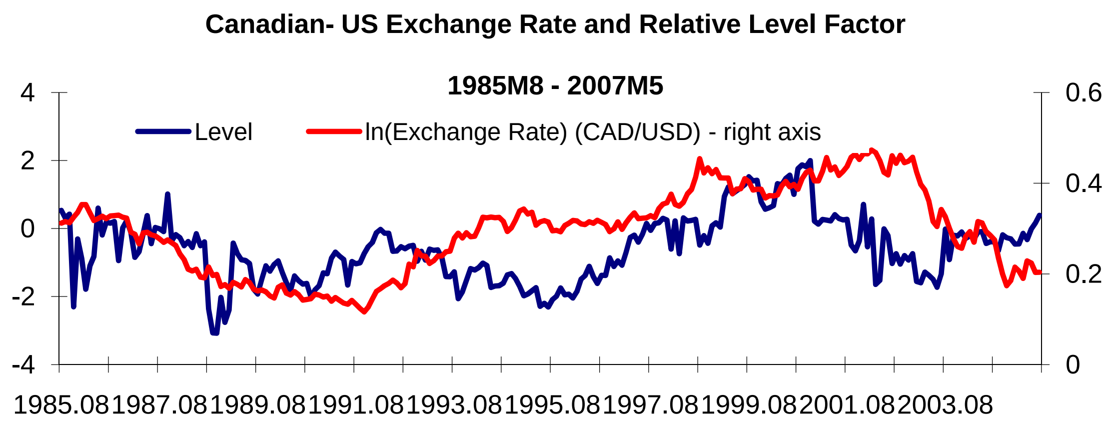
$$\Delta s_{t+m} = \alpha + \beta(i_t^m - i_t^{m*}) + \delta\rho_{t+m}^F + \varepsilon_{t+m}$$

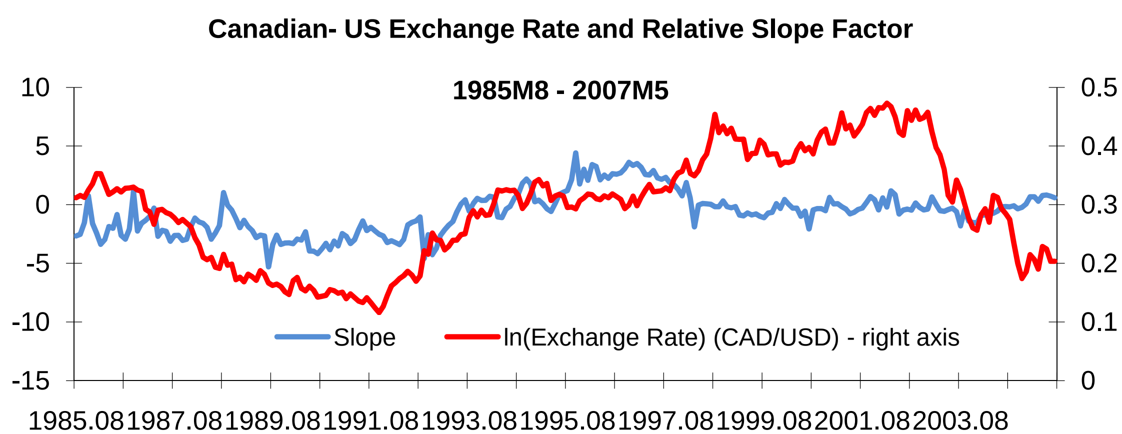
	Canada		Japan		UK	
	UIP	With Long Rates	UIP	With Long Rates	UIP	With Long Rates
			m = 3months			
α	-0.940	-3.471	10.192	-1.222	-3.497	-1.151
	(1.241)	(1.397)	(3.171)	(5.904)	(2.344)	(2.617)
β	-1.009*	1.444	-2.610*	3.923	-2.721*	1.284
	(0.379)	(1.459)	(1.093)	(4.478)	(0.912)	(2.146)
			m= 6 months			
α	-0.088	-2.418	11.866	1.523	-1.175	-0.834
	(1.007)	(1.054)	(2.812)	(5.082)	(1.935)	(1.771)
β	-0.627*	1.643	-3.391*	-4.504	-2.452*	2.200
	(0.341)	(1.121)	(0.911)	(5.909)	(0.924)	(1.972)
			m= 9 months			
α	-0.306	-2.379	12.191	5.726	-1.039	-0.834
	(0.861)	(0.934)	(2.171)	(4.014)	(1.444)	(1.294)
β	-0.750*	2.324*	-3.319*	-6.772	-2.257*	5.868*
	(0.389)	(1.357)	(0.712)	(5.881)	(0.699)	(2.998)

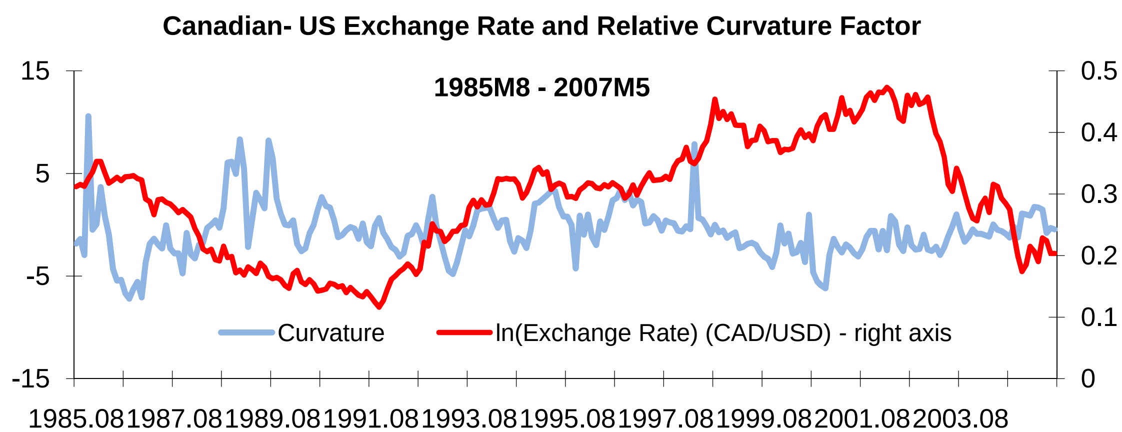
Note: The "UIP" regressions exclude the risk premium term $\delta\rho_{t+m}^F$. One- and five-year interest differentials are added as a proxy for ρ_{t+m}^F in the "UIP-with Long-Rates" regressions.

