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Regime-dependent drivers of the EUR/CHF exchange rate

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Abstract

We analyze drivers of the EUR/CHF exchange rate in different regimes between 2000 and 2020. Structural breaks between these subperiods are estimated in an integrated way together with the drivers that are relevant during these subperiods. Overall, the main drivers of the exchange rate include European equity and volatility indices, interest rate and term structure slope differentials, as well as monetary policy interventions. For the "peg period" September 2011–January 2015, in addition to the observed exchange rate we also analyze the drivers of the latent exchange rate that could have been observed in the absence of the peg. Interestingly, the SNB's foreign currency investments became a significant driver of the EUR/CHF exchange rate only after the end of the peg period when there was no longer an officially communicated target rate.

Keywords Exchange rate drivers, Monetary policy, EUR/CHF exchange rate, Foreign currency interventions, Latent exchange rate

JEL Classification F31, E44

1 Introduction

The Swiss franc's value is very important for the competitiveness of the export-oriented Swiss economy. This holds in particular for its exchange rate to the euro because the eurozone is Switzerland's most relevant trading partner. A good understanding of the drivers of the EUR/CHF exchange rate is key for many market participants including investors, Swiss companies, foreign companies doing business in or with Switzerland, and central banks, in particular the Swiss National Bank (SNB).

The Swiss franc is widely known as a safe-haven currency. Since the beginning of the financial crisis 2007, it has significantly strengthened against a number of major currencies, e.g., the euro. In attempts to counteract its "current massive overvaluation" (Swiss National Bank, 2016), the SNB resorted to drastic policy measures. In September 2011, it imposed a lower bound of 1.20 on the EUR/CHF exchange rate and announced its willingness to intervene in foreign exchange (FX) markets to support this lower bound by unlimited purchases of assets denominated in foreign currency. The associated increase in foreign currency investments during this period made the SNB the central bank with the largest balance sheet in relation to GDP (Cukierman, 2019). Figure 1 shows the SNB's foreign currency investments and the monthly average EUR/CHF exchange rate.

A few years later, in January 2015, the SNB took the markets by surprise when it decided to discontinue this policy. Despite the fact that the SNB only imposed a lower bound on the exchange rate and not an outright peg, the period from September 2011 to January 2015 is often called the "peg period." The SNB has continued to intervene in FX markets in the years after the peg period, still pursuing the goal of mitigating the Swiss franc's overvaluation. The market turmoil brought about by the financial crisis and the ensuing changes in monetary

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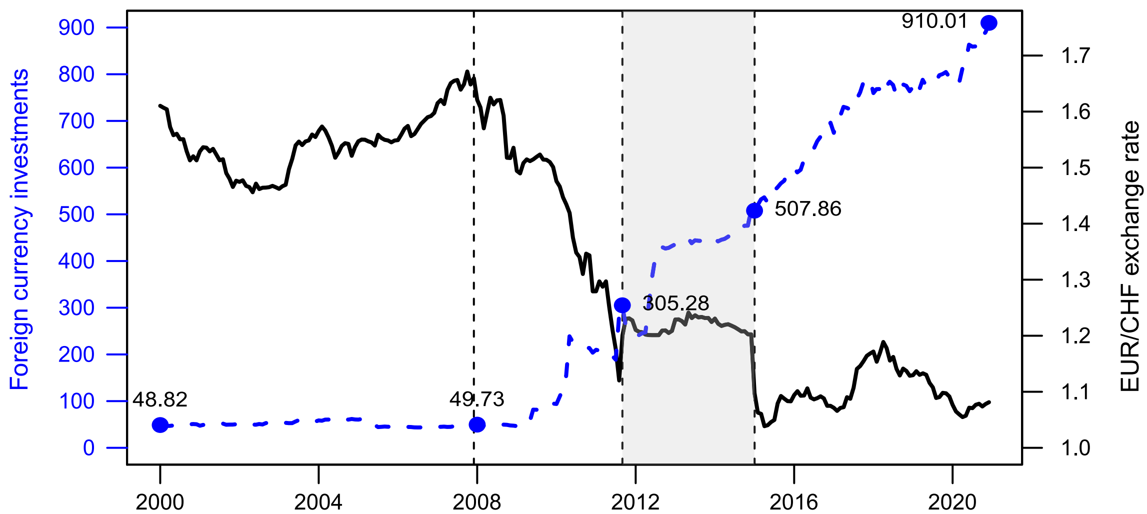

