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US-Swiss Term Structures and Exchange Rate Dynamics

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Abstract

In this study, a multi-country nonlinear model is constructed to simultaneously estimate the exchange rate dynamics and the term structure of interest rates in the US and in Switzerland. The model has better empirical performance compared to the earlier well-known affine international models. Risk premiums of bond yields vary between the two countries. The estimated state variables exhibit local characteristics. These conclusions imply the potential advantages of international diversification and demonstrate the Home Bias phenomenon. Exchange rate dynamics estimated by the models account for the Forward Premium Anomaly. Introduction of jump diffusions provides marginal improvement.

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1. Introduction

The US and Swiss bond markets are both attractive to investors for several reasons. The US has the largest and traditionally the most popular bond markets in the world. Investors range from individuals and investment companies to world governments[1]. On the other hand, with its liberal regulatory environments, comparatively low transaction costs, and beneficial tax regime, Switzerland is a strong contender in attracting investors as well. But the fundamental reasons why Switzerland is an ideal candidate for the joint analysis of the term structures of the US and a foreign country in a comprehensive theoretical setting are the unique characteristics of Swiss fixed income markets. The goals of this study are to shed light on the similarities and differences between these two fixed income investment alternatives, and to provide explanations to some international puzzles and stylized facts.

Switzerland is unique for several reasons, starting with the risk profile of the investment environment. There are two publications that provide semiannual rankings of countries based on their risk profiles. *Institutional Investor* and *Euromoney* develop country risk ratings by calculating the weighted average of chance of default, political risk, economic performance, debt indicators, credit ratings, and access to banks, short term finance, and capital markets. A statistical analysis of these semiannual rankings (the lower the ranking, the less risky the country) produces Switzerland as the country of lowest risk, with a mean of 2.27 and a standard error of 1.92. The US is ranked second with a mean value of 3.42 and a standard error of 1.94. The difference between the risk rankings of Switzerland and the US is significant at conventional levels. In other words, statistically, Switzerland has been the safest country for investment purposes over the last three decades.

The second reason why Switzerland is unique is that its economic dynamics are relatively free from international restrictions. The formation of the European Union (EU) has imposed numerous constraints on its member states. A rigorous examination of the natural dynamics of term structures, exchange rates, pricing kernels, and market prices of risk would yield better results without the presence of such artificial limitations. Furthermore, many currencies of the

[1] Close to fifty percent of the world bond market size - measured by total, government, or Eurobond market size belongs to the US (Merrill Lynch, 2004). The largest US government bond investor is the People's Republic of China.

member states have been replaced by the euro. Switzerland is not an EU member and does not belong to the euro zone.

Third, unlike others around the world, the Swiss banking system is based on the concept of universal banking. With approximately $1.2 trillion in cross-border client assets, Swiss banks hold about one-third of global transnational assets. However, there are several prejudicial and negative perceptions on the Swiss system (see Peppas, 2004, among others). The majority of US investors believe that the Swiss banking confidentiality helps protect money launderers, increases deposits from non-Swiss persons wishing to protect assets and/or earnings from taxation in their home countries, and limits the efforts of law enforcement to bring criminals to justice. Adverse publicity with regard to dormant Holocaust accounts and scandals resulting from the questionable bank deposits of political figures have also tarnished Switzerland's banking image[2]. Even with improvements, the general public appears to hold strong negative perceptions of the Swiss banking secrecy.

Finally, as the fourth reason, the analysis will reveal that the US and Swiss fixed income markets have relatively low correlation compared to the correlations among the US and German bond yields or the correlations among the US and UK bond yields. This will provide a good barometer for gauging the existence of local factors in the empirical investigation of the theoretical setting. It will be demonstrated that local factors are indeed important in dictating the term structure dynamics of US and Switzerland.

The unique characteristics of Switzerland may play a role in accounting for well-known international puzzles in a dual-country setting. This study examines two such puzzles. The first is called the Forward Premium Puzzle (FPP) named by Fama (1984). The rational expectations equilibrium - also known as Expectations Hypothesis (EH) or Uncovered Interest Rate Parity (UIP) - dictates that high interest rate currencies are expected to lose value in the future. That is why the yields are high in the first place; to compensate investors. However, empirically, the complete opposite is seen. High interest rate currencies actually appreciate. The article explores

[2] Swiss authorities have had to re-examine their banking rules. Today, depositors must provide the same information when they open numbered accounts, as they do when opening regular accounts. Banking confidentiality is not absolute; it can be lifted in all serious criminal legal proceedings. The EU and Switzerland reached a tentative agreement for similar tax obligations. The Swiss government has also tried to negotiate a fair transfer of the dormant Holocaust accounts.

whether the puzzle is accounted for by the model developed here. Most studies document the puzzle with short horizon estimations. On the other hand, recent literature claims that the FPP is not seen in long horizon tests. The article examines whether a similar conclusion emerges in the US-Swiss setting.

The second international puzzle is called the Home Bias. In general, there is lower correlation among international bonds compared to domestic bonds (Solnik, 2000). Early studies of the benefits of international diversification show that there are substantial opportunities for risk reduction (Solnik, 1975). However, investors tend to continue placing more emphasis on domestic investments in their portfolios. This 'Home Bias' is more pronounced in fixed income markets than in equity markets. For the US, only three percent of the fixed income market capitalization constitutes international bond securities. Tesar and Werner (1995) rule out transaction costs as a possible reason, but there can be any number of other factors behind the bias, such as unfamiliarity with foreign markets, regulation differences, market efficiency issues (e.g., liquidity and market size), risk perception, additional management fees, custodial (accounting) costs, and finally, currency risks. In the case of Switzerland, an additional reason for the Home Bias may be the negative image of the Swiss banking industry mentioned above.

Do the benefits outweigh the currency risk in international diversification? Ahn (2004) examines the US-German case and finds that the term structure dynamics are driven by common factors (there is no conclusive evidence on the US-UK case). Since there are no localized factors, diversification is not truly beneficial because of the additional currency risk in the international portfolio. But the US-Swiss case reveals different results. As discussed in more detail later, the unconditional yield correlations between the US and Swiss term structures are very low in general (compared to the US-German correlations in Ahn, 2004, for example). Correlations values are as low as 0.45. On the other hand, the lowest domestic-correlation value of the US (Swiss) yields is 0.91 (0.83). In addition to low cross-yield correlations, the study also presents evidence for local factors in addition to common factors. Moreover, the premiums are different in the US term structure compared to the premiums in the Swiss term structure. Thus, diversification may be a more profitable strategy in the US-Swiss setting.

The investigation of a dual country setting requires the empirical application of a sophisticated theoretical model. The model should not only estimate the currency dynamics and the term structure of interest rates in each country, but also reveal information about bond risk premiums, diversification benefits, the currency premium, and the patterns of the shortest and the longest ends of the term structure spectrum. This study uses the extension of the nonlinear asset pricing model of Constantinides (1992) and applies it to the US-Swiss two-country setting. Several versions of the model are examined and evidence of superior empirical performance relative to other well-known models is provided.

The rest of the paper is organized as follows. Section 2 provides links to the literature. Section 3 formally presents the theoretical model. Section 4 describes the data and estimation methodology. Section 5 discusses the empirical results. Conclusion follows.

2. Review of Asset Pricing Literature

Term structure models can be categorized into two classes. The first is the traditional affine class, where yields are linear functions of the underlying state variables driving the economy. The second is the recently emerging nonlinear class, where yields are quadratic functions of the state variables. The affine class is popular due to its analytical tractability. Duffie and Kan's (1996) characterization has led to examples of general econometric estimations by Chen and Scott (1993) and Dai and Singleton (2000), applications to the predictability of interest rates by Dai and Singleton (2002), or currency pricing by Backus, Foresi, and Telmer (2001) (hereafter, BFT). While these applications are successful in one or two dimensions, the irreconcilable problem between delivering good empirical performance and excluding negative interest rates has persisted. Indeed, all successful model designs within the affine framework imply positive probabilities for negative interest rates. Furthermore, the prominent BFT affine model accounts for the FPP in international settings, but at the cost of unreasonably high market price of risk, which leads to long-term yields as high as 80 percent.

The problems associated with the affine class have led researchers to the more flexible nonlinear class. The quadratic model has a number of advantages over the affine version in satisfying certain properties of bond yields. First, the quadratic model ensures positive interest rates, while an affine model cannot. Second, the quadratic model incorporates possible nonlinearities in interest rate dynamics, for instance, a humped shaped term structure for conditional variance. Third, an affine market price of risk and non-orthogonal state variables are possible. Fourth, if an international setting is considered, then the empirical application of a nonlinear model has a better chance of accounting for international puzzles. The earliest example of quadratic models is the double square root model of Longstaff (1989). The squared autoregressive independent variable term structure model of Constantinides (1992) exogenously specifies the pricing kernel as a time-separable quadratic function of Markov processes. Ahn et al. (2001) present a list of assumptions that essentially identify the complete quadratic class. The majority of these theoretical nonlinear asset pricing models have been designed solely for the US term structure.

There are few studies that directly examine the Swiss term structure of interest rates. Chan et al. (1992) extend several classic and commonly used theoretical models of the 1980s and examine their empirical applicability. They find that the Cox et al. (1985) affine term structure model performs best for the 1974 to 1991 period along with the Ornstein-Uhlenbeck process compared to Vasicek (1977). However, Ait-Sahalia (1996) shows that a model that mean reverts nonlinearly better adapts to the term structure. Kilian (1999) examines the relationship between exchange rates and monetary fundamentals with a linear model framework. His long horizon regressions show that the framework is misspecified, and suggest a non-linear data generating process to describe the exchange rate behavior for the Swiss franc.

The number of state variables in a model is another point of argument. Leippold and Wu (2003) choose a two-factor structure to capture the dynamics of the US term structure. Buhler and Zimmerman (1996) document that three-factors are needed to describe the Swiss term structure. However, Bruand (1998) argues that multiple factors (state variables) used in a model on the Swiss term structure would provide a better empirical fit at the cost of specification problems and unclear economic interpretation. Citing also the difficulties in empirical implementation of multi factor models, he uses only one state variable. He further argues that jump models are not frequent in the literature and estimation of more parameters may cause further specification problems.

Considering the recent popularity and superiority of nonlinear models, and considering the limited research on the Swiss term structure in an international context, this study provides several contributions to the literature. Asset pricing implications in the US-Swiss dual country setting are derived under a nonlinear framework. The quadratic model of Constantinides (1992) is extended and applied to the US-Swiss term structures and exchange rate determination. The paper clarifies identification problems by providing the necessary and sufficient conditions with a theoretical model. Multiple state variables with easy economic interpretation are developed, and the powerful empirical estimation methodology of the extended Kalman filter is used. A three factor international setting and a five factor international setting are presented to explore the term structures and exchange rate dynamics. Closed form expressions are obtained for the instantaneous interest rates for both the US and Switzerland, the exchange rate dynamics, the pricing kernels of both countries, and the unobservable bond yield premiums. Different versions of the model account for the well-known international puzzles of the FPP and the Home Bias. The models' performances in explaining the actual time-series movements of exchange rate levels and currency returns are also examined. After all, accounting for the FPP is a minimum requirement. Evidence for the empirical superiority of the nonlinear model over others, such as the affine BFT, is provided. An extension of the quadratic model that incorporates Poisson jump diffusion is also examined.

