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Abstract

The goal of this study is to measure market prices of risk and the associated foreign exchange risk premia extending the approach proposed by Balduzzi and Robotti (2001) to an international framework. Estimations of minimum variance stochastic discount factors permits the determination of market prices of risk, which, in turn, in an international framework, allow to compute foreign exchange risk premia. Market prices of risk are time-varying and surge during financial turmoil. This may be interpreted as an increase of the investors' coefficient of risk aversion during turbulent financial markets. Foreign exchange risk premia are also time-varying and they exhibit most variation from the early '70s onwards, when the Bretton Wood exchange rate system collapsed.

Keywords: Foreign exchange; risk premia; pricing kernel
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1. Introduction

Ex-post changes in foreign exchange rates and survey-based measures of foreign exchange rate expectations provide evidence for the existence of foreign exchange risk premia. The Uncovered Interest rate Parity (*UIP*) condition has been failing when confronted with actual data, either because investors are not fully rational, or because they are risk averse, and, as such, they require an exchange rate risk premium, or due to a combination of irrational behaviour and risk aversion. A large literature has been developed over the years trying to estimate foreign exchange risk premia (see the surveys of Hodrick (1987) and Engle (1996)). Later on, further attempts are due to De Santis and Gerard (1998), Beakert and Gray (1998), Cappiello (1998), Tai (1999), De Santis, Gerard, and Hillion (1999), and Cappiello, Castren, and Jääskelä (2002), among others. Apart from Bekaert and Gray, who developed an empirical model of exchange rates in a target zone framework, all the above pieces of research estimate the exchange rate risk premia in the context of the International Capital Asset Pricing Model (ICAPM) of Adler and Dumas (1983). Conditional estimates of the ICAPM provide evidence of a significant time-varying exchange rate risk premium.

CAPM-type frameworks require a specification for the underlying stochastic discount factor or pricing kernel (see, for instance, Cochrane, 2001). The pricing kernel is a stochastic variable which is related to the (intertemporal) marginal utility of consumption and determines the way investors discount future uncertain payoffs. In the absence of arbitrage, the expected value of the product of the pricing kernel and the asset payoff returns all asset prices. Differently to the studies mentioned above we use a general no-arbitrage model, where the stochastic discount factor is not restricted to assume any particular form. More specifically, the objective of our work is to estimate stochastic discount factors or pricing kernels for several countries which, in turn, can be used to compute foreign exchange risk premia. The use of this approach for foreign exchange risk premia has been examined by Flesaker and Hughston (1997), Backus, Foresi and Telmer (1998), Brandt, Cochrane and Santa-Clara (2001) and Panigirtzoglou (2003).

Our framework does not assume market completeness, that is, we allow for non-traded (or not hedged) sources of risk. In this case, the pricing kernel is not unique. However, we focus on one of all admissible pricing kernels, that with the minimum variance. This is because no-arbitrage condition imposes a relationship between the minimum-variance pricing kernels of investors in two currencies and the exchange rate changes. The currencies that we

examine are the US dollar, the euro and pound sterling. We initially estimate the pricing kernel from the point of view of the US dollar investor (that is, the US dollar pricing kernel) using Generalized Method of Moments (GMM) approach described in Cochrane (1996) and Balduzzi and Robotti (2001), among others. We then use the no-arbitrage equations that link changes to exchange rates and pricing kernels to estimate the pricing kernels for euro and pound sterling investors.

The estimation of the minimum variance pricing kernel in the three economies allows us to compute the market prices of risk (that is, the volatility of the pricing kernels), which, in turn, are related to foreign exchange risk premia. The patterns and sizes of the risk premia are examined with respect to subsequent changes of exchange rates. The size and volatility of the derived risk premia are small compared to the ex-post changes in the exchange rates.

The paper is organized as follows: section 2 discusses the methodology we employ, section 3 describes the data used, section 4 reports the results and section 5 concludes.

2. *Methodology*

When there are no arbitrage opportunities the basic valuation equation is given by

$$E_t\left(\mathbf{R}_{t+1} m_{t+1}\right) = \boldsymbol{\iota}, \tag{1}$$

where $\mathbf{R}_{t+1}$ is a vector of N risky real asset returns, m_{t+1} is the domestic investor's pricing kernel, $\boldsymbol{\iota}$ is an N-vector of ones, while $E_t(\cdot)$ is the expectation operator conditional on the information set Ω_t. Equation (1) simple expresses the price of an asset as the expected discounted value of its future payoffs. The discounting is determined by the pricing kernel, which, in a simple representative agent framework, is related to investor's preferences. In the spirit of Lucas' (1978) consumption-based asset pricing model, the pricing kernel can be shown to be equal to the intertemporal marginal rate of substitution, $m_t = \delta U'(C_{t+1})/U'(C_t)$, where δ is the time discount factor. Campbell, Lo, and MacKinlay (1997) show that the lower the covariance between an asset return and the stochastic discount factor, the larger the asset expected returns. The rationale behind this finding is appealing. A security which exhibits low covariance with m_t tends to have low returns when investor's marginal utility of consumption is high, that is when consumption is low. Since this asset does not deliver wealth when the consumer needs it most, it is risky and it will command a large risk premium. In

other words, the lower the wealth expected in a particular state, the more valuable the wealth in this state becomes and the higher the marginal utility of consumption.

An equation similar to (1) holds for the vector $\mathbf{R}^f_{t+1} = \mathbf{R}_{t+1}\left(\frac{e_{t+1}}{e_t}\right)$ of real foreign asset returns and a foreign investor with pricing kernel m^f_{t+1} (when the *N* assets are traded in both domestic and foreign currency). e_t is the vector of spot real exchange rates, defined as the price of one unit of domestic consumption good in terms of foreign consumption good:

$$E_t\left(\mathbf{R}^f_{t+1} m^f_{t+1}\right) = \iota \Rightarrow E_t\left(\mathbf{R}_{t+1}\frac{e_{t+1}}{e_t} m^f_{t+1}\right) = \iota . \tag{2}$$

When markets are complete (that is, any source of uncertainty can be perfectly hedged using existing assets) the pricing kernel is unique. Since equations (1) and (2) hold for all *N* assets, the following relation should be satisfied by the two pricing kernels:

$$\frac{e_{t+1}}{e_t} m^f_{t+1} = m_{t+1} . \tag{3}$$

In scalar notation and using natural logarithms equation (3) becomes:

$$\ln\left(\frac{e_{t+1}}{e_t}\right) = \ln\left(m_{t+1}\right) - \ln\left(m^f_{t+1}\right). \tag{3'}$$

Equation (3') shows that the change in the real exchange rate is given by the difference between two pricing kernels, the domestic and the foreign. A decrease in marginal utility of consumption, that is in the domestic pricing kernel, (e.g. because of a positive productivity shock which in turn increases supply in the home country), leads to a depreciation in the price of domestic consumption goods relative to foreign consumption goods.