Figures

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

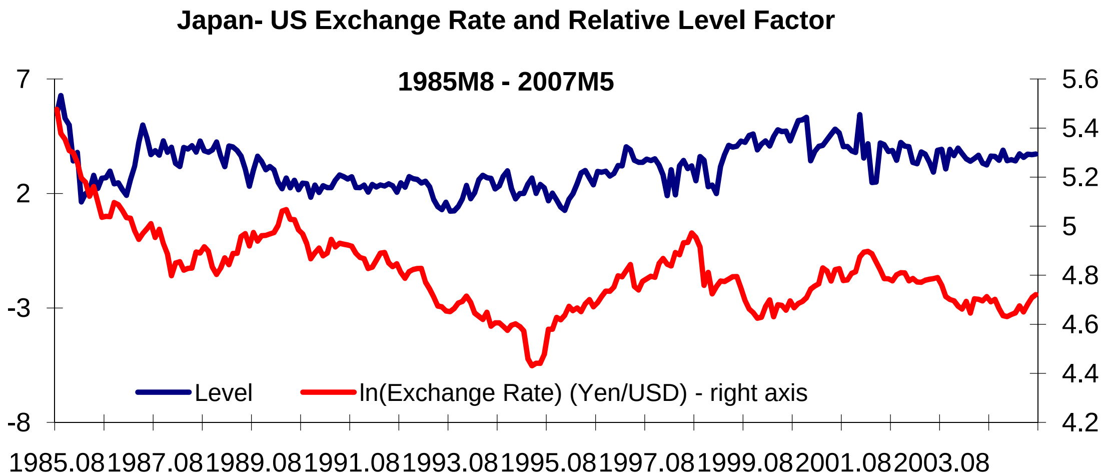


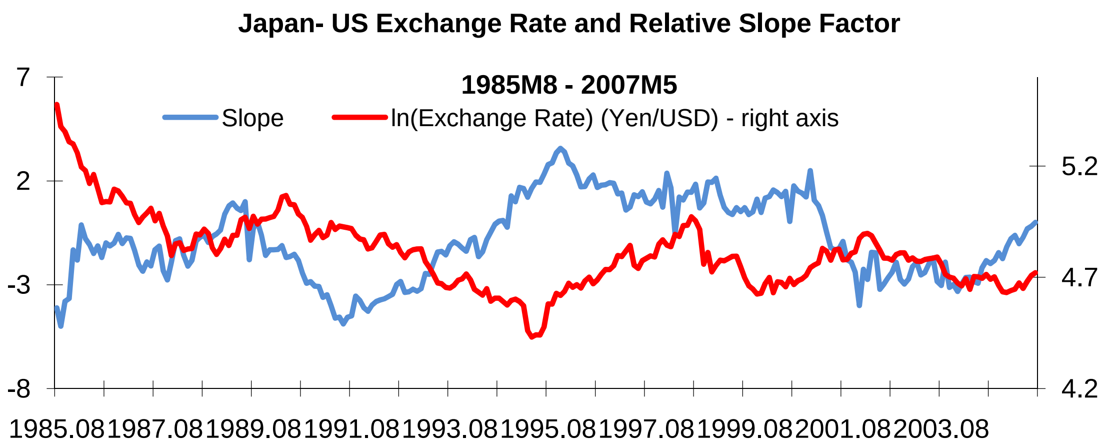


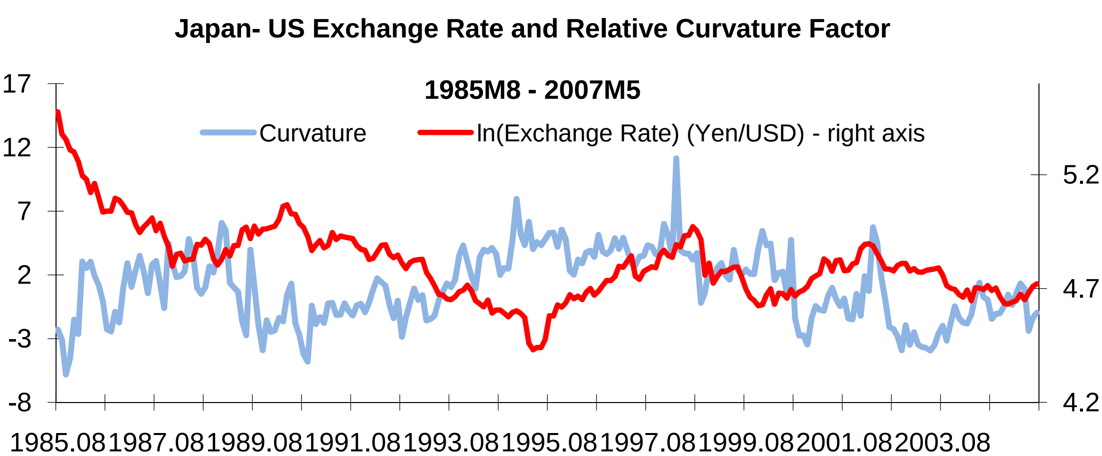


Note: The relative term structure factors are calculated by the following procedure: in each period, we subtract the yields of the country from those of the US with matching maturities. We then fit the Nelson-Siegel yield curve on the yield differences to obtain the level, slope and curvature factors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