3. The Theoretical Model

The quadratic model is an extension of Constantinides (1992) to a dual country framework applied to the US-Swiss setting. Unique pricing kernels, $M_k(t)$, exist in the US and Switzerland and are driven by N unobservable state variables, $X(t)$, such that

$$M_k(t) = \exp[-b_k t + X'(t)\Psi_k X(t)], \qquad (1)$$

where $k = (d, f)$ refers to domestic (US) and foreign (Swiss) economies. The state variables have asymmetric effects on the pricing kernels. Ψ_d for the US is an identity matrix, while Ψ_f for Switzerland is diagonal with non-negative scaling coefficients, ψ_i. The magnitude relative to one measures the relative importance of the ith state variable, $X_i(t)$, in affecting US and Swiss pricing kernels and term structures. If ψ_i far exceeds one, then $X_i(t)$ is a factor with a much greater impact on the Swiss than the US pricing kernel and bond market. If ψ_i is a small fraction, then $X_i(t)$ is a factor with a much greater impact on the US than Swiss pricing kernel and bond market. If ψ_i is close to one, then $X_i(t)$ has a similar impact on both markets. Ψ_d is set as identity in order to avoid identification problems. The parameters b_d and b_f in the pricing kernels are the yields of very long-maturity discount bonds in the two countries. The state variables follow multivariate mean reverting Gaussian processes:

$$dX(t) = K(\mu - X(t))dt + \Sigma\, dW(t), \qquad (2)$$

where K is diagonal, μ is a $N \times 1$ vector, Σ is a lower triangular matrix, and $W(t)$ are N

independent standard Weiner processes. The *i*th diagonal element of K is the mean-reverting parameter, and the *i*th element of μ is the long-run mean of the *i*th state variable. The lower-triangular structure of Σ captures conditional correlations among state variables. This opens the door for an alternative way to determine whether a factor is local to an economy or common to both countries. Let us assume that a factor has significant parameters and has a scaling coefficient indicating that it is a Swiss factor ($\psi_i > 1$). One way to strengthen this evidence would be to verify that it is related to other Swiss factors but not the US factors. This would be extracted from the non-diagonal elements of Σ. The empirical implementation will allow all these parameters to be naturally determined by the data (it should be noted that an alternative representation would be to have a diagonal Σ and a lower triangular K).

The lower triangular nature of Σ is necessary in light of the empirical findings in Dai and Singleton (2000) for affine models, and in Ahn et al. (2001) for quadratic models. They show that orthogonality imposes many more significant restrictions in fitting the term structures. Ahn et al. (2001) give the pricing kernel in their maximally flexible version as:

$$\frac{dM(t)}{M(t)} = -r(t)dt + (\zeta_0 + \zeta_1 X(t))' dW_t, \tag{3}$$

where ζ_1 is lower triangular, and the instantaneous interest rate is given as:

$$r(t) = \ddot{\alpha} + \beta' X(t) + X(t)' \Lambda X(t),$$

with $\beta = 0$, and $\ddot{\alpha}$ as a symmetric matrix with diagonal elements equal to one. The model here imposes the following restrictions for each country, k:

$$\begin{aligned} \zeta_0 &= 0_N, \\ \zeta_1 &= 2\Psi_k \Sigma, \\ \ddot{\alpha} &= b_k - trace(\Psi_k \Sigma\Sigma'), \\ \beta &= -2\Psi_k K\mu, \\ \Lambda &= 2\Psi_k (K - \Sigma\Sigma'\Psi_k). \end{aligned} \tag{4}$$

The time-t price of a zero-coupon bond that has maturity τ and pays one unit of the currency is

$$P_k(t,\tau) = E_t[M_k(t+\tau)]/M_k(t), \tag{5}$$

where E_t is the expectation conditional on information at time t. The term structure in each economy is uniquely determined by its pricing kernel. The price and yield of zero-coupon bonds in each country are expressed in terms of the state variables as in Ahn et al. (2001):

$$P_k(t,\tau) = \exp[A_k(\tau) + B_k(\tau)' X(t) + X(t)' C_k(\tau) X(t)], \tag{6}$$

and since the yield is $y_k(t,\ \tau) = -\ lnP_k(t,\ \tau)\ /\ \tau$, we have

$$y_k(t,\tau) = -\frac{1}{\tau}[A_k(\tau) + B_k(\tau)' X(t) + X(t)' C_k(\tau) X(t)]. \tag{7}$$

A_k, B_k, and C_k satisfy the following ordinary differential equations with the subscript k suppressed:

$$\frac{dC(\tau)}{d\tau} = 2C(\tau)\Sigma\Sigma' C(\tau) + [C(\tau)(-K - \eta_1) + (-K - \eta_1)' C(\tau)] - \Lambda$$

$$\frac{dB(\tau)}{d\tau} = 2C(\tau)\Sigma\Sigma' B(\tau) + (-K - \eta_1)' B(\tau) + 2C(\tau)(K\mu - \eta_0) - \beta$$

$$\frac{dA(\tau)}{d\tau} = trace[\Sigma\Sigma' C(\tau)] + \frac{1}{2} B(\tau)\Sigma\Sigma' B(\tau) + B(\tau)'(K\mu - \eta_0) - \psi,$$

with initial conditions $A_k(0) = 0, B_k(0) = 0_N, C_k(0) = 0_{N\times N}$, and the restrictions in (4).

Under standard asset pricing theory, the spot exchange rate, $Q(t)$, defined in US dollars per unit of Swiss franc, is

$$Q(t) = \left[\frac{Q(0)}{M_f(0)/M_d(0)}\right]\left[\frac{M_f(t)}{M_d(t)}\right]. \tag{8}$$

Thus, the spot exchange rate is the ratio of the pricing kernels of the two countries (Ahn, 2004). Alternatively, the log exchange rate, $q(t) = ln\ Q(t)$, is given by

$$q(t) - q(0) = [ln\ M_f(t) - ln\ M_f(0)] - [ln\ M_d(t) - ln\ M_d(0)].$$

Therefore, the (log) exchange rate can be explicitly derived from the pricing kernel in (1) as:

$$q(t) - q(0) = (b_d - b_f)t + X'(t)(\Psi_f - \Psi_d)X(t) - X'(0)(\Psi_f - \Psi_d)X(0). \tag{9}$$

Accordingly, the (annualized) log currency return from t to $t + \tau$ is given by:

$$q(t+\tau) - q(t) = (b_d - b_f)\tau + [X'(t+\tau)(\Psi_f - \Psi_d)X(t+\tau) - X'(t)(\Psi_f - \Psi_d)X(t)]. \tag{10}$$

The first term, $b_d - b_f$, is the difference of very long-term interest rates in the US and Switzerland.

The second term depends on changes of the state variables and their asymmetric effects on the two pricing kernels.

The uncovered interest rate parity theorem (UIP) predicts that the currency of a country with higher interest rates tends to depreciate. This theory implies that investors would essentially achieve the same return from holding the high-interest-rate currency as from holding the low-interest-rate currency. The UIP has been tested in the literature via the following regression

$$q(t+\tau)-q(t)=\beta_0+\beta_1(y_d(t,\tau)-y_f(t,\tau))+\varepsilon_t, \tag{11}$$

where $q(t+\tau)-q(t)$ is the log return of the foreign currency and $y_d(t,\tau)-y_f(t,\tau)$ is the differential of the domestic and foreign interest rates. The null hypothesis under the UIP is that the slope coefficient, β_1, is one.

Most studies using forecasting horizons less than one year have found that the slope coefficient is negative. If $f(t, \tau)$ is the τ-period forward exchange rate, the foreign currency risk premium (cp) will be $cp(t,\tau)=f(t,\tau)-E_t q(t+\tau)$. This is what investors demand to bear the exchange rate risk. The expected rate of depreciation of the foreign currency (ed) is $ed(t,\tau)=E_t q(t+\tau)-q(t)$. By virtue of covered interest rate parity, the interest rate differential $y_d(t, \tau) - y_f(t, \tau)$ always equals the difference between the τ-period forward rate and current spot exchange rate, $f(t, \tau) - q(t)$. Then, interest rate differentials can be expressed as the sum of the foreign currency premium and expected depreciation:

$$y_d(t,\tau)-y_f(t,\tau)=f(t,\tau)-s(t)=cp(t,\tau)+ed(t,\tau).$$

Fama (1984) shows that a negative slope coefficient is generated in (11) if and only if two conditions are satisfied: (1) the currency risk premium is negatively correlated with expected depreciation ($Cor(cp,ed) < 0$), and (2) the currency risk premium is more volatile than expected depreciation ($std(cp) > std(ed)$). The forward premium puzzle is applied to the quadratic model by checking these two conditions.

The Swiss franc risk premium and expected rate of depreciation can be recovered as follows. First, the interest rate differential $y_d(t, \tau) - y_f(t, \tau)$ can be obtained from the yield functions in (7). Next, the expected rate of depreciation is derived from (10) as:

$$ed(t,\tau) = (b_d - b_f)\tau + E_t [X'(t + \tau)(\Psi_f - \Psi_d)X(t + \tau)] - X'(t)(\Psi_f - \Psi_d)X(t), \tag{12}$$

where the expectation term is given by

$$E_t\,[X'(t+\tau)(\Psi_f - \Psi_d)X(t+\tau)]$$
$$= trace[(\Psi_f - \Psi_d)E_t\,X(t+\tau)X'(t+\tau)]$$
$$= trace[(\Psi_f - \Psi_d)(Var_t\,X(t+\tau) + E_t X(t+\tau)E_t X(t+\tau)')].$$

The conditional means and variance-covariances of the state variables are recovered by the filtering procedure in the empirical estimation of the model. Finally, the foreign currency risk premium is

$$cp(t,\tau) = [y_d(t,\tau) - y_f(t,\tau)] - ed(t,\tau)\,. \qquad (13)$$

If the quadratic model passes Fama's conditions for short-term interest rates, the model will account for the FPP. Some recent papers such as Meredith and Chinn (1998) and Alexius (1998) focus on longer forecasting horizons and find positive slope coefficients in line with the UIP. Therefore, the article also examines whether the model accounts for this stylized finding.

4. Data

The Eurocurrency market is an enormous and very liquid interbank market. A single location ensures comparability across different currency denominations. The use of Eurocurrency rates minimizes possible frictions caused by differences in capital controls, and other government regulations. Therefore, Eurocurrency deposit rates from Global Insight/DRI are used for the interest rate data. The empirical analysis is based on monthly observations from January 1974 through March 2005 covering the floating exchange rate period[3]. The data consists of end-of-month ask quotes of 1-, 3-, 6-, 12-month, 2-, 3-, 4-, and 5-year Eurocurrency deposit rates for the US and Switzerland[4]. The quotes are reported at the close of the London market. The 1-, 3-, 6-, and 12-month Eurocurrency deposits are par zero-coupon bonds whose payoffs at maturity are the principal plus an interest payment. The quoted rates on these deposits are converted into continuously compounded yields on the same-maturity zero-coupon bonds whose only payoffs are the principal amounts at maturity. The 2-, 3-, 4-, and 5-year Eurocurrency deposits are

[3] The international exchange rates became floating in August of 1973; however, the sample starts from the beginning of 1974 so that international markets absorb the changes and adjust to the new system.

