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Short-term determinants of bilateral exchange rates: A decomposition model for the Swiss franc*

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Abstract

This paper develops an FX factor model to decompose short-term bilateral exchange rate dynamics into different global factors and local uniqueness. We apply the model to the Swiss franc exchange rates against the US dollar (USDCHF) and the euro (EURCHF) between 2006 and 2018 and decompose daily dynamics into three global factors: risk, US dollar, and euro. The model captures daily dynamics well, explaining approximately 73% of the variation in USDCHF and 37% of the variation in EURCHF. The risk factor contributes the most to Swiss franc dynamics, especially in times of a worsening risk environment, highlighting the role of the Swiss franc as a safe-haven currency. Global FX factors had been almost completely reflected in USDCHF dynamics before the euro area debt crisis, but once that crisis began, they also became important for EURCHF. Furthermore, momentum is present in daily Swiss franc returns, especially before the introduction of the EURCHF minimum exchange rate.

Keywords: Factor model, variance decomposition, safe haven, carry trade, momentum
JEL-Codes: F31 (Foreign Exchange), G15 (Int. Financial Markets), C38 (Factor Models)

*fabian.fink@snb.ch, lukas.frei@snb.ch, oliver.gloede@snb.ch, Swiss National Bank, Börsenstrasse 15, P.O. Box, 8022 Zurich, Switzerland. We gratefully acknowledge the helpful comments from participants of the SNB Research Conference 2019, the Joint BIS-SNB Research Workshop 2019, the SNB Brown Bag Workshop and the SNB Financial Market Platform, in particular, Angela Abbate, Benjamin Anderegg, Alain Gabler, Christian Grisse, Peter Kugler, Thomas Maag, Christoph Meyer, Nikola Mirkov, Barbara Stahel, and Pinar Yesin, as well as an anonymous referee. The views, opinions, findings, and conclusions or recommendations expressed in this paper are strictly those of the authors. They do not necessarily reflect the views of the Swiss National Bank. The Swiss National Bank takes no responsibility for any errors or omissions in, or for the correctness of, the information contained in this paper.

1 Introduction

Empirical exchange rate models commonly find significant deviations from equilibrium exchange rates and perform poorly in predicting changes in future exchange rates (Meese and Rogoff 1983, Cheung et al. 2005). Most models share a long-term focus and rely on low-frequency nominal and real variables or statistical trend modelling. For example, most studies find the half-life of purchasing power parity deviations to be between 3 and 5 years (Rogoff 1996). While the exchange rate is not in its equilibrium state, currencies are affected by various factors with time-varying weights (Bacchetta and Van Wincoop 2004, Bacchetta and van Wincoop 2013, Fratzscher et al. 2015) and often display short-term trends of appreciation and depreciation (Diebold and Nerlove 1989, Menkhoff et al. 2012b). However, the short-term perspective is important for policymakers and financial market participants alike. Our paper fills this gap and develops an FX factor model to identify short-term determinants of daily bilateral exchange rate returns. In our model, we decompose short-term determinants into different global factors and local uniqueness. The model is applied to Swiss franc exchange rates vis-a-vis the euro and the US dollar.[1] In particular, we provide empirical evidence addressing the following three questions: (1) How does risk sentiment affect the Swiss franc? (2) How do currency-specific developments in the US and Europe affect the Swiss franc? (3) How strong is short-term momentum in the Swiss franc?

We examine the short-term determinants of the Swiss franc by estimating a multivariate time-varying coefficients model of the relationship between bilateral Swiss franc exchange rate returns and observable financial variables. The time-varying form of the model allows us to capture the nonstationary nature of financial markets, similar to the dynamic weights that market participants put on exchange rate drivers in scapegoat models (Bacchetta and Van Wincoop 2004, Bacchetta and van Wincoop 2013, Fratzscher et al. 2015). Moreover, we group and orthogonalize financial variables into global factors resulting in risk, US dollar, and euro factors. A local linear trend captures the short-term trend in each bilateral exchange rate. Capturing all global factors and those factors specific to the bilateral exchange rate, we cautiously interpret the residual as local uniqueness, i.e. Swiss franc specific. This FX factor model allows us to analyse the short-term determinants of daily Swiss franc exchange rate movements within a comprehensive framework.

Using daily financial data from 1 January 2006 to 21 December 2018, the key findings can be summarized as follows: First, the empirical model captures the short-term dynamics of Swiss franc exchange rates well. On average, 73% of the variance of USDCHF daily returns and 37% of the variance of EURCHF daily returns is explained by the model. Second, the risk factor

[1] Throughout this paper, we use market conventions for exchange rates, i.e. EURCHF refers to the Swiss franc price of one euro and USDCHF refers to the Swiss franc price of one US dollar.

explains a relatively large fraction of daily variations, particularly for EURCHF, for which it explains 31% on average (USDCHF 21%). Third, currency-specific developments in the US and Europe mainly affect the USDCHF exchange rate: the US dollar factor explains approximately 36% on average, while the euro factor takes a share of 16%. Fourth, we find that short-term momentum is present in Swiss exchange rate returns. Particularly, there was strong appreciation momentum prior to the introduction of the minimum exchange rate of the Swiss National Bank. Fifth, the unexplained part of the model captures Swiss franc unique factors well, e.g. changes in the monetary policy by the Swiss National Bank.

While we use the Swiss franc as an example of how to analyse bilateral exchange rate dynamics on a daily basis, our model and estimation framework can be easily adapted to other currency pairs. Thereby, policymakers, researchers and practitioners in central banks, private banks, and research institutes can use this approach for other exchange rates, too. Although our approach is novel in its use and application, it builds on existing research and relates to three streams of literature. First, our model uses the findings of FX portfolio analysis of the FX asset pricing literature (Lustig and Verdelhan 2007, Lustig et al. 2011, Menkhoff et al. 2012a, Verdelhan 2018). Closest to our approach are Hoffmann and Suter (2010) and Grisse and Nitschka (2015), who use a cross section of FX factors to explain dynamics of the Swiss franc exchange rate. While Hoffmann and Suter (2010) decompose bilateral exchange rate returns into a global and domestic component, they do not decompose the global factor further and use only monthly data from 1990 to 2009. Grisse and Nitschka (2015) also use monthly data (1990 to 2011) for their analysis of bilateral Swiss franc exchange rates but choose an augmented uncovered interest parity model that adopts a risk factor and an average Swiss franc factor to account for the domestic component.[2]

Second, there is a set of papers on safe haven assets that is related to the role of the risk factor in our paper. Grisse and Nitschka (2015), mentioned above, use the FX asset pricing framework to analyse the safe haven characteristics of the Swiss franc. They focus on the VIX as their single measure of risk, whereas we use the VIX as one of the financial variables in constructing our risk factor. Further, Ranaldo and Söderlind (2010), De Carvalho Filho (2015), Baltensperger and Kugler (2016), Danthine and Danthine (2018), Leutert (2018) use alternative approaches but contribute to establishing the safe haven characteristics of the Swiss franc. Cross-sectional studies using the Swiss franc as one of many potential safe haven assets, such as those of Habib and Stracca (2012), De Bock and de Carvalho Filho (2015), Fatum and Yamamoto (2016), Lee (2017), find that the Swiss franc reacts as a safe haven (in addition to the Japanese yen, US dollar, and gold). Two papers analyse the opposite side of the Swiss franc as a safe haven, namely, as a carry trade funding currency (Gubler 2014, Hossfeld and MacDonald 2015). We

[2] Other short-term models of Swiss franc exchange rates include those of Jochum and Savioz (2005), Reynard (2009), Jäggi et al. (2019) and others that differ from the asset pricing approach that we follow.

relate to this substream of the literature by including the excess return of a carry portfolio in our model.

Third, we include the US dollar and euro as global FX factors to measure the impact of external macroeconomic shocks on the Swiss franc. Thereby, we rely on the finding that macro surprises are priced in the exchange rate (Sarno and Schmeling 2014, Jäggi et al. 2019, Menkhoff et al. 2017). Other papers have also used this interpretation when including global FX factors in their models (Kitamura 2012, Tamakoshi and Hamori 2014, Aloosh and Bekaert 2019). We choose the US dollar and the euro as global FX factors, as they are the most important currency blocks (Hiro Ito 2019), and by doing so, we follow Greenaway-McGrevy et al. (2018).

The paper continues with a description of the data set (Section 2) and the introduction of the model framework (Section 3). We provide our results in Section 4 and discuss the results of further robustness checks in Section 5. Section 6 concludes.

