International Capital Markets and Foreign Exchange Risk*

Michael J. Brennan and Yihong Xia†

July 18, 2003

*We thank Lim Kian Guan for many helpful conversations. Brennan thanks Lancaster University for their hospitality. Xia thanks the Singapore Management University for their hospitality and gratefully acknowledges the financial support from the Wharton-SMU Research Center of the Singapore Management University.

†Michael Brennan is Emeritus Professor at the Anderson School, UCLA, 110 Westwood Plaza, Los Angeles, CA 90095-1481. Yihong Xia is an assistant professor at the Wharton School of University of Pennsylvania. Corresponding address: Finance Department, The Wharton School, University of Pennsylvania; 2300 Steinberg Hall-Dietrich Hall; Philadelphia, PA 19104-6367. Phone: (215) 898-3004. Fax: (215) 898-6200. E-mail: yxia@wharton.upenn.edu.

Abstract

A relation between the volatilities of the pricing kernels for different currencies is derived under the assumption of integrated capital markets, and the volatility of the pricing kernel is related to the foreign exchange risk premium. The time series of the pricing kernel volatilities are estimated from panel data on bond yields for five major currencies using a parsimonious term structure model that allows for time varying risk premia. The resulting estimates are used to estimate the relation between the volatilities of the pricing kernels in different currencies and the volatility of the exchange rate. It is also shown that time variation in the foreign exchange risk premium is related to time variation in the volatility of the pricing kernel for certain currencies.

1 Introduction

The issue of capital market integration is of central importance in the theory of international finance since it has important implications for asset pricing as well as for optimal portfolio choice. Tests of asset pricing models typically rely on an assumption about international capital market integration which becomes part of the maintained hypothesis. For example, tests of national versions of the Capital Asset Pricing Model (CAPM) rely on the implicit assumption of segmented national capital markets, while tests of a world CAPM (see, for example, Harvey (1991)), a world CAPM with exchange risk (see Dumas and Solnik (1995)), or world multi-factor models (Ferson and Harvey (1994)) are all based on the assumption of integrated world markets. An intermediate assumption is that markets are partially integrated. For example, Bekaert and Harvey (1995) adopt a parameterized model of partial integration within a regime-switching model in which expected returns on a country market index are determined by both their covariance with a world market portfolio and the own-variance of the country market returns. In a perfectly integrated market, only the world market covariance counts, while in a perfectly segmented market only the own-variance is relevant. Their integration measure is a time-varying weight that is applied to the covariance and the own-variance. This approach to assessing market integration relies on an underlying single-period beta pricing model which is assumed to apply to equity market returns. In a more recent paper, Bekaert, Harvey and Lumsdaine (2001) specify a reduced-form model for several financial time-series and search for a common, endogenous break in the process that would indicate a change from segmentation to integration.

These studies of international market integration are based either on equity market returns or on the behavior of macroeconomic variables. In this paper on the other hand we assess the integration of capital markets using data on bond prices for different countries. Since government bonds in developed economies are virtually default free, are traded in markets that are highly liquid, and are less likely than stock markets to suffer from problems of informational asymmetry between foreign and domestic investors,[1] these markets offer a natural setting for assessing the degree of capital market integration.

The paper relies on recent evidence of time variation in risk premia in US bond and stock markets and uses the fact that in integrated capital markets the time variation in risk premia in different markets will be related; more precisely, the time variation in risk premia of bonds denominated in different currencies will be related. The nature of the relation is made precise by first deriving the relation between the volatilities of the pricing kernels for returns denominated in different currencies for general arbitrage free markets. The volatility of the pricing kernel is the *maximum* "Sharpe ratio" for returns denominated in that currency. Then the volatilities of the pricing kernels are estimated by making use of a parsimonious valuation model developed by Brennan, Wang and Xia (2003) that allows for time variation in risk premia. The model assumes that the real interest rate and the *maximum* "Sharpe ratio" for each currency follow correlated Ornstein-Uhlenbeck processes.[2] While these two "state" variables are not directly observable, the valuation model allows us to estimate them, along with the expected rate of inflation, from panel data on default-free bond yields and inflation. We carry out the estimation for the United States, the United Kingdom, Japan, Germany, and Canada.

If the markets for returns denominated in two different currencies are integrated, then a simple linear relation obtains between the estimated Sharpe ratios for the currencies, and the volatility of the rate of exchange between them. We test this

[1] Brennan and Cao (1997) and Brennan *et al.* (2003) show that international trading in equities is consistent with informational asymmetries between local and foreign investors. Portes *et al.* (2001) show that the pattern of international bond trading is less influenced by informational considerations than is the pattern of stock trading.

[2] Note that the real interest rate for two different currencies can differ because the price indices that are used for the currencies differ and because the inflation risk of the currencies differ.

hypothesis across country pairs using our estimates of the Sharpe ratios.

Finally, we use the pricing kernel framework to cast further light on the "forward premium puzzle." An extensive empirical literature documents the failure of uncovered interest parity (UIP) and shows that there is often a "perverse" relation between the interest rate differential and the realized exchange rate change, which constitutes the puzzle.[3] Fama (1984) argues that the failure of UIP is associated with evidence of a time-varying foreign exchange risk premium. Adler and Dumas (1993) develop an international version of the Capital Asset Pricing Model (CAPM) in which the risk premium on an asset depends on market risk, as measured by the covariance between returns on the asset return and the market portfolio, and currency risk, as measured by the sum of covariances between the asset return and the currency returns.[4] While earlier studies such as Giovannini and Jorion (1989) and Jorion (1989) found no evidence that exchange rate risk was priced in equity markets, more recent papers, including Korajczyk and Viallet (1990), Dumas and Solnik (1995) and De Santis and Gerard (1998), have found that exchange rate risk is a statistically significant priced factor, and that the International CAPM performs better than the standard CAPM which ignores currency risk. Moreover, Dumas and Solnik (1995) and De Santis and Gerard (1998) report evidence of time-variation in exchange rate risk.

If the pricing kernel is directly specified, then it is straightforward to determine whether foreign exchange risk is priced. The valuation model that we develop does not specify the pricing kernel itself, but only the instantaneous drift and volatility

[3]Hollifield and Uppal (1997) find that segmented commodity markets can lead to a deviation of UIP but fail to explain the negative relation between the expected change in exchange rates and interest rate differentials. Bansal (1997) finds that violation of UIP depends on the sign of the interest rate differential. Meredith and Chinn (1998) finds that UIP holds better at the five to ten year horizon.

[4]Other attempted explanations of the "forward premium puzzle" include 1) changing second moments as in Hansen and Hodrick (1983), Domowitz and Hakkio (1985), and Cumby (1988); 2) non-additive utility functions as in Backus, Gregory and Telmer (1993), Bansal (1996) and Bekaert (1996); and 3) commodity market segmentation due to transportation costs as in Hollifield and Uppal (1997).

of the pricing kernel, which correspond respectively to the real interest rate and the maximum Sharpe ratio for the currency. However, if the *correlation* of the exchange rate with the pricing kernel is constant, as we shall assume, then time series variation in the volatility of the pricing kernel will be mirrored in variation in the foreign exchange risk premium. Therefore we examine the relation between the estimated volatilities of the pricing kernels for the different currencies and the foreign exchange risk premium.

Our continuous-time model of the joint dynamics of interest rates in two countries and of the exchange rate between them is similar in spirit to the models developed in Nielsen and Saá-Requejo (1993), Saá-Requejo (1993), Ahn (1995), Bansal (1997), Backus, Foresi and Telmer (2001), Brandt and Santa-Clara (2002), and Brandt, Cochrane and Santa-Clara (2003). In all the papers including this one, the pricing kernel for the domestic and foreign countries is either derived from a general equilibrium setting or is specified exogenously, and then the relation between the foreign exchange rate dynamics and the two pricing kernels is derived from no-arbitrage arguments. Data from foreign exchange rates and short term interest rates are generally used to examine the model implications. These papers differ from one another mainly in how the pricing kernel and the term structure are specified in each country and thus how the empirical implications are tested. All the papers listed above use complete affine term structure models and only use short term interest rates to proxy for instantaneous interest rates instead of estimating the term structure using zero-coupon bond yields with different maturities, which is the norm in the single country term structure literature.

In this paper, we use instead a parsimonious *essentially* affine model which has more flexibility in modeling risk premia.[5] Because the model contains unobservable

[5]The distinction between an affine model and an *essentially* affine model is that the compensation for interest rate risk can vary independently of interest rate volatility in an essentially affine model while this is not the case in a complete affine model. See Duffee (2002) for more details.

state variables that are directly related to foreign exchange rates, we estimate the model parameters and state variables from bond yields, and finally test the model implications for the exchange rates of five developed economies using the state variables estimated from the bond yield data.

To summarize our empirical results, the state variable and model parameter estimates that are obtained from the bond yield data for the different currencies confirm that real interest rate risk is priced in all five currencies. In contrast, there is no evidence that the risk associated with innovations in expected inflation commands a risk premium. However, innovations in the maximum Sharpe ratio, η, command a positive risk premium for all currencies but the Japanese Yen, where the variation in this variable is much lower than in the other countries and is statistically insignificant. Estimates of lagged cross-effects between currencies for real interest rates and for the pricing kernel volatility are consistent with capital market integration, the estimated correlation matrices for state variable innovations providing evidence of common shocks across capital markets. The linkages between Canada and the US and between Germany and the UK are particularly strong, while those between Japan and all the other countries are particularly weak; while there is evidence that the bond pricing model is particularly mis-specified for Japan, this suggests that geographic proximity may be important.

We find that the volatility of the pricing kernels for different currencies are positively related as the theory predicts. Moreover, the relation appears to be stronger in the period after 1994. We also find that time variation in the foreign exchange risk premium is associated with variation in the volatility of the pricing kernels, especially that of the pricing kernel associated with the U.S. dollar.

The rest of the paper is organized as follows. The second and third sections provide the definition of real and nominal pricing kernels in domestic and foreign countries and derive testable implications. Section 4 discusses the details of data construction and reports descriptive statistics. Section 5 describes the estimation procedure and the state variables. Section 6 reports empirical tests on market integration, the reward to foreign exchange rate risk, and the forward premium puzzle. Section 7 summarizes and concludes.

2 Real Pricing Kernels

Consider a world in which asset prices follow diffusion processes.[6] Let m and m^* denote the real pricing kernels for two currencies which we refer to as the domestic and foreign currency respectively, and write the dynamics of the pricing kernels as:

$$\frac{dm}{m} = -r(X)dt - \eta(X)dz, \tag{1}$$

and

$$\frac{dm^*}{m^*} = -r^*(X)dt - \eta^*(X)dz^*. \tag{2}$$

with $m_0 = m_0^* = 1$, and where it is understood that the diffusion and drift coefficients of (1) and (2) may depend on a set of unspecified state variables X. If markets are complete, then the pricing kernels, m and m^*, are unique. If markets are incomplete, then m and m^* are to be thought of as the *minimum variance* pricing kernels that price all available assets.[7]

The definition of a real pricing kernel implies that any real return process $\frac{dV}{V}$ with volatility σ_V has an instantaneous expected return given by:

$$\begin{aligned} \mathrm{E}\left[\frac{dV}{V}\right] &= -\mathrm{E}\left[\frac{dm}{m}\right] - \mathrm{Cov}\left(\frac{dm}{m}, \frac{dV}{V}\right) \\ &= rdt + \eta\sigma_V\rho_{Vm} \end{aligned} \tag{3}$$

[6] See C-f Huang (1985) for sufficient conditions for this setup.

[7] Note that since risk premia are equal to the covariances of returns with the pricing kernel (see equation (3)), adding noise that is uncorrelated with asset returns to a pricing kernel has no effect on asset prices.

where ρ_{Vm} is the correlation between the return and the pricing kernel. It then follows that r (r^*) is the domestic (foreign) instantaneous real risk free rate and, since $|\rho_{Vm}| \leq 1$, η (η^*) is the maximum Sharpe ratio for returns on assets or portfolios denominated in the domestic (foreign) currency.

Let s denote the real exchange rate expressed in units of domestic currency ("dollars") per unit of foreign currency ("pounds"), and write the stochastic process for the exchange rate as:

$$\frac{ds}{s} = e(X)dt + \sigma_s(X)dz_s, \tag{4}$$

where again the dependence of the drift and diffusion coefficients on X is to be understood.

The definition of the foreign pricing kernel implies that, for any foreign denominated gross return between time t and time $t+\tau$, $x^*_{t,t+\tau}$:

$$m^*_t = \mathrm{E}_t\left[m^*_{t+\tau}x^*_{t+\tau}\right] \tag{5}$$

Moreover, expressing the return on the foreign asset in terms of the domestic currency, the definition of the domestic pricing kernel implies that:

$$m_t = \mathrm{E}_t\left[m_{t+\tau}x^*_{t+\tau}\frac{s_{t+\tau}}{s_t}\right] \tag{6}$$

A sufficient condition for (5) and (6) to hold simultaneously is that:

$$m^* \propto ms$$

This condition is also necessary if markets are complete.[8] In this case, both m and m^* are unique and one of the three variables m, m^* and s is redundant and can be inferred from the other two. If the market is incomplete, there is an infinite number of

[8]See Saá-Requejo (1994) and Backus, Foresi and Telmer (2001).

pricing kernels m and m^* satisfying equations (5) and (6), but the minimum-variance pricing kernel derived from the projection of pricing kernels onto the asset space is unique and satisfies the above conditions.[9] Therefore, if the market is incomplete, m and m^* are to be interpreted as the minimum-variance pricing kernels for the domestic and foreign currencies.

Applying Ito's lemma to the expression, $m^* \propto ms$, leads to the following relation between the stochastic processes for the exchange rate and the two pricing kernels:

$$\frac{dm^*}{m^*} = \frac{dm}{m} + \frac{ds}{s} + \frac{dm}{m}\frac{ds}{s}. \tag{7}$$

Substitution from equations (1-4) into equation (7) yields:

$$-r^*dt - \eta^*dz^* = -rdt + edt - \eta\sigma_s\rho_{sm}dt - \eta dz + \sigma_s dz_s. \tag{8}$$

Equality of the two stochastic processes requires that their drift and volatility coefficients be the same so that:

$$e = r - r^* + \eta\sigma_s\rho_{sm}, \tag{9}$$

$$(\eta^*)^2 = \eta^2 + \sigma_s^2 - 2\eta\sigma_s\rho_{sm}. \tag{10}$$

Equation (9) expresses the drift of the real exchange rate as the sum of the real interest differential and a risk premium which is equal to the instantaneous covariance of the real exchange rate with the domestic pricing kernel, while equation (10) relates the squared volatility of the two pricing kernels to the variance of the real exchange rate and the covariance of the exchange rate with the domestic pricing kernel. Note that equation (9) implies that a positive interest differential for the domestic investor ($r > r^*$) does *not* necessarily mean that the domestic currency is expected to depreciate (more dollars per pound), since the foreign exchange rate risk may command a

[9]See Brandt et. al. (2003).

negative risk premium ($\rho_{sm} < 0$).

Let $s^* \equiv 1/s$ denote the exchange rate expressed in terms of the number of units of foreign currency per unit of domestic currency ('pounds per dollar'). Then $ds^*/s^* = e^*dt - \sigma_s dz_s$ where $e^* = -e + \sigma_s^2$ and $\rho_{sm} = -\rho_{s^*m}$. Equations (9) and (10) depend only on covariances of the exchange rate with the *domestic* real pricing kernel, ρ_{sm}. Since analogous equations must also hold from the foreign perspective, we have, in addition, that:

$$e^* = r^* - r - \eta^* \sigma_s \rho_{sm^*}, \tag{11}$$

$$(\eta)^2 = (\eta^*)^2 + \sigma_s^2 + 2\eta^* \sigma_s \rho_{sm^*}. \tag{12}$$

Combining equations (10) and (12) yields

$$0 = \sigma_s \rho_{sm^*} \eta^* + \sigma_s^2 - \sigma_s \rho_{sm} \eta. \tag{13}$$

Equation (13) implies that if there is foreign exchange rate risk, $\sigma_s \neq 0$, then it must be priced from both the domestic and the foreign investors' point of view: that is, if $\sigma_s \neq 0$ then $\eta^* \rho_{sm^*} \neq 0$ or $\eta \rho_{sm} \neq 0$, or both.[10]

Equations (9) and (13) will be used as the basis of our tests of market integration between the capital markets in pairs of countries: if the two markets are integrated and there is no arbitrage opportunity, then the maximum Sharpe ratios in the two markets are linearly related to each other by equation (13), and the expected change in the real exchange rate is related to the real interest rate differential by a time-varying risk premium which is related to the Sharpe ratio of the domestic currency as shown in equation(11).[11] So far, we have focused on the pricing of real returns. Since the exchange and interest rate data that we shall analyze are in nominal terms, we develop the implications of the analysis for nominal variables in the next section.

[10] This is a consequence of Siegel's paradox.

[11] Only two of equations (9), (11) and (13) are linearly independent.

3 Nominal Pricing Kernels

Using capital letters to denote nominal variables, let M_t (M_t^*) denote the nominal pricing kernel and P_t (P_t^*) the general price level of the domestic (foreign) country. Then $M_t \equiv \frac{m_t}{P_t}$. Assume that the stochastic process for the price level of the domestic country can be written as:

$$\frac{dP}{P} = \pi dt + \sigma_P dz_P, \tag{14}$$

where π, the expected rate of inflation, will in general depend on the unspecified vector of state variables X, and define the process for the foreign price level, P^*, similarly.

Then, using Ito's Lemma and equations (1) and (14), the process for M can be written as:

$$\begin{aligned}
\frac{dM}{M} &= \frac{dm}{m} - \frac{dP}{P} - \frac{dm}{m}\frac{dP}{P} + \left(\frac{dP}{P}\right)^2 \\
&= -rdt - \eta dz - \pi dt - \sigma_P dz_P + \eta\sigma_P\rho_{Pm}dt + \sigma_P^2 dt \\
&= -\left[r + \pi - \eta\sigma_P\rho_{Pm} - \sigma_P^2\right]dt - \left[\eta dz + \sigma_P dz_P\right] \\
&\equiv -Rdt - \eta_N dz_N
\end{aligned} \tag{15}$$

where $R \equiv r + \pi - \eta\sigma_P\rho_{Pm} - \sigma_P^2$ is the nominal instantaneous risk free rate, and η_N is the volatility of the nominal pricing kernel. The process for M^* is defined similarly.