[4] The choice of monthly returns is actual practice in comparable studies such as Backus et al. (2001) and Hess (2003) since the presence of more noise at higher frequencies may obscure the analysis.

equivalent to par bonds paying annual coupons at the quoted rates. The corresponding zero-coupon bond yields or spot rates from the quoted Eurocurrency rates are recovered by forward substituting the shorter spot rates to account for the intermediate coupon payments. The monthly exchange rate is defined as the number of US dollars per Swiss franc. Thus, an increase of exchange rate means the depreciation of the US dollar or the appreciation of the Swiss franc. The exchange rate data are also from Global Insight/DRI.

4.1. Estimation Methodology

The empirical estimations are conducted using the extended Kalman filter from Anderson and Moore (1979). The filter generates conditional densities of unobserved state variables over time, in addition to providing maximum-likelihood estimates of model parameters. The densities are then used to construct estimates of the unobserved state variables.

The model in the previous section is in state-space form and consists of observation equations and state equations. The observation equations are the exchange rate equation in (9) and yield equations in (7), augmented by error terms. Different versions of the model are estimated using the exchange rate data and term structure data jointly in the two countries. The observation errors are normally distributed with zero means, serially uncorrelated, cross-sectionally uncorrelated, and independent of the state variables, as in Chen and Scott (1993) and others in the term structure literature. The state equations are based on transitional densities of the state variables implied by their stochastic processes in (2). The transitional densities are normally distributed with the mean vector and variance-covariance matrix given as

$$E_t X(t+\tau) = \mu + \exp(-\tau K)[X(t) - \mu] \quad (14)$$

$$Var_t X(t+\tau) = \left[\frac{\sigma_{ij}(\exp((-\kappa_i - \kappa_j)\tau) - 1)}{-\kappa_i - \kappa_j} \right]_{N \times N},$$

where σ_{ij} is the *(i,j)*th element of Σ and κ_i is the *i*th diagonal element of *K*.

A variety of models are estimated using interest rate and exchange rate data. Here the focus is on models with at least three state variables for each country following Litterman and Scheinkman (1991), with the added flexibility of potential correlations between state variables.

5. Empirical Results and Discussion

The parameter estimates of various models and relevance of correlations between state variables are discussed first. This is followed by the interpretation of the term structures. The performance of nonlinear models is compared to the performance of affine models. Economic interpretations of unobservable state variables, instantaneous interest rates, bond risk premiums are analyzed. In this context, Home Bias puzzle is also examined. Finally, the results of the exchange rate dynamics are provided along with the discussion of the forward premium puzzle. As a preliminary justification of examining the US-Swiss term structures, the correlations between the US and Swiss yields are presented in Panel A of Table 1. The term structure of unconditional yield correlations is upward sloping with maturity. More importantly, the cross-correlations are lower than those of the US-German and US-UK yields (Ahn, 2004). Correlation values are not more than 0.62 (between US-Swiss long term yields), and are as low as 0.45 (between the 1-month Swiss yield and middle maturity US yields). Meanwhile, the lowest domestic-correlation value of the US (Swiss) yields is 0.91 (0.83). This result suggests potential advantages of international diversification using both the US and Swiss markets.

5.1 .Parameter Estimates

Table 2 presents parameter estimates and their standard errors for the 3-factor and 5-factor quadratic models. The parameters of the stochastic state variables are listed first. Most parameters are statistically significant for both the 3-factor and the 5-factor versions.

One of the new features here is the flexibility that the state variables may be correlated with each other. Is this indeed useful? The 3-factor correlation coefficients show a negative and significant relationship between the first and third factors, and a positive and significant correlation between the second and third state variables. Finally, there is a positive but insignificant relationship between the first and second variables. The correlation structure for the 5-factor model is more complicated. The first, second, and fourth factors are positively correlated with each other, and the relationships are significant. The third factor is negatively related to these three state variables. The fifth factor seems to be an independent variable since it is not significantly related to others. These results clearly indicate the importance of including the possibility of correlation in the theoretical model and allow the data to determine whether the factors are independent or not.

The parameters describing the pricing kernels show that the very long-term bond yield for Switzerland, b_f, is estimated at 6.95 percent according to the 3-factor model, and at 9.76

percent according to the 5-factor model. Over the same sample period, the very long term US government bond yield is estimated at 11.18 percent in the 3-factor model, and at 10.56 percent in the 5-factor model. The high interest rate period of the late 1970s and early 1980s is reflected to the high long-term yields estimated by the model. Long yields also summarize the fact that rates have been lower in Switzerland compared to the US. This is consistent with the early analysis from *Institutional Investor* and *Euromoney*, where Switzerland statistically has lower country risk.

The first scaling coefficient estimated in the 3-factor model, ψ_1, is 0.27 and indicates that the factor has an impact in both the US and Swiss markets (perhaps more in the US market). The second factor, with a scaling coefficient of 5.48, clearly has more emphasis on the Swiss economy. Finally, the third factor has a direct impact only on the US because the scaling coefficient of 0.0003 is not statistically different from zero. While the first two factors do have an impact on both economies with varying degrees, the third factor seems to be local to the US economy.

The scaling coefficients of the 5-factor model also imply the presence of local as well as common factors. The first factor with a scaling coefficient of 0.98 has similar impact on the US and Swiss economies. The second factor has a slightly greater impact in Switzerland, while the fourth factor has slightly more influence in the US. The third factor, with an insignificant scaling value of 0.0003, is a local US factor and has no impact on the Swiss economy; while the fifth factor is a Swiss local factor because its scaling coefficient is 54.01.

The presence of local factors in a dual country term structure model has interesting implications for portfolio diversification across international bond markets. An investor holding both domestic and foreign bonds and hedging the currency risk would have significant diversification benefits only if there existed prominent local factors in the domestic and foreign economies. Ahn (2004) and Inci and Lu (2004) do not find significant evidence for local factors in the US-German and US-UK settings. However, the evidence from the US-Swiss dual country term structure does indicate the presence of local factors, and thus the potential advantages of diversification in this particular environment. Although Home Bias makes sense in certain environments because countries such as Germany and the UK may not be very useful for diversification, Switzerland may indeed provide international diversification benefits.

5.2. Term Structure Analysis

The term structures summarize the impact of important domestic and foreign events on the economy. The interest rates at the opposite end of the maturity spectrum (1-month and 5-year yields) are plotted for the US and Switzerland in Fig. 1. The US term structure starts with a peak in the early 1970s, representing the first oil shock. However, the highest yields are seen in the 1979-1982 period. This is the experimental monetary policy period, when the Federal Reserve raised the federal funds rate in order to control money supply and to fight inflation and recession. The yields gradually decline with a temporary increase during the recession around 1990 and the first Gulf War. The term structure is stable throughout the 1990s - the largest expansion in US history. In the first two years of the millennium, the rates increase just before the recession, and during the World Trade Center bombings and the second Gulf War. This is followed by the aggressive rate reduction policy to stimulate the economy. Finally, the rates start to increase from mid-2004, partly to react to the weakening US dollar.

The Swiss term structure is characterized by rates lower than those in the US. The peak during 1974 due to the first oil shock is much more pronounced. The early 1980s period is characterized by high yields first because of the second oil shock, and then because of the Soviet invasion of Afghanistan and the recession in the US, which is the second largest importer of Swiss products. The depression in the Swiss economy from the late 1980s until the mid-1990s corresponds to the high inflation-high interest rate period. Since then, the recovering Swiss economy is characterized by declining rates except for the temporary increase at the end of 1999 because of the EU unification, introduction of the euro, Swissair bankruptcy, and the tightening of monetary policy by the Swiss National Bank (SNB) with rate hikes to slow down the growth. We also see an interesting pattern when the rates are high. The term structure is inverted during these periods. This is also documented in Hess (2003), and referred to as regime shifts. According to Hess (2003), these reversions result from the SNB instituting a very restrictive monetary policy to keep inflation low.

Mean and standard deviation values of the actual and model implied Eurodollar yields are provided in Panel A of Table 3. The actual means in the first row increase with maturity indicating, on average, an upward sloping term structure. On the other hand, actual volatilities of longer term rates are lower compared to those of shorter rates. The next two rows are the means and standard deviations of the forecasts of the 5-factor and 3-factor models estimated with interest rate and exchange rate data. The last row is from the 3-factor model, where only the interest rate data are used in the estimation. The forecasts are based on the prediction values of the unobservable state variables recovered in the estimation. Every model captures the upward sloping yield curve and declining volatility. The average pricing errors range from less than 1 basis point up to 13 basis points for the 1-year maturity in the 5-factor model. The pricing errors are higher in general in the 3-factor models (16 basis points and 19 basis points for the 1-year maturity). The models seem to slightly overestimate the yields. On the other hand, the volatilities are slightly underestimated. The 5-factor model produces results that are closer to the actual values.

Panel B is for the Swiss term structure. The actual yields exhibit a similar upward sloping yield curve with maturity, and a downward sloping volatility structure. Each model captures these general patterns. As before, the models slightly overestimate the yields and underestimate the volatilities. The three-factor models have slightly smaller pricing errors compared to the 5-factor model in Swiss Eurocurrency yield estimations. However, the opposite is true for volatility results: the 5-factor model produces the closest estimates to the actual values. Overall, performance of the nonlinear models in the US-Swiss international setting is quite reasonable compared to affine model results from Backus et al. (2001).

5.2.1. Residual Analysis of the 5-factor Model

The residual means and standard deviations of Eurocurrency yields of the best model from above - the 5-factor version - are presented in the first two rows of the panels in Table 4. Residual means are very low compared to their standard deviations. None of the ratios produces a t-statistic to indicate a significant residual. The means are generally negative, implying overestimation of the 5-factor estimates compared to the actual values. Of particular interest is the ratio of the standard deviation of the residual error to the standard deviation of the actual yield, reported in the third column. One minus this ratio gives the fraction of the variation in the actual yield explained by the model. The 5-factor model explains at least 75 percent of the variations for each yield in the US from Panel A. The portion explained by the model increases to 85 percent with maturity. This may be due to lower volatility of actual yields as maturity increases. A similar pattern emerges from the Swiss term structure residuals. The model explains 65 percent to 80 percent of the actual yield variation with maturity. Finally, the 5-factor model performs very well in explaining about 85 percent of the variation in the exchange rate dynamics.

5.3. Affine Models or Nonlinear Models?

Even though a growing literature provides evidence for the flexibility, estimation accuracy, and predictive power of non-affine models over affine ones (see, for example, Leippold and Wu, 2002, and Ahn et al., 2001), no study has directly examined this issue in the context of the US-Swiss dual country setting. The empirical performance of the 5-factor model is compared to the two 3-factor versions, the prominent affine international term structure model - the BFT, the uncovered interest parity model, and the random walk model of the exchange rate[5]. The initial expectation is that the 5-factor model should be better in empirical fit and forecast accuracy because of its richness and flexibility. However, it is also the model with the highest number of parameters, susceptible to overfitting. To resolve the issue, two different comparisons are conducted, both with the Schwarz Information Criterion (SIC). SIC penalizes a model more heavily if it includes more parameters. The first comparison considers both the interest rate fitting and exchange rate fitting. The SIC criteria calculated from the full-likelihood values generated by the extended Kalman filter are reported in Panel A of Table 5. The 5-factor model is ranked first, followed by the 3-factor model. The BFT model places last. Thus, nonlinear models clearly outperform in the joint estimation of US-Swiss term structures and exchange rate dynamics.