2 Data

We retrieve daily financial data from Bloomberg L.P. Reported results span from 14 July 2005 to 21 December 2018, covering a representative time series of macrofinancial conditions and dynamics. However, we report only the results starting from 1 January 2006, when parameter training converged. Hence, data from 2005 are used only to train our Bayesian estimator.

Table 1 provides the variable definitions and shows the descriptive statistics. We capture periods of calm financial markets as well as elevated market volatility starting with the global financial crisis (2008 2009) and the euro area debt crisis (starting in 2009). The data period also covers the time period of the introduction of the EURCHF minimum exchange rate (6 September 2011) and its discontinuation (15 January 2015). Internationally, the data period captures a comprehensive universe of macroeconomic conditions with monetary policy easing and tightening cycles in the US as well as in the euro area. In the currency space, this implies multiple episodes of appreciation and depreciation trends in the Swiss franc, US dollar and the euro. The 13 years from 2006 to 2018 give us 3565 trading days of observations.

During the observation period, the Swiss franc appreciates overall (Figure 1). With the onset of the global financial crisis, and especially the euro area debt crisis, the Swiss franc gains significantly. In 2011, the Swiss franc is massively overvalued, which leads to the introduction of the EURCHF minimum exchange rate by the Swiss National Bank (Swiss National Bank 2011). During the period of the minimum exchange rate, the EURCHF rate is relatively stable and USDCHF movements mirror EURUSD dynamics. In 2014, monetary policy divergence between the US and the euro area culminates in the discontinuation of the minimum exchange rate on 15 January 2015, and both crosses float again. In the short term, there are many episodes of

Table 1: Descriptive statistics of financial variables

Variable	Description	Mean	Std. Dev.	Min.	Max.
EURCHF	Daily log return, in %	-0.01	0.56	-20.79	7.46
USDCHF	Daily log return, in %	-0.01	0.73	-19.38	8.95
USD	Mean across 26 daily log returns of USD bilateral exchange rates, in %	0.00	0.48	-2.60	3.21
EUR	Mean across 26 daily log returns of EUR bilateral exchange rates, in %	0.00	0.32	-1.89	1.94
VIX	Daily change of S&P500 volatility index, in %-pts	0.00	1.79	-17.36	20.01
Gold	Daily log return, USD-adjusted, in %	0.04	1.06	-8.69	10.29
Periphery spread	Daily change of 10Y yield differential (IT, ES, PT equally weighted versus DE), in %-pts	0.00	0.08	-0.97	0.88
Carry index	Daily excess return of carry portfolio, buying high and selling low yielding currencies, in %	0.51	1.93	-10.59	7.22

Notes: The table provides an overview of the variables used in our model as well as their definition and descriptive statistics. The observation period spans from 1 January 2006 to 21 December 2018 (3565 observations).

short-lived trends of appreciation and depreciation in both crosses.

Figure 1: EURCHF and USDCHF exchange rates

Notes: The figure shows daily EURCHF (blue solid, left scale) and USDCHF (red dash, right scale) spot exchange rates from 1 January 2006 to 21 December 2018.

The financial variables in our model capture the risk environment as well as USD and EUR macro-financial dynamics. We compute the USD and EUR factors corresponding to Verdelhan

(2018) as the arithmetic mean of USD returns and EUR returns, respectively. We use the 26 bilateral exchange rates of the USD and EUR of Verdelhan (2018) and exclude the exchange rate with the Swiss franc as well as the EURUSD, to avoid a mechanical correlation with the left hand side variable and between the two FX factors. The exchange rate returns capture all currency-specific dynamics, including macroeconomic releases (Menkhoff et al. 2017), and surprises (Jäggi et al. 2019), and expected future fundamentals (Sarno and Schmeling 2014).

Financial variables that measure the risk environment include the VIX, gold, the euro area periphery spread, and the excess return of a carry portfolio. First, the VIX is an option-implied volatility of the S&P500 equity index and well established in the literature as an observed risk factor (Ang et al. 2006). Deteriorating risk sentiment goes along with an increase in the VIX. There are four notable episodes of heightened risk: (i) the global financial crisis (2008 2009), (ii) the euro area debt crisis in 2010, (iii) the volatility selloff in August 2015, and (iv) the volatility selloffs in February and December 2018.

Second, gold is also found to be closely correlated with the risk environment as a safe haven asset (Baur and McDermott 2010, Barro and Misra 2016). As the risk environment worsens, gold is expected to appreciate. Between 2006 and 2012, gold appreciates in the overall adverse risk environment of the global financial crisis and the euro area sovereign debt crisis. After 2012, gold loses as opportunity costs of holding gold increase with the gradual normalization of US monetary policy.

Third, we compute the euro area periphery spread as the equally weighted average spread between Italian, Spanish and Portuguese 10-year treasury bond yields and the 10-year German Bund yield. As a measure of euro area risks, the periphery spread increases significantly during the euro area debt crisis and only normalizes after the "whatever-it-takes" remarks of then ECB president Draghi during the Global Investment Conference in London on 26 July 2012.

Fourth, we include the daily excess return of an FX carry portfolio strategy using the strategy of Verdelhan (2018), i.e. buying high-yielding currencies, and selling low-yielding currencies. Precisely, we use the 27 currencies of Verdelhan (2018) with the US dollar as a base but exclude the Swiss franc to avoid multicollinearity. We build six portfolios and sample currencies by their forward premium.[3] Entering 1-month forward contracts with monthly rebalancing, we buy the portfolio of highest-yielding currencies (highest 16.67% quantile) against the US dollar and sell the portfolio of the three lowest-yielding currencies (lowest 16.67% quantile) against the US dollar. Daily variations in the excess return originate from the changes in the daily spot rate of the carry trades. As shown by Menkhoff et al. (2012a), the carry trade is a risky strategy and correlated with FX risk: the worse the risk environment is, the lower the return on the carry

[3]The forward premium approximates interest rate differential as long as covered interest parity holds. In practice, however, the forward premium resembles the actual return of the carry trader. The investor will only use derivatives to gain exposure against interest rate differentials but do not place cash.

portfolio. During our observation period the carry strategy yields gradual excess returns with sharp reversals during risk-off periods, i.e. the global financial crisis in 2008, the acceleration of the euro area debt crisis in the summer of 2011, and the emerging market selloff during the US-China trade conflict in 2018.

3 Model

Our modelling approach includes two stages: first, we estimate an exchange rate model with observable financial indicators as explanatory variables. Second, we aggregate subsets of the variable contributions and orthogonalize the resulting factors. The following two sections detail these two stages.

3.1 Model based on observed variables

The model for exchange rate returns is a multivariate linear model with time-varying coefficients and multivariate stochastic volatility. The approach is similar to the one pursued by Quintana and West (1987) and presented in more detail in Prado and West (2010, chapter 10).

Denote the number of exchange rates by q and the number of explanatory variables by p. As dependent variables we use the difference in the logarithm of the price of foreign currency in Swiss francs, collected in a q-dimensional vector Δs_t. The state-space form of the model for the exchange rates is given by

$$\Delta s_t = \Theta_t' F_t + \mu_t' + \nu_t, \;\; \nu_t \sim N(0, \Sigma_t), \tag{1}$$

$$\begin{bmatrix} \Theta_t \\ \mu_t \end{bmatrix} = \begin{bmatrix} \Theta_{t-1} \\ \mu_{t-1} \end{bmatrix} + \Omega_t, \quad \Omega_t \sim N(0, W_t, \Sigma_t), \tag{2}$$

where (1) is the observation equation, (2) is the state evolution equation, Δs_t is the q-dimensional column vector of exchange rate returns, F_t is the p-dimensional column vector of observed financial variables, Θ_t is the $p \times q$ matrix of factor loadings, μ_t is a q-dimensional row vector of local linear exchange rate trends, ν_t is the q-dimensional column vector of observational errors, Σ_t is a $q \times q$ covariance matrix, Ω_t is a $p + 1 \times q$ matrix of state evolution innovations, and W_t is a $p + 1 \times p + 1$ state evolution covariance matrix.