Let S_t denote the nominal spot exchange rate expressed in terms of dollars per unit of foreign currency. Then one unit of purchasing power in the foreign country is equivalent to P_t^* units of foreign currency, which can be exchanged for s_t units of domestic purchasing power or $s_t P_t$ units of domestic currency, so that the real and nominal exchange rates are related to the foreign and domestic price levels by:

$$S_t P_t^* = s_t P_t.$$

Using Ito's Lemma again, the nominal foreign exchange rate process is given by

$$
\begin{aligned}
\frac{dS}{S} &= \frac{ds}{s} + \frac{d\left(P_t/P_t^*\right)}{P_t/P_t^*} + \frac{ds}{s}\frac{d\left(P_t/P_t^*\right)}{P_t/P_t^*} \\
&= edt + \sigma_s dz_s + \left[\pi - \pi^* + \left(\sigma_P^*\right)^2 - \sigma_P \sigma_P^* \rho_{PP^*}\right] dt + \sigma_P dz_P - \sigma_P^* dz_P^* \\
&+ \sigma_s \left(\sigma_P \rho_{sP} - \sigma_P^* \rho_{sP^*}\right) dt \\
&= \left[e + \pi - \pi^* + \left(\sigma_P^*\right)^2 - \sigma_{PP^*} + \sigma_{sP} - \sigma_{sP^*}\right] dt + \sigma_s dz_s + \sigma_P dz_P - \sigma_P^* dz_P^* \\
&\equiv Edt + \sigma_S dz_S, \qquad (16)
\end{aligned}
$$

where $\sigma_{xy} \equiv \sigma_x \sigma_y \rho_{xy}$ denotes the covariance between the innovations to variables x and y, and

$$
\begin{aligned}
E &\equiv e + \pi - \pi^* + \left(\sigma_P^*\right)^2 - \sigma_{PP^*} + \sigma_{sP} - \sigma_{sP^*}, \qquad (17) \\
\sigma_S dz_S &= \sigma_s dz_s + \sigma_P dz_P - \sigma_P^* dz_P^*. \qquad (18)
\end{aligned}
$$

Arguments that are similar to those used to derive the implication for the real variables in Section 2 apply also to nominal variables, so that the no arbitrage condition implies the following relationship between the domestic and foreign *nominal* pricing kernels:

$$M^* = kMS,$$

where k is a constant. This, together with Ito's lemma, then implies that

$$-R^* dt - \eta_N^* dz_{M^*} = -Rdt - \eta_N dz_M + Edt + \sigma_S dz_S - \eta_N \sigma_S \rho_{SM}.$$

Using the definitions, $-\eta_N dz_M \equiv -\eta dz_m - \sigma_P dz_P$ and $-\eta_N^* dz_{M^*} \equiv -\eta^* dz_{m^*} - \sigma_{P^*} dz_{P^*}$, it is easy to show that the following relations hold for the nominal exchange rate, the pricing kernels and the price levels:

$$E = R - R^* + \eta\sigma_S\rho_{Sm} + \sigma_{SP}, \tag{19}$$

$$\begin{aligned}(\eta^*)^2 &= \eta^2 + 2\eta\left(\sigma_P\rho_{Pm} - \sigma_S\rho_{Sm}\right) - 2\eta^*\sigma_{P^*}\rho_{P^*m^*} \\ &+ \left[\sigma_S^2 + \sigma_P^2 - 2\sigma_{SP} - (\sigma_{P^*})^2\right].\end{aligned} \tag{20}$$

These equations for the nominal variables correspond to equations (9-10) for real variables.

Equation (19) implies that the expected change in the nominal exchange rate is equal to the nominal interest rate differential, plus the covariance of the nominal exchange rate with the domestic price level, σ_{SP}, plus a time varying exchange rate risk premium which is equal to the product of the covariance of the *nominal* exchange rate with the *real* domestic pricing kernel and the volatility of the pricing kernel, η. Similar relations hold from the foreign perspective as well:

$$E^* = R^* - R - \eta^*\sigma_S\rho_{Sm^*} - \sigma_{SP^*}, \tag{21}$$

$$\begin{aligned}\eta^2 &= (\eta^*)^2 + 2\eta^*\left(\sigma_{P^*}\rho_{P^*m} + \sigma_S\rho_{Sm^*}\right) - 2\eta\sigma_P\rho_{Pm} \\ &+ \left[\sigma_S^2 + \sigma_{P^*}^2 + 2\sigma_{SP^*} - \sigma_P^2\right].\end{aligned} \tag{22}$$

where $E^* = -E + \sigma_S^2$.

Combining equation (19) with (21) yields the following relation between η and η^*:

$$\sigma_S^2 = \eta\sigma_S\rho_{Sm} - \eta^*\sigma_S\rho_{Sm^*} + \left(\sigma_{SP} - \sigma_{SP^*}\right). \tag{23}$$

In what follows we shall explore how well our empirical estimates of the volatility of the real foreign and domestic pricing kernels satisfy the restrictions imposed by condition (13), or equivalently condition (23), which imply a linear relation between the volatility of the two pricing kernels (and the volatility of the exchange rate). We shall also examine the relations between real interest rates and inflation in the different countries, and test whether time variation in exchange risk premia is related to time variation in the volatility of foreign and domestic pricing kernels, as implied by expressions (19) and (21). In order to do this, it is necessary first to estimate the real interest rates and pricing kernels for the individual countries. We consider this in the following sections.

4 Data Construction and Description

The basic data used to estimate real interest rates, expected inflation rates and pricing kernel volatilities consist of estimated zero coupon bond yields for the second day of each month from January 1985 to May 2002.[12] The sample period and the number of countries were limited by the availability of government bond price data. For example, there are sufficient government bond maturities to estimate a zero coupon yield curve for France only after 1993, so this country was dropped from the sample, which then consists of the United States, UK, Germany, Canada and Japan.

Data on bond prices, coupon rates, coupon dates, issue dates, redemption dates and bond names for all available government bonds outstanding on a given date were taken from Datastream. Most bonds in the U.S., UK, Canada and Japan pay semi-annual coupons: those that did not were eliminated from the sample. In Germany most bonds pay annual coupons and those that did not were also excluded. Finally, all zero-coupon and floating-rate bonds and bonds that were callable or extended to dates beyond the original redemption dates were excluded.

Each month a cubic spline was fitted to all government bonds[13] with maturities

[12]Data for the second day of the month were used to avoid any micro-structure effects associated with the end of month.

[13]Bliss (1996) tests and compares five different methods for estimating the term structure. He finds that the unsmoothed Fama-Bliss method does the best but that the differences between this and the cubic spline approach are small. The cubic spline approach is the approach most widely

up to twenty years for each country . No extrapolation was used in the estimation, so that the longest possible zero-coupon bond yield for a given month is always less than or equal to the longest maturity available for the month. For the U.S., UK and Canada, zero-coupon bond yields of maturities 6 months, 1, 2, 3, 5, 7 and 10 years were available for every month, while for Germany and Japan, the maximum maturity that was available for every month was only 7 years and 8 years respectively.

The cubic spline approach has been used by McCulloch (1975) to fit the U.S. term structure, and by Litzenberger and Rolfo (1984) (LR) to study tax effects on yield curves in different countries. The procedure used here follows LR but ignores capital gains and income tax effects since the model developed in Sections 2 and 3 assumes no taxes or other frictions.[14]

Wherever possible, the estimated zero-coupon constant maturity bond yields were compared with existing data from other sources. For the U.S., our estimated yield curve was compared with the Fama-Bliss bond yields from CRSP which are only available for maturities of 1, 2, 3, 4 and 5 years up to December 2001, and also with bond yield data provided directly by Bliss for all maturities up to December 2000. Our estimates have very similar sample means and standard deviations to these two datasets. The correlations of bond yield levels with the same maturities between the two data sets are above 0.95 for maturities of 1, 2, 3, 4 and 5 years but are only 0.7 for 10-year yields. For the UK yield curve, our estimates were compared with those published by the Bank of England for the same sample period for maturities of 1, 2, 3, 5, 7, 10 and 15 years: the correlations are all above 0.9, but the sample means of our estimates are slightly higher. Since the data from the Bank of England are available for the whole sample period, we used this dataset for the UK.

---

used in the U.S.

[14]We also estimated the term structure by specifying a capital gain tax rate of 0 and an income tax rate of 33%. The estimated after yield curve was highly correlated with the before tax curve but with lower sample means. LR found that the minimum absolute standard error of estimate does not vary much with the assumed capital gains tax rate.

Table 1 reports summary statistics for the estimated zero-coupon bond yields. On average, the U.S., Canada, Japan and Germany all have upward-sloping yield curves. For example, the average zero coupon yield for the U.S. increases from 6.07% per year for the six-month bond to 7.41% for the ten-year bond. The sample standard deviation decreases with maturity, from 1.64% for the six-month bond to 0.82% for the ten-year bond. On the other hand, the average yield curve for the U.K. is slightly hump-shaped and almost flat: increasing from 8.02% for the one-year bond to 8.14% for the seven-year bond and then decreasing to 7.88% for the 15-year bond. The sample standard deviation also decreases slightly with maturity. Overall, the Japanese bonds have the lowest yields at around 3-4% while the UK has the highest yields at around 8%.

All bond yields are highly persistent with first order autocorrelation of 0.98 or above. Yields for different maturities are also highly correlated, particularly for nearby maturities. The shortest and the longest maturity bond yields have a correlation of 0.74 in the U.S., 0.80 in the U.K., 0.87 in Canada and 0.63 in Germany. Note that in Japan the 6-month and 8-year yields have a correlation of 0.96, and the correlations between other yields are even higher, suggesting that either a single factor model may capture the dynamics of the Japanese term structure, or more plausibly, the level of rates in Japan has shifted down by so much that the slope effects appear small in comparison.

Table 1 also reports summary statistics for the monthly CPI inflation rates and the excess equity market returns. The CPI inflation rates were calculated from the CPI data obtained Datastream and the excess equity market returns are calculated from the total market index and the one-month Treasury Bill rates also obtained from Datastream. For our sample period the estimate of the equity premium for Japan is only 1.7%, although the estimate doubles if the data from 1980 to 1985 are included. On the other hand, the U.S. equity premium estimate during this period is almost 10%, reflecting the bull market of the 1990s. The average CPI inflation rates range from a low of only 0.84% per year in Japan to a high of 3.8% in UK.

Spot and one month forward exchange rates against the US dollar were also taken from Datastream. Cross-rates between currencies other than the US dollar were obtained by taking the appropriate ratios of the US dollar exchange rates.[15] For Japan, one month Treasury Bill rates are only available from December 1993, so one-month bill rates from the Bank of Japan were used for the earlier period.

Finally, volatilities of US dollar(USD) exchange rates for the pound sterling (BP), Deutsch Mark (DM),[16] Japanese Yen (JY) and Canadian dollar (CAD), and the volatilities of the DM-BP and DM-JY rates were taken as the implied 1 month volatilities calculated from over the counter (OTC) foreign exchange options on the last day of each month and published on the website of the Federal Reserve Bank of New York; the average of the bid and ask implied volatility was used. These data were available only for the period October 1994 to May 2002.

Table 2 reports summary statistics on the foreign exchange and interest rate data used for each of the countries. Consistent with previous studies, changes in spot rates for all four country-pairs are highly volatile and have very low autocorrelation. The monthly volatility ranges from 1.37% for Canadian dollar to 3.74% for Japanese Yen. The autocorrelation is negative for the CAD and DM and positive for the BP and JY, but in all cases the absolute value of the autocorrelation is less than 0.1. In contrast, forward premia exhibit low volatility and much higher autocorrelation: for example, the forward premium for the BP has a monthly volatility of only 0.21% but an autocorrelation of 0.74. Consistent with the spot rate sample standard deviation, the mean implied one-month spot rate (against the USD) volatilities range from the lowest of 5.8% per year for the CAD to the highest of 12% for JY.

Table 3 reports summary statistics on the monthly foreign exchange rate changes

[15] The estimations were repeated using forward rates calculated using one month Euro currency interest rates; the results were essentially unchanged.

[16] The implied volatilities of the DM against the USD, Japanese Yen (JY) and BP were replaced by the corresponding implied volatilities of the Euro starting from January 1999.

and the one-month forward premium across all country pairs. The USD-CAD exchange rate has the lowest monthly volatility at only 1.4%; the DM-BP rate is next at 2.5%, and all the other exchange rate changes have volatilities in excess of 3%. The autocorrelations of all exchange rate changes are less than 0.11 in absolute value. In contrast, the one-month forward premia all have volatilities between 20 to 30 basis points per month, and the autocorrelation is as high as 0.82. Implied exchange rate volatilities are available only for the BP-DM and DM-JY rates which have means of 8.5% and 12.0% respectively.

Figure 1 plots the time series of the implied one-month volatilities for the six country pairs. The levels of the implied volatilities and their monthly changes are all positively correlated, the correlations for the levels ranging from 0.21 to 0.76, and for the changes from 0.21 to 0.85. The CAD-USD implied volatility has the lowest correlations with the other implied volatilities, and the highest correlations are for exchange rates which share a common currency (e.g. USD-DM and USD-BP). The effects of the Russian debt/LTCM crisis of September 1998 are visible in the implied volatilities for the CAD-USD and JY-USD rates.

5 State Variable Estimates

In order to estimate the parameters of the pricing kernel process for each currency from panel data on bond yields, it is necessary to place some further structure on the dynamics of the pricing kernel and the inflation rate. We follow Brennan, Wang and Xia (2003) (BWX) in assuming that the real interest rate, r, and the maximum Sharpe ratio, η, follow Ornstein-Uhlenbeck processes, so that the stochastic process for the pricing kernel may be written as:

$$
\begin{aligned}
\frac{dm}{m} &= -r dt - \eta dz_m && (24)\\
dr &= \kappa_r(\overline{r} - r)dt + \sigma_r dz_r && (25)\\
d\eta &= \kappa_\eta(\overline{\eta} - \eta)dt + \sigma_\eta dz_\eta && (26)
\end{aligned}
$$

The expected rate of inflation, π, is also assumed to follow an Ornstein-Uhlenbeck process:

$$
\frac{d\pi}{\pi} = \kappa_\pi(\bar{\pi} - \pi)dt + \sigma_\pi dz_\pi. \quad (27)
$$

BWX show that, under these assumptions, the nominal yield on a zero-coupon (default-free) bond of maturity τ is a linear function of the state variables, r, π, and η:

$$
-\frac{\ln N}{\tau} = -\frac{\widehat{A}(\tau)}{\tau} + \frac{B(\tau)}{\tau}r + \frac{C(\tau)}{\tau}\pi + \frac{\widehat{D}(\tau)}{\tau}\eta. \quad (28)
$$

where the coefficients, $\widehat{A}(\tau), B(\tau), C(\tau)$ and $\widehat{D}(\tau)$ are functions of the parameters of the joint stochastic process for the pricing kernel (24,25,26), realized inflation (14), and the expected rate of inflation (27).

In principle, it is possible to estimate the parameters of the system (24 - 27) by the standard Maximum Likelihood Method from the yields on three bonds of different maturities based on equation (28). However, the choice of bonds to use in the estimation is arbitrary, and there is no guarantee that the estimates will be consistent with the yields of other bonds. Therefore, to minimize the consequences of possible model misspecification as well as measurement errors in the fitted bond yield data, we allow for errors in the pricing of individual bonds and use a Kalman filter to estimate the time series of the unobservable state variables r, π and η, and their dynamics, from data on bond yields.

In summary, there are three transition equations for the unobserved state variables, r, η, and π, which are the discrete time versions of equations (25), (26), and (27). There are $n+1$ observation equations: the first n observation equations, which are derived from equation (28) by the addition of measurement errors, ϵ_{τ_j}, are for the yields at time t, $y_{\tau_j,t}$, on bonds with maturities τ_j, $j = 1, \cdots, n$:

$$y_{\tau_j,t} \equiv -\frac{\ln N(t, t+\tau_j)}{\tau_j} = -\frac{\widehat{A}(t,\tau_j)}{\tau_j} + \frac{B(\tau_j)}{\tau_j} r_t + \frac{C(\tau_j)}{\tau_j} \pi_t + \frac{\widehat{D}(\tau)}{\tau} \eta_t + \epsilon_{\tau_j}(t). \quad (29)$$

The last observation equation is based on the realized CPI inflation rate at time t:

$$\frac{\Delta P}{P} = \pi \Delta t + \epsilon_P(t).$$

This final observation equation is used to help distinguish r from π since these variables enter the bond yield equation (29) symmetrically.

The measurement errors, $\epsilon_{\tau_j}(t)$, are assumed to be serially and cross-sectionally uncorrelated, and to be uncorrelated with the innovations in the transition equations. To reduce the number of parameters to be estimated, the variance of the yield measurement errors was assumed to be of two possible forms: $\sigma^2(\epsilon_{\tau_j}) = \sigma_b^2$ or $\sigma^2(\epsilon_{\tau_j}) = \sigma_b^2/\tau_j$ where σ_b is a single parameter to be estimated. The first specification assumes that the variance of the measurement error of the log price of the bonds is proportional to maturity, while the second specification assumes that the variance of the measurement error is independent of maturity.[17] The system was estimated using both specifications. The first specification was found to work better for Canada, Germany, Japan and United States, while the second specification was better for the United Kingdom. In addition, it is assumed that the errors in the observation equations are uncorrelated with the innovations of the state variables, i.e., $\rho_{ir} = 0$, $\rho_{i\pi} = 0$ and $\rho_{i\eta} = 0$ ($i = \epsilon_1, \cdots, \epsilon_n,$ and ϵ_P).