Figure 1B: The Japan-US Exchange Rate and Relative Factors

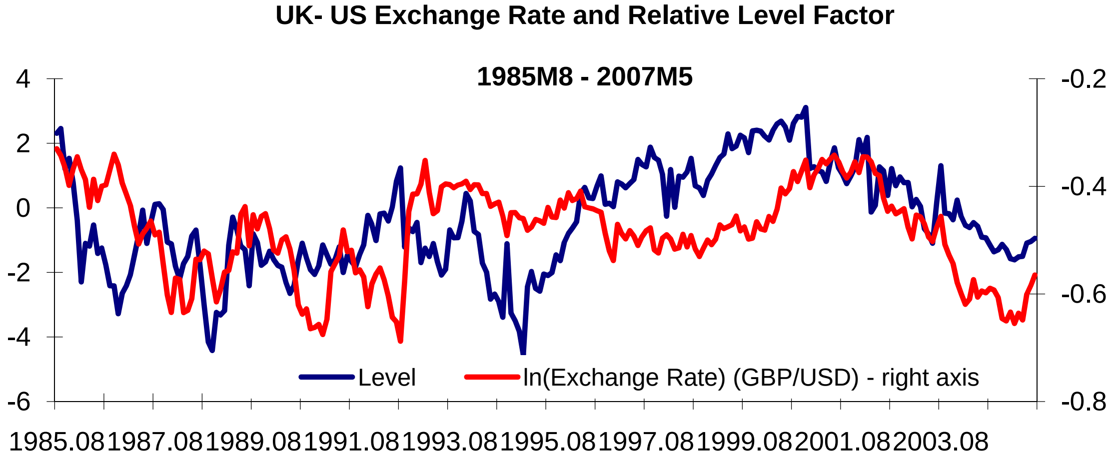


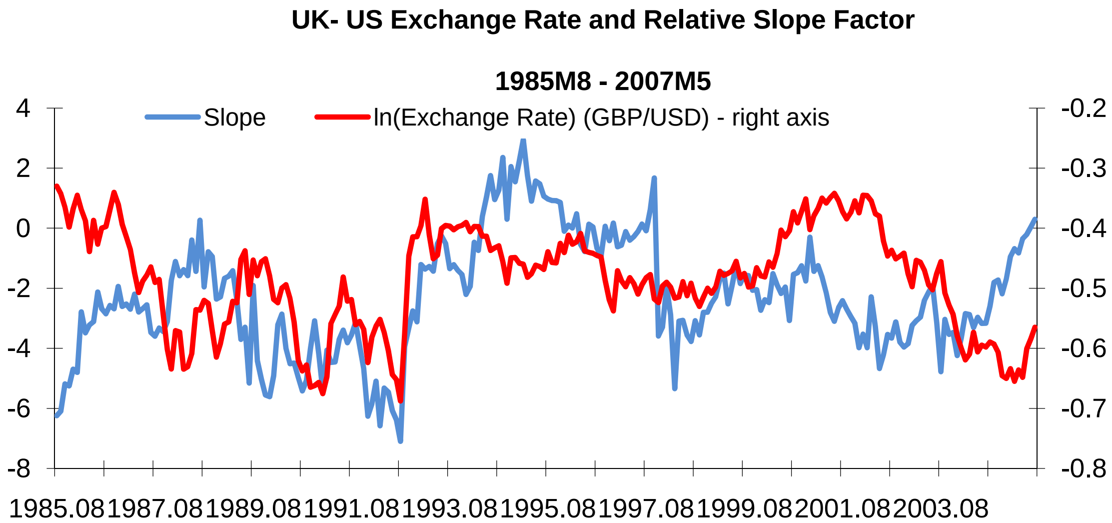


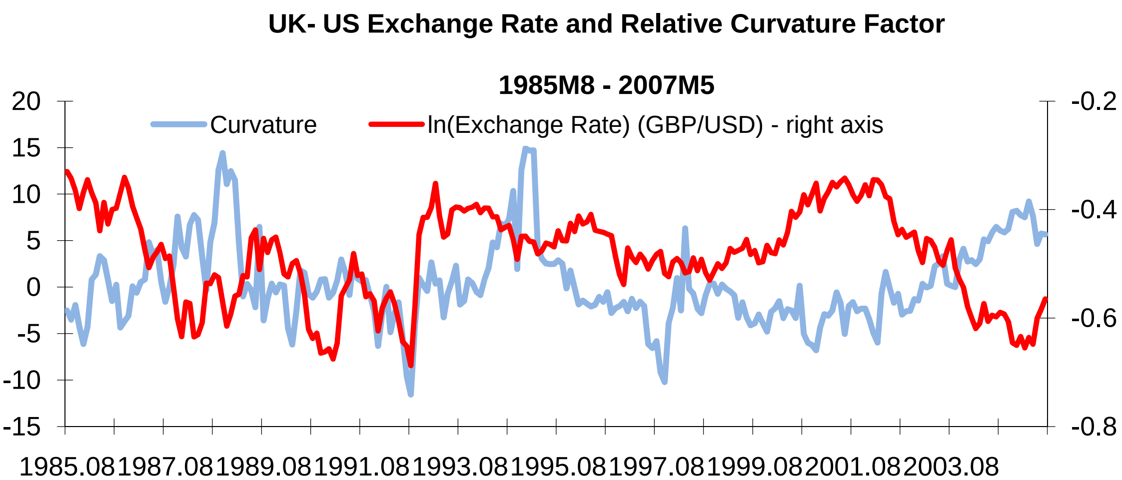


Note: The relative term structure factors are calculated by the following procedure: in each period, we subtract the yields of the country from those of the US with matching maturities. We then fit the Nelson-Siegel yield curve on the yield differences to obtain the level, slope and curvature factors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