The second comparison deals with the exchange rate predictive power. The actual exchange rate is regressed on each model's predicted exchange rate, and the errors are used to determine the SIC values. In Panel B of Table 5, both the 5-factor and the 3-factor quadratic models perform better than the UIP and the affine BFT in US dollar / Swiss franc fitting. However, the random walk model performs better than all the theoretical models. This is not entirely surprising; as a matter of fact, it is consistent with the results from the BFT and Engel and West (2004). Overall, the term structure and exchange rate predictions are best performed by the 5-factor nonlinear term structure model.

5.4. State Variables

State space representation of the extended Kalman filter allows for the estimation of the unobservable state variables as by-products of the procedure. These are the factors that drive the US and the Swiss economy. If the conditional mean pattern of a factor proxies to a US or Swiss

[5] BFT is implemented following the interdependent factor version presented in Backus et al. (2001) and applied to the US and Swiss term structures and exchange rate modeling. The parameters of the state variables are highly statistically significant. The interdependence coefficient, γ^*, is 0.3348, which implies local factors.

macroeconomic variable, that will reveal the factor as local. Otherwise, the factor will be common to both economies. In this investigation, the term structure is considered as the fundamental macroeconomic dimension both for the US and Switzerland.

We start with the 3-factor no exchange rate model which uses only the term structure data in the estimation. The state variables from this model should conform to local or common factors more directly. The fact that there are only three factors in the estimations also forces these factors to be more direct proxies of macroeconomic variables. The estimates of the state variables are based on the filtering densities of the state variables and are presented in Fig. 2. The first state variable (the solid line) follows a very similar pattern to that of the Swiss short rate (the dotted line). This result is perfectly consistent with the scaling coefficient of 13.21 in the last column of Table 2 because both indicate that the state variable represents the Swiss economy. The third state variable has a conditional mean pattern similar to that of the US short rate. Given that the scaling coefficient is only 0.04, it has minimal impact on the Swiss economy and describes mostly the US. Finally, the second state variable parameters are all statistically significant, but the mean pattern is not strictly domestic or foreign. Therefore, the second factor has an impact on both economies (perhaps slightly more on the US term structure) and is vital for the dual country term structure model.

The graphical representations of the conditional means help to provide an economic interpretation of the state variables. The states either conform to US or Swiss local term structures, or have an impact on both economies as common factors. The models with fewer state variables produce patterns that are easier to interpret. Fig. 3 presents the conditional mean patterns of the 3-factor quadratic model, where exchange rate dynamics are also estimated. The first and second state variables follow similar patterns to the US and Swiss term structures, respectively, consistent with scaling coefficient results. The insignificant scaling coefficient of 0.27 also indicates that the first factor has larger impact on the US economy. On the other hand, with a scaling coefficient of 5.48, the second factor clearly describes the Swiss economy. Furthermore, these two state variables are not significantly correlated with each other. Therefore, we have evidence from different perspectives that these two state variables are local factors. The third state variable provides mixed evidence. The pattern is not directly consistent with either economy. The small and insignificant scaling coefficient seems to indicate that the factor is more directly related to the US. On the other hand, the factor has a positive and significant correlation with the second factor (the Swiss factor). Its parameters are all significant; therefore, this third factor is more of a common factor having an impact on both economies.

The state variables of the 5-factor quadratic model are presented in Fig. 4. The state variables seem to share the burden of US and Swiss characteristics. As a result, it is not as straightforward to visualize the pattern of an economy on a specific factor. However, some trends are noted. The second and fourth state variables resemble the Swiss and US term structures, respectively. This is consistent with the scaling coefficient results. The other factors do not have well-recognized graphical representations and, when they do (for example, the fifth state variable can be assumed to be similar to the US interest rate), they are not consistent with the scaling coefficient results.

5.5. Instantaneous Interest Rate (IIR) and Risk Premiums

Most asset pricing models on term structure of interest rates, including the ones examined here, have closed form expressions for the unobservable IIR. Fig. 5 plots the IIR generated by the 5-factor model for the US and for Switzerland.

The US IIR reaches its historical peak during the 1979-1982 period, which corresponds to the US recession and the experimental Federal Reserve policy period. Afterwards, the IRR follows a downward trend in the 1980s with a temporary increase around the stock market crash of 1987. It is stable during much of the expansion of the 1990s. Starting with the millennium, it declines to near zero reflecting the attempts of the Fed to stimulate the economy. Finally, the increase since the mid-2004 is because of the uneasiness of a continually weakening US dollar and fears of stagnation, such as the one in Japan. The IIR has been even lower than the changes in the consumer price index over the last few years.

The Swiss instantaneous rate fluctuates due to uncertainties caused by global events and SNB policies. The SNB monetary policy is planned and updated every three years. There is also approximately a three-year lag between policy and economic activity (Rich, 1997). This leads to the cyclical variations in the economic activity, which is clearly seen from the instantaneous interest rate plot as well as from the term structure plot (Fig. 1).

Since the instantaneous interest rate is not normally observable, studies use the 1-month yield or the 3-month yield as the proxy for the short rate; but are they accurate? And does the proxy differ from one country to the next? Table 6 provides the correlations between the yields of maturity less than one year and the IIR generated by the 5-factor, 3-factor, and 3-factor no exchange rate models. Correlations of levels and first differences in Panel A show that the 3-month yield is the best proxy for the short-term interest rate in the US. This is consistently the case for every model. On the other hand, the 6-month yield seems to be the best proxy for the short-term rate in Switzerland. This is confirmed by all models, and by both the level and first difference results. Longer maturity yield correlations are much lower and are not reported.

The model-generated IIR values make it possible to obtain the unobservable Eurocurrency risk premiums. The US premiums in Fig. 6 generally correspond to periods of uncertainty. Premiums are particularly high during 1974 (the first oil shock), the late 1970s and early 1980s (Iran hostage crises, Soviet invasion of Afghanistan, the recession and experimental Fed monetary policy), 1987 (the US stock market crash), 1990-1991 (recession and the first Gulf War), and the period around the beginning of the second Gulf War. Declining rates correspond to small risk premiums over the last five years. There is an increase in risk premiums near the end, reflecting doubts on the weakening US dollar.

We see a cyclical pattern with Swiss bond premiums, as before. The peaks correspond to global uncertainties, such as the first and second oil shocks, the Swiss economic depression of the first half of the 1990s (which is also the period of high inflation), the rejection of EU unification, declining equity market, and tightening of monetary policies resulting from the German unification. The final peak is due to the uncertainties of the EU formation, the introduction of the euro, and the negative image of the country because of the possible mistreatment of the dormant accounts belonging to Holocaust victims. Lower premiums correspond to declining inflation and stable economic expansion periods. Risk premiums in Switzerland are generally lower than those in the US. This is an indication of a more stable political and economic policy in Switzerland.

The benefits of diversification using US and Swiss bonds, and therefore the Home Bias puzzle, can be demonstrated by how the Eurocurrency risk premiums evolve over time. The cross-correlations between the US and Swiss risk premium movements range from 0.27 to 0.40, which are lower compared to cross country bond yield correlations. They are also much lower compared to the domestic premium correlations. The risk premium correlation structure is downward sloping with maturity[6].

5.6. US Dollar / Swiss Franc Exchange Rate Dynamics

Next, the Swiss exchange rate dynamics and several empirically stylized facts are explored using the comprehensive models developed in the previous sections[7]. Panel B and Panel C of Table 1 reports selected descriptive sample moments of the *$/CHF* exchange rate as well as the well-known regression result that underlies the forward premium anomaly. The depreciation rate has a mean that is indistinguishable from zero, is highly volatile, and displays little, if any, autocorrelation. In contrast, short-term interest rates and interest rate differentials are less volatile, both in absolute terms and relative to their means, and are highly autocorrelated. Finally, forward premium is negatively correlated with the subsequent depreciation rate. The slope coefficient estimate from the forward premium regression is -1.43.

In Table 7, the means and standard deviations of the actual and model fitted Swiss franc and its continuously compounded monthly return with respect to the US dollar summarize the performance of the models in accounting for the exchange rate dynamics. The model fitted exchange rates are the filtered values. The model fitted annualized 1-month returns are computed using these filter values. The data shows that the dollar-franc exchange rate is highly volatile. The actual monthly return is 3.24 percent, while the standard deviation of the return is 43.26 percent. This is consistent with studies such as Backus et al. (2001) and Engel and West (2004) in demonstrating the difficulty asset pricing models have in forecasting exchange rate dynamics. The 5-factor model performs best by producing an average monthly return of 3.48 percent and a volatility of 44.01 percent. Both measurements are the closest to the actual data. The 3-factor model that does not use the exchange rate data in the estimations produces the worst fit. The 3-factor model and the BFT affine model produce mixed results and do not dominate each other.

The empirical fit of the models is further explored in Fig. 7. The time series of the actual and 5-factor model fitted values of the dollar-franc exchange rate show that the Swiss franc has

[6] The correlation between the 1-month US and 1-month Swiss Eurocurrency premiums is 0.40. As maturity increases, correlations between same maturity US and Swiss bond premiums decline uniformly. The 5-year premium correlation at the end of the maturity spectrum is 0.29.

[7] Rich (1990) examines the Swiss approach to the exchange rate management but from only a public policy standpoint. Kohli (1987) creates a simple theoretical model of the Swiss franc-US dollar without any empirical investigation.

appreciated over the last thirty years relative to the US dollar. The changes are tracked by values generated by the 5-factor model very well. The bottom plot is the annualized monthly returns of the Swiss franc versus the contemporaneous filter values of the 5-factor model. The actual return is quite noisy and does not exhibit clear serial correlations or other distinguishable patterns. The model fitted returns track the actual changes quite well. The movements and swings are generally in the same direction with similar magnitudes. The actual returns seem to be slightly more volatile than the model fitted values. In that sense the model seems to slightly underestimate the volatility of the exchange rate. Overall, the 5-factor model does an excellent job in modeling the dollar-franc exchange rate dynamics. The 3-factor model that includes the exchange rate data throughout the estimations performs slightly worse than the 5-factor version. Those graphical outputs are not reported for brevity.