[17]BWX estimate the system assuming that $\sigma^2(\epsilon_{\tau_j}) = \sigma_b^2/\tau_j$. In estimating a version of the model that has a constant value of η, Brennan and Xia (2002) find that measurement errors decline with maturity out to 5 years. Babbs and Nowman (1999) also find that the measurement errors declines slightly with bond maturity in a 3-factor Vasicek model.

The long run means of the state variables were set exogenously in order to permit identification and to facilitate the estimation. More specifically, $\bar{\pi}$ for each country was set equal to the sample mean realized CPI inflation rate, which is 3% for the U.S., 3.8% for UK, 2.8% for Canada, 2% for Germany and 1% for Japan; $\bar{r}$ was set equal to the difference between the sample means of the one-month Treasury bill rate and the CPI inflation rate, which is 2.6% for the U.S., 4.6% for UK, 4% for Canada, 3% for Germany and 2.5% for Japan; and $\bar{\eta}$ was set equal to 1.2 times the sample mean of the country's equity market Sharpe ratio, which is 0.62 for the U.S., 0.58 for UK, 0.44 for Canada, 0.46 for Germany, 0.21 for Japan.[18] $\bar{\eta}$ was set 20% higher than the realized equity market Sharpe ratio to allow for the fact that the equity market is only one component of the investment opportunity set. While the procedure for setting $\bar{\eta}$ is somewhat arbitrary, note that for any asset i, only the product $\rho_{im}\eta$ is identified in the estimation - therefore errors in the predetermined values of $\bar{\eta}$ will be offset by errors in the estimated correlations. Finally, σ_{ϵ_P} was set to the sample standard deviation of realized CPI inflation rates and ρ_{mP} was set to zero to reduce the number of parameters to be estimated.

Note that, while η is *currency* specific, the real interest rate and inflation rates are both country and currency specific since inflation rates are measured within specific geographic regions. Table 4 reports the parameter estimates and their asymptotic t-ratios for each of the five countries/currencies. For all currencies, σ_b is highly significant, falling in the range of 18-48 basis points, which is comparable to values found for previous studies of the U.S. term structure.

[18]Note that the sample means of the ex post equity market Sharpe ratios and the Treasury Bill rates reported here differ from those reported in Tables 1 and 2, because these means are calculated using data starting from January 1980 instead of January 1985. The longer sample period was chosen to improve the efficiency of the estimates for $\bar{r}$, $\bar{\pi}$ and $\bar{\eta}$. The estimates for $\bar{r}$, $\bar{\pi}$ and $\bar{\eta}$ are similar in the long and the shorter sample for Canada, UK and Germany. The estimates of $\bar{r}$ and $\bar{\pi}$ for Japan and U.S. are also similar but the estimates of $\bar{\eta}$ are significantly different in the long sample. The estimates based on the sample starting from January 1985 are $\bar{\eta} = 0.80$ for the U.S. and 0.10 for Japan.

For all countries except the U.S., σ_r, the volatility of the real interest rate innovation, is in the range of 63-92 basis points per year; for the U.S. on the other hand it is 277 basis points. The high volatility of r in the U.S. is offset by strong mean reversion: the estimate of κ_r is more than twice as high for the U.S. as for the next highest country, the U.K., and implies a half life for innovations of about 2.4 years, as compared with almost 5 years in the U.K., almost 6 years in Canada, and more than 10 years in Germany where the mean reversion parameter is not significant. As we shall see below, there is evidence of mean reversion in the estimates of r for all these countries. For Japan on the other hand the estimated value of r declines fairly steadily from 1990 so that there is little evidence of mean reversion in this sample period. It is not surprising then to find that the estimate of κ_r is close to zero and insignificant; the Ornstein-Uhlenbeck assumption clearly fails to capture the behavior of the real interest rate in Japan during this sample period. The estimated correlation between innovations in the real interest rate and the pricing kernel, ρ_{rm}, is negative and highly significant for all five currencies, so that for all there is a significant real interest rate risk premium and long term bonds command a positive premium.

The volatility of innovations in the expected inflation rate, σ_π, is highly significant except for Japan, ranging from 40 basis points in Japan to 115 basis points in Germany. The estimates of the mean reversion parameter for expected inflation, κ_π, are very small and insignificant for the Anglo-Saxon countries, U.S., UK and Canada, but are much larger and significant in Germany and Japan. The estimates for the Anglo-Saxon countries are consistent with previous findings that expected inflation follows close to a random walk. We place little weight on the estimate for Japan since it is clear that expected inflation, like the real interest rate, does not conform to the O-U assumption underlying the estimation during this sample period. Finally, $\rho_{\pi m}$ is not significant for any country so that there is no evidence of a risk premium associated with expected inflation.

The point estimate of the volatility of the maximum Sharpe ratio process, σ_η, is in the range of 0.19 to 0.28 for all currencies except the Japanese Yen (JY) where it is only 0.06 - this may reflect the generally poor fit of the model to Yen yields during this sample period, or it may reflect the fact that we have chosen a low value of the scaling parameter $\bar{\eta}$ for Japan. The point estimate is highly significant only for the Pound (BP); the lack of significance for the USD is a little surprising, since the stochastic nature of risk premia in the U.S. has been widely documented, and Brennan, Wang and Xia (2003) and Brennan and Xia (2003) report estimates of σ_η for the periods 1952-2000 and 1983-2000 that are highly significant. Just as for the real interest rate, the estimate of the mean-reversion parameter, κ_η, is highest for the USD and lowest for the DM and JY where the model does not fit so well.[19] The half life of innovations in η is almost 9.5 years for the Canadian dollar (CAD), around 6.7 years for the BP, and about 2.4 years for the USD.

Finally, $\rho_{\eta m}$, is significant and in the range of 0.8 to 0.92 for all currencies except the JY for which, as mentioned, the model does not fit well. It is also interesting to note that, with the exception of the JY for which $\rho_{\eta m}$ is negative and insignificant, the signs of ρ_{rm} and $\rho_{\eta m}$ are opposite and are consistent across currencies, so that the risk premia for these fundamental investment opportunity set risks are priced in a consistent fashion across currencies. However, the absolute values of the estimated correlations ρ_{rm} and $\rho_{\eta m}$ seem high for most countries, which suggests that we may have underestimated the levels of the pricing kernel volatilities by setting $\bar{\eta}$ too low.

In summary, the estimation results display an encouraging consistency across currencies/countries except for Japan and the Yen where the post-bubble economy has not conformed well to the model assumptions about the real interest rate or inflation.

Table 5 reports summary statistics on the estimated state variables, r, π and η, that are obtained from the Kalman filter for each of the countries/currencies. Note first that the sample mean of a state variable estimate reported in Table 5 may

[19]The Maximized likelihood is lowest for these two countries.

be quite different from the pre-set long run mean reported in Table 3, because the Kalman filter trades off the model fit in time series (ideally, the parameters of the estimated stochastic processes of the state variables correspond to the dynamics of the estimated state variables) and in the cross-sectional prediction of yields on bonds of different maturities. Particularly noticeable are the sample means for $\hat{\eta}$ of 0.145 for the USD and 0.754 for the CAD as compared with our preset estimates of $\bar{\eta}$ of 0.62 and 0.44 respectively. The autocorrelation for all series is above 0.96, indicating high persistence in all state variable estimates. This conflicts with a few large κ estimates reported in Table 3 which may be the result of some model mis-specification.

The state variable estimates are plotted in Figures 2 to 4. Figure 2 plots the time series of the real interest rate estimates for the five countries. The real interest rate estimates for all five countries display considerable volatility, ranging in all cases from a high of between 6 and 8% and a low of between 0 and minus 2%. All the series except that for Japan display strong mean reversion. While there are common elements in the series, country specific factors are clearly relevant also. Thus, while the patterns for U.S. and Canadian rates are broadly similar after 1990, the U.S. rate drops steeply from about 8% in the early part of the sample period while the Canadian is rising sharply from an initial value of around 2%. The U.K. rate generally tracks the U.S. after about 1985 but with a lag: the rates in both countries rise strongly in the late 1990s only to fall after 2000 with the decline in stock markets. The German rate displays a broadly similar pattern, but with a period of elevated rates following German re-unification in 1990 and with an earlier decline towards the end of the 1990s reflecting the sluggishness of the German economy during this period. The Japanese interest rate shows the most anomalous pattern, declining almost monotonically from around 5% in 1990 to minus 2% by the end of the sample period.

Figure 3 plots the time series of expected inflation estimates for the period of January 1985 to May 2002. The estimated expected inflation rates for U.S., Japan and Germany exhibit much smaller volatility than that of the real interest rates: they vary only from around 0.5% to around 4%. On the other hand, the UK rate moves around in a tight range between 3% to 6% until 1997 when it falls rapidly to below 0 and then increases slightly; the estimate for Canada has long swings in the much larger range of 0.5% to over 7%.

Figure 4 plots the Sharpe ratio estimates. The Sharpe ratios for the USD, BP, and DM all reach their lows at the peak of the stock market boom in the 1999-2000 period, the USD decline starting around 1993, the BP around 1995, and the DM around 1996. The ratios for all three currencies recover rapidly towards the end of the sample period. The CAD and JY ratios also decline in the second half of the 1990s, but not so dramatically as in the other three countries, and for both CAD and JY the lows (in both cases below zero) are reached in 1990. In the first half of the 1990s Sharpe ratios for all currencies are generally increasing. Finally, in contrast to the unrelated movements in the real interest rates in Canada and the U.S. up to 1990, their Sharpe ratios display strong comovement, initially rising sharply and then entering a long period of decline from 1986 to 1990.

To explore further the relation between the state variables for the different countries/currencies vector autoregressions were run separately for r, π, and η and the results are reported in Table 6,[20] which also reports the correlation matrix of the estimated state variable innovations. Table 6A shows that feedback between the real interest rates in the different countries is primarily limited to the U.S.-Canada and U.K.-Germany country pairs. While the Canadian interest rate has no influence on the U.S. rate, the U.S. rate acts like the target towards which the Canadian rate adjusts: the VAR coefficients imply that the expected monthly change in the Canadian rate can be written approximately as $0.05\,(r_{US} - r_{CAN})$. Similarly the change in the German rate can be written approximately as $0.05\,(r_{UK} - r_{GER})$. On the other hand, the influence of the German rate appears anomalous since it enters with a *negative*

[20]Strictly speaking, the VAR specification is inconsistent with the parsimonious Ornstein-Uhlenbeck assumption that we have made about the state variable dynamics.

coefficient in the regressions of all the other countries, and the coefficient is significant for Canada and the U.K. We suspect that this is the spurious result of the coincidence of the German re-unification boom and fiscal deficit with economic downturns in the other countries. The correlations between the real interest rate innovations in all countries are positive as seen in Panel II, the highest correlations being between Canada and the U.S. (0.48) and Germany and the U.K. (0.44); the next highest correlation is between Germany and Japan (0.38). These results are consistent with the hypothesis that geographical proximity and trade relations are associated with common shocks to real interest rates.

The (real) pricing kernel volatilities or 'Sharpe ratios'[21] show a more complicated pattern. First, as shown in Table 6B the estimated USD Sharpe ratio is significantly influenced by the lagged CAD Sharpe ratio, though the weight on this variable is very small and *negative*. The CAD Sharpe ratio is influenced strongly by the lagged value of both the USD and JY ratios. The DM Sharpe ratio is influenced strongly by the lagged BP ratio and *negatively* by the JY ratio. As with the real interest rate, the DM Sharpe ratio has a small *negative* influence on those of the other currencies (excluding the USD.). However, the correlations between the Sharpe ratio innovations for all currencies are positive, once again the highest correlations being between the CAD and USD ratios (0.54) and between the DM and BP ratios (0.41)., all other correlations being considerably smaller. The high correlations for the Sharpe ratio innovations for CAD and USD and for DM and BP are consistent with the much lower levels of exchange risk between these currencies: as seen in Table 3 these two exchange rates have the lowest volatilities.

Table 6C reports the results for expected inflation rates. The most striking aspect of the VAR coefficients is the strong dependence of Canadian (expected) inflation on (expected) inflation in the other countries, especially the U.S. and Japan. U.S.

[21]The (absolute value of) the volatility of the pricing kernel is equal to the maximum Sharpe ratio for returns in a given currency.

inflation is moderately affected by inflation in all countries except Germany and the coefficient for Canada is *negative*. The correlations between the innovations in expected inflation are much smaller than for the other series except between the three Anglo-Saxon countries where the correlations range from 0.46 to 0.63.

Overall, we have found strong links between Canada and the U.S. and between Germany and the U.K. for the real variables, the interest rate and the Sharpe ratio, and between the three Anglo-Saxon countries for expected inflation.

6 Empirical Evidence on Capital Market Integration

In this section, we carry out a direct test of market integration using our estimates of the pricing kernel volatilities. We first examine whether the pricing kernel volatilities are linearly related as prescribed by the model, and then test whether the uncovered currency return, defined as the realized spot rate appreciation minus the forward premium, is related to the pricing kernel volatilities.

6.1 Volatility of the Domestic and Foreign Real Pricing Kernels

In this section we consider how well the restriction implied by condition (23) is satisfied in the data:

$$\eta^* = \frac{\rho_{Sm}}{\rho_{Sm^*}}\eta - \frac{\sigma_S}{\rho_{Sm^*}} + \frac{\sigma_P \rho_{SP} - \sigma_{P^*}\rho_{SP^*}}{\rho_{Sm^*}}.$$

A simple regression of η^* on η will yield spurious results since η^*, and η are highly autocorrelated.[22] Therefore we report the results under two different estimations, one

[22] See Chapter 18 of Hamilton (1994) for detailed discussions. Roll and Yan (2000) discuss this problem in the context of the forward premium puzzle.

using first differences, and the second a cointegrating regression approach. We treat σ_S as a constant for some of the regressions and also include it as a variable using data on the implied volatility of the exchange rate when they are available.

The first difference regression with constant σ_S is specified as:

$$\eta^*_{t+1} - \eta^*_t = a_0 + a_1 \left(\eta_{t+1} - \eta_t \right) + \epsilon, \tag{30}$$

where, under the null hypothesis, $a_0 = 0$ and $a_1 \neq 0$. If σ_S is stochastic, then the first difference regression is given by:

$$\eta^*_{t+1} - \eta^*_t = a_0 + a_1 \left(\eta_{t+1} - \eta_t \right) + a_2 \left(\sigma_{S,t+1} - \sigma_{S,t} \right) + \epsilon, \tag{31}$$

where $a_0 = 0, a_1 \neq 0,$ and $a_2 \neq 0$ under the null.

Table 7 reports the first difference regression results for the whole sample in the first three columns. Consistent with the null hypothesis, the estimates of a_0 are all small in magnitude and statistically insignificant, while the estimate of a_1 is highly significant for all except the USD/JY regressions. The positive sign of the coefficient a_1 implies that the correlation of the exchange rate change with both pricing kernels has the same sign. The regressions have R^2 of between 5 and 19% (except for the USD/JY, DM/JY and JY/USD regressions).

Table 7A reports the results when σ_S is added to the first difference regression. Since the implied exchange rate volatility is available only for all currencies against the USD and for the BP-DM, and DM-JY exchange rates, the sample is reduced to regressions that include the USD η as either dependent or independent variable or the BP-DM and DM-JY pairs, and the sample period is restricted to the period beginning October 1994. When σ_S is included the estimated value of a_1 increases in all cases, and all estimates except for the DM-JY pair are positive and significantly different from zero. As before, regressions involving JY have small $\bar{R}^2$ and insignificant or only marginally significant estimates of a_1. The R^2 of other regressions increase to between 24 and 56 % while the R^2 in Table 7 were all less than 20% and most were less than 10%. However, it is not the inclusion of σ_S but the reduced sample period that accounts for the improved results, for the estimated coefficient of the change in the exchange rate is nowhere significant. Therefore, regression (30) was repeated for all currencies for two sub-periods and the results are reported in the second and third blocks of Table 7. The first sub-period is from January 1985 to September 1994, and the second sub-period, consistent with the sample in Table 7A, is from October 1994 to May 2002.

The first sub-period generally has low $\bar{R}^2$ (all less than 10%) and only three out of twenty currency pairs yield a significant (at 5% level) estimate of a_1. In contrast, the estimates of a_1 are highly significant in the second sub-period except for three currency pairs, all of which involve the JY. The goodness of fit is broadly improved in the second sub-period, the $\bar{R}^2$'s all being above 20% except for those involving JY. For example, the $\bar{R}^2$ for the DM-USD pair improves from 0 to around 27% while the DM-BP pair moves from only 5% to over 40%. Even for currency pairs that include JY, the goodness of fit also increases. For example, the $\bar{R}^2$ for the BP-JY pair increases from only 1.8% to over 16%. The much stronger results in the second sub-period are consistent with increasing capital market integration over time. For the whole sample, as well as for the two sub-periods, the currency pairs that include JY always have the weakest results. This is consistent with Brandt, Cochrane and Santa-Clara (2002), who report that their risk sharing index is the lowest for Japan.

In addition to the first difference regression, we examine the relation given in (23) directly, using a cointegration regression since both η and η^* are highly persistent. Table 8 reports the cointegration coefficient estimates for the whole sample and the two sub-periods. The cointegration coefficient estimates are generally larger in absolute values than their counterparts reported in Table 7 and eleven, twelve, and fifteen out of twenty pairs have significant slope estimates for, respectively, the whole, the first and the second sub-periods. The sign of the significantly estimated slope coefficient is opposite to that in Table 7 for eight country pairs for the whole sample, but it is broadly consistent between the two tables for the second sub-period.

Table 8A reports the cointegration regression results when the implied foreign exchange volatility, σ_S, is treated as a stochastic variable. In contrast to the results reported in Table 7A, the cointegration coefficients for σ_S, $\hat{c}_2$, are now all highly significant except for the BP-DM pair, and the magnitude of $\hat{c}_2$ is comparable to that of $\hat{c}_1$, the estimated coefficient of η. Nine out of twelve pairs have highly significant values of $\hat{c}_1$ while the first difference regression also yielded nine out of twelve significant estimates for the coefficient of η. Note that the cointegration results may be less reliable because of the short sample period (November 1994 to May 2002). The results involving the DM may be even less reliable because of the transition from DM to Euro in January 1999.