Figure 1C: The UK-US Exchange Rate and Relative Factors



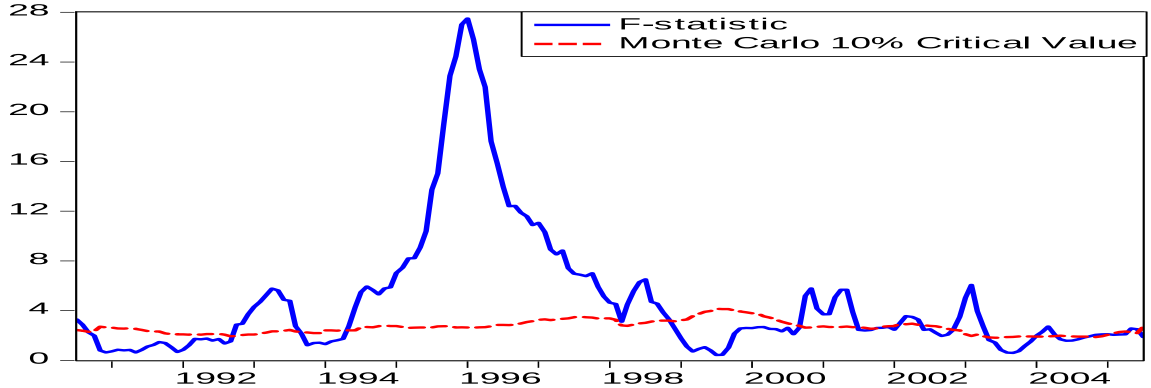




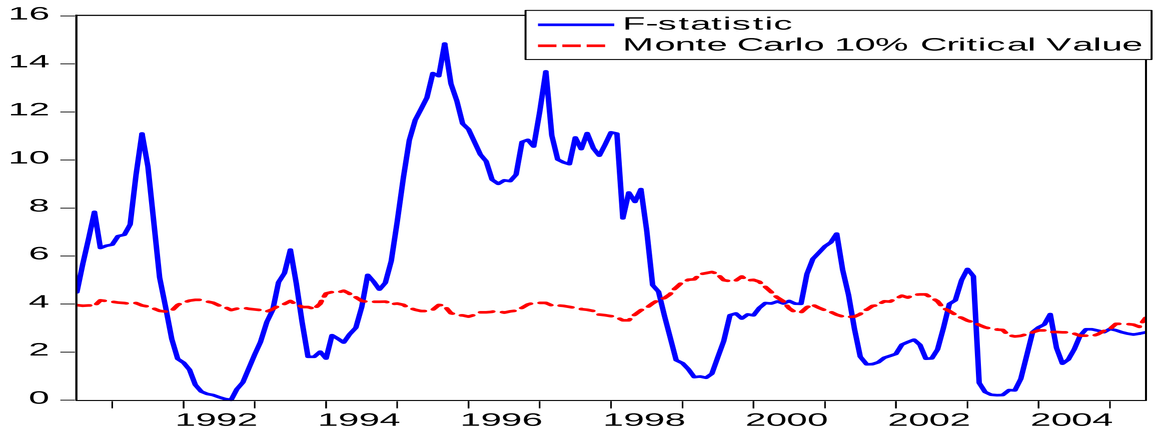
Note: The term structure factors for each country are calculated by the following procedure: in each period, we subtract the yields of each country from those of the US, matching the maturities. We then fit the Nelson-Siegel yield curve on the yield differences and obtain the level, slope and curvature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

Figure 2A: Rolling Test of the Interest Differential Restrictions (Canada)