Fig. 1 Development of the SNB's foreign currency investments (FCI) in billion CHF (left vertical axis, blue dashed line) and the observed EUR/CHF exchange rate (right vertical axis, black solid line). Dotted lines indicate the estimated breakpoints (discussed in Sects. 2.2 and 4.1). The shaded area marks the peg period. Marked dots indicate the level of FCI at the end of January 2000, January 2008, September 2011, January 2015, and December 2020, respectively. Sample period: January 2000–December 2020. Data sources: SNB Data Portal and Refinitiv

policy suggest that drivers of the EUR/CHF exchange rate might have changed as well over the past decades. For this reason, we select a sample period starting in 2000, which covers both pre- and post-crisis periods, the peg period, and the time after the peg. Using statistical techniques, we detect subperiods in which drivers and their parameters are relatively constant and the locations of the breakpoints between them. Comparing and contrasting the drivers across these periods is one contribution of this paper. For the detection of drivers, we use a step-forward procedure based on simple linear regression models which are common in the empirical FX literature (see, e.g., Fama, 1984, Ranaldo & Söderlind, 2010, Grisse & Nitschka, 2015, Yeşin, 2015; 2017, Dahlquist & Penasse, 2017). The main research question we investigate in this paper is, "What are the main drivers of the EUR/CHF exchange rate at a monthly horizon, and how do these drivers change across different subperiods, including the SNB's minimum exchange rate policy 2011–2015?" In this paper, we focus on a monthly frequency. This choice is driven by our interest in medium-term effects, by the availability of data (one of our variables is available only at a monthly frequency), and by the lower noise in monthly data compared to higher frequencies.

Starting with Meese and Rogoff (1983), there is a range of papers which found exchange rates to be essentially unpredictable. Using economic fundamentals as potential drivers, such as trade balance, national income and money supply, Meese and Rogoff (1983) find exchange rates to be almost unpredictable in the short and medium term. A simple random walk seems to perform significantly better than existing forecasting methods. This finding is widely known as the "Meese and Rogoff puzzle." On the contrary, some papers find exchange rates to robustly explain certain macroeconomic fundamentals (Mussa, 1979, Engel & West, 2005, Chen et al., 2010, Sarno & Schmeling, 2014, Pincheira & Hardy, 2018).

Other parts of the literature successfully identified economic variables that are able to explain exchange rates. Based on this literature, we identify potential drivers for the EUR/CHF exchange rate. For example, the relation between exchange rates and monetary policy has been addressed by a significant body of the literature (Sarno & Taylor, 2001, Chaboud & Humpage, 2005, Reitz, 2005, Engel & West, 2004, Staiger & Sykes, 2010, Sinnakkannu, 2010). Fratzscher et al. (2019) examine foreign exchange interventions based on data covering 33 countries from 1995 to 2011. They find fairly high success rates of FX interventions, especially in terms of reducing exchange rate volatility, i.e. smoothing the path of the exchange rate. Interest rate parities suggest that changes in interest rates might be potential drivers of exchange rates. Although empirical evidence against both the Covered Interest Rate Parity and the Uncovered Interest Rate Parity has been extensively discussed in the literature (e.g., Fama, 1984, Brunnermeier et al., 2008, Engel, 2016, Dahlquist & Penasse, 2017, Du et al., 2018), Rime et al. (2022) argue that the Covered Interest Rate Parity actually continued to hold in international money markets also after the global financial crisis when accounting for marginal funding costs, arguing that the seeming arbitrage opportunities found by Du et al. (2018) disappear once funding costs are included in the calculation. In addition to levels of interest rates, term structure slopes and their changes over time may have explanatory power for exchange rate movements (Ang & Chen, 2010, Andrews et al., 2022).