The top plot in Fig. 7 shows how global and local events have had an impact on the exchange rate dynamics between the US dollar and Swiss franc. The Swiss franc strengthened during the cyclical expansions of 1975-1981 and 1984-1988. At the end of both expansions, the franc weakened. Near the end of the 1970s, the high value started to undermine the competitive position of the Swiss industry and raised the specter of a slump in Swiss economy (Rich, 1990). As a result, the SNB abandoned the growth policy using the monetary control in M1 (base money plus deposits) and adopted the exchange rate control. A relaxed monetary policy was readopted from the 1980s with the control of only the base money, M0. The decline in inflation and in Swiss currency ended in the mid 1980s. The exchange rate increased quickly and reached another peak around the stock market crash of 1987. This, again, could not be justified with the fundamentals and affected exports. The peak was followed by a sharp decline in 1988-1989 because the growth rate in Germany had exceeded expectations. The tightening of the German economy with higher rates caused a decline in the Swiss franc. This was followed by a surge in inflation in Switzerland and the appreciation of the franc in the early 1990s. During the US expansion of the 1990s, the Swiss exchange rate remained high with respect to the dollar. During 1994-1996, the franc appreciated against many currencies. Rich (2000) shows that this was because investors did not believe in the EU and moved their investments to Swiss denominated assets. Just like in 1992, the SNB relaxed its monetary policy and lowered interest rates. As a result, the upward pressure on the franc subsided. The decline in the franc in 2000-2001 corresponds to the introduction of the euro. Since 2001, there has been a significant appreciation of the franc, just like all the other currencies, against the dollar. As a result, even though the US economy continues to be sluggish, the US interest rates have increased since mid-2004 partly because of concerns of the weak dollar.

Do the term structure data alone help to explain exchange rate movements? If the answer is yes, then the currency dynamics should be explained from the state variables estimated only for the US and Swiss term structures. And there should not be any other independent factors that would improve the Swiss franc dynamics. To resolve the issue, the 3-factor model estimated only with the interest rate data is utilized. The state variables of the model are then used to construct the exchange rate which is presented in Fig. 8. It is quite clear from the figure that the contemporaneous model values underestimate the actual exchange rate in the first half of the sample and overestimate the actual values in the second half. The bottom plot is the annualized 1-month actual returns and prediction returns obtained from the 3-factor term structure model. The model generated filter values sometimes overestimate the returns and sometimes underestimate them throughout the sample period. Overall, the term structure of interest rates cannot explain exchange rate movements alone.

The US dollar-Swiss franc exhibits the well-known forward premium puzzle (FPP). Table 7 Panel C reports the conditions of Fama (1984) generated by the 5-factor and 3-factor nonlinear models. Both conditions are satisfied for the 1-month and 3-month short-term yields with the corresponding forecast horizons. The UIP is rejected, and both models overcome one of the hurdles in the development of an exchange rate asset pricing model.

Recent studies by Alexius (1993) and Meredith and Chinn (1998) document that the UIP holds for longer horizons, such as 5- or 10-years. This would mean that the FPP does not exist for long horizons. Do the models demonstrate this stylized fact as well? Using 5-year yields, the second part of Panel C shows that the FPP does not exist for long-term rates and the UIP is not rejected. Therefore, the quadratic models have the flexibility to account for different stylized facts about the dollar-franc dynamics.

5.6.2. Jump Diffusion Process

The 3-factor model results in Fig. 8 clearly indicate that term structure factors alone cannot explain exchange rate dynamics. This implies that there are independent factors that should account for the unexplainable portions of the exchange rate dynamics. Daal (2004) suggests jump processes for this purpose. On the other hand, Bruand (1998) conjectures that jump diffusion would lead to specification problems due to over-parameterization. There are also studies that claim for monthly or quarterly data that jump processes do not help estimations since jumps are smoothed out during the sampling period. Ultimately this is an empirical issue which depends on the specific dual-country setting as well. To investigate the impact of jump processes, equation (10) for the exchange rate dynamics is extended with a jump diffusion process:

$$q(t+\tau) - q(t) = (b_d - b_f)\tau + [X'(t+\tau)(\Psi_f - \Psi_d)X(t+\tau) - X'(t)(\Psi_f - \Psi_d)X(t)]) + Sdp(t),$$

where $dp(t)$, with mean and variance $\lambda_{jump}dt$, represents the Poisson process, and $S = ln(1+J(S))$, normally distributed with mean μ_{jump} and variance σ_{jump}^2, is the underlying Poisson amplitude mark process ($J(S)$ is the Poisson jump amplitude)[8]. The Poisson process and amplitude process are independent. Estimates of the Poisson parameters are all significant (λ_{jump} is 0.0302, μ_{jump} is 0.0008, and σ_{jump} is 0.0822). However, the SIC value for this augmented nonlinear model is -72.317. Panel A of Table 5 shows that the original 5-factor model is better for forecasting purposes. The additional currency risk does not seem to be described by jump diffusions. Therefore, although contemporaneous fit of the estimations may improve with Poisson jumps, the predictive power of the augmented model is actually inferior because of over-parameterization in the US-Swiss three-decade monthly sample. Quadratic term structure models inherently assume that state variables follow multivariate normal distributions; in this sense, before augmenting with the explicit jump diffusion, the original 5-factor quadratic model can be considered to already have jump diffusion processes. Furthermore, recent literature suggests that higher frequency data, such as intraday data, provides a more accurate separation between continuous and jump components of a dynamic process. These may be some potential reasons why the empirical estimations have not improved after incorporating the jump process.

6. Conclusion

This study examines the term structure dynamics of Eurocurrency yields and the exchange rate in the US and Switzerland. A nonlinear asset pricing model and its different versions are examined in the US-Swiss dual country setting. Nonlinear and affine international models are also

[8] An excellent discussion of Poisson jump processes and their incorporation into a more general stochastic framework is provided in Chapter 5 of Hanson (2005).

compared. The 5-factor quadratic asset pricing model performs better than affine and other non-linear versions. Unobservable variables such as instantaneous interest rates, currency risk premium, and Eurocurrency premiums are obtained and interpreted. Two international puzzles are addressed. The forward premium puzzle in the exchange rate dynamics exists for short horizon forecasts but diminishes for longer horizons, consistent with recent studies. Home Bias is a puzzle in the US-Swiss setting because the joint estimation produces local factors in addition to common factors suggesting different characteristics and potential benefits from diversification.

For future research, a multi-country setting with more than two countries can be examined. The currency risk problem might be reduced because the risk gets partly diversified away in such a multi-country portfolio. The results of the study also indicate that currency futures and options contracts can be useful to hedge currency risk. The results justify the popularity of these derivatives and a more comprehensive model can incorporate them to measure their risk reduction and contribution to diversification. Presence of local factors may also lead to interesting implications in forecasting macroeconomic variables and indicators of the corresponding domestic economies as in Ang and Piazzesi (2003).

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Table 1 Summary Statistics of Variables

Panel A. Correlation matrix of the US and Swiss Yields

		Yields (Switzerland)							
		1-m	3-m	6-m	1-y	2-y	3-y	4-y	5-y
Yields (US)	1-m	0.47	0.51	0.55	0.55	0.54	0.55	0.54	0.54
	3-m	0.46	0.51	0.55	0.54	0.54	0.55	0.55	0.55
	6-m	0.45	0.50	0.54	0.54	0.54	0.56	0.56	0.56
	1-y	0.45	0.50	0.54	0.54	0.55	0.57	0.57	0.57
	2-y	0.45	0.50	0.54	0.55	0.56	0.58	0.59	0.59
	3-y	0.46	0.51	0.55	0.56	0.58	0.60	0.61	0.61
	4-y	0.46	0.51	0.56	0.57	0.58	0.61	0.61	0.62
	5-y	0.47	0.52	0.56	0.57	0.59	0.61	0.62	0.62

Panel B. Properties of Short Interest Rates and the Exchange Rate

	Mean	Std	Skewness	Kurtosis	Autocorr
US 1-m:	0.07	0.04	0.94	4.19	0.99
Swiss 1-m:	0.04	0.03	0.75	2.69	0.98
Forward Premium: $f(t) - q(t) = r(t) - r_f(t)$	0.03	0.04	0.32	3.55	0.98
Depreciation Rate: $q(t+1) - q(t)$	0.03	0.43	-0.09	3.84	0.06

Panel C. Forward Premium Regression: $q_{t+1} - q_t = \beta_0 + \beta_1(f_t - q_t) + \varepsilon_t$

β_0	β_1	Std Er	R^2
0.0797	-1.4269	0.4297	0.0137
(0.0305)	(0.6289)		

Panel A is the correlations between the yields in the US and yields in Switzerland. In panel B, q denotes the logarithm of the exchange rate, measured in dollars per unit of Swiss franc, and *r* (r_f) denotes the continuously compounded one month yield in the US (Switzerland). In panel C, Newey-West standard errors of the regression estimates are provided in the parenthesis.

Table 2 Parameter Estimates of the quadratic US-Swiss Models

	3-Factor Model	5-Factor Model	3-Factor no $/CHF
State Variables			
κ_1	0.1041 (0.0039)	0.6956 (0.0119)	0.3434 (0.0064)
μ_1	0.9660 (0.0233)	0.2131 (0.0049)	0.1539 (0.0113)
σ_1	0.1265 (0.0036)	0.0951 (0.0026)	0.0155 (0.0013)
κ_2	0.3812 (0.0073)	0.0894 (0.0015)	0.8895 (0.0215)
μ_2	0.0211 (0.2256)	0.1809 (0.0193)	-0.2102 (0.0038)
σ_2	0.0024 (0.0255)	0.0513 (0.0054)	0.0811 (0.0025)
κ_3	0.7760 (0.0176)	0.5300 (0.0103)	0.0748 (0.0018)
μ_3	0.2742 (0.0069)	0.1652 (0.0065)	1.2386 (0.0502)
σ_3	0.0593 (0.0023)	0.0884 (0.0032)	0.1049 (0.0039)
κ_4	-	0.0635 (0.0028)	-
μ_4	-	1.0956 (0.0686)	-
σ_4	-	0.1126 (0.0036)	-
κ_5	-	0.0024 (0.0016)	-
μ_5	-	0.0610 (0.4155)	-
σ_5	-	0.0098 (0.0663)	-
ρ_{12}	0.0596 (0.0797)	0.2003 (0.0484)	-0.1626 (0.0691)
ρ_{13}	-0.2492 (0.0611)	-0.1604 (0.0561)	0.2227 (0.0671)
ρ_{14}	-	0.0995 (0.0529)	-
ρ_{15}	-	-0.0475 (0.0550)	-
ρ_{23}	0.3284 (0.0611)	-0.0800 (0.0710)	0.2095 (0.0506)
ρ_{24}	-	0.2336 (0.0533)	-
ρ_{25}	-	0.0543 (0.0573)	-
ρ_{34}	-	-0.0327 (0.0600)	-
ρ_{35}	-	0.0564 (0.0596)	-
ρ_{45}	-	0.7261 (0.0284)	-
Swiss Pricing Kernel			
b_f	0.0695 (0.0012)	0.0976 (0.0003)	0.0641 (0.0012)
ψ_1	0.2686 (0.0146)	0.9827 (0.0202)	13.2091 (1.8487)
ψ_2	5.4804 (11.7074)	9.0488 (1.7807)	0.1067 (0.0144)
ψ_3	0.0003 (0.0151)	0.0003 (0.0063)	0.0401 (0.0184)
ψ_4	-	0.3891 (0.0123)	-
ψ_5	-	54.0086 (7.183562)	-
US Pricing Kernel			
b_d	0.1118 (0.0004)	0.1056 (0.0011)	0.1118 (0.0007)

Parameter estimates of three- and five-factor models on the Eurocurrency term structures of the US and Switzerland and dollar-franc exchange rate are presented. Parameter estimates of the 3-factor model for only the term structures and not the exchange rate estimation are also reported. Standard errors of the estimates are reported in parentheses.