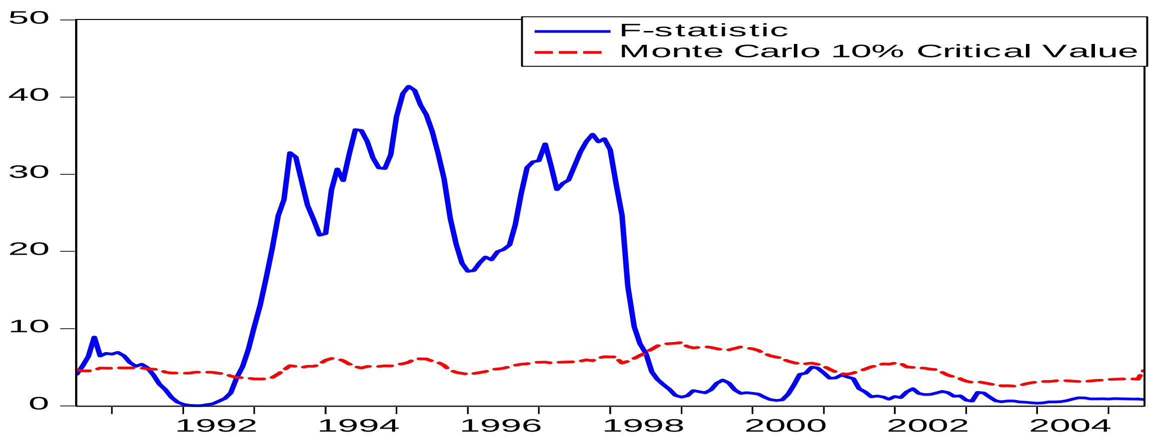
3-Month Horizon



6-Month Horizon



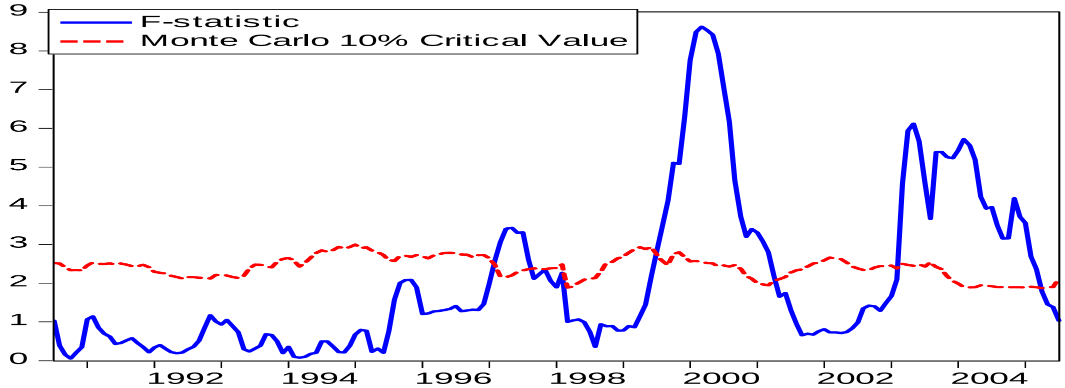
12-Month Horizon



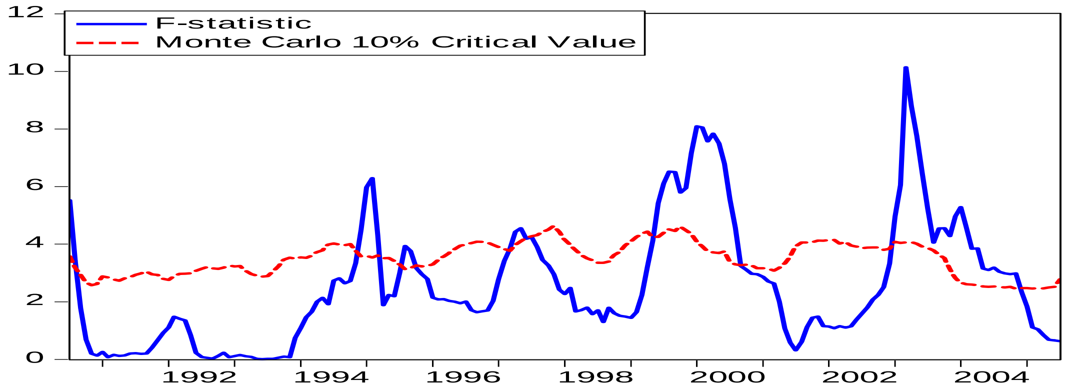
Note: The solid line plots the F-statistic for the null hypothesis that the restriction imposed by the UIP on the N-S factors is correct. The red dotted line is the Monte Carlo 10% critical value, accounting for small sample bias and persistence of the data. For more details see the Appendix.

Figure 2B: Rolling Test of the Interest Differential Restrictions (Japan)