6.2 Exchange Rate Risk Premia and Currency Sharpe Ratios

Finally we examine whether time-variation in exchange rate risk premia is related to time-variation in the Sharpe ratios associated with the individual currencies as our model predicts. Equation (19) relates the expected rate of currency appreciation, $E_t \equiv (\mathrm{E}[S_{t+1}] - S_t)/S_t$, to the interest rate differential, $R_t^* - R_t$ and the domestic Sharpe ratio, η. Since covered interest rate parity implies that the interest rate differential is equal to the forward premium, $R_t - R_t^* = (F_t - S_t)/S_t$, where F_t is the one period forward exchange rate at time t, equation (19) implies that:

$$\frac{E[S_{t+1}] - S_t}{S_t} = \frac{F_t - S_t}{S_t} + \eta\sigma_S\rho_{Sm} + \sigma_S\sigma_P\rho_{SP},$$

or equivalently,

$$\frac{E[S_{t+1}] - F_t}{S_t} = \eta\sigma_S\rho_{Sm} + \sigma_S\sigma_P\rho_{SP}$$

where S_t (F_t) is the foreign spot (one-period forward) exchange rate at time t denominated as the domestic currencies per unit of foreign currency and η is the domestic

Sharpe ratio. This motivates the following regression under the assumption that σ_S is constant:

$$\frac{S_{t+1} - F_t}{S_t} = a_0 + a_1 \eta + \epsilon \tag{32}$$

with $H_0 : a_1 \neq 0$.

We first carry out the simple OLS regression to examine equation (32) and report the results in Table 9. The results are generally disappointing: the adjusted R^2's are quite low, and only four out of twenty exchange rates yield significant estimates for a_1. One interesting observation is that $\hat{a}_1$ is generally significant when η_{US} is on the right hand side of equation (32). In addition, the BP-DM regression is significant. Although the unit-root null hypothesis is strongly rejected for the spot rate appreciation, $(S_{t+1} - S_t)/S_t$, and the uncovered currency return, $(S_{t+1} - F_t)/S_t$, for all country pairs,[23] η is highly persistent with close-to-unit root autocorrelations. It is possible that the *unobservable* ex ante uncovered currency return is persistent and has close-to-unit root, but the i.i.d. measurement errors in the *realized* currency return is so large that the persistence in the true variable is obscured, as argued by Ferson et. al. (2003). Therefore, we re-estimate the relation (32) using the cointegration approach.

Table 10 reports the results when a constant σ_S is assumed. The estimated coefficient of η is significant is seven out of the twenty regressions - interestingly, the coefficient is always significant when the relevant independent variable is the USD Sharpe ratio. In addition, the DM Sharpe ratio is significant for the USD-DM and CAD-DM regressions while the CAD Sharpe ratio is significant for the DM-CAD regression. For most of the other currencies the coefficient of the Sharpe ratio is positive but not significant. Thus foreign exchange risk premia move with the premia

[23] The forward premium or the uncovered currency return in general does not have a close-to-unit-root autocorrelation coefficient: the highest among all country pairs is only 0.82. Roll and Yan (2000) find non-stationarity in the forward premium, $(F_t - S_t)/S_t$, for a different sample period.

on other USD denominated assets, but they do not appear to be strongly influenced by risk premia on assets denominated in other currencies. This may reflect the predominance of the USD as a reserve currency. The OLS and cointegration regressions were also repeated using Euro-currency one-month interest rate differentials instead of the forward premium, with virtually identical results.

However, if σ_S is not constant, then equation(32) will be mis-specified. Therefore, we also repeat the analysis allowing for a time varying σ_S by estimating the co-integrating regression:

$$\frac{S_{t+1} - F_t}{S_t} = c_0 + c_1 \eta \sigma_S + c_2 \sigma_S + \epsilon. \tag{33}$$

with $H_0 : c_0 = 0, c_1 \neq 0$.

As before, this restricts the sample to currency pairs that include the USD plus two DM exchange rates. Table 10A reports the results for all exchange rates relative to the USD and the DM-JY and DM-BP rates for October 1994 to May 2002, the period for which implied volatility data are available. The coefficient of σ_S is significant in ten out of the twelve regressions for which a co-integrating regression could be estimated - the risk premia are clearly related to risk.[24] The estimated coefficient of the Sharpe ratio, $\hat{c}_1$, is always significant for the BP-DM and USD-DM pairs no matter whether the relevant independent variable is the USD, the BP, or the DM Sharpe ratio. On the other hand, $\hat{c}_1$ is significant for the CAD-USD and BP-USD regressions only when the independent variable is the USD Sharpe ratio. $\hat{c}_1$ is also significant in the DM-JY regression where the independent variable is the JY Sharpe ratio. However, this variable is not significant in the USD-JY regression. In general, the results are slightly strengthened by allowing for stochastic σ_S.

It is possible that the influence of η is obscured by its multiplication in regression

[24] Brandt and Santa-Clara (2002) have also found that the implied volatility of the exchange rate is significant in explaining the risk premium for the USD-BP and USD-DM exchange rates.

(33) by σ_S, which also enters as an independent variable. Therefore we also estimate the following equation which separates the influence of η from that of σ_S:

$$\frac{S_{t+1} - F_t}{S_t} = c_0 + c_1\eta + c_2\sigma_S + \epsilon. \tag{34}$$

The results, which are reported in Table 10B, are broadly consistent with those reported in Table 10A.

These results, taken together, show that, consistent with a rational model, time variation in foreign exchange risk premia may be attributed to both changing risk-return trade-offs available in domestic capital markets and to the changing level of exchange rate volatility. While it is somewhat discouraging that neither the Canadian nor UK Sharpe ratios are significantly related to the dollar risk premium, this may possibly be accounted for by the shortness of the period for which exchange rate volatility data can be calculated.

7 Conclusion

We have shown that in integrated capital markets in which there are no arbitrage opportunities there exists a simple relation between the volatilities of the (minimum variance) pricing kernels (or maximum Sharpe ratios) for returns denominated in different currencies and the volatility of the exchange rates between them. We have also shown that, for a given exchange rate volatility, the foreign exchange risk premium is a linear function of the maximum Sharpe ratio. Then, using the parsimonious three-factor essentially affine model of the pricing kernel proposed by Brennan, Wang and Xia (2003), we have estimated real interest rates, expected inflation and the volatility of the pricing kernels (maximum Sharpe ratios) for five major currencies from panel data on zero coupon bond yields and inflation.

To explore the inter-relations between the state variables for different currencies we ran vector autoregressions for each of the state variables across currencies. The innovations in both the real interest rates and the Sharpe ratios were found to be positively correlated across all currencies, the strongest correlations being for the CAD/USD and DM/BP pairs. The innovations in expected inflation were much less correlated, the highest correlations being between CAD, USD and BP. The CAD real interest rate and Sharpe ratio were found to be strongly influenced by the lagged values of the corresponding USD variables; other significant lag relations were found between the CAD Sharpe ratio and the lagged JY Sharpe ratio and between the DM Sharpe ratio and the lagged BP ratio.

The relations between Sharpe ratios for different currencies were further explored by regressing changes in one ratio on changes in another and by co-integrating regressions. The first difference regressions have R^2 of between 5 and 19% (except for the USD/JY, DM/JY and JY/USD regressions for which the R^2 are lower). The point estimate of the regression coefficient is close to its theoretical value of unity for CAD/USD, CAD/JY, and DM/JY. Despite the fact that the Sharpe ratio is identified only up to a scalar multiple by the model, several of the estimates of the regression coefficient are too far from their theoretical value of unity to be explicable in terms of an inappropriate scaling for particular currencies; in particular, all of the regressions in which the JY η is the dependent variable have coefficient estimates below 0.1. Regressions for the post October 1994 period yielded higher R^2 and the regression coefficient was significant in 18 out of 20 regressions. The results were generally unchanged by the inclusion of the change in the exchange rate volatility in the regression. Cointegrating regressions between pairs of η's confirmed the first difference regression results: for the post 1994 period 16 out of 20 coefficients were significant. When the exchange rate volatility was added to the co-integrating regression its coefficient was significant in 8 out of 12 regressions as was the coefficient of η. The weakest relations were observed between changes in the JY η and the η's of other currencies.

Finally, the uncovered return on foreign currency investment was regressed on the domestic Sharpe ratio for each of the currencies. These results also are stronger for the post 1994 period. For this period, when the volatility of the exchange rate is included in the regression the returns were found to be significantly related to the volatility of the exchange rate in nine out of the twelve regressions, while the Sharpe ratio was significant in seven out of the twelve regressions. The strongest results were for the USD Sharpe ratio which was significant in three out of four regressions (not in the JY regression), while the JY Sharpe ratio was significant in explaining risk premia on investments denominated in DM (but not USD) and the DM Sharpe ratio was significant in explaining returns on investments in BP and USD (but not JY). The BP Sharpe ratio was significant for the returns on investments denominated in DM but not USD. Thus uncovered returns on foreign currency investment are generally related both to the risk of that investment as measured by the volatility of the exchange rate and to the level of risk premia prevailing in the domestic capital market as measured by the domestic Sharpe ratio. The influence of the domestic market Sharpe ratio is weakest for foreign investments in JY and in USD.

Overall, the results are consistent with a high degree of integration in international capital markets in the period since 1994, except possibly for the JY market whose η was little related to those of other currencies and whose currency returns denominated in other currencies were little related to the η's of those currencies. This may reflect the continuing importance of government intervention in the JY market even in the post 1994 period, and the poor quality of the state variable estimates derived from the Japanese bond market.

References

Ahn, Dong-Hyun, 1997, Generalized squared-autoregressive-independent-variable nominal term structural model, unpublished working paper, University of North Carolina.

Adler, M., and B. Dumas, 1993, International Portfolio Choice and Corporate Finance: A Synthesis, *The Journal of Finance* 38, 925-984.

Babbs, Simon H., and K. Ben Nowman, 1999, Kalman filtering of generalized Vasicek term structure models, *Journal of Financial and Quantitative Analysis* 34, 115-130.

Backus, D., A. Gregory, and C. Telmer, 1993, Accounting for Forward Rates in Markets for Foreign Currency, *The Journal of Finance* 48, 1887-1908.

Backus, D., S. Foresi, and C. Telmer, 2001, Affine Term Structure Models and the Forward Premium Anomaly, *Journal of Finance* 56, 279-304.

Bansal, R., 1997, An Exploration of the Forward Premium Puzzle in Currency Markets, *Review of Financial Studies* 10, 369-403.

Bekaert, G., 1995, The Time Variation of Expected Returns and Volatility in Foreign Exchange Markets, *Journal of Business and Economic Statistics* 13, 397-408.

Bekaert, G., 1996, The Time-variation of Risk and Return in Foreign Exchange Markets: A General Equilibrium Perspective, *Review of Financial Studies* 9, 427-470.

Bekaert, G., and C. Harvey, 1995, Time-Varying World Market Integration, *The Journal of Finance* 50, 403-444.

Bliss, R. R., Testing Term Structure Estimation Methods, *Advances in Futures and Option Research* 9, 197-231.

Brandt, M., and P. Santa-Clara, 2002, Simulated likelihood estimation of diffusions with an application to exchange rate dynamics in incomplete markets, *Journal of Financial Economics* 63, 161-210.

Brandt, M., J. Cochrane, and P. Santa-Clara, 2003, International risk sharing is better than you think (or exchange rates are much too smooth), unpublished manuscript, UCLA.

Brennan, M.J., and H.H. Cao, 1997, International Portfolio Investment Flows, *The Journal of Finance* 52, 1851-1880.

Brennan, M.J., H.H. Cao, N. Strong and X. Xu, 2003, The Dynamics of International Equity Market Expectations, Working Paper, UCLA.

Brennan, Michael J., and Yihong Xia, 2002, Dynamic asset allocation under inflation, *Journal of Finance* 57, 1201-1238.

Brennan, M.J., and Y. Xia, 2003, Risk and Valuation under an Intertemporal Capital Asset Pricing Model, Working Paper, University of Pennsylvania.

Brennan, M.J., A. Wang, and Y. Xia, 2003, Estimation and Test a Simple Intertemporal Capital Asset Pricing Model, Working paper, University of Pennsylvania.

Cappiello, L., O. Castrén, and J. Jäaskelä, 2003, Measuring the Euro Exchange Rate Risk Premium: the Conditional International CAPM Approach, Working paper, European Central Bank.

Cumby, R., 1988, Is It Risk? Explaining Deviations from Uncovered Interest Parity, *Journal of Monetary Economics* 22, 279-299.

De Santis, G., and B. Gerard, 1997, International Asset Pricing and Portfolio Diversification with Time-Varying Risk, *The Journal of Finance* 52, 1881-1912.

De Santis, G., and B. Gerard, 1998, How Big is the Premium for Currency Risk?, *Journal of Financial Economics* 49, 375-412.

Domowitz, I., and C. Hakkio, 1985, Conditional Variance and the Risk Premium in the Foreign Exchange Market, *Journal of International Economics* 19, 47-66.

Duffee, G., 2002, Term Premia and Interest Rate Forecasts in Affine Models, *Journal of Finance* 57, 405-443.

Dumas, B., and B. Solnik, 1995, The World Price of Foreign Exchange Risk, *The Journal of Finance* 50, 445-479.

Engel, C., 1996, The Forward Discount Anomaly and the Risk Premium: A Survey of Recent Evidence, *Journal of Empirical Finance* 3, 123-192.

Engsted, T., and C. Tanggaard, 2002, The Relation between Asset Returns and Inflation at Short and Long Horizons, *Journal of International Financial Markets, Institutions and Money* 12, 101-118.

Fama, E., 1984, Forward and Spot Exchange Rates, *Journal of Monetary Economics* 14, 319-338.

Ferson, W., and C. Harvey, 1994, Sources of Risk and Expected Returns in Global Equity Markets, Journal of Banking and Finance 18, 775-803.

Ferson, W., Timothy Simin, and Sergei Sarkissian, 2003, Spurious regressions in Financial Economics?, *The Journal of Finance*, forthcoming.

Giovannini, A., and P. Jorion, 1989, The Time-Variation of Risk and Return in the Foreign Exchange and Stock Markets, *The Journal of Finance* 44, 307-325.

Hamilton, J., 1994, Time Series Analysis, (Princeton University Press, Princeton, New Jersey).

Hansen, L., and R. Hodrick, 1983, Risk Averse Speculation in the Forward Foreign Exchange Market, in J. A. Frankel, ed.: *Exchange Rates and International Macroeconomics* (University of Chicago Press, Chicago, IL).

Harvey, C., 1991, The World Price of Covariance Risk, *The Journal of Finance* 46, 111-157.

Hollifield, B., and R. Uppal, 1997, An Examination of Uncovered Interest Rate Parity in Segmented International Commodity Markets, *The Journal of Finance*) 52, 2145-2170.

Huang, C-f., 1985, Information Structure and Equilibrium Asset Prices, *Journal of Economic Theory* 31, 33-71.

Ilmanen, A., 1995, Time-Varying Expected Returns in International Bond Markets, *The Journal of Finance* 50, 481-506.

Jorion, P., 1995, Predicting Volatility in the Foreign Exchange Market, *The Journal of Finance* 50, 507-528.

Korajczyk, R., and C. Viallet, 1990, An Empirical Investigation of International Asset Pricing, *Review of Financial Studies* 2, 53-85.

Lewis, K., 1995, Puzzles in International Financial Markets, in G. M. Grossman and K. Rogeff eds *Handbook of International Economics*, Vol. 3, Chapter 13, Amsterdam, Elsevier.

Litzenberger, R.H., and J. Rolfo, 1984, An International Study of Tax Effects on Government Bonds *Journal of Finance* 39, 1-22.

McCrown, J. R., 2001, Yield Curves and International Equity Returns, *Journal of Banking and Finance* 25, 767-788.

McCulloch, J.H., 1975, The Tax Adjusted Yield Curves, *The Journal of Finance* 30, 811-830.

Meredith, G., and M. Chinn, 1998, Long-Horizon Uncovered Interest Rate Parity, NBER Working Paper #6797.

Nielsen, Lars Tyge, and Jesús Saá-Requejo, 1993, Exchange Rate and term structure dynamics and the pricing of derivative securities, working paper, INSEAD.

Portes, R., H. Rey, and Y. Oh, 2001, Information and Capital Flows, *European*

Economic Review 45, 783–796.

Robotti, C., 2001, The Price of Inflation and Foreign Exchange Risk in International Equity Markets, Working Paper 2001-26, Federal Reserve Bank of Atlanta.

Roll, R., and S. Yan, 2000, An Explanation of the Forward Premium ”Puzzle”, *European Financial Management* 6, 121-148.

Saá-Requejo, J., 1993, The dynamics and the term structure of risk premium in foreign exchange market, working paper, INSEAD.

Tzavalis, E., and M. R. Wickens, 1996, Forecasting Inflation from the Term Structure, *Journal of Empirical Finance* 3, 103-122.