Table 3 Term structures of the US and Swiss Eurocurrency rates

Panel A. Eurodollar interest rates								
Maturity:	1-m	3-m	6-m	1-y	2-y	3-y	4-y	5-y
				Mean				
Actual	0.0726	0.0734	0.0741	0.0739	0.0779	0.0805	0.0826	0.0843
5-factor w/	0.0730	0.0734	0.0739	0.0752	0.0780	0.0805	0.0827	0.0846
3-factor w/	0.0731	0.0735	0.0742	0.0755	0.0781	0.0805	0.0827	0.0848
3-factor w/o	0.0739	0.0742	0.0747	0.0758	0.0783	0.0807	0.0829	0.0849
				Standard Deviation				
Actual	0.0385	0.0381	0.0372	0.0338	0.0320	0.0305	0.0296	0.0289
5-factor w/	0.0386	0.0375	0.0362	0.0341	0.0316	0.0302	0.0293	0.0285
3-factor w/	0.0378	0.0369	0.0357	0.0339	0.0315	0.0300	0.0289	0.0280
3-factor w/o	0.0378	0.0370	0.0359	0.0342	0.0318	0.0302	0.0291	0.0282

Panel B. Eurofranc interest rates								
Maturity:	1-m	3-m	6-m	1-y	2-y	3-y	4-y	5-y
				Mean				
Actual	0.0395	0.0413	0.0425	0.0426	0.0463	0.0485	0.0503	0.0516
5-factor w/	0.0416	0.0420	0.0428	0.0442	0.0468	0.0489	0.0506	0.0522
3-factor w/	0.0408	0.0414	0.0421	0.0437	0.0464	0.0486	0.0505	0.0521
3-factor w/o	0.0410	0.0415	0.0422	0.0437	0.0463	0.0486	0.0505	0.0522
				Standard Deviation				
Actual	0.0282	0.0283	0.0273	0.0249	0.0218	0.0201	0.0189	0.0179
5-factor w/	0.0275	0.0267	0.0257	0.0240	0.0215	0.0196	0.0182	0.0171
3-factor w/	0.0273	0.0267	0.0259	0.0243	0.0215	0.0191	0.0170	0.0153
3-factor w/o	0.0272	0.0267	0.0259	0.0244	0.0216	0.0191	0.0170	0.0151

Means and standard deviations of actual and model implied Eurocurrency rates are provided. The yield maturities range from 1-month to 5-years. Panel A is for the US; panel B is for Switzerland. Five-factor, three-factor, and three-factor with no exchange rate estimation are considered. Model implied yields are one-month-ahead prediction values based on the prediction densities of the unobservable state variables.

Table 4 Residual Analysis of the five-factor nonlinear model

Panel A. Eurodollar	1-m	3-m	6-m	1-y	2-y	3-y	4-y	5-y
Mean	-0.0005	0.0000	0.0002	-0.0013	-0.0001	0.0000	-0.0001	-0.0004
Std	0.0104	0.0092	0.0087	0.0074	0.0059	0.0052	0.0050	0.0047
Std(resid)/Std(yield)	0.2691	0.2429	0.2328	0.2190	0.1853	0.1711	0.1688	0.1619
RMSE	0.0104	0.0092	0.0087	0.0075	0.0059	0.0052	0.0050	0.0047

Panel B. Eurofranc	1-m	3-m	6-m	1-y	2-y	3-y	4-y	5-y
Mean	-0.0021	-0.0008	-0.0003	-0.0016	-0.0004	-0.0003	-0.0004	-0.0006
Std	0.0098	0.0094	0.0080	0.0067	0.0049	0.0041	0.0038	0.0038
Std(resid)/Std(yield)	0.3491	0.3318	0.2939	0.2681	0.2264	0.2035	0.2000	0.2146
RMSE	0.0115	0.0094	0.008	0.0069	0.005	0.0041	0.0038	0.0039

Panel C. $/CHF	
Mean	0.0000
Std	0.0399
Std(resid)/Std(yield)	0.1628
RMSE	0.0399

The residuals are one-period ahead forecasting errors on the yields, based on prediction densities of the unobservable state variables. Residuals are defined as actual values minus model estimates. Means and standard deviations of the residuals are followed by the ratio of the residual to actual yield standard deviations. Finally, the root mean square error value follows. Panel A is for the US, panel B is for Switzerland, and panel C is for the US dollar to Swiss franc (*$/CHF*) exchange rate.

Table 5 Schwarz information criterion for model predictive power comparison

Panel A. Interest Rate and Exchange Rate Estimations		
Rank	Model	SIC value
1	5-factor model	-73.04
2	3-factor model	-66.92
3	BFT	-45.31
Panel B. Exchange Rate Estimation		
Rank	Model	SIC value
1	RW	-6.6267
2	5-factor model	-6.6212
3	3-factor model	-6.6129
4	UIP	-6.6068
5	BFT	-5.0859

Schwarz information criterion is calculated from full likelihood values of the models. Panel A is for models both for the exchange rate and for the US and Swiss interest rate forecasting. 5-factor, two 3-factor nonlinear models (the second does not use exchange rate data in estimations), and the interdependent BFT affine model are compared. In Panel B, only the exchange rate forecasting is considered. Random walk, uncovered interest parity, 5- and 3-factor nonlinear model, and the interdependent BFT affine model are compared. $SIC = ln(u'u/T) + \xi ln(T)/T$, where u is the residual, ξ is the number of parameters in the model, and T is the sample size.

Table 6 Proxies for the Instantaneous Interest Rates

Panel A: US	5-factor		3-factor		3-factor noex	
	yield level	yield diff	yield level	yield diff	yield level	yield diff
1-month	0.9832	0.7491	0.9941	0.8906	0.9941	0.8895
3-month	0.9858	0.8011	0.9979	0.9751	0.9973	0.9602
6-month	0.9829	0.7913	0.9957	0.9717	0.9946	0.9475
Panel B: SW	**5-factor**		**3-factor**		**3-factor noex**	
	yield level	yield diff	yield level	yield diff	yield level	yield diff
1-month	0.9526	0.5160	0.9686	0.7894	0.9666	0.7841
3-month	0.9683	0.5660	0.9870	0.9099	0.9865	0.9057
6-month	0.9727	0.5797	0.9949	0.9444	0.9954	0.9446

Correlation coefficients between model generated instantaneous interest rates (IIRs) and short-term actual yields are presented. 5-factor, 3-factor, and 3-factor with no exchange rate models are used. 1-month, 3-month, and 6-month yields are considered as the short term proxies. Correlations between using levels and first differences are provided. Panel A is for the US; panel B is for Switzerland.

Table 7 US dollar / Swiss Franc exchange rate dynamics

Panel A. Mean	$/CHF	Monthly CHF return
Actual	0.5922	0.0324
5-factor w/ exchange rate	0.5932	0.0348
3-factor w/ exchange rate	0.5310	0.0490
3-factor w/o exchange rate	0.5380	0.0596
BFT w/ exchange rate	0.5782	0.0373

Panel B. Standard deviation	$/CHF	Monthly CHF return
Actual	0.2453	0.4326
5-factor	0.2445	0.4401
3-factor	0.6204	0.5596
3-factor w/o exchange rate	0.8172	0.8623
BFT	0.2604	0.9117

Panel C. FPP conditions	Correlation(ed, cp) < 0	Std(cp) > Std(ed)
Short-horizon (1-month) results		
5-factor nonlinear model	-0.7641 < 0	0.0521 > 0.0367
3-factor nonlinear model	-0.8016 < 0	0.0583 > 0.0466
Short-horizon (3-month) results		
5-factor nonlinear model	-0.9090 < 0	0.0771 > 0.0657
3-factor nonlinear model	-0.9349 < 0	0.0937 > 0.0877
Long-horizon (5-year) results		
5-factor nonlinear model	-0.9966 < 0	0.2717 < 0.2721
3-factor nonlinear model	-0.9977 < 0	0.2912 < 0.2992

Statistics for the US dollar-Swiss franc exchange rate (*$/CHF*) values and monthly returns are presented. Model values are recovered from the filtering densities of unobserved state variables. Panel A provides the mean values. Panel B provides standard deviations. Panel C presents the conditions necessary to account for the forward premium puzzle. Currency risk premium is *cp*, expected rate of depreciation is *ed*. Five factor and three factor nonlinear models are tested both for short horizon and long horizon analysis.

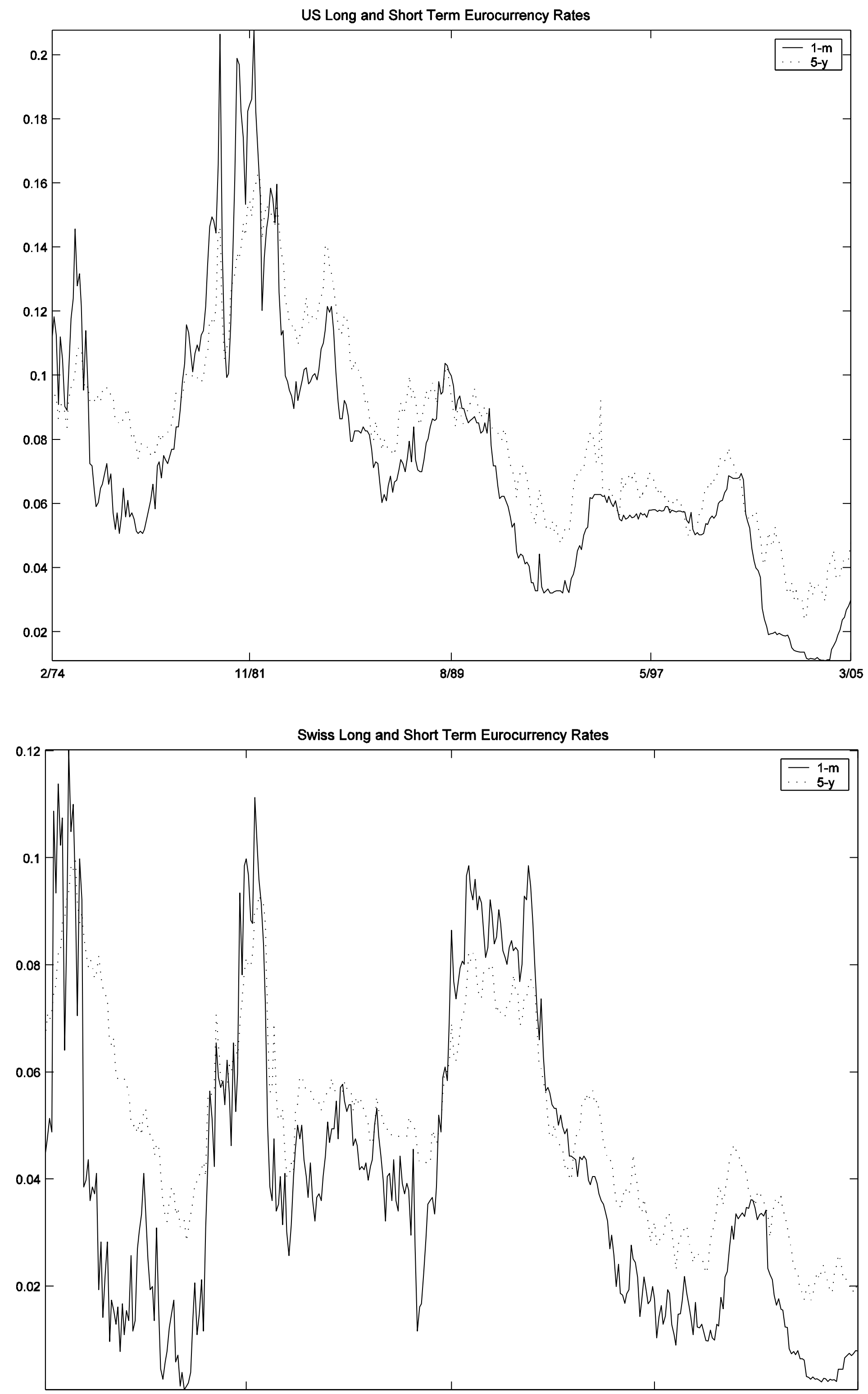


Fig. 1. US and Swiss long term yields and short term Eurocurrency yields.