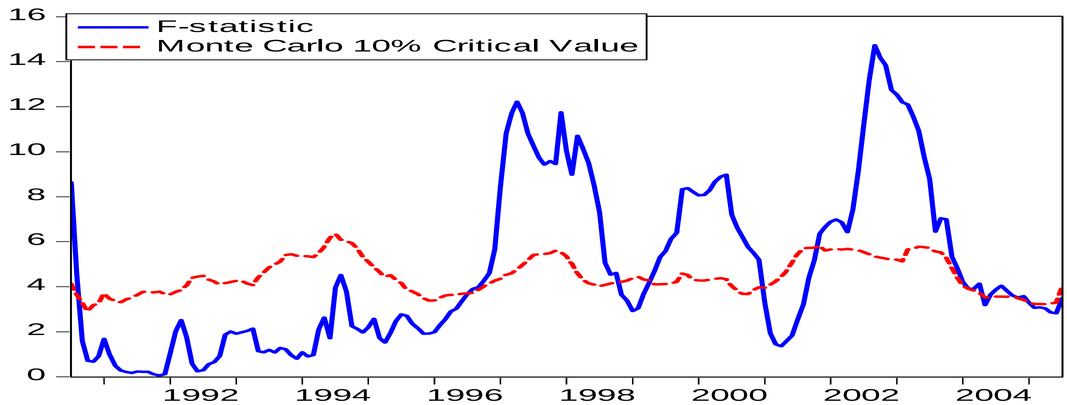
3-Month Horizon



6-Month Horizon



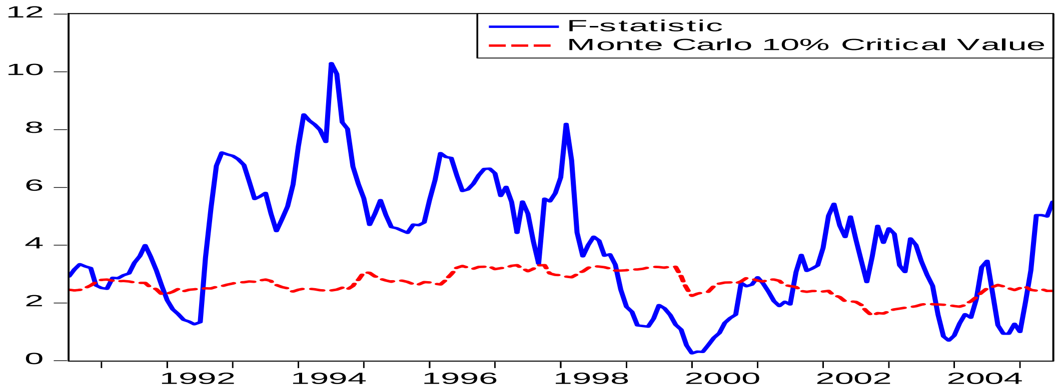
12-Month Horizon



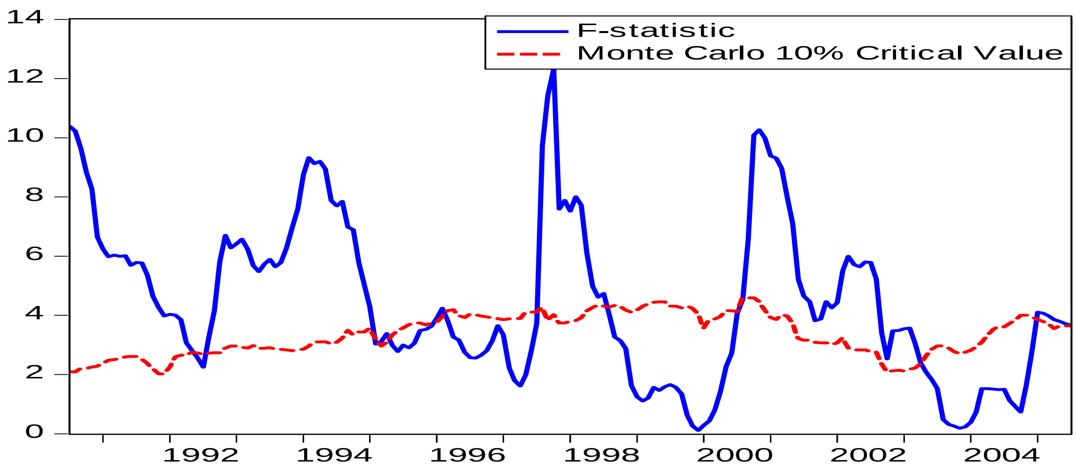
Note: The solid line plots the F-statistic for the null hypothesis that the restriction imposed by the UIP on the N-S factors is correct. The red dotted line is the Monte Carlo 10% critical value, accounting for small sample bias and persistence of the data. For more details see the Appendix.

Figure 2C: Rolling Testing of the Interest Differential Restrictions (UK)