Note that $N(\dots)$, with two arguments in the observation equation (1), refers to the multivariate normal distribution, whereas the function with three arguments in the state evolution equation (2) refers to the matrix normal distribution (Prado and West 2010, section 10.6.1). To be precise, the notation $\Omega_t \sim N(0, W_t, \Sigma_t)$ means that the matrix Ω_t (of dimension $p + 1 \times q$) has a matrix normal distribution with a zero mean matrix, left variance matrix W_t $(p + 1 \times p + 1)$ and right covariance matrix Σ_t $(q \times q)$. Stacking columns of Ω_t yields a multivariate normal distribution

$\text{vec}(\Omega_t) \sim N(0, \Sigma_t \otimes W_t)$, where $\otimes$ denotes the Kronecker product. The left covariance matrix W_t determines the correlation structure between factor loadings, whereas the right covariance matrix Σ_t governs the variances of individual exchange rates and correlations between them. Realization of the explanatory variables F_t are common across the q exchange rate equations. The covariance matrix Σ_t induces a correlation pattern among the exchange rate returns and at the same time also shows up as the right covariance matrix in the state evolution equation.

Prado and West (2010) provide the theory for Bayesian estimation of the system given by (1) and (2) and give algorithms to filter forward in time. Loosely speaking, this is similar to the techniques usually referred to as Kalman filtering, but with the extension to allow for stochastic volatility, as discussed later. In the forward filtering step we update existing estimates of the state variables, i.e. the coefficients of the explanatory variables in our case, when new information becomes available.[4]

In order to complete the model specification, we need a prior for the initial state Θ_0 and the initial covariance matrix Σ_0. The conjugate prior is a matrix normal, inverse Wishart distribution:

$$(\Theta_0|\Sigma_0) \sim N(M_0, W_0, \Sigma_0), \tag{3}$$

$$\Sigma_0 \sim IW(n_0, D_0), \tag{4}$$

where $IW(n, D_0)$ is the inverse Wishart distribution with degrees of freedom n_0 and scale matrix D_0.

The theory presented so far allows for time variation in the factor loadings Θ_t, but we said nothing about the evolution of the covariance matrices Σ_t and W_t. Prado and West (2010) show that it is possible to learn about these time-varying covariances by using a simple discounting idea. We specify both a discount parameter $\delta \in (0, 1]$ for Σ_t and $\beta \in (0, 1]$ for W_t. The discount parameter can be interpreted as the loss of information per time unit. For example, if the discount parameter is equal to 0.99, it means that approximately 1 percent of information is lost every time unit. In practice, it is similar to exponential smoothing of the covariance matrices, with the important distinction that it can be neatly integrated into the forward filtering. The discounted learning model for the observational variance Σ_t can be regarded as a simple stochastic volatility model that induces robustness and protection against potential biases.

The filtering step gives us the posterior distribution of the state Θ_t given the information up to time t, denoted by $\mathcal{D}_t$. It is matrix normal conditional on the left and right covariance matrices

[4]Note that there are also techniques to smooth backward in time, by updating past estimates of the states given the new information that was not yet available when the filtered estimate was formed. We do not use backward smoothing because in our opinion the filtered estimate is more informative when analysing financial markets. Current market prices can only reflect past information and expectations based on past information, not future information. This is reflected by the forward filtered estimates, not the backward smoothed ones. The backward smoothed estimates can give the impression that future information and structural breaks could have been anticipated by markets.

Σ_t and W_t:

$$(\Theta_t|\Sigma_t, \mathcal{D}_t) \sim N(M_t, W_t, \Sigma_t),$$
$$(\Sigma_t|\mathcal{D}_t) \sim IW(n_t, D_t).$$

The marginal posterior distribution of Θ_t is thus a matrix T distribution

$$(\Theta_t|\mathcal{D}_t) \sim T(n_t, M_t, W_t, S_t),$$

where $T(\dots)$ denotes the matrix variate t distribution and $S_t = D_t/n_t$. This means in turn that the posterior of any row i of Θ_t is multivariate t distributed with degrees of freedom n_t:

$$(\theta_{i\cdot t}|\mathcal{D}_t) \sim t_{n_t}(m_{i\cdot t}, w_{iit}S_t),$$

where $t_\nu(\dots)$ is the multivariate t distribution with ν degrees of freedom and $x_{i\cdot t}$ is the vector in the i-th row and x_{iit} the i-th element of the diagonal of a matrix X_t.

3.2 Factor identification

In the next step, we want to move from the linear model with observed variables to orthogonal factors. We achieve this by aggregating the contributions of financial variables attributable to risk to a risk factor, and orthogonalizing the resulting factors such that we can perform a variance decomposition. For the orthogonalization we use a Cholesky decomposition, hence the ordering of the variables matters. However, only the ordering for variables that are attributed to different factors matter, whereas the ordering of the variables aggregated to the risk factor is irrelevant. The ordering of the factors will be discussed in section 4.2. We first present the details of the orthogonalization of the variables and the resulting variance decomposition.

To orthogonalize the system, we need an estimate of the structure of our variables. For this we estimate a separate system for our explanatory variables, using an autoregressive specification:

$$F_t = \Phi_t' F_{t-1} + m_t' + \xi_t, \quad \xi_t \sim N(0, \Xi_t), \tag{5}$$

$$\begin{bmatrix} \Phi_t \\ m_t \end{bmatrix} = \begin{bmatrix} \Phi_{t-1} \\ m_{t-1} \end{bmatrix} + \zeta_t, \qquad \zeta_t \sim N(0, V_t), \tag{6}$$

where (5) is the observation equation of factor returns, (6) is the evolution equation of the local trend, F_t is the p-dimensional column vector of observed financial variables, Φ_t is the $p \times p$-dimensional matrix of AR(1) coefficients, m_t is the p-dimensional row vector of time-varying intercepts, ξ_t is the p-dimensional column vector of factor return innovations, Ξ_t is the $p \times p$ factor return covariance matrix, ζ_t is the coefficient matrix innovation, and V_t is covariance matrix of local trend innovations.

Hence the explanatory variables are distributed as

$$F_t \sim N(m_t, \Xi_t).$$

To orthogonalize the variables, we compute the Cholesky decomposition of the their covariance matrix:

$$\Xi_t = L_t L_t',$$

where L_t is lower triangular. Then

$$F_t^{\perp} \equiv L_t^{-1} F_t \sim N(L_t^{-1} m_t, \underbrace{L_t^{-1} L_t L_t' L_t'^{-1}}_{I_p}),$$

with I_p denoting the $p \times p$ identity matrix. We can thus state (1) as

$$\Delta s_t = \underbrace{\Theta_t' L_t}_{\Theta_t^{\perp\prime}} \underbrace{L_t^{-1} F_t}_{F_t^{\perp}} + \mu_t' + \nu_t$$

The transformed factors $F_t^{\perp} = L_t^{-1} F_t$ are then orthogonal and the respective factor loadings are given by $\Theta_t^{\perp} = L_t' \Theta_t$.

The conditional covariance matrix of the exchange rate returns given information available at time $t-1$ is

$$Cov_{t-1}(\Delta s_t) = \Theta_t^{\perp\prime} \Theta_t^{\perp} + \Sigma_t.$$

For element i of s_t, denoted by s_{it}, we can derive the variance decomposition

$$var_{t-1}(s_{it}) = \underbrace{\sum_{k=1}^{p} {\theta_{kit}^{\perp}}^2}_{\text{communality}} + \underbrace{\sigma_{it}^2}_{\substack{\text{unique-}\\ \text{ness}}},$$

where $\theta_{kit}^{\perp}$ denotes the element in row k and column i of $\Theta_t^{\perp}$ and σ_{it}^2 the i-th element of the diagonal of Σ_t. We can interpret the component ${\theta_{kit}^{\perp}}^2$ as the variance contribution of factor j, whereas σ_{it}^2 is the variance component unexplained by the factors.

Similar, we can decompose the covariance between elements s_{it} and s_{jt} as

$$cov_{t-1}(s_{it}, s_{jt}) = \underbrace{\sum_{k=1}^{p} \theta_{kit}^{\perp} \theta_{kjt}^{\perp}}_{\text{communality}} + \underbrace{\sigma_{ijt}}_{\substack{\text{unique-}\\ \text{ness}}},$$

where σ_{ijt} is the element in row i and column j of Σ_t. We will refer to the total variance or covariance explained by the factors as "communality" and the unexplained component as "uniqueness".