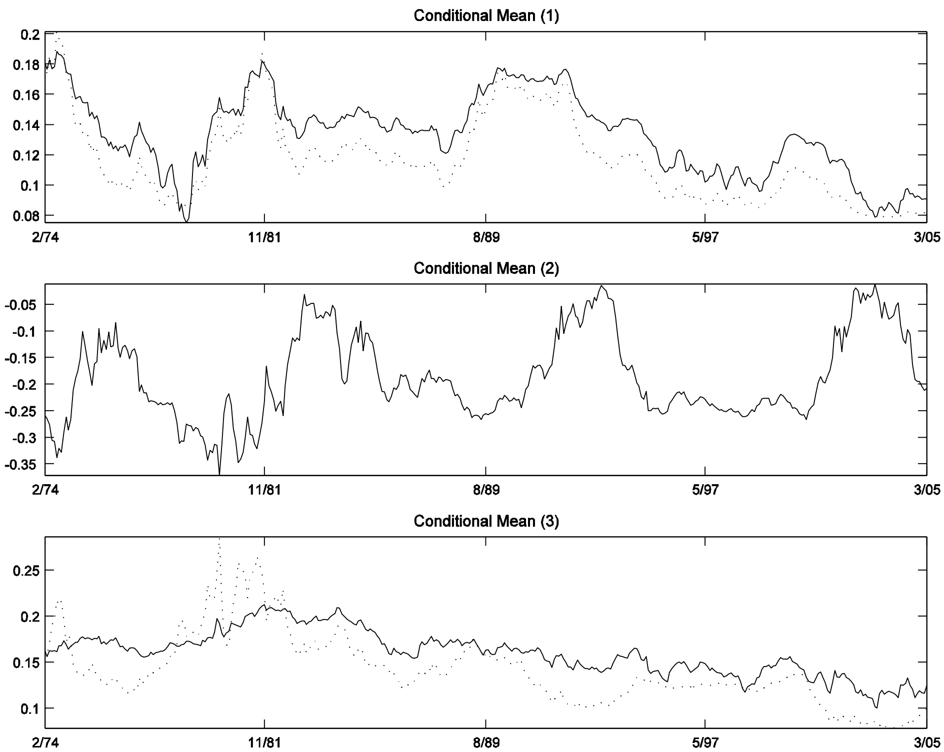


Fig. 2. Conditional means of the states in the three-factor no exchange rate model.

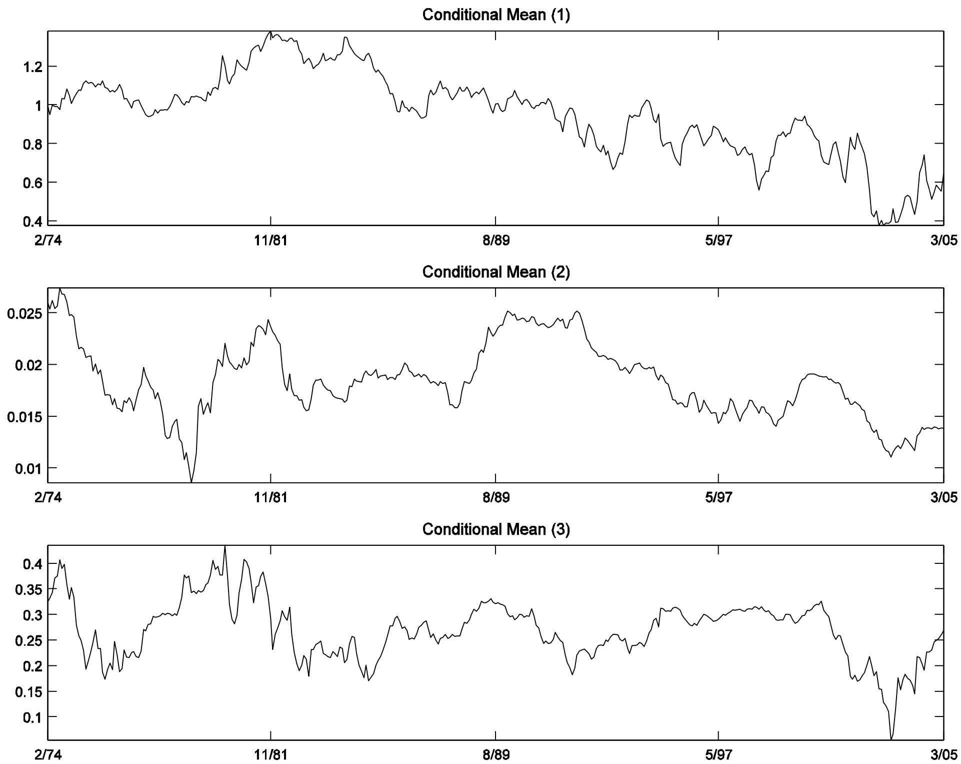


Fig. 3. Conditional means of the states in the three-factor model with yields and exchange rate.

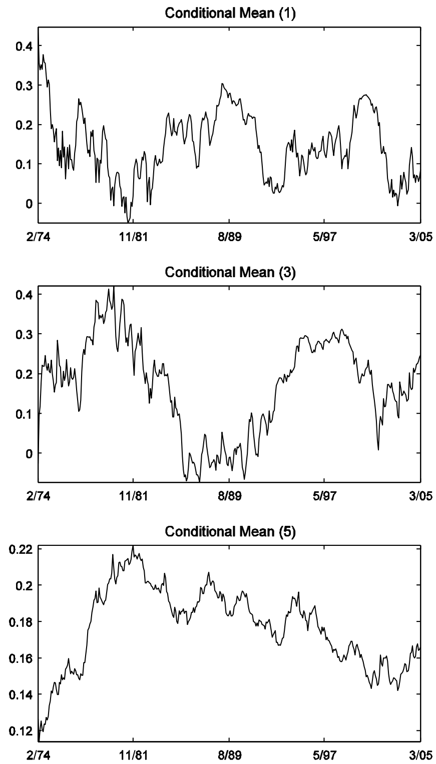


Fig. 4. Conditional means of the states in the five-factor nonlinear model.

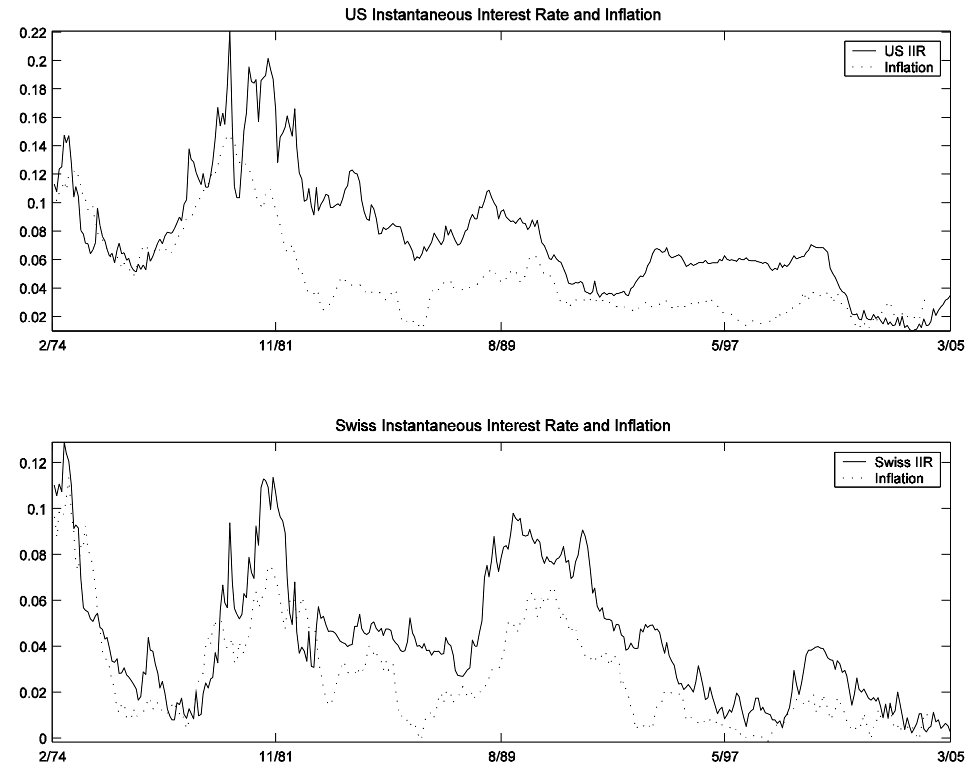
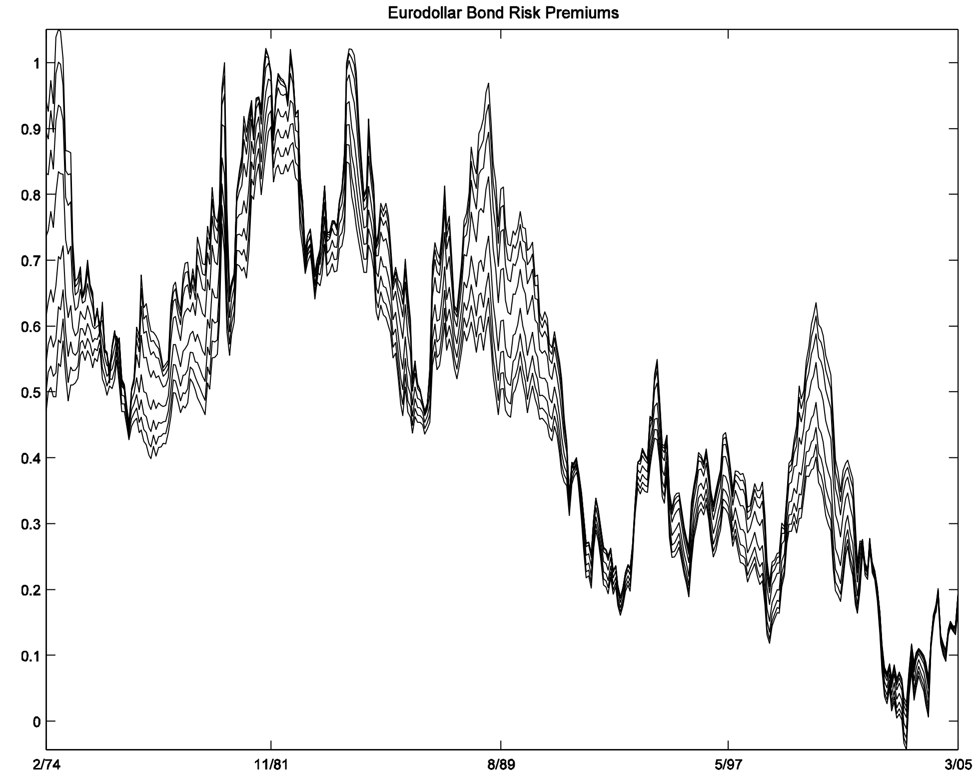


Fig. 5. US and Swiss Instantaneous Interest Rates.