When markets are not complete there are more than one admissible pricing kernels, that is, different investors' pricing kernels are not equalized. Hansen and Jagannathan (1991) show that the set of admissible pricing kernels should satisfy some restrictions given a set of asset returns. In particular, within the set of admissible pricing kernels, the one that exhibits minimum variance should be equal to the maximum Sharpe ratio. The Sharpe ratio is the expected excess return (over the risk-free rate) per unit of return volatility. It can be easily shown that the pricing kernel volatility is related to the Sharpe ratio and, in particular, that assets with high Sharpe ratios restrict the volatility of the pricing kernel to be high (see Appendix *A*). Hansen and Jagannathan (1991) demonstrate that the minimum-variance pricing

kernel is the projection of each individual's pricing kernel on the space of asset payoffs, i.e. it is a linear combination of existing asset returns.

As explained in Balduzzi and Robotti (2001), when markets are incomplete, the use of the minimum-variance pricing kernel has an advantage over traditional multi-beta models because it is not necessary to identify all sources of risk or to assume linearity of returns with respect to the factors. Furthermore, the precision of risk premia estimates is higher since the pricing kernel with the minimum variance is used. Most importantly, though, provided that the minimum-variance pricing kernel is adopted, equation (3) still holds in the incomplete market framework.

To see this, consider again equations (1) and (2). Equation (3) was derived based on the assumption that the two pricing kernels m_{t+1} and m_{t+1}^{f} in equations (1) and (2) are unique. When markets are incomplete, investors' pricing kernels may be different. For example, given a domestic investor's pricing kernel m_{t+1}, any one of the form $m_{t+1} + u_{t+1}$, where u_{t+1} is a random variable uncorrelated with available (traded) asset returns, is an admissible pricing kernel. However, since the minimum variance price kernel is the projection of each individual's pricing kernel on the space of asset payoffs, it has to be unique for all individuals (see Cochrane (2001) for further details). Therefore, the assumption of uniqueness of the two pricing kernels (used in the derivation of equation (3)) holds for the minimum variance pricing kernels. As a result, equation (3) holds for the minimum variance pricing kernels.

Hence, in this paper we adopt the approach of Balduzzi and Robotti (2001) and Brandt, Cochrane and Santa-Clara (2001) and work with the minimum-variance pricing kernels. Equation (3) implies that given an estimate of the domestic currency investor's minimum-variance pricing kernel and the foreign exchange rate changes, we can obtain the foreign currency investor's minimum-variance pricing kernel. Moreover, if we consider three bilateral exchange rate changes, we only need to specify one pricing kernel. The other two are determined by the foreign exchange rate changes. In particular, for the three bilateral exchange rates, *DEMUSD* (value of Deutschemark in dollars), *GBPUSD* (value of pound sterling in dollars) and *GBPDEM* (value of pound sterling in Deutschemarks) and the three minimum-variance real pricing kernels, equation (3) reads as follows:

$$ln\left[\frac{DEMUSD_{t+1}\cdot\left(P_{t+1}^{GER}/P_{t+1}^{USD}\right)}{DEMUSD_t\cdot\left(P_t^{GER}/P_t^{USD}\right)}\right]=ln\left(m_{t+1}^{GER}\right)-ln\left(m_{t+1}^{US}\right), \quad (5)$$

$$ln\left[\frac{GBPUSD_{t+1}\cdot\left(P_{t+1}^{GBP}/P_{t+1}^{USD}\right)}{GBPUSD_t\cdot\left(P_t^{GBP}/P_t^{USD}\right)}\right]=ln\left(m_{t+1}^{UK}\right)-ln\left(m_{t+1}^{US}\right) \quad (6)$$

$$ln\left[\frac{GBPDEM_{t+1}\cdot\left(P_{t+1}^{GBP}/P_{t+1}^{GER}\right)}{GBPDEM_t\cdot\left(P_t^{GBP}/P_t^{GER}\right)}\right]=ln\left(m_{t+1}^{UK}\right)-ln\left(m_{t+1}^{GER}\right) \quad (7)$$

where $P_t^{USD}, P_t^{GBP}, P_t^{GER}$ are the price levels in United States, United Kingdom and Germany respectively.

The variables

$DEMUSD_t^{real}=DEMUSD_t\cdot\left(P_t^{GER}/P_t^{USD}\right)$,

$GBPUSD_t^{real}=GBPUSD_t\cdot\left(P_t^{GBP}/P_t^{USD}\right)$ and

$GBPDEM_t^{real}=GBPDEM_t\cdot\left(P_t^{GBP}/P_t^{GER}\right)$

correspond to the real exchange rates.

We first estimate econometrically the US dollar investor's real pricing kernel, m_{t+1}^{US}, and obtain the other two pricing kernels, m_{t+1}^{GER} and m_{t+1}^{UK}, from equations (5) and (6). It is shown in Appendix *B* that the results do not depend on the choice of the pricing kernel to be initially estimated (the US dollar investor's pricing kernel in our case). The results are equivalent to estimating initially the pound sterling or Deutschemark investor's pricing kernel and using the system of equations (5) to (7) to derive the other two pricing kernels.[1]

In the spirit of Cochrane (1996) and Balduzzi and Robotti (2001), among others, we estimate the US dollar investor's real pricing kernel m_{t+1}^{US} with a GMM methodology. To derive the system of equations to be estimated we use equation (1). Pricing the risk-free asset, whose real gross return rf_t is know at time *t*, implies that

$$E_t\left(rf_t\cdot m_{t+1}\right)=1\Rightarrow E_t\left(q_{t+1}\right)=1, \quad (8)$$

[1] Given the restriction that differences in pricing kernels are driven by exchange rate changes, equations (5)-(7) are equivalent. Therefore there would be no gain in efficiency in estimating the three pricing kernels simultaneously. In fact, the simultaneous estimation of the three equations would be redundant.

where $q_{t+1} = rf_t \cdot m_{t+1}$ is the normalized pricing kernel. By the same token, pricing a vector of risky-assets with real gross returns $\mathbf{R}_{t+1}$ implies that

$$E_t(\mathbf{R}_{t+1} \cdot m_{t+1}) = \boldsymbol{\iota} \Rightarrow E_t(\mathbf{R}_{t+1} \cdot q_{t+1}) = \boldsymbol{\iota} \cdot rf_t . \tag{9}$$

As already mentioned if the pricing kernel is the one with the minimum variance, it will be the projection on the space of asset returns, and hence it can be written as a linear combination of asset returns

$$q_{t+1} = a_t + \mathbf{b}_t' \cdot \mathbf{R}_{t+1} . \tag{10}$$

By combining (9) and (10) we derive expressions for a_t and $\mathbf{b}_t$ as follows:

$$\mathbf{b}_t = -\Sigma_{rrt}^{-1}\left[E_t(\mathbf{R}_{t+1}) - \boldsymbol{\iota} \cdot rf_t\right] \text{ and } a_t = 1 - \mathbf{b}_t' \cdot E_t(\mathbf{R}_{t+1}) \tag{10b}$$

Equation (10) in its general form allows for time varying coefficients a_t and $\mathbf{b}_t$. However, the focus of our exercise is to estimate the *average* response of the pricing kernel to asset returns over the sample period, that is, we assume that a_t and $\mathbf{b}_t$ are constant. The derivation of time varying a_t and $\mathbf{b}_t$ is a more formidable task and it is beyond the scope of this paper. In addition, the assumption that a_t and $\mathbf{b}_t$ are constant is not very restrictive when several risky asset returns are assumed to impact on the pricing kernel.