4 Results

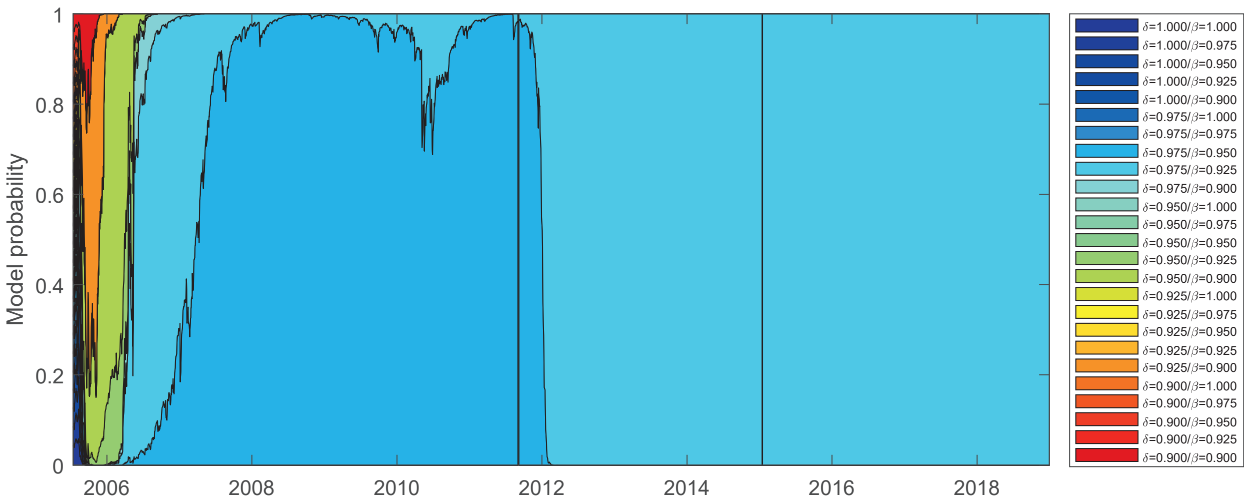
In the following sections, we apply our factor model to the Swiss franc exchange rates using the estimation and identification approach detailed above. Section 4.1 shows the model calibration and performance. Section 4.2 discusses the application of our identification approach, and Section 4.3 provides our results of identified factor changes to the Swiss franc exchange rates.

4.1 Model calibration and performance

Using the Bayesian estimation approach outlined in Section 3, we fit our time-varying coefficients model. We use a data-driven process to set the optimal discount parameters. We assume that a priori all the models that we compare are equally likely. Then we update the respective model probabilities by looking at the likelihood of one-step ahead prediction errors of the individual models and accumulate this information over time.

Figure 2 shows the cumulative model probabilities for different combinations of the coefficients and volatility discount parameters δ and β between 0.9 and 1.0. The lower the discount rate is, the faster models forget previous information. Models colored dark red correspond to models that forget past information quickly, whereas in the model with the darkest blue both discount rates are equal to one and therefore the model does not discount for past information, resulting in an equal weight for all observations.

Figure 2: Model comparison for different discount parameters



Notes: The figure shows the posterior probability of models with different discount parameters for the coefficients (δ) and the stochastic volatility (β). All models start with the same a priori probability and are then updated based on the likelihood of one-step ahead predictions of the models accumulated over time.

The figure reveals that highly adaptive models as well as rather constant ones can only compete in the very beginning, when there is not much information available yet. After less than a year (or

200 observations), two very similar models dominate. In the long-run, one model outperforms, which we use as our baseline model. It has a coefficient discount parameter δ of 0.975 and a volatility discount parameter β of 0.925. These discount parameters correspond to a half-life of information of 28 days for the coefficients and 9 days for volatility.

We start the calibration of the model before the beginning of the reporting period in 2006. The initialization period is discarded in the presentation of the following results. This means that the assumption about the prior state is not important, as this prior information will be washed out fairly quickly. Furthermore, we skip both the day of the introduction and the discontinuation of the EURCHF minimum exchange rate in the filtering. Thereby, the model does not learn on these days that are characterized by structural breaks and severe financial frictions.

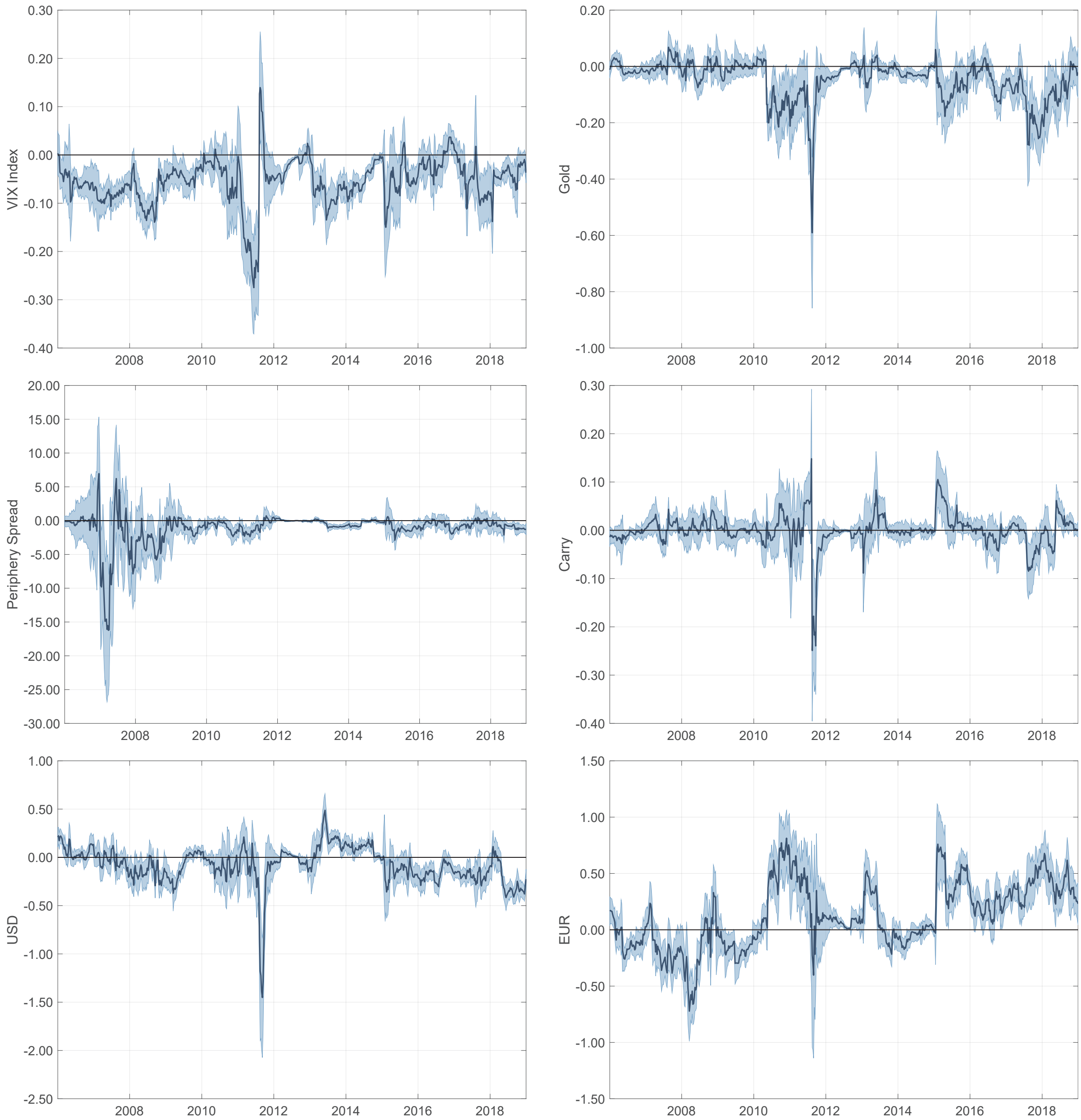
Using these discount parameters, we retrieve variable coefficients of financial variables with EURCHF returns (Figure 3) and USDCHF returns (Figure 4). The time-varying coefficient estimates are presented with posterior 68% probability bands (Sims and Zha 1999).

The USD and EUR variable coefficients suggest that, before the euro area debt crisis, global FX dynamics impact mainly the Swiss franc exchange rate vis - à - vis the US dollar. For this time period, the USD coefficient for USDCHF is approximately one, and the EUR coefficient is minus one. At the same time, EURCHF are broadly unrelated to both FX variables.[5] Put differently, the euro and the Swiss franc are close substitutes before the euro area debt crisis. When there is a EUR-specific shock, this impacts the euro and the Swiss franc equally such that the EURCHF exchange rate is not significantly affected. This mechanic changes with the outbreak of the euro area sovereign debt crisis, when the EUR variable coefficient rises close to one and the euro loses almost all of its significance for USDCHF dynamics. With the introduction of the minimum exchange rate, the previous mechanic is reintroduced as dynamics in euro cannot transmit into changes in EURCHF as long as the exchange rate is close to the EURCHF minimum exchange rate. After the discontinuation of the EURCHF minimum exchange rate, the global FX dynamics become important again for EURCHF, notably not only the euro but also the US dollar.