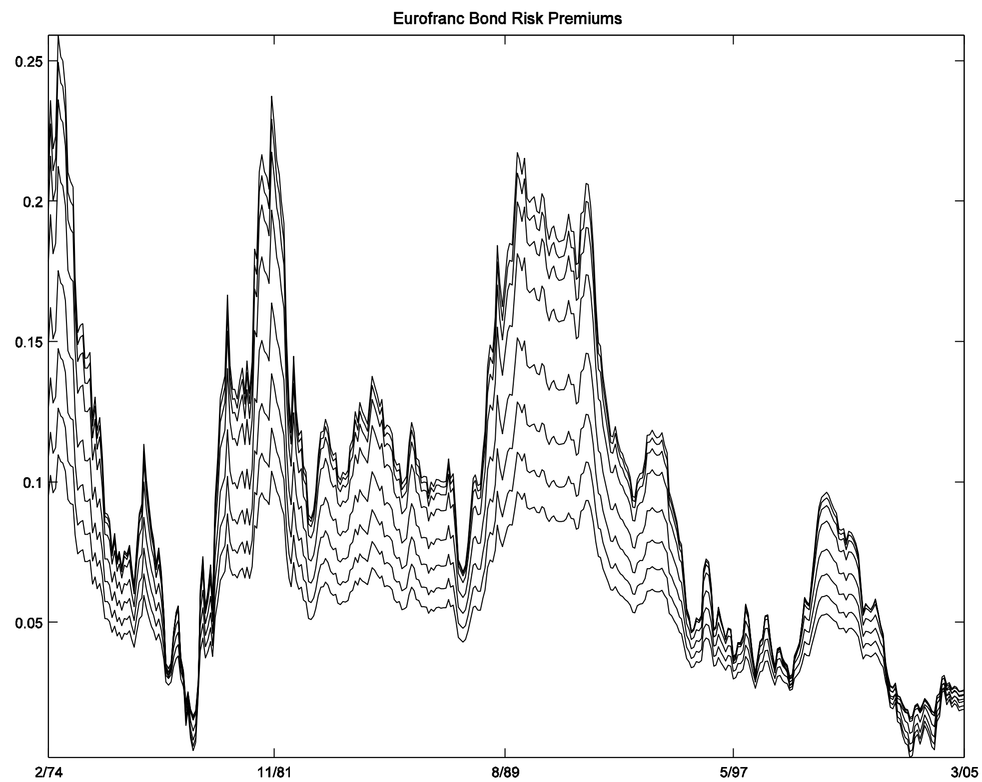


Fig. 6. US and Swiss Eurocurrency risk premiums (in percentage).

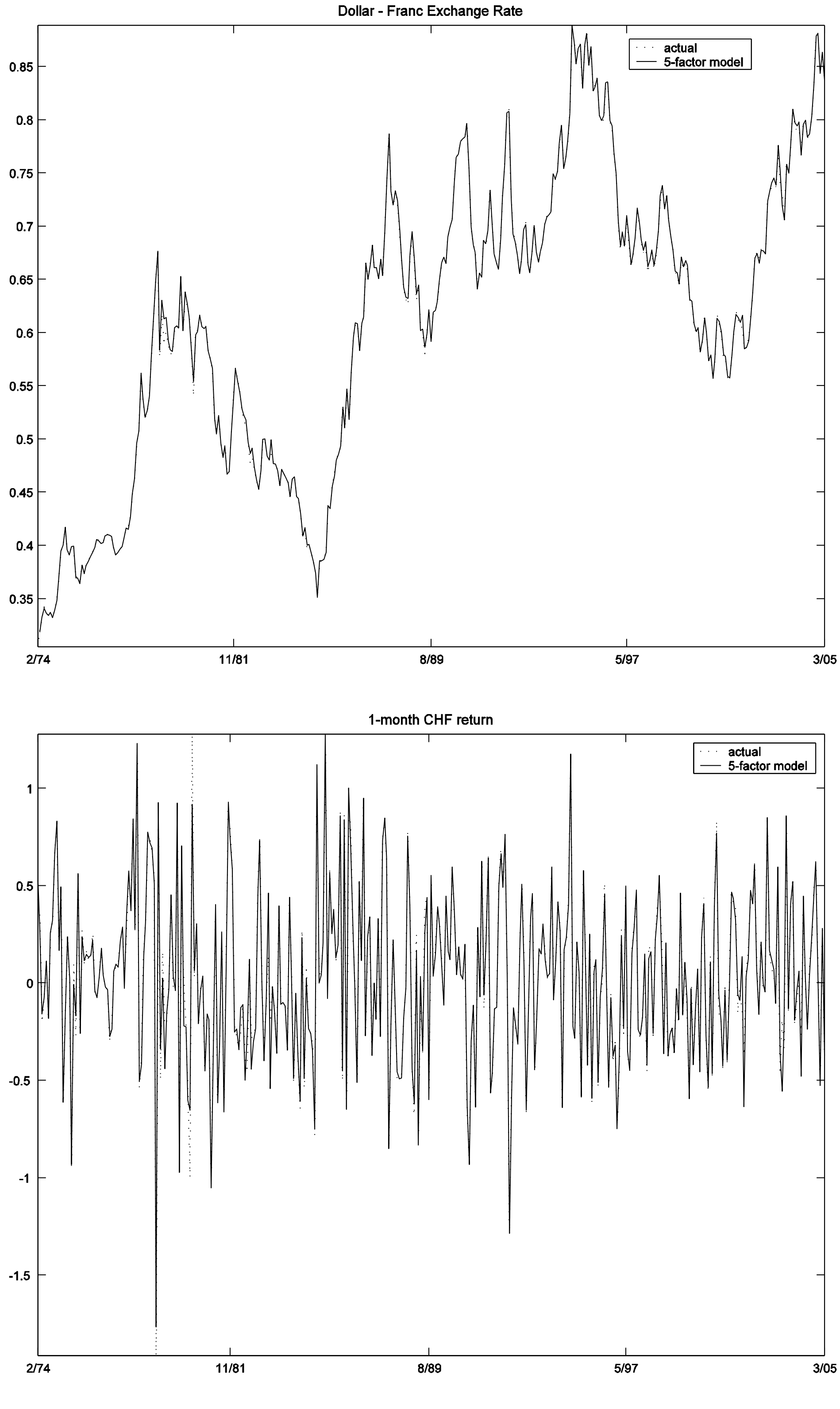


Fig. 7. Actual and five-factor model filtered US dollar-Swiss franc exchange rate and monthly return values.

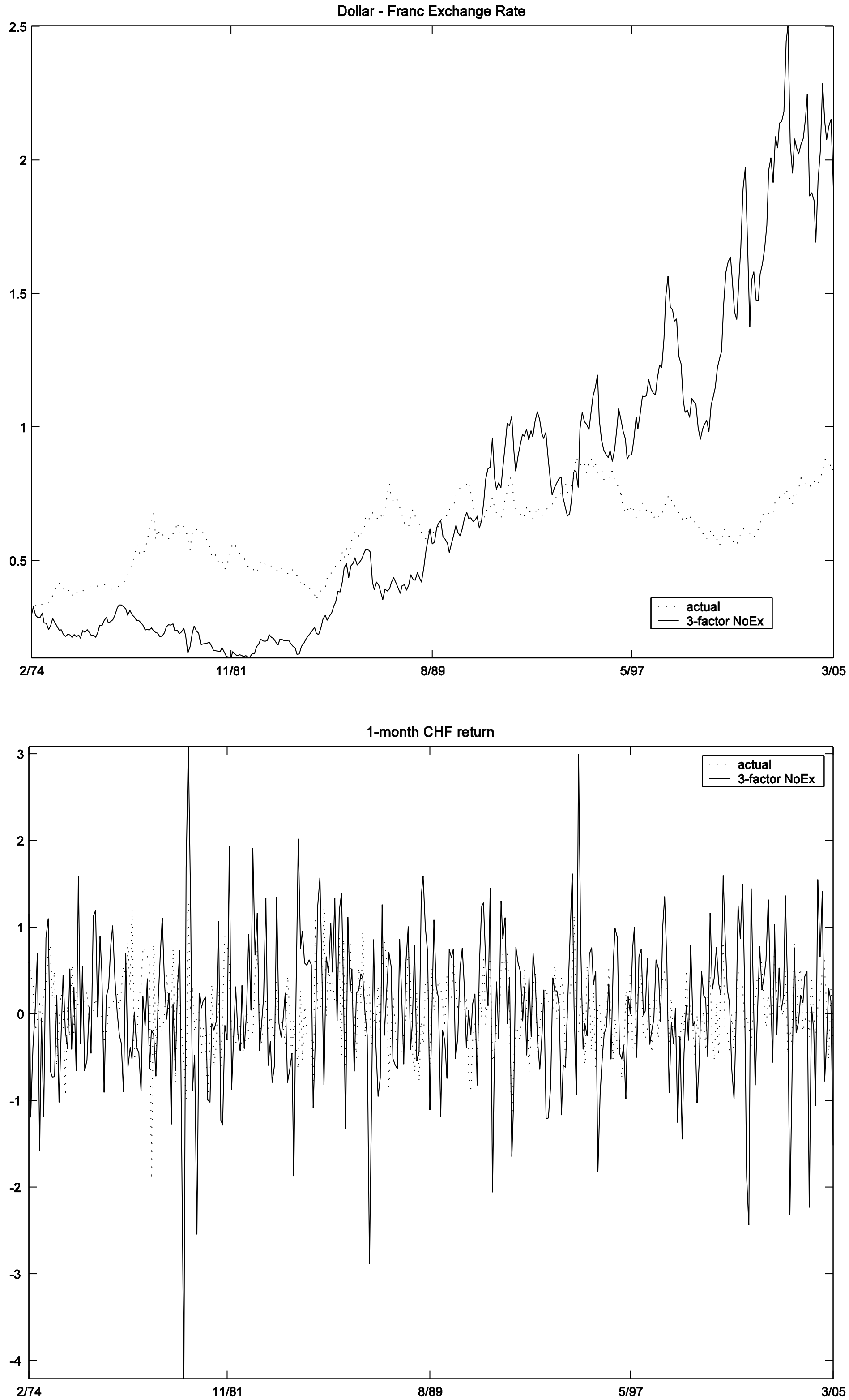


Fig. 8. Actual and three-factor no exchange rate model filtered US dollar-Swiss franc exchange rate and monthly return values.