To see this, let's assume first that the pricing kernel is a linear function of the return of only one risky asset. It is easy to see from restrictions (10b) that the constancy assumption for a_t and $\mathbf{b}_t$ implies constant return and volatility for the risky asset and thus constant market price of risk. However, the system becomes less restrictive if we assume two risky assets. In this case, we have five free parameters (two returns, two volatilities and a correlation coefficient) and three restrictions from equations (10b). Increasing the number of risky assets relaxes the restrictiveness even more. In our case we use eight risky assets, which corresponds to 44 free parameters and only 9 restrictions.

Equations (8) to (10) are used to derive the moment conditions. If $\mathbf{z}_t$ represents the set of *s* instruments, the sample moment conditions can be written as follows:

$$(1/T)\sum_{t=1}^{T}(a + \mathbf{b}' \cdot \mathbf{R}_{t+1} - 1) \odot \mathbf{z}_t = \mathbf{0} , \tag{8'}$$

$$(1/T)\sum_{t=1}^{T}\left[\left(a+\mathbf{b}'\cdot\mathbf{R}_{t+1}\right)\cdot\mathbf{R}_{t+1}-\boldsymbol{\iota}\cdot rf_t\right]\odot\mathbf{z}_t=\mathbf{0}, \tag{9'}$$

where $\mathbf{0}$ is a *s*-vector of zeros. $\odot$ represents the Hadamard (element by element) matrix product.

We consider eight risky assets, that is, the vector $\mathbf{R}_{t+1}$ has dimension eight by one. Therefore there are nine equations in total. The risky assets used are a US equity index, the US long-term bond, a UK equity index, the UK long-term bond, a German equity index, the German long-term bond, and pound sterling and Deutschemark money market accounts.[2] All returns are gross returns in US dollars since we take the point of view of the US dollar investor and are deflated by US inflation to be converted to real returns. A detailed description of the equations used in the estimation of the US normalized pricing kernel can be found in Appendix *C*.

The system of nine equations is estimated using different instruments for each equation. Lagged values (time *t* information) of the following information variables are used as instruments: the equity index dividend yield, the term spread (defined as the difference between the long-term yield and the short rate), the one-period change in the short rate, and equity, long-term bond and foreign exchange rate real returns for all three currencies. The choice of instruments is motivated by the literature on equity, bond and foreign exchange return predictability and is further discussed in the next sections.[3]

The estimation of the three pricing kernels allows us to compute the market prices of risk and hence foreign exchange risk premia. Equation (A2) in Appendix *A* describes the stochastic process followed by the logarithm of the pricing kernel:

$$ln\left(m_{t+1}\right)=-rf_t-\frac{1}{2}\lambda_t^2-\lambda_t\Delta W_{t+1}, \tag{11}$$

[2] In this study we use major financial asset classes. Securities like real estate, private equities or even hedge funds could be considered in the analysis. However, limitations due to data availability prevent us from doing so.

[3] Notice that results are not sensitive to the choice of instruments.

where $rf_t = ln(Rf_t)$ is the logarithmic return of the risk-free asset in the domestic economy, λ_t is the volatility of the domestic investor's pricing kernel, that is, the market price of risk, and W_{t+1} is a source of uncertainty.

A similar equation holds for the pricing kernel of the foreign investor:

$$ln\left(m_{t+1}^f\right) = -rf_t^f - \frac{1}{2}\left(\lambda_t^f\right)^2 - \lambda_t^f \Delta W_{t+1}^f, \tag{11b}$$

where the superscript f denotes variables from the point of view of the foreign investor. Combining equation (3'), (11) and (11b) we derive the following relationship:

$$ln\left(\frac{e_{t+1}}{e_t}\right) = rf_t^f - rf_t + \frac{1}{2}\left[\left(\lambda_t^f\right)^2 - \lambda_t^2\right] - \lambda_t \Delta W_{t+1} + \lambda_t^f \Delta W_{t+1}^f \Rightarrow$$

$$E_t\left[ln\left(\frac{e_{t+1}}{e_t}\right)\right] = \left(rf_t^f - rf_t\right) + \frac{1}{2}\left[\left(\lambda_t^f\right)^2 - \lambda_t^2\right]. \tag{12}$$

Equation (12) is the Uncovered Interest rate Parity (*UIP*) condition augmented by risk premia. The first term on the right-hand side is the interest rate differential. If there is no uncertainty in the economy or investors are risk neutral, the proportional change in the exchange rate would be driven only by differences in the one-period bond (risk-free) rates in the two currencies, i.e. $\left(rf_t^f - rf_t\right)$: a higher domestic risk-free rate compensates investors for an expected depreciation of the domestic currency in terms of foreign currency. However, when there is uncertainty in the economy and investors require compensation for that, an exchange rate risk premium $\frac{1}{2}\left[\left(\lambda_t^f\right)^2 - \lambda_t^2\right]$ appears in the *UIP* equation. As explained in Appendix *A*, the market price of risk λ_t is defined as the excess return (compensation for risk) per unit of volatility (quantity of risk). Similarly to the risk-free rate differential, a higher excess return per unit of volatility in the domestic risky assets compensates investors for an expected depreciation of the domestic currency in terms of foreign currency. The term $\frac{1}{2}\left[\left(\lambda_t^f\right)^2 - \lambda_t^2\right]$ also includes a convexity adjustment component due to the use of the logarithm of the real exchange rate in the *UIP* equation (12).

3. Data

In this section we describe the data used in equations (8') and (9'). Data are observed at monthly frequency, from September 1953 to December 2002 and were taken from the *Global Financial Data Inc.* database (http://www.globalfindata.com).