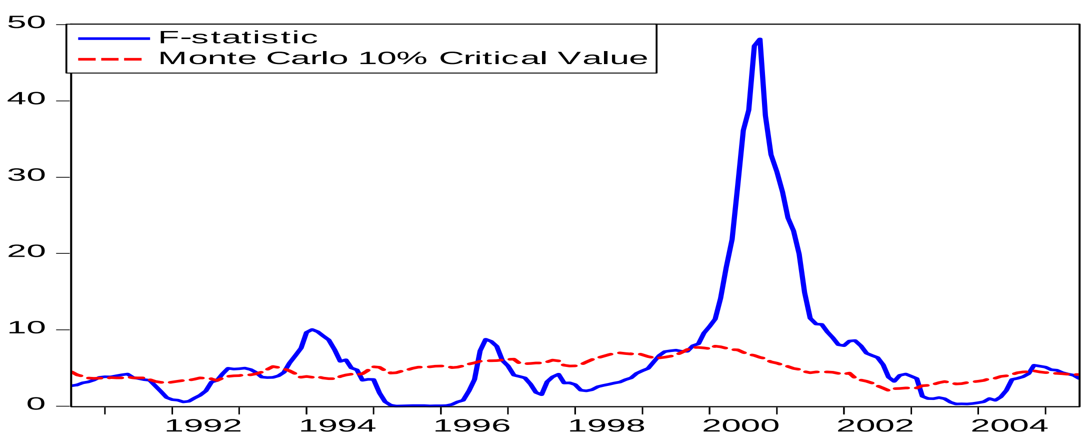
3-Month Horizon



6-Month Horizon



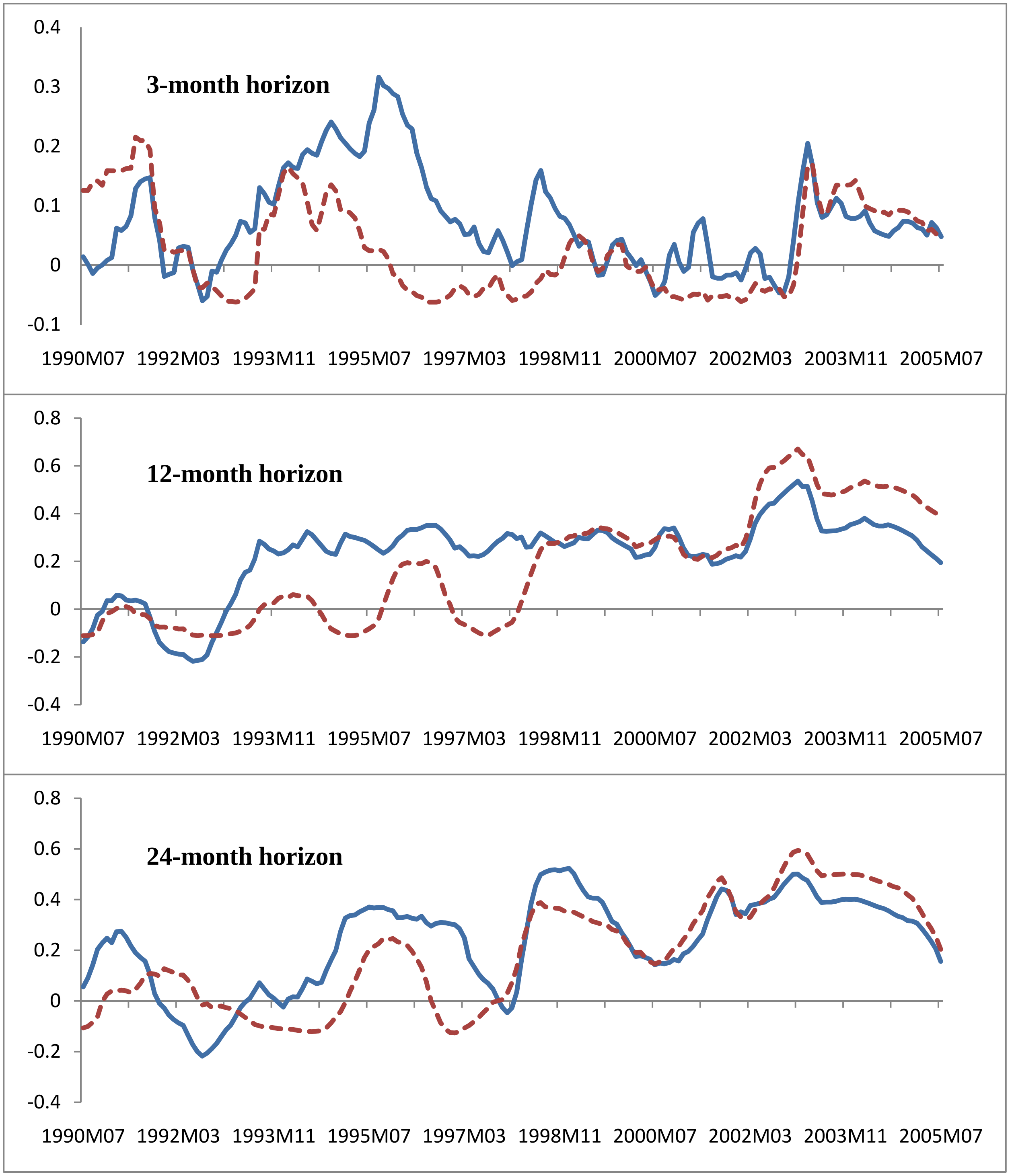
12-Month Horizon



Note: The solid line plots the F-statistic for the null hypothesis that the restriction imposed by the UIP on the N-S factors is correct. The red dotted line is the Monte Carlo 10% critical value, accounting for small sample bias and persistence of the data. For more details see the Appendix.