Table 1

Summary Statistics of Fitted Zero-Coupon Constant Maturity Bond Yields

This table reports sample summary statistics for the fitted zero-coupon constant maturity bond yields. The bond yields are estimated from government coupon bonds using a cubic spline. The raw government coupon bond data are collected from Datastream. The sample is from January 1985 to May 2002

1. The United States

	Bond Yield Maturities							CPI	Excess
Securities	0.5	1	2	3	5	7	10	Infl	Mkt Ret.
Mean (% per year)	6.07	6.14	6.27	6.41	6.69	6.96	7.41	3.08	9.97
Std. Dev. (% per year)	1.64	1.59	1.58	1.61	1.53	1.19	0.82	0.77	15.04
Autocorrelation	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.34	0.00
Correlation									
0.5	1.0	0.99	0.92	0.84	0.73	0.74	0.74	0.26	-0.03
1		1.0	0.97	0.91	0.81	0.81	0.72	0.29	-0.02
2			1.0	0.98	0.93	0.88	0.67	0.27	0.01
3				1.0	0.98	0.92	0.62	0.26	0.03
5					1.0	0.95	0.61	0.25	0.02
7						1.0	0.80	0.28	-0.05
10							1.0	0.29	-0.17
Infl								1.0	-0.09

2. Canada

	Bond Yield Maturities							CPI	Excess
Securities	0.5	1	2	3	5	7	10	Infl	Mkt Ret.
Mean (% per year)	6.99	7.09	7.18	7.45	7.70	7.84	8.01	2.78	5.50
Std. Dev. (% per year)	2.53	2.43	2.26	2.14	1.99	1.88	1.82	1.13	14.84
Autocorrelation	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.09	0.09
Correlation									
0.5	1.0	0.998	0.98	0.96	0.89	0.87	0.87	0.32	-0.16
1		1.0	0.99	0.97	0.91	0.90	0.89	0.32	-0.16
2			1.0	0.99	0.96	0.94	0.92	0.32	-0.15
3				1.0	0.98	0.97	0.94	0.32	-0.15
5					1.0	0.99	0.96	0.30	-0.13
7						1.0	0.99	0.28	-0.12
10							1.0	0.25	-0.12
Infl								1.0	-0.01

Table 1 (continued)

3. The United Kingdom (from Bank of England)

Securities	Bond Yield Maturities 1	2	3	5	7	10	15	CPI Infl	Excess Mkt Ret.
Mean (% per year)	8.02	8.03	8.06	8.11	8.14	8.10	7.88	3.80	6.16
Std. Dev. (% per year)	2.65	2.35	2.21	2.13	2.12	2.10	1.97	1.63	16.73
Autocorrelation	0.99	0.98	0.98	0.98	0.98	0.99	0.99	0.24	0.03
Correlation									
1	1.0	0.99	0.97	0.93	0.90	0.87	0.80	0.36	-0.03
2		1.0	0.99	0.97	0.95	0.92	0.86	0.36	-0.04
3			1.0	0.99	0.98	0.95	0.90	0.35	-0.04
5				1.0	0.99	0.98	0.95	0.34	-0.03
7					1.0	0.99	0.97	0.32	-0.03
10						1.0	0.99	0.30	-0.01
15							1.0	0.27	0.01
Infl								1.0	-0.09

4. Germany

Securities	Bond Yield Maturities 0.5	1	2	3	5	7	CPI Infl	Excess Mkt Ret.
Mean (% per year)	5.25	5.59	5.69	5.67	5.84	6.17	1.96	7.45
Std. Dev. (% per year)	1.90	1.64	1.50	1.45	1.38	1.24	0.91	19.87
Autocorrelation	0.97	0.98	0.98	0.99	0.99	0.98	0.26	0.07
Correlation								
0.5	1.0	0.92	0.85	0.81	0.69	0.63	0.25	-0.06
1		1.0	0.97	0.88	0.71	0.66	0.25	-0.07
2			1.0	0.96	0.83	0.78	0.26	-0.07
3				1.0	0.95	0.90	0.26	-0.07
5					1.0	0.98	0.24	-0.07
7						1.0	0.22	-0.08
Infl							1.0	-0.04

5. Japan

Securities	Bond Yield Maturities 0.5	1	2	3	5	8	CPI Infl	Excess Mkt Ret.
Mean (% per year)	2.98	2.92	2.95	3.12	3.52	3.92	0.84	1.67
Std. Dev. (% per year)	2.37	2.36	2.32	2.23	2.05	1.89	1.46	20.31
Autocorrelation	0.99	0.99	0.99	0.99	0.99	0.99	0.18	0.10
Correlation								
0.5	1.0	0.99	0.99	0.98	0.97	0.96	0.20	-0.05
1		1.0	0.99	0.99	0.98	0.96	0.20	-0.05
2			1.0	0.99	0.98	0.97	0.19	-0.05
3				1.0	0.99	0.98	0.20	-0.05
5					1.0	0.99	0.19	-0.05
8						1.0	0.18	-0.04
Infl							1.0	-0.00

Table 2

Summary Statistics For Foreign Exchange Rates, Foreign Exchange Volatilities and Interest Rates

This table reports sample summary statistics for changes in spot exchange rates, $S_{t+1}/S_t - 1$, one-month treasury bill rates, R, and the one-month forward premium, $\ln F_t - \ln S_t$. Both F_t and S_t are measured as dollars per unit of foreign currency. The sample is from January 1985 to May 2002 for British pounds, Canadian dollar and Japanese Yen, and the sample ends in December 1998 for German Mark due to the introduction of Euro. The German Mark treasury bill rates are from Bloomberg and the Japanese treasury bill rates are imputed from other treasury yields. All other data except for the implied volatility data are as of the beginning of the month and are from Datastream. The implied volatility of exchange rates are for foreign currencies per U.S. dollar. The data are measured at the end of the month from October 1994 to May 2002 and are from the Federal Reserve Bank of New York.

Currency	Mean	Std Deviation	Autocorrelation
1. Change in the Spot Rate: $S_{t+1}/S_t - 1$			
(% per month)			
British Pound	0.17	3.09	0.052
Canadian Dollar	-0.07	1.37	-0.063
German Mark	0.44	3.43	-0.011
Japanese Yen	0.39	3.74	0.030
2. Forward Premium: $100 \times (\ln F_t - \ln S_t)$			
(% per month)			
British Pound	-0.23	0.21	0.744
Canadian Dollar	-0.09	0.21	0.470
German Mark	0.04	0.29	0.746
Japanese Yen	0.24	0.26	0.494
3. One-month Treasury Bill Rates			
(% per year)			
U.S. Dollar	5.27	1.55	0.886
British Pound	8.34	3.16	0.985
Canadian Dollar	6.78	2.96	0.977
German Mark	5.19	1.91	0.989
Japanese Yen	2.99	2.69	0.995
4. One-month Implied Volatility of Exchange Rates:			
(% per year)			
British Pound	8.32	1.54	0.603
Canadian Dollar	5.82	1.60	0.824
German Mark	10.64	2.21	0.718
Japanese Yen	12.02	3.15	0.716

Table 3

Summary Statistics For Cross Foreign Exchange Rates

This table reports sample summary statistics for changes in spot exchange rates, $S_{t+1}/S_t - 1$, and the one-month forward premium, $\ln F_t - \ln S_t$ for all cross-country pairs. All data are as of the beginning of the month and are from Datastream.

Currency	Mean	Std Deviation	Autocorrelation
1. Change in the Spot Rate: $S_{t+1}/S_t - 1$			
(% per month)			
Canadian Dollar/German Mark	0.33	3.56	0.010
Canadian Dollar/Japanese Yen	0.48	3.90	0.014
Canadian Dollar/British Pound	0.25	3.17	-0.007
Canadian Dollar/U.S. Dollar	0.09	1.38	-0.061
German Mark/Japanese Yen	0.20	3.37	0.015
German Mark/British Pound	-0.04	2.48	0.109
German Mark/U.S. Dollar	-0.13	3.36	0.014
Japanese Yen/British Pound	-0.14	3.60	0.053
Japanese Yen/U.S. Dollar	-0.26	3.63	0.031
British Pound/U.S. Dollar	-0.07	3.13	-0.070
2. Forward Premium: $100 \times (\ln F_t - \ln S_t)$			
(% per month)			
Canadian Dollar/German Mark	0.16	0.28	0.629
Canadian Dollar/Japanese Yen	0.33	0.26	0.092
Canadian Dollar/British Pound	-0.14	0.21	0.139
Canadian Dollar/U.S. Dollar	0.09	0.21	0.470
German Mark/Japanese Yen	0.17	0.22	0.496
German Mark/British Pound	-0.31	0.26	0.821
German Mark/U.S. Dollar	-0.04	0.29	0.746
Japanese Yen/British Pound	-0.47	0.22	0.322
Japanese Yen/U.S. Dollar	-0.24	0.26	0.494
British Pound/U.S. Dollar	0.23	0.21	0.744
4. One-month Implied Volatility of Exchange Rates:			
(% per year)			
British Pound/German Mark	8.48	2.02	0.735
German Mark/Japanese Yen	12.04	3.39	0.834

Table 4

Model Parameter Estimates

This table reports estimates of the parameters of the stochastic process of the investment opportunity set, equations (25) to (27), obtained from a Kalman filter applied to the inflation and bond yield data. The state variables are r, the real interest rate, π, the expected rate of inflation, and η the volatility of the pricing kernel or the maximum Sharpe ratio for the currency. In the table, m denotes the pricing kernel and P is the price level. Asymptotic t-ratios are in parentheses.

1. The United States							
	σ_b	σ_r	σ_π	σ_η	κ_r	κ_π	κ_η
Estimate	0.48%	2.77%	0.81%	0.193	0.290	0.002	0.292
t-ratio	(52.82)	(10.92)	(5.15)	(1.88)	(1.97)	(0.70)	(3.84)
	$\rho_{r\pi}$	$\rho_{r\eta}$	ρ_{rm}	$\rho_{\pi\eta}$	$\rho_{\pi m}$	$\rho_{\eta m}$	
Estimate	0.027	-0.413	-0.801	-0.199	-0.276	0.919	
t-ratio	(0.11)	(0.54)	(6.22)	(0.69)	(1.66)	(2.57)	
	$\bar{r}$	$\bar{\pi}$	$\bar{\eta}$	σ_P	ρ_{Pm}	ML	
Pre-set Value	2.62%	3.00%	0.62	0.77%	0.00	9,334.6	
2. Canada							
	σ_b	σ_r	σ_π	σ_η	κ_r	κ_π	κ_η
Estimate	0.38%	0.78%	0.74%	0.196	0.119	0.000	0.073
t-ratio	(50.65)	(6.77)	(4.64)	(1.48)	(3.35)	(0.68)	(2.44)
	$\rho_{r\pi}$	$\rho_{r\eta}$	ρ_{rm}	$\rho_{\pi\eta}$	$\rho_{\pi m}$	$\rho_{\eta m}$	
Estimate	-0.080	-0.181	-0.865	-0.254	0.122	0.915	
t-ratio	(0.37)	(0.70)	(2.51)	(0.91)	(1.23)	(2.09)	
	$\bar{r}$	$\bar{\pi}$	$\bar{\eta}$	σ_P	ρ_{Pm}	ML	
Pre-set Value	4.00%	2.78%	0.44	1.33%	0.00	8,561.5	

Table 4 (continued)

3. The United Kingdom							
	σ_b	σ_r	σ_π	σ_η	κ_r	κ_π	κ_η
Estimate	0.44%	0.63%	0.92%	0.207	0.143	0.000	0.104
t-ratio	(49.74)	(10.35)	(12.94)	(2.45)	(4.68)	(0.76)	(1.89)
	$\rho_{r\pi}$	$\rho_{r\eta}$	ρ_{rm}	$\rho_{\pi\eta}$	$\rho_{\pi m}$	$\rho_{\eta m}$	
Estimate	-0.104	-0.234	-0.714	-0.191	0.178	0.833	
t-ratio	(0.75)	(1.14)	(3.49)	(0.78)	(1.93)	(4.38)	
	$\bar{r}$	$\bar{\pi}$	$\bar{\eta}$	σ_P	ρ_{Pm}	ML	
Pre-set Value	4.56%	3.78%	0.58	1.63%	0.00	8,522.2	

4. Germany							
	σ_b	σ_r	σ_π	σ_η	κ_r	κ_π	κ_η
Estimate	0.34%	0.83%	1.15%	0.281	0.067	0.799	0.002
t-ratio	(44.14)	(5.93)	(4.91)	(0.75)	(1.17)	(4.44)	(0.68)
	$\rho_{r\pi}$	$\rho_{r\eta}$	ρ_{rm}	$\rho_{\pi\eta}$	$\rho_{\pi m}$	$\rho_{\eta m}$	
Estimate	-0.101	-0.217	-0.984	-0.142	0.257	0.939	
t-ratio	(0.33)	(0.65)	(3.41)	(0.54)	(0.51)	(2.12)	
	$\bar{r}$	$\bar{\pi}$	$\bar{\eta}$	σ_P	ρ_{Pm}	ML	
Pre-set Value	3.02%	2.45%	0.46	0.98%	0.00	7,405.9	

5. Japan							
	σ_b	σ_r	σ_π	σ_η	κ_r	κ_π	κ_η
Estimate	0.18%	0.92%	0.40%	0.065	0.001	0.119	0.048
t-ratio	(44.78)	(4.52)	(1.42)	(1.76)	(0.75)	(1.86)	(1.35)
	$\rho_{r\pi}$	$\rho_{r\eta}$	ρ_{rm}	$\rho_{\pi\eta}$	$\rho_{\pi m}$	$\rho_{\eta m}$	
Estimate	-0.154	-0.259	-0.979	-0.237	0.343	-0.146	
t-ratio	(0.27)	(1.05)	(9.16)	(0.42)	(0.39)	(0.23)	
	$\bar{r}$	$\bar{\pi}$	$\bar{\eta}$	σ_P	ρ_{Pm}	ML	
Pre-set Value	2.54%	1.14%	0.21	1.62%	0.00	7,969.4	

Table 5

Summary Statistics For Estimated State Variables

This table reports sample summary statistics for the state variables r, π and η estimated from government bond yields in the different countries. Bond prices and coupon rates are from the Datastream, and then a cubic spline following Litzenberger and Rolfo (1976) is used to derive zero-coupon yields for maturities of 0.5, 1, 2, 3, 5, 7, and 10 years. The state variables are then estimated from these yields using a Kalman filter. The sample is from January 1985 to May 2002. All data are as of the beginning of the month and are reported as percent per year for r and π.

Currency	Mean	Std Deviation	Autocorrelation
1. Instantaneous real risk free rate: r			
U.S. Dollar	3.21	1.70	0.964
Canadian Dollar	3.15	2.72	0.992
British Pound	4.34	2.40	0.989
German Mark	2.91	1.54	0.987
Japanese Yen	1.12	2.40	0.986
2. Expected Inflation: π			
U.S. Dollar	2.79	0.71	0.970
Canadian Dollar	3.69	1.94	0.986
British Pound	3.52	2.10	0.984
German Mark	2.34	0.96	0.974
Japanese Yen	1.70	0.46	0.974
3. Maximum Sharpe Ratio: η			
U.S. Dollar	0.145	0.450	0.989
Canadian Dollar	0.754	0.940	0.995
British Pound	0.686	0.711	0.992
German Mark	0.468	0.803	0.994
Japanese Yen	0.306	0.186	0.995

Table 6A

Vector Autoregression Regression Results for Real Interest Rates and the Correlation Matrix of Their Innovations

This table reports VAR estimates for the estimated real interest rates for U.S., Canada, UK, Germany and Japan. The standard errors are in parentheses and the t-statistics are in brackets.

Panel I: VAR Results

	$r_{US,t}$	$r_{CAN,t}$	$r_{UK,t}$	$r_{GER,t}$	$r_{JAP,t}$
$r_{US,t-1}$	0.9661	0.0605	0.0378	-0.0158	0.0193
	(0.0228)	(0.0192)	(0.0242)	(0.0149)	(0.0172)
	[42.29]	[3.14]	[1.56]	[1.06]	[1.12]
$r_{CAN,t-1}$	0.0015	0.9591	-0.0154	-0.0116	0.0093
	(0.0159)	(0.0134)	(0.0169)	(0.0104)	(0.0120)
	[0.09]	[71.48]	[0.91]	[1.12]	[0.77]
$r_{UK,t-1}$	0.0118	0.0180	1.0028	0.0458	0.0002
	(0.0200)	(0.0169)	(0.0212)	(0.0130)	(0.0151)
	[0.59]	[1.07]	[47.26]	[3.52]	[0.01]
$r_{GER,t-1}$	-0.0289	-0.0461	-0.0564	0.9560	-0.0080
	(0.0220)	(0.0185)	(0.0233)	(0.0143)	(0.0166)
	[1.32]	[2.49]	[2.42]	[66.91]	[0.48]
$r_{JAP,t-1}$	-0.0069	-0.0003	-0.0049	0.0111	0.9841
	(0.0123)	(0.0103)	(0.0130)	(0.0800)	(0.0093)
	[0.56]	[0.03]	[0.38]	[1.38]	[106.33]
C	0.0012	-0.0002	0.0008	-0.0000	-0.0008
	(0.0007)	(0.0006)	(0.0008)	(0.0005)	(0.0005)
	[1.64]	[0.31]	[1.06]	[0.08]	[1.53]
R^2	0.963	0.990	0.980	0.982	0.990

Panel II: Correlation Matrix of Innovations

	US	CAN	UK	GER	JAP
US	1.00	0.48	0.16	0.26	0.19
CAN		1.00	0.13	0.26	0.16
UK			1.00	0.44	0.15
GER				1.00	0.38
JAP					1.00

Table 6B

Vector Autoregression Regression Results for Sharpe Ratios and the Correlation Matrix of Their Innovations

This table reports VAR estimates for the estimated real interest rates for U.S., Canada, UK, Germany and Japan. The standard errors are in parentheses and the t-statistics are in brackets.

Panel I: VAR Results

	$r_{US,t}$	$r_{CAN,t}$	$r_{UK,t}$	$r_{GER,t}$	$r_{JAP,t}$
$r_{US,t-1}$	1.0042	0.1205	0.0416	-0.0386	0.0071
	(0.0091)	(0.0212)	(0.0239)	(0.0234)	(0.0051)
	[110.71]	[5.69]	[1.74]	[1.65]	[1.40]
$r_{CAN,t-1}$	-0.0131	0.9779	-0.0165	0.0143	-0.0029
	(0.0031)	(0.0071)	(0.0081)	(0.0079)	(0.0017)
	[4.28]	[137.01]	[2.04]	[1.82]	[1.73]
$r_{UK,t-1}$	-0.0096	-0.0054	1.0019	0.0730	0.0072
	(0.0081)	(0.0189)	(0.0213)	(0.0208)	(0.0045)
	[1.19]	[0.29]	[46.95]	[3.50]	[1.59]
$r_{GER,t-1}$	0.0072	-0.0339	-0.0195	0.9537	-0.0067
	(0.0051)	(0.0119)	(0.0135)	(0.0131)	(0.0029)
	[1.41]	[2.85]	[1.45]	[72.56]	[2.35]
$r_{JAP,t-1}$	0.0129	0.1724	0.0176	-0.1495	0.9893
	(0.0240)	(0.0560)	(0.0634)	(0.0619)	(0.0134)
	[0.54]	[3.08]	[0.28]	[2.42]	[73.75]
C	0.0048	-0.0332	0.0054	0.0096	0.0031
	(0.0050)	(0.0117)	(0.0133)	(0.0130)	(0.0028)
	[0.96]	[2.82]	[0.40]	[0.74]	[1.09]
R^2	0.995	0.994	0.987	0.990	0.992

Panel II: Correlation Matrix of Innovations

	US	CAN	UK	GER	JAP
US	1.00	0.54	0.28	0.32	0.06
CAN		1.00	0.23	0.29	0.16
UK			1.00	0.41	0.21
GER				1.00	0.18
JAP					1.00

Table 6C

Vector Autoregression Regression Results for Expected Inflation Rates and the Correlation Matrix of Their Innovations

This table reports VAR estimates for the estimated real interest rates for U.S., Canada, UK, Germany and Japan. The standard errors are in parentheses and the t-statistics are in brackets.