For the real risk-free rate rf_t we choose the one-month Treasury bill rates deflated by the one-month change in Consumer Price Index in the three countries. The Treasury bill rate is derived from the change in the Treasury bill total return index. The equations for the real risk-free rates in the three currencies are given below:

$$rf_t^{US} = \frac{TB_t^{US}}{TB_{t-1}^{US}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}},$$

$$rf_t^{UK} = \frac{TB_t^{UK}}{TB_{t-1}^{UK}} \Big/ \frac{CPI_t^{UK}}{CPI_{t-1}^{UK}},$$

$$rf_t^{GER} = \frac{TB_t^{GER}}{TB_{t-1}^{GER}} \Big/ \frac{CPI_t^{GER}}{CPI_{t-1}^{GER}}$$

The risky asset returns R_{t+1} are the one-month gross total[4] real[5] returns in US dollars of:

- US *S&P 500* Composite total return index, (SP_t);
- UK *FT*-Actuaries All-Share total return index, (FT_t);
- German *CDAX* total return index, (DAX_t);
- US ten-year government bond total return index, (GB_t^{US});
- UK ten-year government bond total return index, (GB_t^{UK});
- German ten-year government bond total return index, (GB_t^{GER});
- *GBPUSD* returns, that is, the real return in dollars of investing in a pound sterling money market account, where *GBPUSD* is the nominal exchange rate, (R_t^{GBPUSD});
- *DEMUSD* returns, that is, the returns in dollars of investing in a Deutschemark money market account, where *DEMUSD* is the nominal exchange rate, (R_t^{DEMUSD}).

The equations for risky asset returns are given below:

$$R_{eq,t}^{US} = \frac{SP_t}{SP_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}},$$

[4] Total returns include dividend or coupon payments along with capital gains.

[5] As with the risk free real rates, we deflate nominal returns by the consumer price index to convert to real returns.

$$R_{eq,t}^{UK} = \frac{FT_t}{FT_{t-1}}\left[\frac{GBPUSD_t}{GBPUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right],$$

$$R_{eq,t}^{GER} = \frac{DAX_t}{DAX_{t-1}}\left[\frac{DEMUSD_t}{DEMUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right],$$

$$R_{gb,t}^{US} = \frac{GB_t^{US}}{GB_{t-1}^{US}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}},$$

$$R_{gb,t}^{UK} = \frac{GB_t^{UK}}{GB_{t-1}^{UK}}\left[\frac{GBPUSD_t}{GBPUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right],$$

$$R_{gb,t}^{GER} = \frac{GB_t^{GER}}{GB_{t-1}^{GER}}\left[\frac{DEMUSD_t}{DEMUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right],$$

$$R_t^{GBPUSD} = \frac{TB_t^{UK}}{TB_{t-1}^{UK}}\left[\frac{GBPUSD_t}{GBPUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right],$$

$$R_t^{DEMUSD} = \frac{TB_t^{GER}}{TB_{t-1}^{GER}}\left[\frac{DEMUSD_t}{DEMUSD_{t-1}} \Big/ \frac{CPI_t^{US}}{CPI_{t-1}^{US}}\right].$$

As far as the instruments are concerned, we use lagged values of the above risky asset returns, as defined above, along with the following variables:

- the three equity index dividend yields, DY_t^{SP}, DY_t^{FT}, and DY_t^{DAX};

- the three currencies yield curve slopes, $\left(CY_t^{US}, CY_t^{UK}, CY_t^{GER}\right)$, which is the differences in the monthly logarithmic change of the ten-year government bond total return index less the monthly logarithmic change of the Treasury bill total return index,

- the monthly change in the one-month nominal short-rate (Treasury bill), drf_t^{US}, drf_t^{UK}, drf_t^{GER}, where the nominal short rate is based on the monthly logarithmic change of the Treasury Bill index in the three currencies.

The equations for the last two sets of instruments are given below:

$$CY_t^{US} = ln\left(\frac{GB_t^{US}}{GB_{t-1}^{US}}\right) - ln\left(\frac{TB_t^{US}}{TB_{t-1}^{US}}\right),$$

$$CY_t^{UK} = ln\left(\frac{GB_t^{UK}}{GB_{t-1}^{UK}}\right) - ln\left(\frac{TB_t^{UK}}{TB_{t-1}^{UK}}\right),$$

$$CY_t^{GER} = ln\left(\frac{GB_t^{GER}}{GB_{t-1}^{GER}}\right) - ln\left(\frac{TB_t^{GER}}{TB_{t-1}^{GER}}\right),$$

$$drf_t^{US} = ln\left(\frac{TB_t^{US}}{TB_{t-1}^{US}}\right) - ln\left(\frac{TB_{t-1}^{US}}{TB_{t-2}^{US}}\right),$$

$$drf_t^{UK} = ln\left(\frac{TB_t^{UK}}{TB_{t-1}^{UK}}\right) - ln\left(\frac{TB_{t-1}^{UK}}{TB_{t-2}^{UK}}\right),$$

$$drf_t^{GER} = ln\left(\frac{TB_t^{GER}}{TB_{t-1}^{GER}}\right) - ln\left(\frac{TB_{t-1}^{GER}}{TB_{t-2}^{GER}}\right).$$

Table 1 reports descriptive statistics of monthly returns on the stock market, government bond, and T-bill indices for US, UK, and Germany, respectively; log changes in DEM/USD, USD/GBP, and DEM/GBP exchange rates; and annualized inflation rates for US, UK, and Germany, respectively.[6] There is strong evidence of excess skewness and leptokurtosis, a clear sign of non-normality, which is confirmed by the Jarque-Bera normality test. Table 2 contains summary statistics of instruments and Table 3 the unconditional correlations. As expected, correlation tend to increase among instruments belonging to the same class.

4. Results

The system of the nine pricing equations (8) and (9) is estimated with GMM. The instrumental variables which are used differ across equations. In the equity index pricing equations, the term spread, the dividend yield and the change in the short rate have been found to be significant in the literature on equity return predictability; the lagged equity return variables capture potential momentum effects; the lagged value of same currency long-term bond index return captures potential links between bond and equity markets. In the case of UK and German equity index returns, lagged values of the US equity index returns are also included to capture international equity market linkages. In the long-term bond index pricing equations, the term spread, the change in the short rate have been found to be significant in the bond risk premia determination; the lagged value of the bond index return is included to capture potential momentum effects; the lagged value of same currency equity index return captures potential links between the bond and equity markets; the lagged value of the bond index return is included to capture potential momentum effects; lagged values of other currency bond index returns are incorporated to capture international bond market linkages. In