Figure 3A: Recursive Adjusted R-squares with a 5-Year Rolling Window

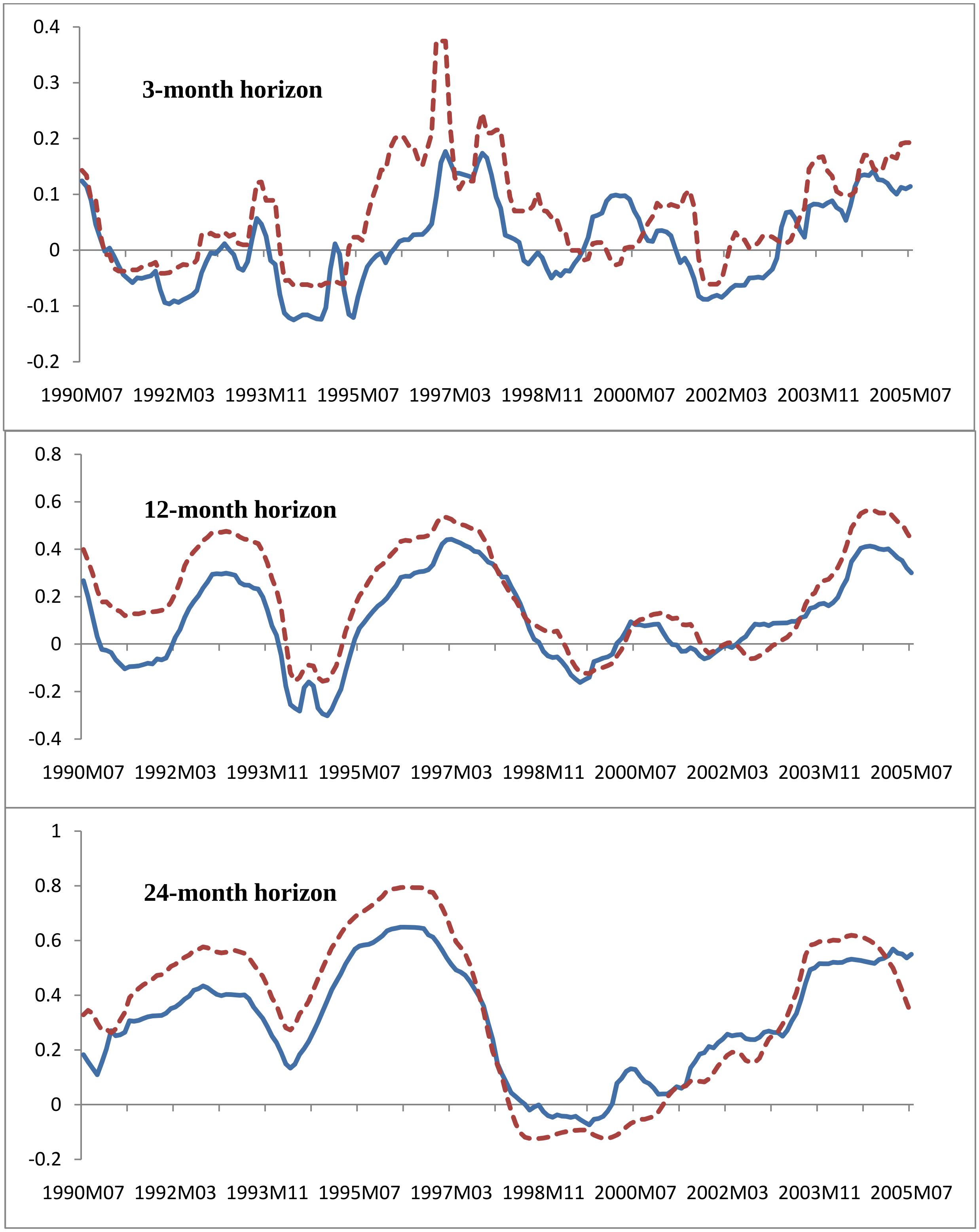
Canada



Blue solid line (factor model); Red dotted line (interest differential model)

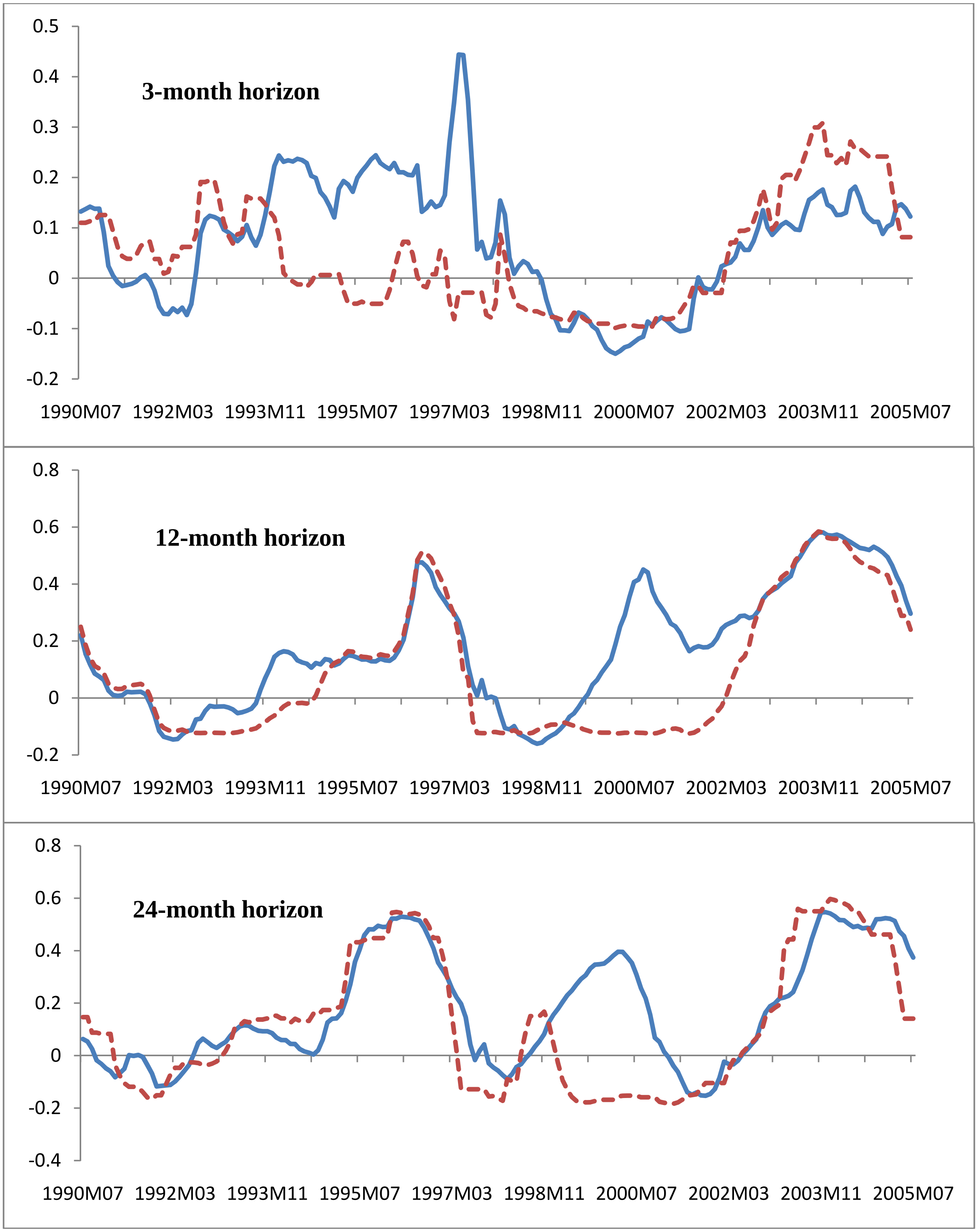
Figure 3B: Recursive Adjusted R-squares with a 5-Year Rolling Window

Japan



Blue solid line (factor model); Red dotted line (interest differential model)

Figure 3C: Recursive Adjusted R-squares with a 5-Year Rolling Window
UK



Blue solid line (factor model); Red dotted line (interest differential model)