The risk variable coefficients confirm the stylized fact of the Swiss franc being a safe haven currency. Coefficients of risk variables vary with changes in the risk environment. In episodes of deteriorating risk sentiment, risk variables become more closely related to Swiss franc exchange rate returns. However, it is unclear to which extent these correlations are exogenous as they are correlated with each other and might even pick up some macroeconomic developments of the FX variables. At the same time, the FX variables might also react to changes in risk. We address this issue in the following.

[5]Because of the no-arbitrage condition in the currency triangle of EURCHF, USDCHF and EURUSD, the variable coefficients of EURCHF and USDCHF with each of the global FX factors must sum to one.

Figure 3: Time-varying coefficients of EURCHF returns



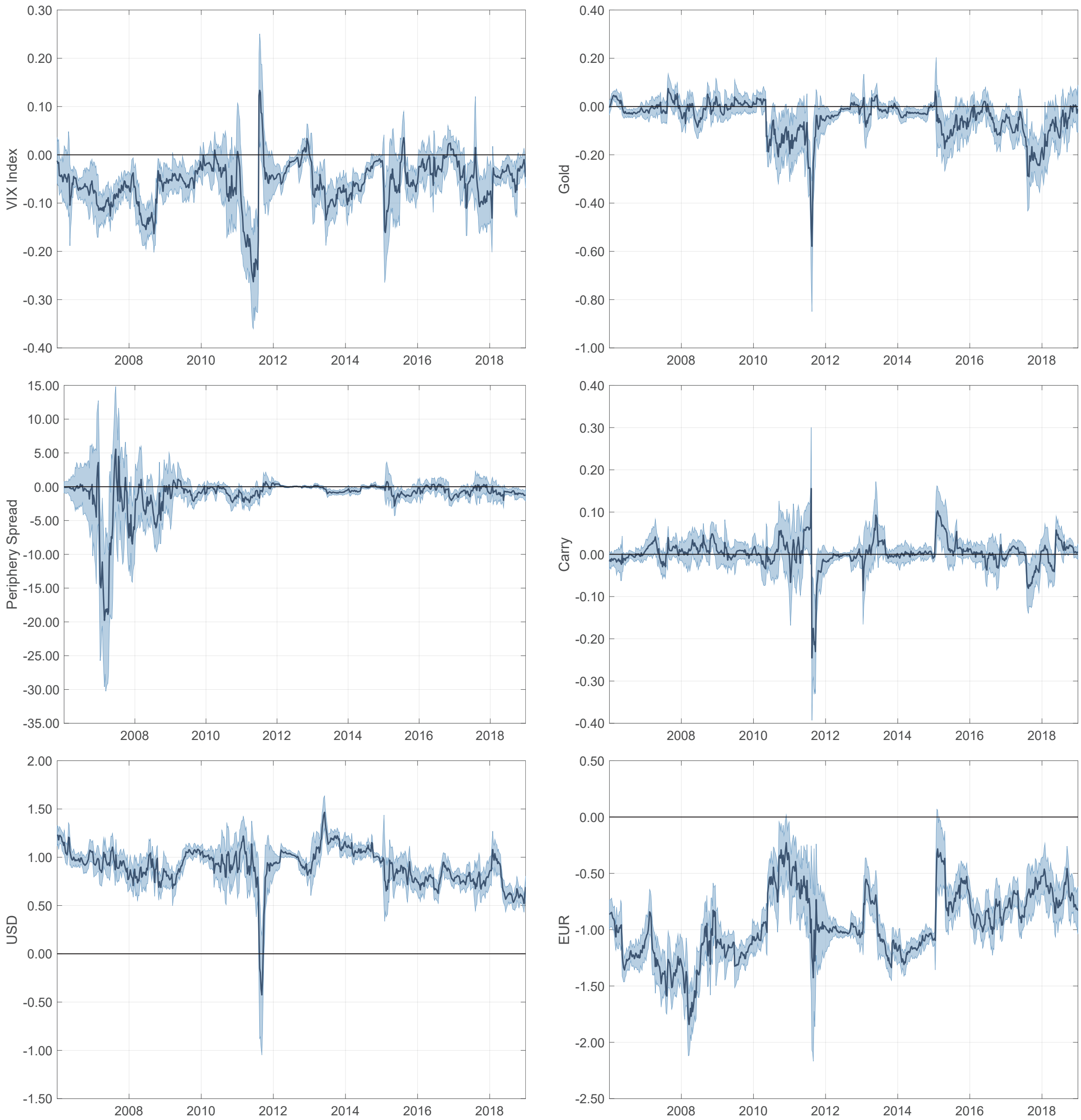
Notes: The figures show the time-varying coefficients of the EURCHF equation with 68% highest posterior density intervals.

4.2 Orthogonalization

To identify the causal impact of the factors on the Swiss franc exchange rate, we first analyse the correlation matrix of the variables (Figure 5). The diagonal shows the variable names, the lower triangle the pairwise time-varying correlation, and the upper triangle the median correlation, colored red if larger than 0.25 and blue if smaller than 0.25. We observe a correlation above 0.25 in absolute value for the correlations among the VIX, carry excess returns, USD returns, and EUR returns.

However, the correlation between two variables can be positive just because they are both related

Figure 4: Time-varying coefficients of USDCHF returns

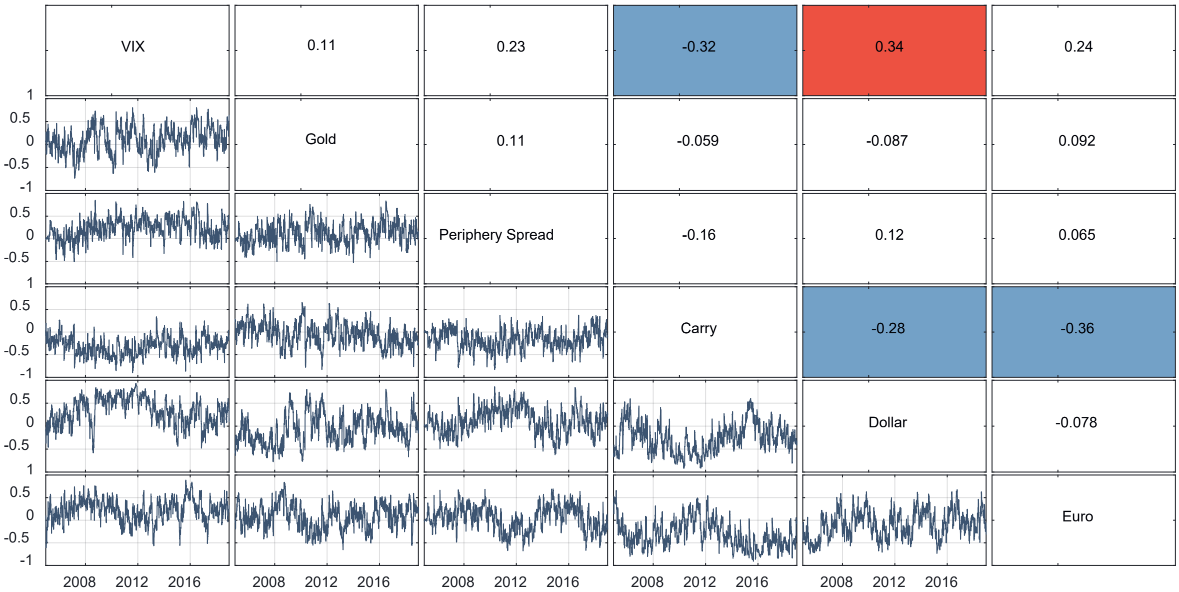


Notes: The figures show the time-varying coefficients of the USDCHF equation with 68% highest posterior density intervals.

to a third variable. To identify the pairs that are generating the correlation structure, Figure 6 shows the partial correlation matrix. Partial correlations show the association between a pair of variables, controlling for the effect of all other variables. The partial correlations show that there are two important correlations: a positive correlation between the US dollar and the VIX and a negative correlation between carry excess returns and the euro.