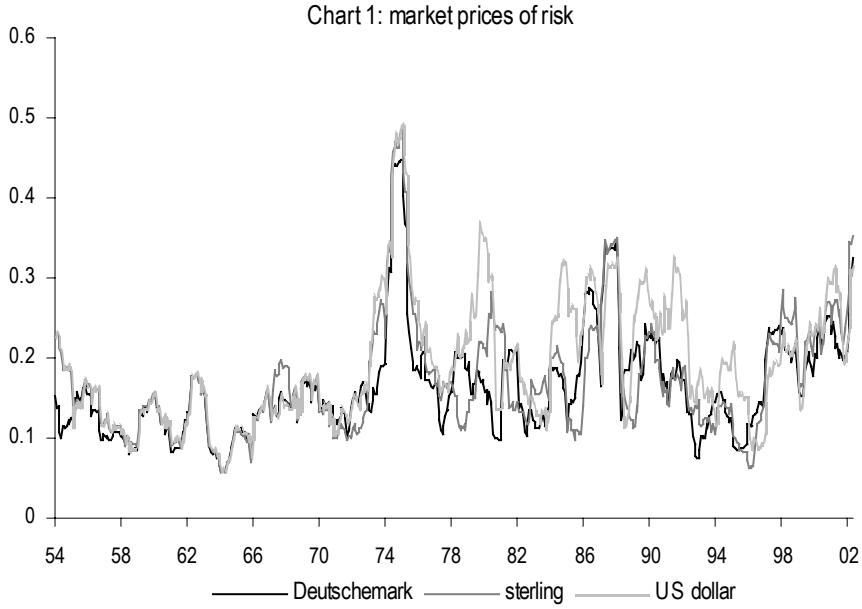
[6] Returns are continuously compounded, while (annualised) inflation rates are computed as log changes of Consumer Price Indices.

the pricing equations of both bond and equity index returns, exchange rate changes are additionally used as instruments to capture the potential information that exchange rates can contain for relative (across countries) equity or bond price movements. Finally, the instruments used in the pricing equations for pound sterling and Deutschemark money market accounts are relative returns in the corresponding currencies equity and bond indices as well as yield curve slopes and short rate changes. Appendix *C* provides a detailed description of the instruments used for each pricing equation.

Since nine instruments are used for each equation (including a constant), apart from the pricing equations for pound sterling and Deutschemark money market accounts where five instruments are used, there are 73 moment conditions for nine parameters, that is, 64 overidentifying restrictions in total. The p-value of the GMM *J*-statistic is 0.15. Therefore the null hypothesis that the sample moments are as close to zero as would be expected if the corresponding population moments were truly zero cannot be rejected.

The results along with the Newey-West (heteroskedasticity and autocorrelation robust) standard errors are shown in Table *B1* in Appendix *B*. Since the pricing kernel is a linear combination of the eight risky asset returns we consider, each of them serves as a risk factor. Therefore, the coefficients reported in Table *B1* provide the sensitivities of the expected return of an asset to these risk factors. All the coefficients are significantly different from zero and negative. This means that positive exposure or covariation to each of the risk factors generates a positive contribution to the risk premium required to hold that risky asset. The three long-term bond index return factors make an exception: they are insignificant for the US dollar and Deutschemark and significant but positive for the pound sterling. This means that exposure to the US dollar and Deutschemark long-term bond return factors is not priced and that a positive exposure to pound sterling long-term bond return factor makes a negative contribution to the risk premium.

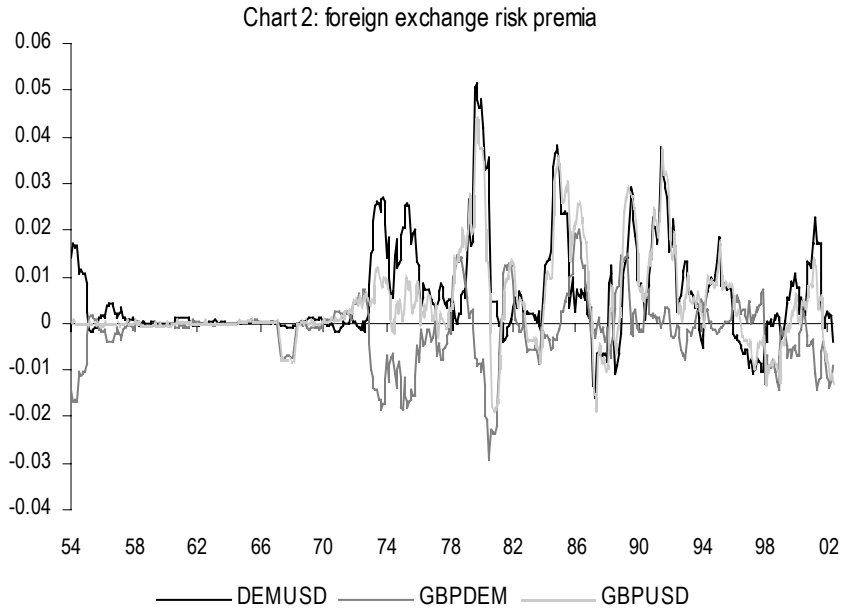
The computation of the Deutschemark and pound sterling investors' pricing kernels is carried out with equations (5) and (6) respectively. A one-year moving average of squared logarithmic changes in the pricing kernels is then used to derive a volatility measure of all three pricing kernels, that is, the market price of risk. The produced market prices of risk are shown in Chart 1.



The averages for the Deutschemark, the pound sterling and the US dollar investor's market price of risk are 0.16, 0.17 and 0.19, respectively. The three market prices of risk are seen to increase in correspondence of financial turmoil, that is during the contraction caused by the first oil shock in 1973, at the time of stock market crashes in 1987 and 1989, during the 1997/1998 Asian-Russian-Latin-American crisis, and finally after the terrorist attacks in 2001. The increase in the value of market prices of risks between 1979 and 1982 could be due to the Federal Reserve policy which deviated from its usual practice of targeting interest rates preferring to control non-borrowed reserves. In asset pricing theory, and in particular in Consumption CAPM (CCAPM) -type models, it is shown that the market price of risk is closely related to investor's coefficient of risk aversion. Therefore, the time evolution assumed by the market prices of risk in figure 1 may have the appealing intuition that investors become more risk averse when financial markets are more turbulent. These results need to be interpreted with caution. As we mentioned earlier, the market prices of risk can depend on investors' risk preferences or macro-economic uncertainty. It is definitely difficult to disentangle the two. Therefore the episodes of a sharp rise in the market price of risk can be associated with both heightened macro-economic uncertainty and increase of risk aversion.

Once market prices of risk are estimated, it is straightforward to compute foreign exchange risk premia through equation (12). Chart 2 reports these premia, which are seen to be quite flat and close to zero until the beginning of the '70s. Not surprisingly this coincides with the collapse of the Bretton Woods adjustable peg exchange rate system. Thereafter, US investors have required, on average, a positive premium to hold Deutschemark and pound

sterling, while, when the point of view of a Deutschemark investor is assumed, she will demand a positive average premium to hold pound sterling.[7] The positive premium required by US investors to hold the two European currencies during the early to mid 1980s could be due to the strong and chronic overvaluation of the US dollar. After the Plaza Agreement (September 1985), during the late 1980s the US dollar declined, which may explain the troughs seen in the foreign exchange rate premia demanded by the US investors. The Louvre Agreement (February 1987) reverted somehow the pattern.