Panel I: VAR Results

	$\pi_{US,t}$	$\pi_{CAN,t}$	$\pi_{UK,t}$	$\pi_{GER,t}$	$\pi_{JAP,t}$
$\pi_{US,t-1}$	0.9797	0.0859	-0.0635	0.0046	0.0032
	(0.0162)	(0.0202)	(0.0299)	(0.0222)	(0.0091)
	[60.51]	[4.25]	[2.12]	[0.21]	[0.36]
$\pi_{CAN,t-1}$	-0.0334	0.9520	-0.0043	-0.0144	-0.0021
	(0.0085)	(0.0107)	(0.0158)	(0.0117)	(0.0048)
	[3.91]	[89.29]	[0.28]	[1.23]	[0.45]
$\pi_{UK,t-1}$	0.0274	0.0251	0.9925	0.0042	-0.0055
	(0.0083)	(0.0104)	(0.0154)	(0.0114)	(0.0047)
	[3.28]	[2.41]	[64.45]	[0.37]	[1.18]
$\pi_{GER,t-1}$	-0.0046	0.0519	0.0280	0.9805	0.0171
	(0.0133)	(0.0166)	(0.0246)	(0.0182)	(0.0074)
	[0.35]	[3.13]	[1.14]	[53.77]	[2.30]
$\pi_{JAP,t-1}$	0.0645	0.1477	0.0602	0.0103	0.9584
	(0.0321)	(0.0401)	(0.0593)	(0.0440)	(0.0179)
	[2.01]	[3.69]	[1.01]	[0.23]	[53.45]
C	-0.0002	-0.0054	0.0003	0.0005	0.0005
	(0.0007)	(0.0009)	(0.0013)	(0.0009)	(0.0004)
	[0.24]	[6.38]	[0.23]	[0.56]	[1.39]
R^2	0.949	0.989	0.980	0.949	0.962

Panel II: Correlation Matrix of Innovations

	US	CAN	UK	GER	JAP
US	1.00	0.63	0.51	-0.-1	0.12
CAN		1.00	0.46	0.11	-0.03
UK			1.00	0.01	-0.02
GER				1.00	-0.08
JAP					1.00

Table 7

Linear Regression of Innovations in Sharpe Ratios (30)

The table reports regression results for

$$\eta^*_{t+1} - \eta^*_t = a_0 + a_1 \left(\eta_{t+1} - \eta_t \right) + \epsilon.$$

The whole sample period is from January 1985 to May 2002, the first sub-period is from January 1985 to September 1994, and the second sub-period is from October 1994 to May 2002. Newey-West standard errors are in parentheses and the t-statistics are in brackets.

	Whole Sample			First Sub-period			Second Sub-period		
Currency Pairs	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. USD-CAD	-0.003	0.177	18.4	-0.006	0.109	9.7	-0.002	0.413	48.0
	(0.004)	(0.050)		(0.005)	(0.064)		(0.004)	(0.065)	
	[0.93]	[3.52]		[1.17]	[1.70]		[0.54]	[6.36]	
2. USD-BP	-0.003	0.118	8.5	-0.007	0.078	4.3	0.004	0.258	24.4
	(0.004)	(0.054)		(0.005)	(0.056)		(0.006)	(0.071)	
	[0.81]	[2.20]		[1.37]	[1.39]		[0.72]	[3.62]	
3.USD-DM	-0.003	0.104	6.1	-0.006	-0.046	-0.0	0.002	0.170	26.5
	(0.004)	(0.035)		(0.005)	(0.055)		(0.005)	(0.037)	
	[0.76]	[2.97]		[1.21]	[0.83]		[0.29]	[4.54]	
4. USD-JY	-0.003	0.142	0.1	-0.006	0.043	-0.0	0.002	0.555	3.8
	(0.004)	(0.144)		(0.005)	(0.172)		(0.006)	(0.328)	
	[0.80]	[0.99]		[1.23]	[0.25]		[0.29]	[1.69]	

Table 7 (continued)

Currency Pairs	Whole Sample			First Sub-period			Second Sub-period		
	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
5. CAD-USD.	0.004	1.063	18.4	0.003	0.960	9.7	0.006	1.175	48.0
	(0.009)	(0.308)		(0.015)	(0.573)		(0.006)	(0.217)	
	[0.49]	[3.45]		[0.17]	[1.68]		[0.87]	[5.42]	
6. CAD-BP	0.002	0.268	7.1	-0.005	0.239	4.7	0.013	0.404	20.3
	(0.009)	(0.145)		(0.014)	(0.181)		(0.010)	(0.136)	
	[0.18]	[1.84]		[0.38]	[1.32]		[1.31]	[2.98]	
7. CAD-DM	0.001	0.270	7.0	-0.004	0.228	1.2	0.008	0.292	27.6
	(0.009)	(0.067)		(0.015)	(0.169)		(0.008)	(0.058)	
	[0.14]	[4.06]		[0.25]	[1.35]		[0.97]	[5.00]	
8. CAD-JY	0.000	1.037	4.7	-0.007	1.170	5.3	0.008	0.891	3.4
	(0.005)	(0.359)		(0.009)	(0.483)		(0.006)	(0.391)	
	[0.06]	[2.88]		[0.75]	[2.43]		[1.42]	[2.28]	
9. BP-USD	-0.001	0.759	8.5	0.012	0.660	4.3	-0.018	0.980	24.4
	(0.008)	(0.174)		(0.010)	(0.244)		(0.011)	(0.206)	
	[0.08]	[4.36]		[1.17]	[2.70]		[1.62]	[4.75]	
10. BP-CAD	-0.004	0.283	7.1	0.009	0.231	4.7	-0.021	0.523	20.3
	(0.005)	(0.061)		(0.008)	(0.075)		(0.006)	(0.083)	
	[0.65]	[4.67]		[1.05]	[3.07]		[3.48]	[6.33]	
11. BP-DM	-0.002	0.398	14.9	0.008	0.375	4.9	-0.015	0.399	40.1
	(0.007)	(0.080)		(0.009)	(0.189)		(0.009)	(0.067)	
	[0.35]	[4.95]		[0.83]	[1.98]		[1.70]	[5.91]	
12. BP-JY	-0.004	1.150	5.6	0.006	0.746	1.8	-0.013	2.002	16.5
	(0.008)	(0.414)		(0.010)	(0.457)		(0.011)	(0.723)	
	[0.47]	[2.78]		[0.59]	[1.63]		[1.13]	[2.77]	

Table 7 (continued)

Currency Pairs	Whole Sample			First Sub-period			Second Sub-period		
	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
13. DM-USD	-0.000	0.637	6.1	-0.000	-0.158	-0.0	-0.007	1.604	26.5
	(0.009)	(0.251)		(0.009)	(0.201)		(0.015)	(0.405)	
	[0.01]	[2.53]		[0.03]	[0.78]		[0.45]	[3.96]	
14. DM-CAD	-0.002	0.277	7.0	0.001	0.089	1.2	-0.012	0.971	27.6
	(0.010)	(0.105)		(0.009)	(0.066)		(0.015)	(0.272)	
	[0.25]	[2.64]		[0.12]	[1.36]		[0.81]	[3.57]	
15. DM-BP	-0.001	0.385	14.9	-0.000	0.153	4.9	0.012	1.022	40.1
	(0.008)	(0.195)		(0.008)	(0.135)		(0.013)	(0.210)	
	[0.13]	[1.97]		[0.06]	[1.13]		[0.92]	[4.86]	
16. DM-JY	-0.003	0.916	3.5	-0.006	0.519	2.2	-0.001	2.039	6.0
	(0.010)	(0.461)		(0.008)	(0.372)		(0.017)	(1.282)	
	[0.27]	[0.99]		[0.08]	[1.39]		[0.06]	[1.59]	
17. JY-USD	0.001	0.041	0.1	0.003	0.017	-0.0	-0.002	0.088	3.8
	(0.002)	(0.042)		(0.003)	(0.068)		(0.002)	(0.043)	
	[0.27]	[0.99]		[0.87]	[0.25]		[1.32]	[2.05]	
18. JY-CAD	0.000	0.050	4.7	0.003	0.053	5.3	-0.003	0.050	3.4
	(0.002)	(0.022)		(0.003)	(0.031)		(0.002)	(0.021)	
	[0.19]	[2.23]		[0.95]	[1.71]		[1.46]	[2.38]	
19. JY-BP	0.001	0.053	5.6	0.002	0.035	1.8	-0.001	0.087	16.5
	(0.002)	(0.031)		(0.003)	(0.033)		(0.001)	(0.021)	
	[0.32]	[1.70]		[0.80]	[1.04]		[0.60]	[4.23]	
20. JY-DM	0.000	0.043	3.5	0.003	0.060	2.2	-0.002	0.034	6.0
	(0.002)	(0.018)		(0.003)	(0.038)		(0.002)	(0.019)	
	[0.27]	[2.44]		[0.87]	[1.56]		[1.37]	[1.83]	

Table 7A

Linear Regression of Innovations in Sharpe Ratios and Exchange Rate Volatility

In this table, we assume that σ_S is stochastic and report the regression results of the following equation

$$\eta^*_{t+1} - \eta^*_t = a_0 + a_1 \left(\eta_{t+1} - \eta_t\right) + a_2 \left(\sigma_{S,t+1} - \sigma_{S,t}\right) + \epsilon.$$

The sample period is from October 1994 to May 2002. Newey-West standard errors are in parentheses and the t-statistics are in brackets.

Currency Pairs	a_0	a_1	a_2	Adj. R^2 (%)	Currency Pairs	a_0	a_1	a_2	Adj. R^2 (%)
1. USD-CAD	-0.002	0.426	0.003	49.1	7. CAD-USD	0.005	1.179	-0.005	49.3
	(0.002)	(0.046)	(0.003)			(0.006)	(0.216)	(0.003)	
	[0.73]	[9.33]	[0.90]			[0.76]	[5.45]	[1.73]	
2. USD-BP	0.005	0.265	-0.000	24.2	8. BP-USD	-0.019	0.979	0.000	24.2
	(0.006)	(0.075)	(0.002)			(0.011)	(0.203)	(0.003)	
	[0.77]	[3.54]	[0.22]			[1.71]	[4.81]	[0.12]	
3. USD-DM	0.001	0.170	0.000	25.7	9. DM-USD	-0.006	1.604	-0.001	25.7
	(0.005)	(0.037)	(0.001)			(0.015)	(0.410)	(0.003)	
	[0.28]	[4.55]	[0.17]			[0.42]	[3.91]	[0.42]	
4. USD-JY	0.002	0.562	-0.000	2.8	10. JY-USD	-0.003	0.087	-0.000	3.5
	(0.007)	(0.340)	(0.001)			(0.002)	(0.043)	(0.000)	
	[0.30]	[1.65]	[0.00]			[1.42]	[2.04]	[0.96]	
5. JY-DM	-0.002	0.036	0.000	5.7	11. DM-JY	0.001	2.147	-0.002	5.6
	(0.002)	(0.019)	(0.001)			(0.017)	(1.351)	(0.006)	
	[1.55]	[1.83]	[0.46]			[0.03]	[1.59]	[0.34]	
6.DM-BP	0.016	1.110	-0.001	43.8	12. BP-DM	-0.018	0.405	0.003	44.3
	(0.012)	(0.217)	(0.006)			(0.008)	(0.065)	(0.003)	
	[1.34]	[5.12]	[0.20]			[2.09]	[6.24]	[0.97]	

Table 8

Cointegration Regression for Sharpe Ratios (23)

The table reports cointegration regression results for

$$\eta^{*}_{t+1} = c_0 + c_1 \eta_{t+1} + \epsilon.$$

The whole sample period is from January 1985 to May 2002, the first sub-period is from January 1985 to September 1994, and the second sub-period is from October 1994 to May 2002. Asymptotic standard errors are in parentheses and t-statistics are in brackets.

	Whole Sample			First Sub-period			Second Sub-period		
Currency Pairs	c_0	c_1	LL	c_0	c_1	LL	c_0	c_1	LL
1. USD-CAD	0.212	-0.294	905.8	0.642	-3.356	498.4	-1.850	2.392	443.2
	(0.176)	(0.168)		(0.772)	(0.762)		(0.484)	(0.689)	
	[1.20]	[1.75]		[0.83]	[4.40]		[3.82]	[3.47]	
2. USD-BP	0.080	-0.081	795.3	0.310	-0.105	425.7	-0.350	0.347	472.5
	(0.164)	(0.171)		(0.153)	(0.216)		(0.073)	(0.068)	
	[0.49]	[0.48]		[2.02]	[0.49]		[4.76]	[5.13]	
3. USD-DM	-0.074	0.304	848.1	0.369	-0.235	495.9	-0.190	0.236	370.9
	(0.089)	(0.099)		(0.144)	(0.185)		(0.057)	(0.057)	
	[0.83]	[3.06]		[2.56]	[1.27]		[3.34]	[4.10]	
4. USD-JY	0.281	-0.757	1122.8	0.339	-0.697	619.0	-0.748	1.467	522.3
	(0.157)	(0.442)		(0.104)	(0.453)		(0.267)	(0.577)	
	[1.78]	[1.71]		[3.28]	[1.54]		[2.80]	[2.54]	

Table 8 (continued)

	Whole Sample			First Sub-period			Second Sub-period		
Currency Pairs	c_0	c_1	LL	c_0	c_1	LL	c_0	c_1	LL
5. CAD-USD	0.763	-7.386	892.2	1.592	-5.248	493.4	0.808	0.647	437.8
	(0.994)	(2.301)		(0.981)	(2.012)		(0.088)	(0.258)	
	[0.77]	[3.21]		[1.62]	[2.61]		[9.23]	[2.51]	
6. CAD-BP	0.959	-0.741	618.3	-0.864	1.906	302.4	0.530	0.022	422.1
	(0.525)	(0.542)		(0.921)	(1.223)		(0.082)	(0.076)	
	[1.83]	[1.37]		[0.94]	[1.56]		[0.45]	[0.29]	
7. CAD-DM	1.114	-1.417	672.1	-4.956	8.481	377.1	0.598	0.127	331.5
	(0.557)	(0.619)		(1.389)	(1.737)		(0.041)	(0.042)	
	[2.00]	[2.29]		[3.57]	[4.88]		[14.56]	[3.04]	
8. CAD-JY	0.048	1.370	941.7	-0.561	1.960	491.6	0.217	0.801	475.9
	(0.661)	(1.851)		(1.063)	(4.430)		(0.273)	(0.586)	
	[0.07]	[0.74]		[0.53]	[0.44]		[0.80]	[1.37]	
9. BP-USD	0.986	-12.310	795.3	2.941	-9.500	425.7	1.009	2.884	472.5
	(1.517)	(3.531)		(1.044)	(2.182)		(0.245)	(0.731)	
	[0.65]	[3.49]		[2.82]	[4.35]		[4.12]	[3.95]	
10. BP-CAD	1.294	-1.350	618.3	0.453	0.525	302.4	-24.561	46.364	422.1
	(0.643)	(0.561)		(0.235)	(0.164)		(8.375)	(13.670)	
	[2.01]	[2.41]		[1.93]	[3.19]		[2.93]	[3.39]	
11. BP-DM	1.479	-2.233	546.8	5.046	-5.235	303.6	1.148	3.163	356.1
	(0.808)	(0.908)		(1.864)	(2.232)		(0.587)	(0.720)	
	[1.83]	[2.46]		[2.71]	[2.35]		[1.95]	[4.39]	
12. BP-JY	0.229	1.016	831.2	0.071	3.107	423.9	-1.362	4.514	505.5
	(0.449)	(1.256)		(0.199)	(0.818)		(0.508)	(1.134)	
	[0.51]	[0.81]		[0.36]	[3.62]		[2.68]	[3.98]	

Table 8 (continued)

Currency Pairs	Whole Sample			First Sub-period			Second Sub-period		
	c_0	c_1	LL	c_0	c_1	LL	c_0	c_1	LL
13. DM-USD	0.243	3.288	848.1	1.571	-4.261	495.9	0.807	4.246	370.9
	(0.265)	(0.623)		(0.439)	(0.924)		(0.306)	(0.948)	
	[0.92]	[5.28]		[3.58]	[4.61]		[2.64]	[4.48]	
14. DM-CAD	1.030	-0.847	646.0	0.537	0.259	360.9	-4.208	7.026	322.6
	(0.732)	(0.613)		(0.127)	(0.086)		(0.842)	(1.225)	
	[1.41]	[1.38]		[4.25]	[2.99]		[5.00]	[5.74]	
15.DM-BP	0.572	-0.354	561.7	0.914	-0.083	304.2	-0.263	-0.085	353.4
	(0.525)	(0.535)		(0.470)	(0.610)		(0.296)	(0.261)	
	[1.09]	[0.66]		[1.94]	[0.14]		[0.89]	[0.33]	
16. DM-JY	1.123	-2.018	881.1	0.851	0.098	492.4	-1.191	2.700	418.9
	(0.607)	(1.693)		(0.254)	(1.084)		(1.144)	(2.476)	
	[1.85]	[1.19]		[3.35]	[0.09]		[1.04]	[1.09]	
17. JY-USD	0.347	-1.105	1124.6	0.397	-1.075	621.9	-2.073	-27.793	513.7
	(0.115)	(0.253)		(0.150)	(0.283)		(6.071)	(18.216)	
	[3.03]	[4.37]		[2.65]	[3.80]		[0.34]	[1.53]	
18. JY-CAD	0.974	-0.894	924.3	-0.169	0.416	481.8	-0.583	1.826	470.0
	(0.504)	(0.423)		(0.394)	(0.265)		(0.377)	(0.545)	
	[1.93]	[2.11]		[0.43]	[1.57]		[1.55]	[3.35]	
19. JY-BP	-0.225	0.984	831.2	-0.023	0.322	423.9	0.302	0.222	505.5
	(0.321)	(0.329)		(0.083)	(0.110)		(0.034)	(0.034)	
	[0.70]	[2.99]		[0.27]	[2.93]		[8.77]	[6.61]	
20. JY-DM	0.557	-0.496	881.1	-8.661	10.175	492.4	0.441	0.370	418.9
	(0.180)	(0.198)		(3.465)	(4.113)		(0.114)	(0.115)	
	[3.09]	[2.50]		[2.50]	[2.47]		[3.89]	[3.21]	

Table 8A

Cointegration Regression of Innovations in Sharpe Ratios and Exchange Rate Volatility

In this table, we assume that σ_S is stochastic and report the cointegration regression results of the following equation

$$\eta_t^* = c_0 + c_1\eta_t + c_2\sigma_{S,t} + \epsilon.$$

The sample period is from October 1994 to May 2002. Asymptotic standard errors are in parentheses and t-statistics are in brackets.