Despite Switzerland's small size, its economic strength and political stability increase the demand for the Swiss franc in times of crises. This safe-haven property has been documented, among others, by Ranaldo and Söderlind (2010), Grisse and Nitschka (2015), Auer (2015), Fatum and Yamamoto (2016), and Lee (2017). Grisse and Nitschka (2015) find in response to a rise in global risk, the Swiss franc appreciates against the euro and against typical carry trade investment currencies, but depreciates against the US dollar and the Japanese yen. They also find statistically significant time variation in the relation between Swiss franc returns and risk factors, with this link becoming stronger in times of stress. Another strand of the literature investigates the link between FX and equity. Depending on the level of financial stress, their relation can vary over time. Hossfeld and MacDonald (2015) document major differences in correlations between currency returns and global stock market returns conditional on the level of financial stress, which is another indication of regime dependence of exchange rate drivers. Controlling for the impact of carry trade reversal, they provide further evidence that the Swiss franc qualifies as a safe-haven currency since its returns are negatively related to global stock market returns in times of high financial stress. Leutert (2018) also document regime dependence of the relation between equity indices and the EUR/CHF exchange rate with the correlation changing from positive before 1999 to highly negative after 1999.

The Swiss National Bank's monetary policy during and after the peg period (September 2011–January 2015) has been controversially discussed. However, this policy has a significantly longer history with its roots going back to the mid-1970s, when the SNB was one of the first national banks that heavily intervened in the FX market. An increase in interventions was observed again from 2008 onward when the Swiss franc significantly appreciated against the euro. It culminated in the introduction of a strict exchange rate floor in September 2011, which was defended by the SNB until January 2015. The announcement of a minimum exchange rate against the euro and the SNB's commitment to purchase unlimited amounts of foreign currency assets have been the subject of controversy and raised the question where the exchange rate would have been in the absence of the SNB's policy. Using option pricing theory, Hanke et al. (2019) estimate the hypothetical exchange rate that would have been observed in the absence of the SNB's interventions. Figure 2 shows the observed EUR/CHF exchange rate versus

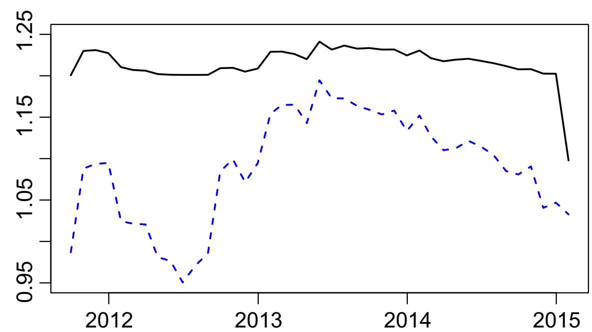

Fig. 2 EUR/CHF observed (black) and latent exchange rate (blue, calculated following Hanke et al., 2019), monthly averages. Sample: September 2011–January 2015

this latent exchange rate during the peg period. The latent exchange rate is significantly below the floor of 1.20 and varies between 1.01 and 1.18 Swiss francs per euro. Based on their results, we investigate also the drivers of this unobserved or latent exchange rate. This provides a new perspective on the SNB's policy during the peg period.

While our results confirm that all categories of candidate drivers we select from the literature are indeed relevant for the EUR/CHF exchange rate, we find different combinations of these variables to drive the exchange rate during different subperiods or regimes. Our results confirm previous findings regarding the Swiss franc's safe-haven properties. The effects of interest rate differentials and the relative development of yield curve slopes in the Swiss franc relative to the euro and the US dollar show the signs that are expected from economic theory. Foreign currency interventions by the Swiss National Bank become a relevant driver only after the end of the peg period in 2015.

The paper is structured as follows: Sect. 2 describes our methodology, followed by a presentation of the data in Sect. 3. Section 4 discusses the empirical results, and Sect. 5 concludes.

2 Methodology

The main goal of this paper is to identify the most important explanatory variables or drivers of the EUR/CHF exchange rate across different time periods which represent different regimes. To this end, we investigate the explanatory power of a range of candidate variables which are selected based on the existing literature discussed in Sect. 1. Our approach is descriptive rather than trying to embed these drivers in a structural economic model.

In principle, time variation could be accounted for by either estimating time-varying parameters or by assuming time-constant parameters during subperiods separated by breakpoints. We opt for the second choice, since in the context of FX models, previous literature has argued that changes in exchange rate regimes tend to occur abruptly, especially when caused by policy interventions of central banks or by external events such as financial crises.