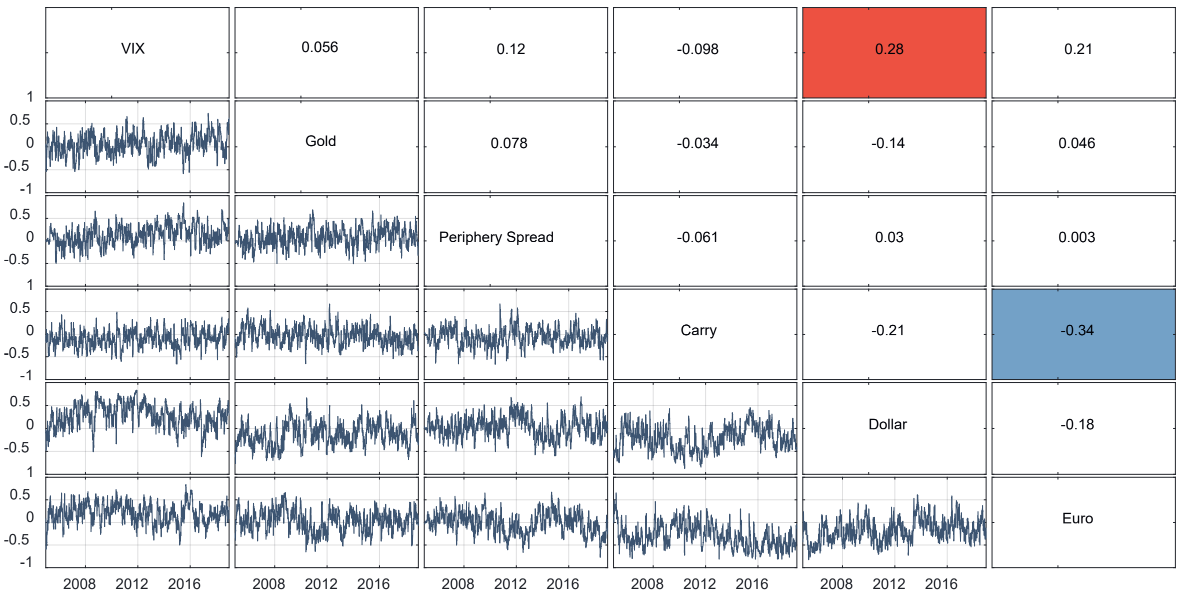
The positive correlation between the US dollar and the VIX refers to the well-known fact that the US dollar reacts positively in risk-off moves (De Bock and de Carvalho Filho 2015). The negative correlation between carry excess returns and EUR returns is due to the fact that the

Figure 5: Correlations of explanatory variables



Notes: The figure shows the contemporaneous correlations between the explanatory variables, i.e. the correlation structure in the covariance matrix Ξ in equation (5). On the diagonal are the names of the financial variables, below the diagonal are the pairwise time-varying correlations, and above the diagonal are the median correlation over the fill time period, marked red if above 0.25 and blue if below -0.25.

Figure 6: Partial correlations of explanatory variables



Notes: The figure shows the partial correlations between the variables based on the same covariance matrix as in Figure 5. Partial correlation measure the association between two variables, controlling for the effect of all other variables.

euro has the property of a funding currency of the carry trade (Hossfeld and MacDonald 2015). The negative correlation stems only to a marginal extent from the direct effect, as the euro is included in the carry portfolios. However, most of the effect originates from the euro as a funding currency for carry portfolios, as the correlation remains negative if we exclude the euro from the computation of the carry portfolios. To sum it up, we find that risk and the US dollar are positively correlated (via the VIX) and that risk and the euro are negatively correlated (via the carry excess return). Hence, part of the correlation between the euro and the US dollar is explained by risk.

Considering these results, the variable ordering matters for the results of our Cholesky variance decomposition. However, as we aggregate the contributions of the risk variable, the ordering among them is irrelevant. Hence, we focus in our discussion on the ordering of the risk, US dollar, and euro factors.

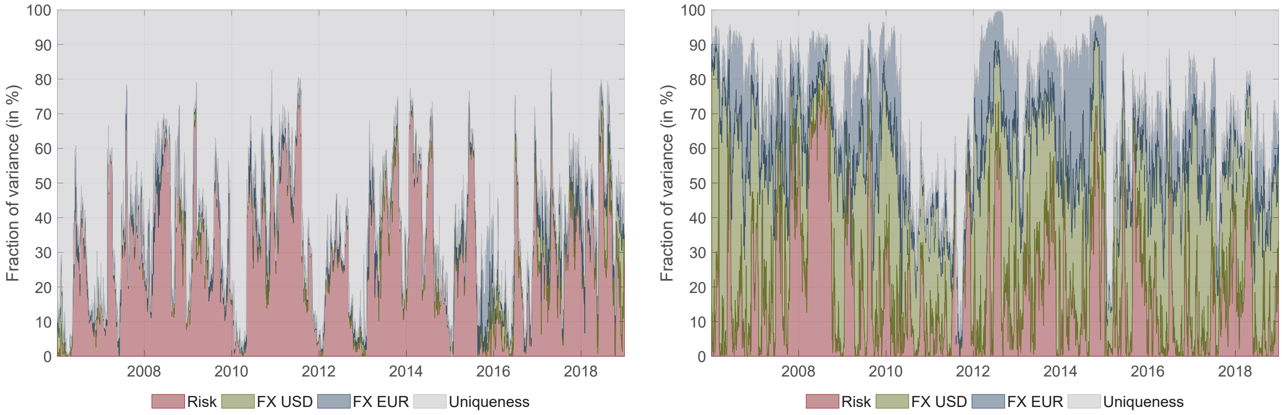
We assume that (i) all information correlated with risk is attributed to the risk factor, and (ii) all remaining information correlated with US dollar is attributed to the USD factor. Finally, the EUR factor captures all remaining information correlated with the euro. The first assumption seems very intuitive and is warranted. Whatever is captured in the US dollar that is risk, we would like to identify as risk. In contrast, there is presumably very little risk that we should attribute to the US dollar, as it is actually a USD-specific dynamic. The second assumption derives from the importance of the currencies as the US dollar is the most traded (Bank for International Settlements 2019) and the largest reserve currency (International Monetary Fund 2019). In our robustness section, we show that the results are robust to the second assumptions and remain qualitatively the same.

4.3 Variance decomposition

We decompose Swiss franc returns by three global factors, namely risk, US dollar and euro. This leaves the residual as Swiss franc unique dynamics in the Swiss franc exchange rates. Evidently, the residual captures also model miss-specification. However, as we update the variable coefficients with optimized discount parameters, we are confident that the largest share of the residual is driven by local uniqueness, i.e. Swiss franc specific, dynamics. The respective variance and covariance decompositions are shown in Figure 7 and 8. We scrutinize the economic relevance of the global factors by analysing the cumulated factor contributions to EURCHF and USDCHF returns (Figure 9).

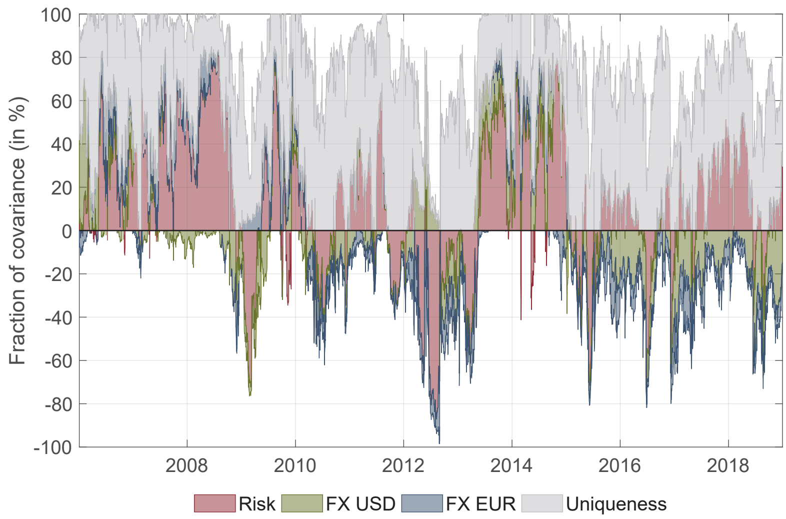
Risk is the most important contributor to Swiss franc variations, especially in the EURCHF exchange rate (EURCHF 31%, USDCHF 21%). Risk explains a particularly large fraction of the variance for those episodes in which there is an adverse risk environment (instead of a benign risk environment), e.g. the global financial crisis and the euro area sovereign debt crisis. Looking at the covariance, shocks to risk usually generate a positive covariation between EURCHF and USDCHF. These findings underline the role of the Swiss franc as a safe haven currency. In terms of contributions to Swiss franc returns, risk contributes significantly to the Swiss franc's

Figure 7: Variance decomposition of EURCHF and USDCHF returns



Notes: The figure shows the variance decomposition of EURCHF (left panel) and USDCHF (right panel). The areas are normalized such that they add to 100%. Hence the size of the area gives the percentage share of the total EURCHF variance explained by a factor.