Currency Pairs	c_0	c_1	c_2	LL	Country Pairs	c_0	c_1	c_2	LL
1. USD-CAD	-2.348	1.572	0.185	321.9	7. CAD-USD	1.493	0.636	-0.117	321.9
	(0.493)	(0.292)	(0.061)			(0.193)	(0.192)	(0.035)	
	[4.76]	[5.39]	[3.04]			[9.75]	[3.30]	[3.35]	
2. USD-BP	-4.015	0.436	0.424	321.6	8. BP-USD	9.215	2.295	-0.974	321.6
	(1.026)	(0.139)	(0.119)			(2.310)	(1.295)	(0.274)	
	[3.91]	[3.12]	[3.55]			[3.99]	[1.77]	[3.55]	
3. USD-DM	-1.485	0.293	0.116	198.9	9. DM-USD	5.063	3.410	-0.394	198.9
	(0.505)	(0.076)	(0.046)			(1.672)	(1.063)	(0.156)	
	[2.94]	[3.84]	[2.50]			[3.03]	[3.21]	[2.53]	
4. USD-JY	-14.121	10.327	0.738	321.3	10. JY-USD	1.367	0.097	-0.071	321.3
	(3.049)	(2.878)	(0.161)			(0.140)	(0.106)	(0.012)	
	[4.63]	[3.59]	[4.57]			[9.78]	[0.92]	[6.00]	
5. JY-DM	-0.838	0.415	0.104	246.0	11. DM-JY	2.018	2.410	-0.251	246.0
	(0.418)	(0.102)	(0.034)			(1.317)	(1.431)	(0.061)	
	[2.00]	[4.08]	[3.08]			[1.53]	[1.68]	[4.13]	
6. DM-BP	0.713	-0.168	-0.136	203.1	12.BP-DM	4.229	-5.947	-0.809	203.1
	(1.268)	(0.275)	(0.138)			(7.377)	(1.731)	(0.846)	
	[0.56]	[0.61]	[0.99]			[0.57]	[3.44]	[0.96]	

Table 9

Linear Regression of Forward Premium on the Sharpe Ratio

The table reports OLS regression results for

$$\frac{S_{i,j,t+1} - F_{i,j,t}}{S_{i,j,t}} = a_0 + a_1 \eta_{i,t} + \epsilon.$$

where $S_{i,j,t}$ and $F_{i,j,t}$ denote the spot and one month forward exchange rates between currencies i and j at time t measured in currency units of i per currency unit of j and $\eta_{i,t}$ is the volatility of the real pricing kernel for currency i at time t. The whole sample period is from January 1985 to May 2002, the first sub-period is from January 1985 to September 1994, and the second sub-period is from October 1994 to May 2002. Newey-West standard errors are in parentheses and t-statistics are in brackets.

	Whole Sample			First Sub-period			Second Sub-period		
Currency Pairs	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
1.USD- Canada	0.000	-0.000	-0.4	-0.001	-0.000	-0.7	0.001	0.002	-0.9
	(0.001)	(0.001)		(0.001)	(0.001)		(0.003)	(0.004)	
	[0.29]	[0.45]		[0.92]	[0.42]		[0.27]	[0.53]	
2.USD- UK	-0.001	-0.003	-0.1	-0.000	-0.008	-0.2	0.001	-0.001	-0.7
	(0.003)	(0.002)		(0.008)	(0.008)		(0.002)	(0.002)	
	[0.40]	[1.22]		[0.01]	[0.91]		[0.68]	[0.82]	
3. USD-DM	-0.006	0.005	-0.0	-0.006	0.001	-0.9	-0.001	0.007	1.9
	(0.004)	(0.004)		(0.008)	(0.010)		(0.004)	(0.004)	
	[1.60]	[1.09]		[0.75]	[0.09]		[0.39]	[1.83]	
4. USD-JY	-0.009	0.028	1.5	-0.005	-0.005	-0.8	-0.005	0.030	-0.1
	(0.005)	(0.015)		(0.006)	(0.018)		(0.015)	(0.033)	
	[1.62]	[1.90]		[0.91]	[0.26]		[0.35]	[0.90]	

Table 9 (continued)

Currency Pairs	Whole Sample			First Sub-period			Second Sub-period		
	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
5. CAD-USD	-0.000	0.001	-0.3	0.004	-0.005	0.7	-0.002	0.001	-1.1
	(0.001)	(0.002)		(0.002)	(0.003)		(0.002)	(0.005)	
	[0.01]	[0.63]		[2.36]	[1.64]		[1.00]	[0.19]	
6. CAD-BP	-0.001	-0.003	0.0	-0.001	-0.001	-0.9	0.005	-0.012	0.8
	(0.003)	(0.003)		(0.003)	(0.002)		(0.008)	(0.009)	
	[0.22]	[1.22]		[0.30]	[0.47]		[0.64]	[1.42]	
7.CAD-DM	-0.009	0.009	1.1	-0.010	0.009	-0.1	-0.006	0.009	3.1
	(0.004)	(0.005)		(0.009)	(0.010)		(0.005)	(0.005)	
	[2.0]	[1.83]		[1.19]	[0.83]		[1.08]	[1.75]	
8. CAD-JY	-0.005	0.017	0.2	-0.001	-0.017	-0.3	-0.008	0.031	-0.1
	(0.006)	(0.015)		(0.006)	(0.020)		(0.016)	(0.034)	
	[0.90]	[1.07]		[0.15]	[0.85]		[0.50]	[0.91]	
9. BP-USD	0.002	0.013	2.8	0.001	0.015	1.2	0.002	0.011	1.4
	(0.002)	(0.004)		(0.005)	(0.008)		(0.002)	(0.006)	
	[1.14]	[2.82]		[0.15]	[1.79]		[1.11]	[1.88]	
10. BP-CAD	0.002	0.003	0.3	0.003	0.002	-0.3	-0.005	0.011	1.4
	(0.003)	(0.003)		(0.005)	(0.003)		(0.005)	(0.005)	
	[0.51]	[1.09]		[0.71]	[0.81]		[1.03]	[1.84]	
11.BP-DM	-0.005	0.009	3.6	-0.009	0.012	2.7	-0.001	0.008	5.3
	(0.003)	(0.004)		(0.006)	(0.007)		(0.003)	(0.003)	
	[1.57]	[2.63]		[1.51]	[1.88]		[0.18]	[2.34]	
12. BP-JY	-0.001	0.012	-0.1	0.005	-0.024	0.4	-0.012	0.044	1.0
	(0.005)	(0.015)		(0.006)	(0.022)		(0.015)	(0.033)	
	[0.10]	[0.82]		[0.86]	[1.10]		[0.80]	[1.34]	

Table 9 (continued)

	Whole Sample			First Sub-period			Second Sub-period		
Currency Pairs	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)	a_0	a_1	R^2 (%)
13. DM-USD	-0.001	0.019	4.1	-0.001	0.020	3.2	-0.002	0.003	-2.0
	(0.003)	(0.005)		(0.005)	(0.007)		(0.004)	(0.026)	
	[0.41]	[3.51]		[0.29]	[2.88]		[0.57]	[0.13]	
14. DM-CAD	0.002	0.003	-0.1	0.003	0.003	0.0	0.015	-0.018	0.3
	(0.004)	(0.003)		(0.005)	(0.003)		(0.014)	(0.016)	
	[0.44]	[0.86]		[0.61]	[1.00]		[1.09]	[1.13]	
15. DM-BP	0.001	-0.003	-0.2	0.002	-0.003	-0.7	-0.003	-0.001	-1.9
	(0.003)	(0.003)		(0.006)	(0.007)		(0.005)	(0.004)	
	[0.31]	[0.79]		[0.40]	[0.41]		[0.62]	[0.28]	
16. DM-JY	-0.000	0.005	-0.5	0.003	-0.017	0.0	-0.018	0.044	-0.6
	(0.005)	(0.013)		(0.006)	(0.021)		(0.034)	(0.058)	
	[0.05]	[0.39]		[0.54]	[0.79]		[0.54]	[0.75]	
17. JY-USD	-0.001	0.019	4.5	-0.002	0.024	5.3	-0.007	-0.003	-1.1
	(0.003)	(0.006)		(0.005)	(0.008)		(0.006)	(0.018)	
	[0.40]	[3.20]		[0.52]	[2.78]		[1.09]	[0.14]	
18. JY-CAD	-0.002	0.004	0.4	0.002	0.004	0.9	-0.001	-0.005	-0.9
	(0.003)	(0.003)		(0.004)	(0.003)		(0.010)	(0.012)	
	[0.45]	[1.40]		[0.61]	[1.41]		[0.09]	[0.42]	
19. JY-BP	0.001	-0.004	0.1	-0.001	0.003	-0.8	-0.002	-0.006	0.7
	(0.004)	(0.005)		(0.008)	(0.009)		(0.005)	(0.005)	
	[0.18]	[0.87]		[0.12]	[0.33]		[0.40]	[1.04]	
20. JY-DM	0.003	-0.004	-0.2	0.000	0.001	-0.8	0.002	-0.006	-0.6
	(0.007)	(0.007)		(0.008)	(0.008)		(0.011)	(0.009)	
	[0.37]	[0.52]		[0.01]	[0.15]		[0.15]	[0.67]	

Table 10

Cointegration Regression Results for the Forward Premium

The table reports parameter estimates for the cointegrating regression:

$$\frac{S_{i,j,t+1} - F_{i,j,t}}{S_{i,j,t}} = c_0 + c_1 \hat{\eta}_{i,t} + \epsilon.$$

where $S_{i,j,t}$ and $F_{i,j,t}$ denote the spot and one month forward exchange rates between currencies i and j at time t measured in currency units of i per currency unit of j and $\eta_{i,t}$ is the volatility of the real pricing kernel for currency i at time t. The coefficient estimates and their standard errors in the table have been multiplied by 100. Asymptotic standard errors are in parentheses and t-statistics are in brackets.

			Whole Sample			First Sub-period			Second Sub-period		
	Currency j	Currency i	c_0	c_1	LL	c_0	c_1	LL	c_0	c_1	LL
1	USD	CAD	0.079	-0.121	959.4	-0.080	-0.089	528.5	-0.005	0.349	456.0
			(0.106)	(0.091)		(0.102)	(0.071)		(0.295)	(0.428)	
			[0.75]	[1.33]		[0.78]	[1.25]		[0.02]	[0.82]	
2	USD	BP	-0.185	-0.071	678.4	-0.365	-0.200	328.2	0.177	-0.195	462.9
			(0.292)	(0.298)		(0.757)	(1.002)		(0.171)	(0.159)	
			[0.63]	[0.24]		[0.48]	[0.20]		[1.04]	[1.23]	
3	USD	DM	-1.071	0.968	589.0	-0.610	0.079	401.4	-1.453	2.032	204.7
			(0.571)	(0.620)		(0.732)	(0.881)		(0.811)	(0.703)	
			[1.88]	[1.56]		[0.83]	[0.09]		[1.79]	[2.89]	
4	USD	JY	-0.765	2.501	960.4	-0.429	-0.602	525.8	-0.574	2.810	454.4
			(0.496)	(1.386)		(0.631)	(2.653)		(1.199)	(2.579)	
			[1.54]	[1.80]		[0.68]	[0.23]		[0.48]	[1.09]	

Table 10 (continued)

	Currency j	Currency i	Whole Sample c_0	Whole Sample c_1	Whole Sample LL	First Sub-period c_0	First Sub-period c_1	First Sub-period LL	Second Sub-period c_0	Second Sub-period c_1	Second Sub-period LL
5	CAD	USD	-0.015	0.522	1124.4	0.676	-1.900	633.0	-0.126	0.482	502.3
			(0.098)	(0.229)		(0.201)	(0.429)		(0.140)	(0.429)	
			[0.15]	[2.28]		[3.36]	[4.43]		[0.90]	[1.12]	
6	CAD	BP	-0.136	-0.077	671.0	0.134	-0.594	327.5	-0.102	0.089	450.2
			(0.307)	(0.313)		(0.796)	(1.053)		(0.222)	(0.205)	
			[0.44]	[0.25]		[0.17]	[0.56]		[0.46]	[0.43]	
7	CAD	DM	-1.297	1.393	573.1	-0.988	0.907	391.5	-1.495	1.914	195.0
			(0.582)	(0.631)		(0.827)	(0.994)		(0.721)	(0.623)	
			[2.23]	[2.21]		[1.19]	[0.91]		[2.07]	[3.07]	
8	CAD	JY	-0.385	1.365	950.1	0.073	-1.674	518.7	-1.043	3.627	448.9
			(0.549)	(1.534)		(0.713)	(3.001)		(1.216)	(2.618)	
			[0.70]	[0.89]		[0.10]	[0.56]		[0.86]	[1.39]	
9	BP	USD	0.249	1.013	969.0	0.244	1.184	523.1	0.206	0.974	475.1
			(0.186)	(0.432)		(0.472)	(0.996)		(0.157)	(0.480)	
			[1.34]	[2.34]		[0.52]	[1.19]		[1.31]	[2.03]	
10	BP	CAD	0.137	0.255	782.2	0.278	0.260	403.0	-0.824	1.627	412.4
			(0.257)	(0.220)		(0.378)	(0.262)		(0.421)	(0.611)	
			[0.53]	[1.16]		[0.74]	[0.99]		[1.96]	[2.66]	
11	BP	DM	-0.508	0.778	637.0	-0.559	0.728	439.1	-0.804	1.380	211.4
			(0.433)	(0.470)		(0.496)	(0.597)		(1.014)	(0.874)	
			[1.17]	[1.66]		[1.13]	[1.22]		[0.79]	[1.58]	
12	BP	JY	-0.130	1.342	967.3	0.301	-1.868	538.1	-1.152	3.991	449.6
			(0.545)	(1.522)		(0.647)	(2.720)		(1.297)	(2.293)	
			[0.24]	[0.88]		[0.47]	[0.69]		[0.89]	[1.43]	

Table 10 (continued)

			Whole Sample			First Sub-period			Second Sub-period		
	Currency j	Currency i	c_0	c_1	LL	c_0	c_1	LL	c_0	c_1	LL
13	DM	USD	-0.073	1.867	774.6	-0.491	3.937	526.9	-1.123	2.747	263.1
			(0.295)	(0.657)		(0.439)	(0.926)		(0.530)	(2.710)	
			[0.25]	[2.84]		[1.12]	[4.25]		[2.12]	[1.01]	
14	DM	CAD	0.287	0.153	599.1	0.373	0.353	400.3	4.264	5.567	223.2
			(0.378)	(0.294)		(0.378)	(0.262)		(1.265)	(1.523)	
			[0.76]	[0.52]		[0.99]	[1.35]		[3.37]	[3.66]	
15	DM	BP	-0.008	0.022	556.7	-0.547	1.008	366.2	4.662	-0.725	252.1
			(0.452)	(0.414)		(0.565)	(0.750)		(3.334)	(1.675)	
			[0.02]	[0.05]		[0.97]	[1.34]		[1.40]	[0.43]	
16	DM	JY	-0.009	0.425	794.7	0.225	-1.042	557.6	1.803	-1.793	263.5
			(0.509)	(1.397)		(0.613)	(2.580)		(2.599)	(4.672)	
			[0.02]	[0.30]		[0.37]	[0.40]		[0.69]	[0.38]	
17	JY	USD	-0.095	1.773	920.0	-0.517	3.572	522.4	-0.746	-0.942	409.3
			(0.245)	(0.569)		(0.421)	(0.887)		(0.433)	(1.329)	
			[0.39]	[3.12]		[1.23]	[4.03]		[1.72]	[0.71]	
18	JY	CAD	-0.078	0.353	737.4	0.412	560	406.6	0.862	-1.917	366.4
			(0.352)	(0.301)		(0.278)	(0.193)		(0.829)	(1.204)	
			[0.22]	[1.17]		[1.48]	[2.90]		[1.04]	[1.59]	
19	JY	BP	0.023	-0.150	634.0	-0.949	1.768	340.5	-0.101	-0.575	396.8
			(0.425)	(0.434)		(0.940)	(1.245)		(0.410)	(0.381)	
			[0.05]	[0.35]		[1.01]	[1.42]		[0.25]	[1.51]	
20	JY	DM	0.632	-0.807	594.1	0.244	-0.141	430.8	-0.255	-0.441	186.3
			(0.611)	(0.664)		(0.810)	(0.974)		(1.109)	(0.961)	
			[1.03]	[1.22]		[0.30]	[0.14]		[0.23]	[0.46]	

Table 10A

Cointegration Regression Results for the Forward Premium including Exchange Rate Volatility

The table reports parameter estimates for the cointegrating regression with stochastic σ_S:

$$\frac{S_{i,j,t+1} - F_{i,j,t}}{S_{i,j,t}} = c_0 + c_1 \hat{\eta}_{i,t} \sigma_S + c_2 \sigma_S + \epsilon.$$

where $S_{i,j,t}$ and $F_{i,j,t}$ denote the spot and one month forward exchange rates between currencies i and j at time t measured in currency units of i per currency unit of j and $\eta_{i,t}$ is the volatility of the real pricing kernel for currency i at time t. Asymptotic standard errors are in parentheses and the t-statistics are in brackets.