5. Conclusions

The goal of this paper is to measure market prices of risk and the associated foreign exchange risk premia extending to an international framework the approach proposed by Balduzzi and Robotti (2001) for a domestic economy. A general no-arbitrage model where the stochastic discount factor does not have to take on any specific form is considered. Although markets are not assumed to be complete, among the set of possible pricing kernels, we choose the one with minimum variance. This turns out to be the projection of each investor's pricing kernel on the space of asset payoffs. The estimation of stochastic discount factors permits to determine market prices of risk, which, in turn, in an international framework, allow

[7] Notice that since market prices of risk are annualised, the resulted foreign exchange risk premia are per annum. Interestingly, excluding the 1954-1973 period, on average US investors approximately require a 2% premium per year to hold Deutschemarks.

computing foreign exchange risk premia. Market prices of risk are time-varying and increase during financial turmoil. In CCAPM-type models, market prices of risk are proportionally related to investor's coefficient of risk aversion. Therefore, it seems that investors become more risk averse during turbulent financial markets. Foreign exchange risk premia are also time-varying and they exhibit most variation from the early '70s onwards, when the Bretton Wood exchange rate system collapsed.

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APPENDIX A

The goal of this appendix is to show that the standard deviation of the pricing kernel equals the Sharpe ratio corrected for the Jensen's inequality of a security perfectly negatively correlated with the pricing kernel itself.

Consider a one-period risk-free bond with gross return $Rf_t = exp(rf_t)$. Since its payoff at time $t+1$ is certain and equal to £1 in all states of the world, according to equation (1) it will satisfy

$$\frac{1}{Rf_t} = E_t(m_{t+1}), \tag{A1}$$

that is, the pricing kernel is expected to fall according to the risk-free rate. If we take the logarithm of both sides of equation (A1) we get the following approximation

$$E_t\, ln(m_{t+1}) = -rf_t - \frac{1}{2} Var_t[ln(m_{t+1})].$$

The stochastic process of the pricing kernel can then be written as

$$ln(m_{t+1}) = -rf_t - \frac{1}{2}\lambda_t^2 - \lambda_t \Delta W_{t+1}, \tag{A2}$$

where W_{t+1} is the source of uncertainty (negatively related to the pricing kernel) and the quantity $\lambda_t = Stdev_t[ln(m_{t+1})]$ is the volatility of the pricing kernel, commonly referred to as the market price of risk. The market price of risk is the excess return per unit of volatility (or unit of quantity of "risk") of an asset that is perfectly correlated with the source of uncertainty W_t (that is, perfectly negatively correlated with the pricing kernel). To see this, consider equation (1) for the gross return $R_{t+1} = exp(r_{t+1})$ of a risky asset:

$$1 = E_t(m_{t+1} \cdot R_{t+1}) \Rightarrow 0 = E_t[ln(m_{t+1}) + ln(R_{t+1})] + \frac{1}{2} Var_t[ln(m_{t+1}) + ln(R_{t+1})] \Rightarrow$$

$$0 = -rf_t - \frac{1}{2} Var_t(\ln(m_{t+1})) + E_t(r_{t+1}) + \frac{1}{2} Var_t(\ln(m_{t+1})) + \frac{1}{2} Var_t(r_{t+1}) + Cov_t(\ln(m_{t+1}), r_{t+1}) \Rightarrow$$

$$E_t(r_{t+1}) + \frac{1}{2} Var_t(r_{t+1}) - rf_t = -Cov_t[ln(m_{t+1}), r_{t+1}]. \tag{A3}$$

The left hand side of equation (A3) is the excess return of the risky asset (including the convexity adjustment[8]). Consider an asset that is perfectly negatively correlated with the pricing kernel. The above equation then implies

[8] See Campbell (1998) for the Jensen's inequality adjustment in the excess logarithmic returns.

$$E_t(r_{t+1}) + \frac{1}{2} Var_t(r_{t+1}) - rf_t = Stdev_t[ln(m_{t+1})] \cdot Stdev_t(r_{t+1}) \Rightarrow$$

$$Stdev_t[ln(m_{t+1})] = \frac{E_t(r_{t+1} - rf_t) + \frac{1}{2} Var_t(r_{t+1})}{Stdev_t(r_{t+1})}, \quad \text{(A4)}$$

that is, the standard deviation of the of the pricing kernel (the volatility parameter λ_t) is equal to the excess return per unit of volatility of an asset perfectly negatively correlated with the pricing kernel. Since the pricing kernel is related to marginal utility of consumption, which is then negatively related to consumption itself, this asset will be positively correlated to consumption growth. This asset has a positive risk premium since it delivers wealth when consumption if high (that is, when it is less valuable). So the market price of risk is positive.

APPENDIX B

The following system of nine equations is estimated for the US dollar investor's real pricing kernel q_{t+1}^{US}:

$$q_{t+1}^{US} - 1 \tag{B1}$$

$$R_{eq,t+1}^{US} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B2}$$

$$R_{eq,t+1}^{UK} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B3}$$

$$R_{eq,t+1}^{GER} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B4}$$

$$R_{gb,t+1}^{UK} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B5}$$

$$R_{gb,t+1}^{GER} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B6}$$

$$R_{gb,t+1}^{US} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B7}$$

$$R_{t+1}^{GBPUSD} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B8}$$

$$R_{t+1}^{DEMUSD} \cdot q_{t+1}^{US} - rf_t^{US} \tag{B9}$$

where

$$\begin{aligned} q_{t+1}^{US} = rf_t^{US} \cdot \big(c_1 + c_2 \cdot R_{eq,t+1}^{US} + c_3 \cdot R_{gb,t+1}^{US} + c_4 \cdot R_{t+1}^{GBPUSD} + c_5 \cdot R_{t+1}^{DEMUSD}{}_{t+1} + \\ c_6 \cdot R_{gb,t+1}^{UK} + c_7 \cdot R_{gb,t+1}^{GER} + c_8 \cdot R_{eq,t+1}^{UK} + c_9 \cdot R_{eq,t+1}^{GER} \big) \end{aligned} \tag{B10}$$

is the US dollar investor's normalized pricing kernels and

rf_t^{US} is the one-month gross real US dollar risk-free rate;

$R_{eq,t+1}^{US}$ is the one-month gross real return on the US equity total return index;