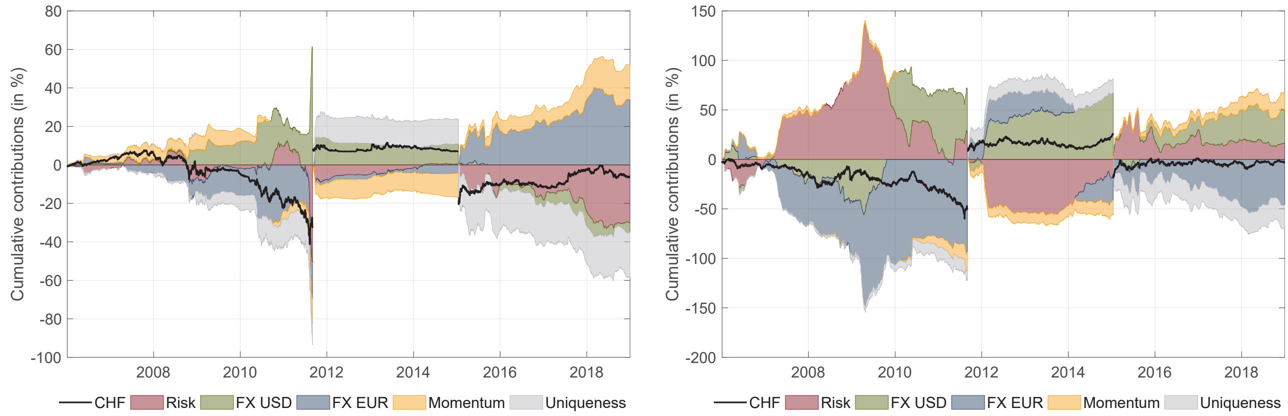
Figure 8: Covariance decomposition of EURCHF and USDCHF returns



Notes: The figure shows the decomposition of the covariance between EURCHF and USDCHF returns. The areas are normalized such that they add to 100% in absolute values. Hence the size of the area gives the percentage share of the total EURCHF variance explained by a factor, with areas above zero contributing to positive covariance and areas below zero contributing to negative covariance.

appreciation against the euro during the euro area debt crisis before the introduction of the minimum exchange rate. With the introduction of the minimum exchange rate and at the latest in early 2012, the appreciation pressure of the risk factor recedes. Until the discontinuation of the minimum exchange rate, the risk factor rather weighs on the Swiss franc. Since then, risk contributes occasionally to the Swiss franc's strength, such as the Greek referendum in the first

Figure 9: Cumulated contributions to EURCHF and USDCHF returns



Notes: The figures show the cumulated daily contributions of the factor accumulated over time. This corresponds to the respective components in a decomposition of the level of EURCHF and USDCHF. We reset on the dates on the introduction (6 September 2011) and discontinuation (15 January 2015) of the minimum exchange rate.

half of 2015 or the Brexit referendum in May 2016.

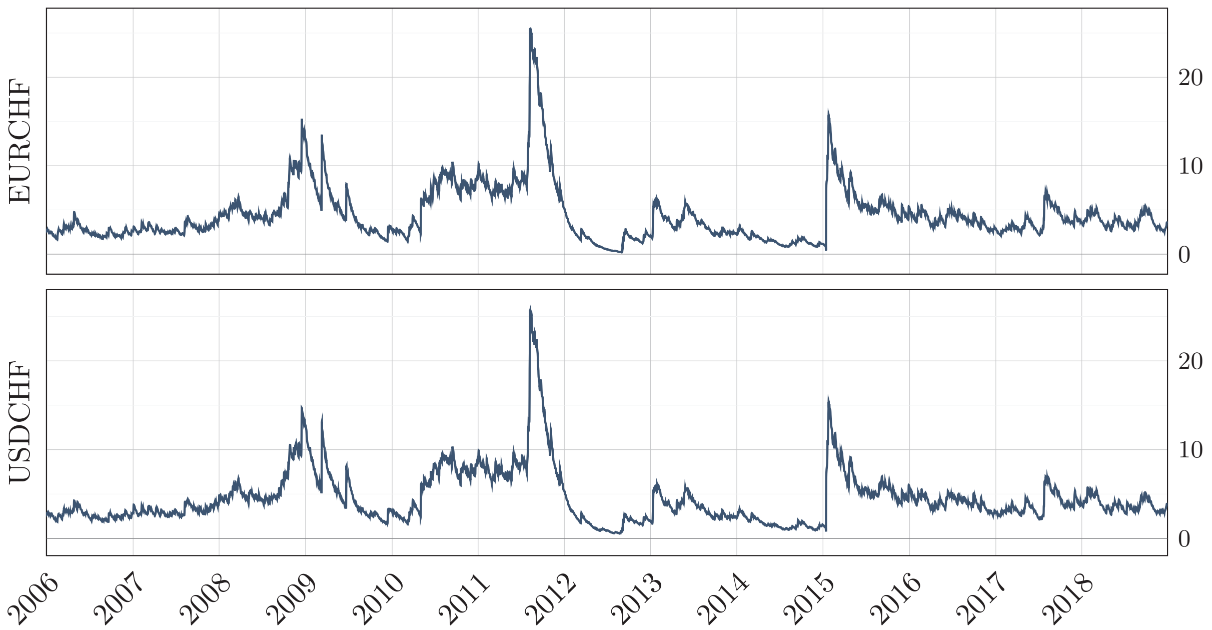
Overall, the global FX factors explain a larger share of variance in USDCHF than in EURCHF. Specifically, USD dynamics are more important than EUR dynamics for the explanation of the variance of USDCHF (USD 36%, EUR 16%) but also EURCHF (USD 3%, EUR 3%). During the minimum exchange rate period, the explained variance is almost 100% as long as dynamics lead to a Swiss franc appreciation which could not manifest in a lower EURCHF. After the discontinuation of the minimum exchange rate, global FX dynamics explain a larger share of the EURCHF variance than before. Recently, also USD dynamics become notably important for the EURCHF variance. These findings underline the change in the nature of the euro versus Swiss franc assets since the beginning of the euro area debt crisis. In terms of contributions, USD dynamics naturally offset some of the EUR dynamics.[6] Before the introduction of the minimum exchange rate, the euro contributes significantly to the Swiss franc appreciation, which is only partly compensated by US dollar contributions. While FX contributions during the minimum exchange rate period are relatively muted, especially in EURCHF, monetary policy divergence impacts FX developments in 2014 and early 2015. While the Fed tightens monetary policy, the ECB eases monetary policy further. This leads to a depreciation in the euro and an appreciation of the US dollar. Consequently, the weakening euro appreciates the Swiss franc, while the strengthening US dollar weighs on the Swiss franc.

Momentum is estimated as a short-term trend in USDCHF and EURCHF. Therefore, it is specific to each cross and can coincide with trends in the Swiss franc, the euro or the US dollar. Economically, this is different from the long-term macroeconomic trend that could lead

[6] As noted above, the partial factor correlation of USD and EUR is -0.18 on average.

to exchange rate trends, such as for purchasing power or current account balances. With a half-time of 28 days, we interpret the momentum as a short-term cross-specific trend, e.g. based on interest rate differentials, order flows or trend-amplifying trading strategies such as momentum trading (Menkhoff et al. 2012b). On average, the momentum is small as a short-term trend of the Swiss franc. However, we observe several episodes when momentum picked up significantly. Momentum is fairly strong before the introduction of the minimum exchange rate as Swiss franc returns increase faster than financial variables suggest amid trend speculation (Moser 2012). The introduction of the minimum exchange rate stops the momentum shortly after. During the time of the minimum exchange rate, momentum provides only small contributions to Swiss franc returns. After the discontinuation of the minimum exchange rate in 2015, there are occasional episodes of strong momentum. For example, in the second half of 2017, the Swiss franc depreciates with a strong unique trend in an overall environment of a benign risk environment and an appreciating euro.