No.	Currency j	Currency i	c_0	c_1	c_2	LL	No.	Currency j	Currency i	c_0	c_1	c_2	LL
1	USD	CAD	0.012	-0.001	-0.001	121.9	7	CAD	U.S.	-0.013	0.002	0.002	150.7
			(0.006)	(0.001)	(0.001)					(0.005)	(0.001)	(0.001)	
			[2.10]	[0.94]	[1.71]					[2.74]	[2.14]	[2.53]	
2	USD	UK	-0.033	-0.000	0.004	-56.0	8	UK	USD	0.022	0.001	-0.002	55.2
			(0.011)	(0.000)	(0.001)					(0.009)	(0.0005)	(0.001)	
			[3.06]	[1.15]	[3.15]					[2.56]	[2.74]	[2.27]	
3	USD	DM	0.022	0.002	-0.004	-36.1	9	DM	USD	-0.257	-0.029	0.027	13.2
			(0.014)	(0.001)	(0.001)					(0.052)	(0.006)	(0.005)	
			[1.56]	[3.00]	[2.71]					[4.95]	[4.68]	[4.94]	
4	USD	JY	0.033	0.002	-0.003	-32.0	10	JY	USD	-0.071	-0.0001	0.005	-106.4
			(0.014)	(0.002)	(0.001)					(0.016)	(0.001)	(0.001)	
			[2.30]	[1.15]	[2.82]					[4.33]	[0.14]	[3.60]	
5	JY	DM	27.749	-0.112	-2.801	-44.0	11	DM	JY	-0.622	0.151	-0.022	29.9
			(7.144)	(0.221)	(0.740)					(0.153)	(0.044)	(0.011)	
			[3.84]	[0.52]	[3.79]					[4.07]	[3.80]	[1.91]	
6	DM	UK	0.116	-0.014	0.021	-29.3	12	UK	DM	0.170	0.007	-0.027	-11.4
			(0.191)	(0.006)	(0.025)					(0.050)	(0.002)	(0.008)	
			[0.61]	[2.45]	[0.86]					[3.39]	[2.83]	[3.35]	

Table 10B

Cointegration Regression Results for Simplified Model of the Forward Premium including Exchange Rate Volatility

The table reports parameter estimates for the cointegrating regression with stochastic σ_S:

$$\frac{S_{i,j,t+1} - F_{i,j,t}}{S_{i,j,t}} = c_0 + c_1 \hat{\eta}_{i,t} + c_2 \sigma_S + \epsilon.$$

where $S_{i,j,t}$ and $F_{i,j,t}$ denote the spot and one month forward exchange rates between currencies i and j at time t measured in currency units of i per currency unit of j and $\eta_{i,t}$ is the volatility of the real pricing kernel for currency i at time t. Asymptotic standard errors are in parentheses and the t-statistics are in brackets.

No.	Currency j	Currency i	c_0	c_1	c_2	LL	No.	Currency j	Currency i	c_0	c_1	c_2	LL
1	USD	CAD	0.018	-0.006	-0.002	330.4	7	CAD	USD	-0.012	0.010	0.002	374.3
			(0.008)	(0.005)	(0.001)					(0.004)	(0.004)	(0.001)	
			[2.21]	[1.31]	[2.10]					[2.76]	[2.37]	[2.73]	
2	USD	UK	-0.021	-0.001	0.003	314.8	8	UK	USD	0.030	0.009	-0.003	331.3
			(0.010)	(0.001)	(0.001)					(0.010)	(0.005)	(0.001)	
			[2.16]	[0.50]	[2.45]					[3.17]	[1.84]	[2.97]	
3	USD	DM	0.016	0.023	-0.003	117.8	9	DM	USD	-0.747	-0.926	0.081	175.0
			(0.013)	(0.004)	(0.001)					(0.174)	(0.216)	(0.019)	
			[1.21]	[5.34]	[2.91]					[4.28]	[4.28]	[4.30]	
4	USD	JY	0.023	0.027	-0.002	247.8	8	JY	USD	-0.054	-0.008	0.004	211.2
			(0.023)	(0.025)	(0.001)					(0.017)	(0.013)	(0.001)	
			[1.02]	[1.06]	[1.84]					[3.27]	[0.57]	[2.61]	
5	JY	DM	-0.061	0.006	0.005	94.8	11	DM	JY	11.540	-12.566	-0.431	171.3
			(0.051)	(0.013)	(0.004)					(2.101)	(2.328)	(0.081)	
			[1.19]	[0.42]	[1.25]					[5.49]	[5.40]	[5.31]	
6	DM	UK	0.145	-0.046	-0.004	169.1	12	UK	DM	0.086	0.039	-0.015	120.3
			(0.028)	(0.009)	(0.003)					(0.034)	(0.012)	(0.005)	
			[5.11]	[5.19]	[1.16]					[2.49]	[3.12]	[3.04]	

Figure 1
Time Series of Implied One-Month Foreign Exchange Volatilities

The figure plots the time series of the implied one-month foreign exchange volatilities of the US dollar for the Canadian dollar, the British pound, the German Mark and the Japanese Yen and of the Japanese Yen for the German Mark and of the German Mark for the British Pound from October 1994 to May 2002. The implied volatility is in percent per year.

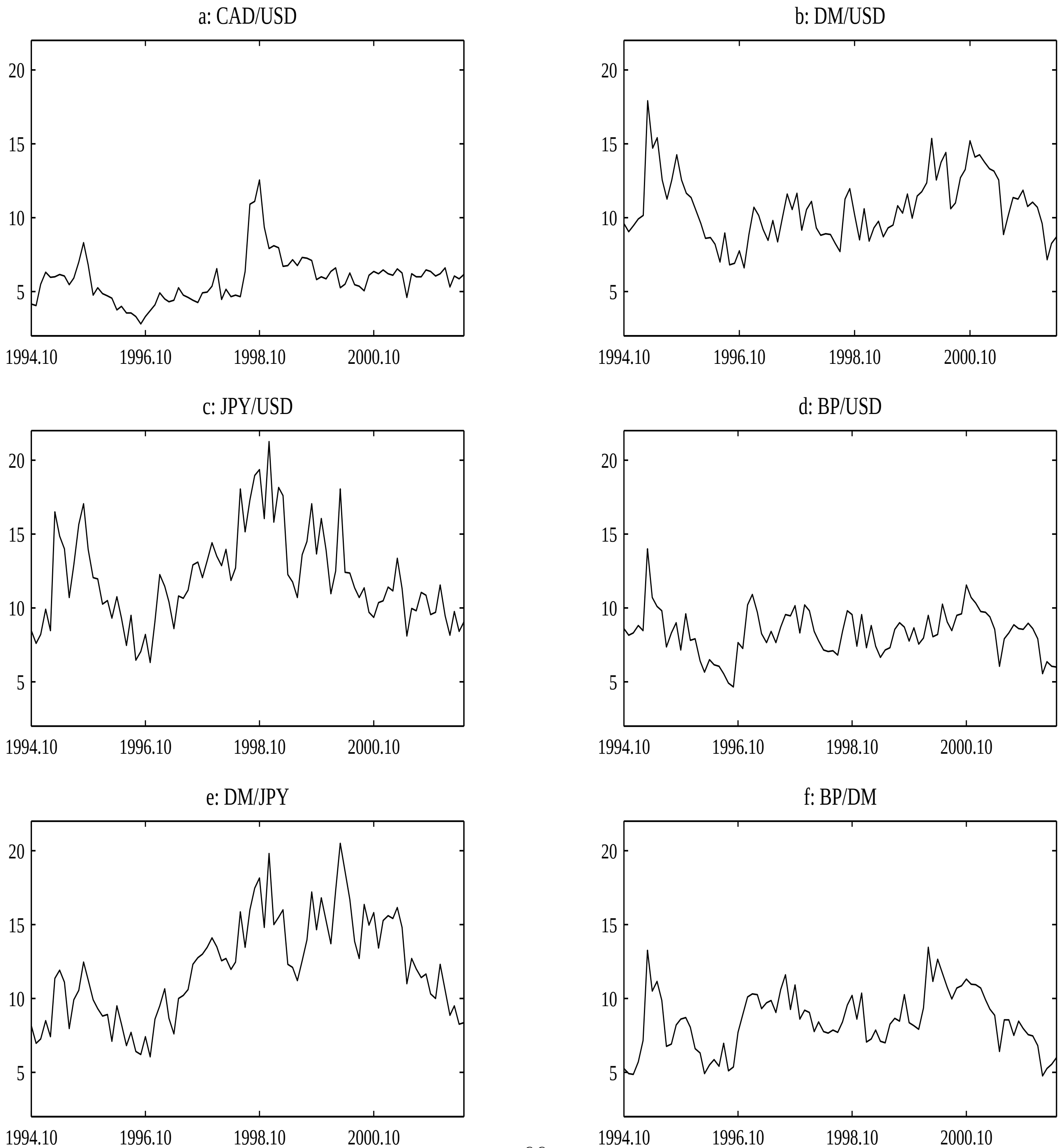

Figure 2
Time Series of Real Interest Rate Estimates

The figure plots the estimated real interest rate for the United States, Canada, the United Kingdom, Germany and Japan from January 1985 to May 2002. The series are estimated from bond yield and inflation data.

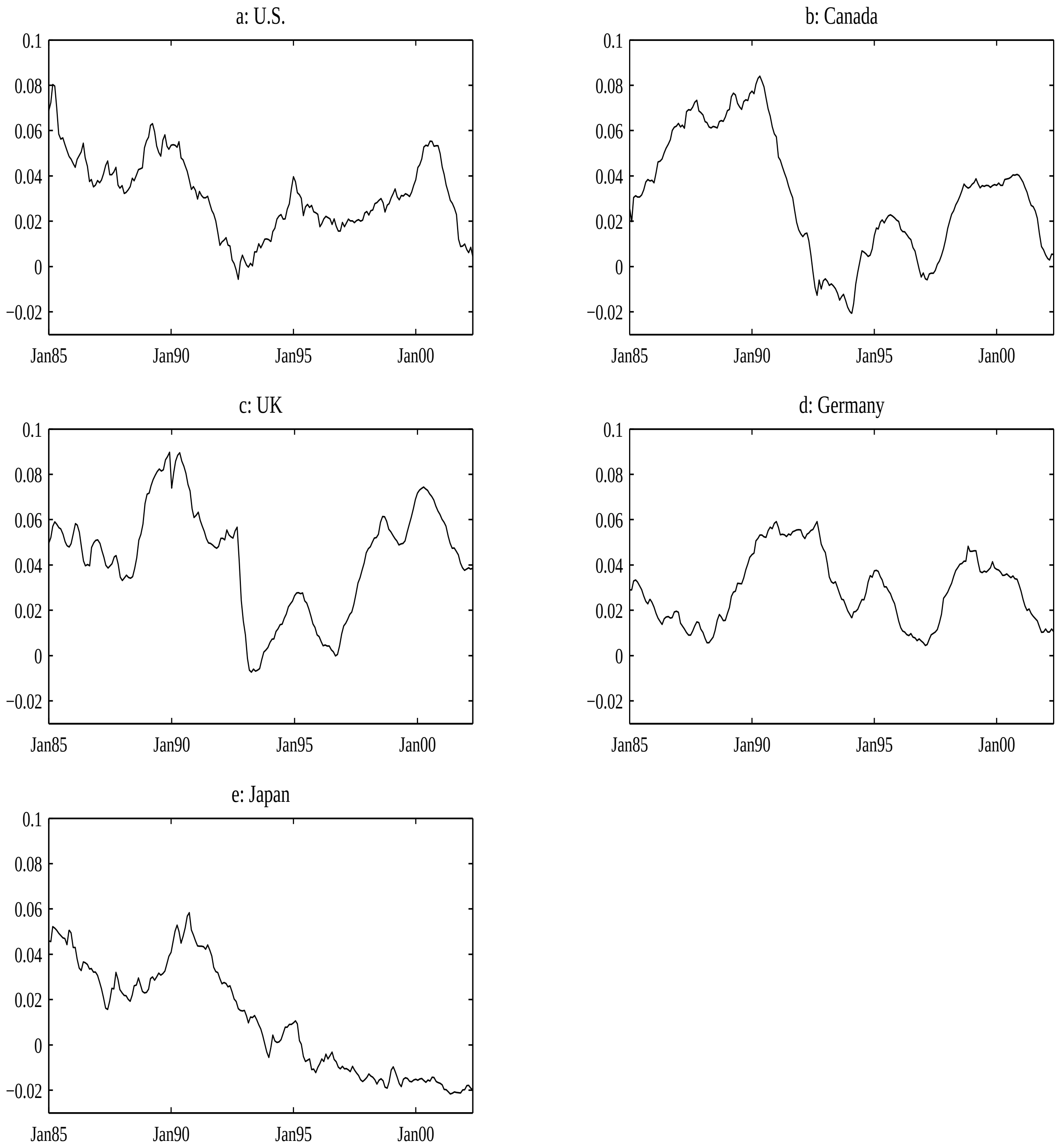

Figure 3
Time Series of Expected Inflation Estimates

The figure plots the estimated expected inflation for the United States, Canada, the United Kingdom, Germany and Japan from January 1985 to May 2002. The series are estimated from bond yield and inflation data.

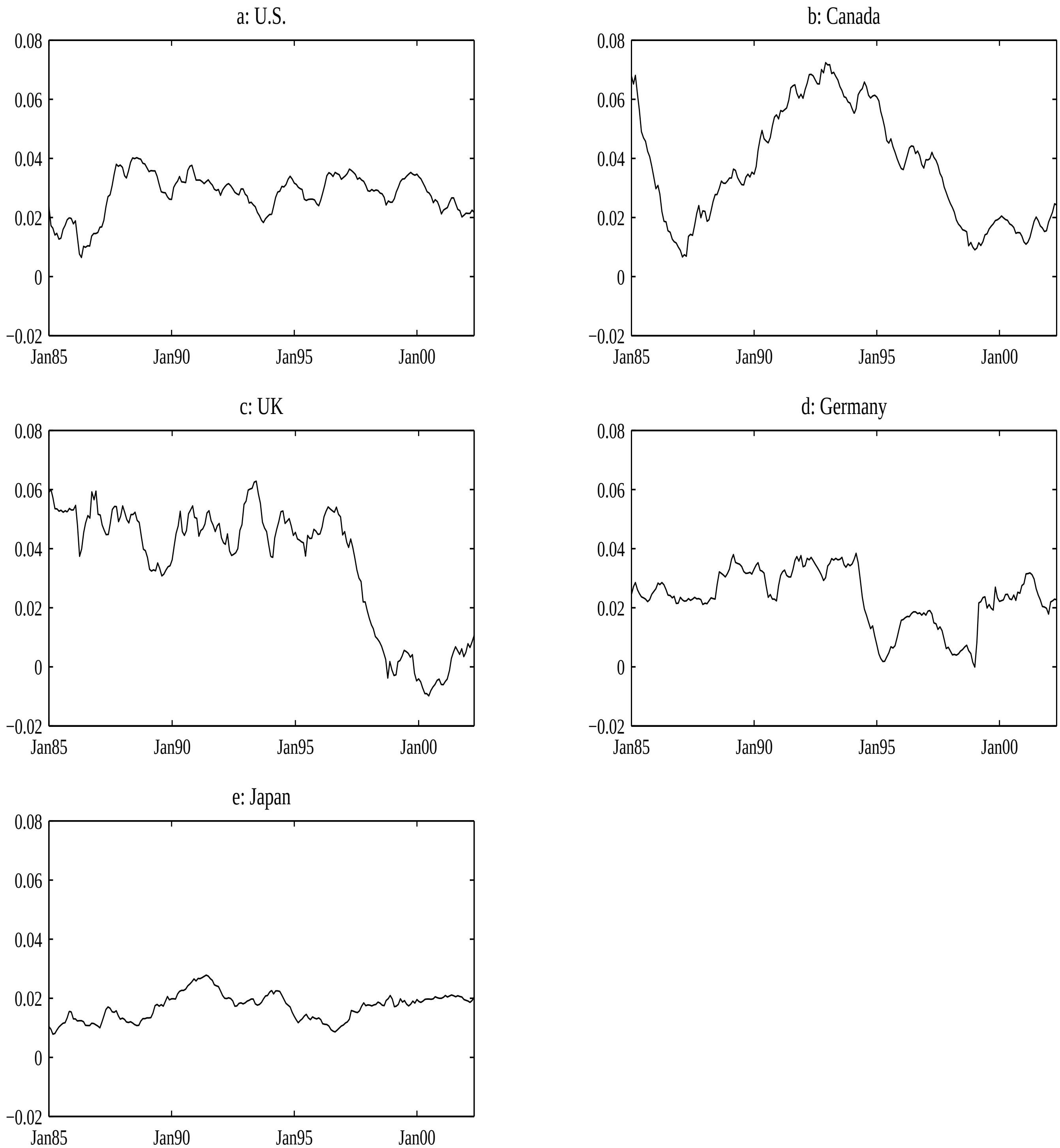

Figure 4

Time Series of Maximum Sharpe Ratio Estimates

The figure plots the estimated Sharpe ratio for the United States, Canada, the United Kingdom, Germany and Japan from January 1985 to May 2002. The series are estimated from bond yield and inflation data.