$R_{eq,t+1}^{UK}$ is the one-month gross real return on the UK equity total return index in US dollars;

$R_{eq,t+1}^{GER}$ is the one-month gross real return on the German equity total return index in US dollars;

$R_{gb,t+1}^{US}$ is the one-month gross real return on the US ten-year government bond total return index;

$R_{gb,t+1}^{UK}$ is the one-month gross real return on the UK ten-year government bond total return index in US dollars;

$R_{gb,t+1}^{GER}$ is the one-month gross real return on the German ten-year government bond total return index in US dollars;

R_{t+1}^{GBPUSD} is the one-month gross real return on the pound sterling money market account in US dollars;

R_{t+1}^{DEMUSD} is the one-month gross real return on the Deutschemark money market account in US dollars;

where $R_{t+1}^{GBPUSD} = rf_t^{UK} \frac{GBPUSD_{t+1}^{real}}{GBPUSD_t^{real}}$, $R_{t+1}^{DEMUSD} = rf_t^{GER} \frac{DEMUSD_{t+1}^{real}}{DEMUSD_t^{real}}$,

rf_t^{UK} is the one-month gross real pound sterling risk-free rate and rf_t^{GER} is the one-month gross real Deutschemark risk-free rate.

The GMM results along with the Newey-West standard errors are shown in Table *B1*:

Table B1

	Coefficient	**Std. Error**	**p-value**
c_1	2.35	0.14	0.00
c_2	-0.53	0.22	0.02
c_3	0.18	0.17	0.30
c_4	-0.39	0.16	0.02
c_5	-0.58	0.19	0.00
c_6	0.27	0.13	0.03
c_7	0.14	0.17	0.42
c_8	-0.31	0.08	0.00
c_9	-0.11	0.03	0.00

The pound sterling and Deutschemark investor's normalized pricing kernels, denoted as q_{t+1}^{UK} and q_{t+1}^{GER} respectively, can then be estimated, according to equations (5) to (7):

$$q_{t+1}^{UK} = \frac{GBPUSD_{t+1}^{real}}{GBPUSD_{t}^{real}} \frac{rf_t^{UK}}{rf_t^{US}} q_{t+1}^{US} \tag{B11}$$

$$q_{t+1}^{GER} = \frac{DEMUSD_{t+1}^{real}}{DEMUSD_{t}^{real}} \frac{rf_t^{GER}}{rf_t^{US}} q_{t+1}^{US} \tag{B12}$$

The results do not depend on the choice of the pricing kernel that is initially estimated. We could initially estimate the pound sterling or Deutschemark investor's pricing kernel and the system of equations would be equivalent to B(1) to B(9).

For example, consider the estimation of the pound sterling investor's pricing kernel q_{t+1}^{UK}. The following system of equations would be required to be estimated:

$$q_{t+1}^{UK} - 1 \tag{B1'}$$

$$R_{eq,t+1}^{US} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B2'}$$

$$R_{eq,t+1}^{UK} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B3'}$$

$$R_{eq,t+1}^{GER} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B4'}$$

$$R_{gb,t+1}^{GER} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B5'}$$

$$R_{gb,t+1}^{GER} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B6'}$$

$$R_{gb,t+1}^{US} \cdot \frac{GBPUSD_{t}^{real}}{GBPUSD_{t+1}^{real}} q_{t+1}^{UK} - rf_t^{UK} \tag{B7'}$$

$$\frac{GBPUSD_t^{real}}{GBPUSD_{t+1}^{real}} rf_t^{US} \cdot q_{t+1}^{UK} - rf_t^{UK} \tag{B8'}$$

$$\frac{GBPDEM_t^{real}}{GBPDEM_{t+1}^{real}} rf_t^{GER} \cdot q_{t+1}^{UK} - rf_t^{UK} \tag{B9'}$$

where $\frac{GBPUSD_t^{real}}{GBPUSD_{t+1}^{real}} rf_t^{US}$ and $\frac{GBPDEM_t^{real}}{GBPDEM_{t+1}^{real}} rf_t^{GER}$ represent the one-month gross real return on the US dollar and Deutschemark money market account in pound sterling;

The US dollar and Deutschemark investor's pricing kernels would then be estimated using equations (B11) and (B12).

However, it is easy to show that system of equation (B1') to (B9') is equivalent to the system of equations (B1) to (B9). Equation (B1') is equivalent to equation (B8) by using equation (B11). Equations (B2') to (B7') and equation (B9') are equivalent to equations (B2) to (B7) and equation (B9) respectively by using equation (B11). Finally equation (B8') is equivalent to equation (B1) by using equation (B11).

APPENDIX C

Equation (8), pricing the risk free asset rf_t^{US}: instruments are a constant and the variables $R_{eq,t-1}^{US}$, $R_{gb,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{UK}$, $R_{gb,t-1}^{GER}$, $R_{eq,t-1}^{UK}$, and $R_{eq,t-1}^{GER}$.

Equation (9), pricing returns on the US equity index $R_{eq,t}^{US}$: instruments are a constant and the variables CY_{t-1}^{US}, DY_{t-1}^{SP}, drf_{t-1}^{US}, $R_{eq,t-1}^{UK}$, $R_{gb,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, and $R_{eq,t-2}^{US}$.

Equation (9), pricing returns on the UK equity index $R_{eq,t}^{UK}$: instruments are a constant and the variables CY_{t-1}^{UK}, DY_{t-1}^{FT}, drf_{t-1}^{UK}, $R_{eq,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{UK}$, and $R_{eq,t-1}^{UK}$.

Equation (9), pricing returns on the German equity index $R_{eq,t}^{GER}$: instruments are a constant and the variables CY_{t-1}^{GER}, DY_{t-1}^{DAX}, drf_{t-1}^{GER}, $R_{eq,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{GER}$, and $R_{eq,t-1}^{GER}$.

Equation (9), pricing returns on the US long-term bond index $R_{gb,t}^{US}$: instruments are a constant and the variables CY_{t-1}^{US}, drf_{t-1}^{US}, $R_{eq,t-1}^{US}$, $R_{gb,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{UK}$, and $R_{gb,t-1}^{GER}$.

Equation (9), pricing returns on the UK long-term bond index $R_{gb,t}^{UK}$: instruments are a constant and the variables CY_{t-1}^{UK}, drf_{t-1}^{UK}, $R_{eq,t-1}^{UK}$, $R_{gb,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{UK}$, and $R_{gb,t-1}^{GER}$.

Equation (9), pricing returns on the German long-term bond index $R_{gb,t}^{GER}$: instruments are a constant and the variables CY_{t-1}^{GER}, drf_{t-1}^{GER}, $R_{eq,t-1}^{GER}$, $R_{gb,t-1}^{US}$, R_{t-1}^{GBPUSD}, R_{t-1}^{DEMUSD}, $R_{gb,t-1}^{UK}$, and $R_{gb,t-1}^{GER}$.