Figure 10: Volatility of uniqueness



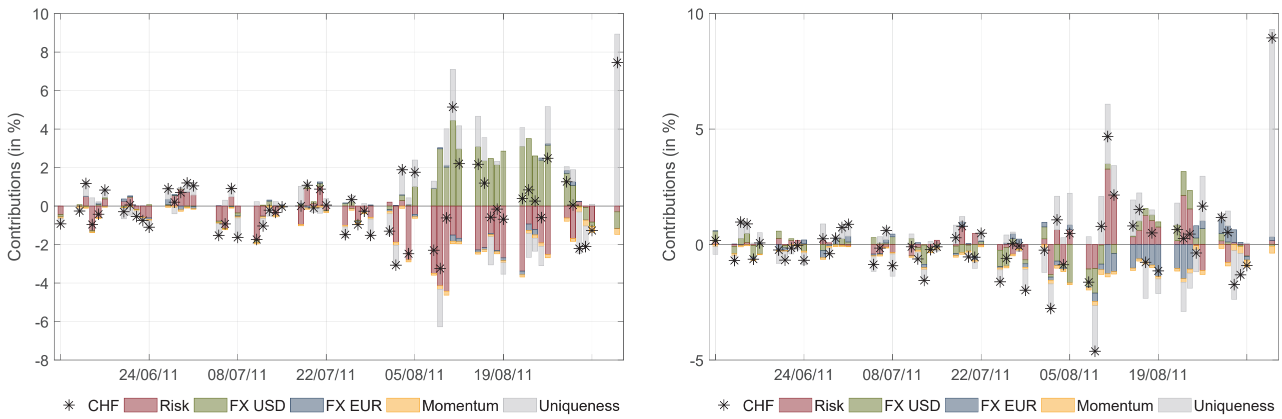
Notes: The figure shows the estimated volatility of the error term in the EURCHF and USDCHF equations, i.e. σ_{1t} and σ_{2t}.

We interpret contributions that are not explained by our observed factors cautiously as Swiss franc unique drivers. These could stem from either (i) a lag in the updating of coefficients, or (ii) information that is missing in the model. We are confident that the financial variables in our model capture well global factors, leaving Swiss franc unique developments as the residual. This interpretation is backed by the volatility pattern of uniqueness in EURCHF and USDCHF. The volatility of the uniqueness in EURCHF and USDCHF is quite similar (Figure 10) and the correlation between the error terms in the EURCHF and USDCHF equation is close to one for most of the time, only dropping towards zero at a time when the EURCHF was very close to the minimum exchange rate. Looking at the uniqueness contribution to Swiss franc returns, there is a strong Swiss franc unique appreciation pressure since the beginning of the euro area debt crisis. The introduction and discontinuation of the minimum exchange rate stand out as external Swiss franc unique policy events. During the minimum exchange rate period, there is hardly any Swiss franc unique dynamic. After the discontinuation of the minimum exchange rate, the Swiss franc unique contributions are also fairly stable with occasional swings matching changes in the risk environment.

4.4 Case study: The introduction of the SNB minimum exchange rate

In the following, we demonstrate the performance of our model in a case study, namely, the introduction of the SNB minimum exchange rate on 6 September 2011. Figure 11 shows the daily contributions to EURCHF and USDCHF returns before and at the event. With the euro area debt crisis intensifying during the summer of 2011, risk contributions appreciate the Swiss franc exchange rate, particularly against the euro. In contrast, the US dollar is sought as a safe haven similarly to the Swiss franc, weighing somewhat on the Swiss franc and compensating some of the risk appreciation in EURCHF. The continuous appreciation of the Swiss franc manifests gradually in momentum amplifying its appreciation trend in both crosses. Finally, Swiss franc unique factors contribute to Swiss franc strength until the introduction of the EURCHF minimum exchange rate, which depreciate the Swiss franc as a Swiss franc unique factor.

Figure 11: Contributions to daily EURCHF and USDCHF returns



Notes: The figure displays daily factor contributions to EURCHF and USDCHF returns in the months before the introduction of the EURCHF minimum exchange rate.

5 Robustness

We conduct several robustness checks to challenge our assumptions and results.[7]

Dynamic factors. Our baseline model is quasi-dynamic factor model as the financial variables follow an AR(1). As an adjustment to our model, we augment the model to be dynamic in the exchange rate returns:

$$\Delta s_t = \Theta_{1t}' F_t + \Theta_{2t}' F_{t-1} + \mu_t' + \epsilon_t.$$

The model performance and qualitative results remain broadly the same.

Identification assumptions. As an identifying assumption, we attribute all joint variation in the euro and the US dollar to the global USD factor. We reverse the ordering in Cholesky decomposition and attribute the joint variation to the euro (ordering EUR > USD). Results remain qualitatively the same. In particular, US dollar shocks remain more important for the EURCHF and USDCHF dynamics than euro shocks.

Factor definition. We combine the excess return of the carry portfolio to three other risk variables (VIX, gold, European periphery spread). However, one could be interested in the different channels as safe havens are often considered as the opposite side of carry strategies (Hossfeld and MacDonald 2015). When we separate the carry from the risk factor, there is no intuitive assumption for the identification restriction. Regardless of the ordering, the carry factor is never as important as the risk factor.

Risk variables. We combine the excess return of the carry portfolio to three other risk variables (VIX, gold, European periphery spread). However, one could be interested in the different channels as safe havens are often considered as the opposite side of carry strategies (Hossfeld and MacDonald 2015). When we separate the carry from the risk factor, there is no intuitive assumption for the identification restriction. Regardless of the ordering, the carry factor is never as important as the risk factor. As an additional robustness check of our risk variables, we use the Euro Stoxx 50 Volatility index instead of the VIX. The results remain qualitatively the same.

Asymmetric risk factor. We allow for asymmetric effects of the VIX and the carry index, by including positive and negative changes in these variables separately. The data do not confirm that the Swiss franc reacted more strongly to adverse risk shocks than benign risk shocks. However, risk episodes are typically clustered such that the identification of the asymmetric coefficients is very limited due to the availability of data.

Discount parameters. We set the discount parameter to be one on the days of the introduction and the discontinuation of the minimum exchange rate. Hence, the model does not update the variable coefficients on these days. The corresponding reasoning is that it might be challenging

[7] Detailed results are available on request.

to learn something about the short-term determinants of the Swiss franc exchange rates on these days of structural changes and severe financial frictions. As the period of financial stress carried on for some time even after the policy events, we extend in a robustness exercise the period after the introduction and discontinuation of the minimum exchange rate during which the model does not learn. Results remain qualitatively the same.

6 Conclusions

We develop a factor model of daily returns of EURCHF and USDCHF and estimate it using Bayesian techniques with a data set from 2006 to 2018. The identification of the factors is based on a time-varying coefficients model with observed financial variables and stochastic volatility. In the second stage, the contributions of individual explanatory variables are aggregated and the resulting factors are orthogonalized.

To discount for the loss of historical information and to meet the challenges of the nonstationary nature of financial markets, we use discount rates in the Bayesian filtering that implicitly give rise to exponentially decreasing weights of past observations. The optimal model to capture Swiss franc dynamics has an implied half-life of 28 days for the variable coefficients and 9 days for the volatility.

The factor model is able to explain a large part of the Swiss franc exchange rate variation, with approximately 73% of USDCHF variance and 37% of EURCHF variance explained.

USD and EUR coefficients with EURCHF and USDCHF returns reflect structural changes in the features of euro and Swiss franc assets. Before the euro area debt crisis, the euro and the Swiss franc traded as substitutes. Afterwards, EUR shocks affected the euro and the Swiss franc separately and caused changes in the EURCHF exchange rate. The EURCHF minimum exchange rate set by the Swiss National Bank reestablished the substitutability of the euro and Swiss franc. Recently, EUR and USD factors have become gradually more important for EURCHF dynamics.

The risk factor is the most important contribution to Swiss franc dynamics, especially in times of a worsening risk environment, confirming the finding that Swiss franc trades as a safe haven asset (Grisse and Nitschka 2015). Risk can explain a particularly large part of EURCHF variation.

Momentum is present in Swiss franc exchange rate returns, especially before the introduction of the minimum exchange rate. Swiss franc unique contributions to Swiss franc returns are driven by structural breaks and unobserved factors.

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