Equation (9), pricing returns on the pound sterling money market account R_t^{GBPUSD}: instruments are a constant and the variables $CY_{t-1}^{US} - CY_{t-1}^{UK}$, $drf_{t-1}^{US} - drf_{t-1}^{UK}$, $R_{eq,t-1}^{US} - R_{eq,t-1}^{UK}$, and $R_{gb,t-1}^{US} - R_{gb,t-1}^{UK}$.

Equation (9), pricing returns on the Deutschemark money market account R_t^{DEMUSD}: instruments are a constant and the variables $CY_{t-1}^{US} - CY_{t-1}^{GER}$, $drf_{t-1}^{US} - drf_{t-1}^{GER}$, $R_{eq,t-1}^{US} - R_{eq,t-1}^{GER}$, and $R_{gb,t-1}^{US} - R_{gb,t-1}^{GER}$.

Table 1

Descriptive statistics of: returns on stock market, government bond, and T-bill indices; log changes in exchange rates; and inflation rates

This table reports the summary statistics of: monthly returns on the stock market, government bond, and T-bill indices for US, UK, and Germany, respectively; log changes in DEM/USD, USD/GBP, and DEM/GBP exchange rates; and annualized inflation rates for US, UK, and Germany, respectively. Returns are continuously compounded and inflation rates are computed as log changes of Consumer Price Indices (CPIs). Mean, min., max and standard deviation are in %. The Jarque-Bera (J-B) test for normality combines excess skewness and kurtosis, and is asymptotically distributed as χ^2_m with m=2 degrees of freedom. ** denotes 1% significance level.

	S&P500	UK FT	DAX	US Bond	UK Bond	Ger Bond
Mean	0.901	1.032	0.765	0.545	0.704	0.585
Min.	-24.253	-30.049	-27.241	-9.479	-5.109	-7.682
Max.	15.537	43.244	13.918	13.406	8.019	6.676
Std. Dev.	4.261	5.437	4.962	2.265	1.411	1.590
Skew.	-0.586	0.116	-0.831	0.584	0.912	-0.619
Kurt.	5.347	11.387	6.607	6.730	6.874	6.142
J-B	169.749**	1736.310**	389.055**	376.845**	452.328**	281.403**

Table 1 – Continued

	US T-bills	UK T-bills	Ger T-bills	DEM/USD	USD/GBP	DEM/GBP
Mean	0.444	0.623	0.386	-0.212	-0.094	-0.282
Min.	0.048	0.131	0.156	-14.288	-13.980	-14.420
Max.	1.285	1.339	0.999	10.831	13.585	7.164
Std. Dev.	0.229	0.276	0.160	2.845	2.471	2.388
Skew.	1.036	0.604	1.034	-0.372	-0.506	-1.160
Kurt.	4.461	2.462	3.663	6.269	8.732	8.165
J-B	158.460**	43.095**	116.296**	277.267**	835.656**	789.498**

Table 1 – Continued

	US CPI	UK CPI	Ger CPI
Mean	3.548	5.276	2.534
Min.	-0.746	-0.545	-2.765
Max.	12.625	23.316	6.978
Std. Dev.	2.631	4.329	1.720
Skew.	1.298	1.645	0.323
Kurt.	4.504	5.661	3.071
J-B	222.084**	441.802**	10.471**

Table 2

Descriptive statistics of instruments: equity index dividend yields; currency yield curve slopes; and changes in the one-month nominal short rates

This table reports the summary statistics of: equity index dividend yields for US (S&P500 DY), UK (UK FT DY), and Germany (DAX DY), respectively; currency yield curve slopes, which are the differences in the monthly log change of the ten-year government bond total return index less the monthly log change of the Treasury bill total return index for US (Slope US), UK (Slope UK), and Germany (Slope Ger), respectively; and the monthly change in the nominal short-rate for US $\left(drf^{US}\right)$, UK $\left(drf^{UK}\right)$, and Germany $\left(drf^{GER}\right)$, respectively. Mean, min., max and standard deviation are in %. The Jarque-Bera (J-B) test for normality combines excess skewness and kurtosis, and is asymptotically distributed as χ^2_m with m=2 degrees of freedom. ** denotes 1% significance level.

	S&P500 DY	UK FT DY	DAX DY	Slope US	Slope UK	Slope Ger
Mean	3.408	4.672	3.434	0.101	0.081	0.199
Min.	1.060	2.060	1.500	-10.639	-6.378	-8.114
Max.	6.400	12.040	6.120	12.544	7.199	5.978
Std. Dev.	1.106	1.269	0.951	2.276	1.401	1.587
Skew.	0.040	0.742	0.531	0.327	0.569	-0.792
Kurt.	2.911	6.166	3.125	6.588	6.837	6.367
J-B	0.352	301.560**	28.251**	328.075**	395.183**	341.618**

Table 2 – Continued

	drf^{US}	drf^{UK}	drf^{GER}
Mean	-1.07*e*-04	2.20*e*-04	-1.68*e*-05
Min.	-0.318	-0.141	-0.138
Max.	0.198	0.218	0.123
Std. Dev.	0.041	0.041	0.025
Skew.	-1.414	1.001	0.618
Kurt.	15.781	8.140	9.111
J-B	4226.702**	750.534**	958.889**

Table 3

Unconditional correlation of instruments

This table reports unconditional correlations among instruments: equity index dividend yields for US (S&P500 DY), UK (UK FT DY), and Germany (DAX DY), respectively; currency yield curve slopes, which are the differences in the monthly log change of the ten-year government bond total return index less the monthly log change of the Treasury bill total return index for US (Slope US), UK (Slope UK), and Germany (Slope Ger), respectively; and the monthly change in the nominal short-rate for US $\left(drf^{US}\right)$, UK $\left(drf^{UK}\right)$, and Germany $\left(drf^{GER}\right)$, respectively.

	S&P500 DY	UK FT DY	DAX DY	Slope US	Slope UK	Slope Ger	drf^{US}	drf^{UK}	drf^{GER}
S&P500 DY	1.000	0.752	0.717	-0.013	0.024	0.004	-0.033	0.012	-0.007
UK FT DY		1.000	0.629	0.002	-0.003	0.097	-0.061	-0.012	-0.032
DAX DY			1.000	-0.026	0.024	0.006	-0.024	-0.027	-0.040
Slope US				1.000	0.194	0.424	-0.573	-0.031	-0.060
Slope UK					1.000	0.291	-0.126	-0.568	-0.143
Slope Ger						1.000	-0.301	-0.139	-0.284
drf^{US}							1.000	0.065	0.025
drf^{US}								1.000	0.157
drf^{GER}									1.000

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