The methodology applied for the selection of drivers in each subperiod is described in Sect. 2.1. The subperiods are based on breaks in the dependence structure which are detected using statistical techniques to be discussed in Sect. 2.2.

2.1 Linear regression models and variables selection procedure

We use linear regression models based on ordinary least squares (OLS) to assess the importance of explanatory variables. In the empirical FX literature, linear regression models are very common (see, e.g., Fama, 1984, Ranaldo & Söderlind, 2010, Grisse & Nitschka, 2015, Yeşin, 2015; 2017, Dahlquist & Penasse, 2017). For each subperiod identified by structural break detection models described in Sect. 2.2, we estimate multivariate linear regression models with the following basic structure:

$$\ln \frac{S_t}{S_{t-1}} = \alpha + \sum_{j \in \mathcal{J}_0} \beta_j x_{j,t-1} + \epsilon_t, \tag{1}$$

where time t is measured in months, S_t is the average EUR/CHF exchange rate in the time interval $(t-1, t]$, $x_{j,t-1}$ are explanatory variables at time $t-1$ with regression coefficients β_j, and ϵ_t is an error term. $\mathcal{J}_0$ is a subset of a predetermined set $\mathcal{J}$ of candidate or potential drivers, $\mathcal{J}_0 \subset \mathcal{J}$. Based on the rich literature on FX and EUR/CHF models (see Sect. 1), we select the following categories of variables as potential drivers x_j of the EUR/CHF exchange rate: equity indices and their corresponding volatility indices (Ranaldo & Söderlind, 2010), interest rate differentials (Fama, 1984), proxies for the slope of the term structures (Ang & Chen, 2010), and foreign currency investments (Fratzscher et al., 2019). The data are described in detail in Sect. 3.

From this set of variables $\mathcal{J}$, we identify subsets $\mathcal{J}_0$ of drivers for each subperiod using a stepwise multivariate regression approach (for a review of variable selection methods in multivariate regression, see, e.g., Thompson, 1978). At each step, we rank all candidate variables from the set $\mathcal{J}$ which have not yet been included in the model by their Newey–West adjusted p values. The variable with the smallest p value is selected as the next candidate to enter the model. Whereas in the literature on stepwise regression the highest correlation with the residuals is frequently used for variable selection, we prefer the adjusted p values because we explicitly search for variables that are not only correlated with the dependent variable, but also causally important, which is indicated by a regression coefficient that is significantly different from 0. At each step, one variable from $\mathcal{J}$ is selected into the subset $\mathcal{J}_0$. As a stopping criterion, we use Mallows's C_p (Mallows, 1973). The goal of this statistic is to determine a subset of explanatory variables in linear regression from a set of candidate variables. Unlike criteria like the R^2 which improve monotonically when including more explanatory variables, this statistic aims at relatively sparse models to avoid overfitting. To this end, the sample size, the effect sizes of different predictors, and the degree of collinearity between them is taken into account. A low value of Mallows's C_p is desirable. We compute the statistic after each iteration. Once it increases for the first time, we discard this iteration and use the model (the variables in $\mathcal{J}_0$) from the previous iteration, i.e. the model with the minimum C_p value. Regardless of the C_p value, we only consider variables that are statistically significantly different from zero, at least at the 10% level.

As a robustness check, we compare our sets of selected drivers to variables chosen by other established selection methods, such as the "lars"-method developed by Efron et al. (2004), which implements various selection procedures called "lars" (select variables incrementally based on their correlations with the residuals of the previous stage), "lasso" (sparse variable selection that includes shrinkage of the selected regression coefficients), "stepwise" for stepwise forward variable selection and "forward stagewise" for stagewise variable selection.

The structure of Eq. (1) is predictive with a time lag of one month. Excluding contemporaneous observations avoids potential endogeneity issues. One of the explanatory variables (FCI, see Sect. 3) is published with some delay, so it may not be available in time to use Eq. (1) for forecasting in real time. Since our primary goal is to detect drivers of the exchange rate ex post, this is not a problem for our analysis.

Some of the candidate drivers may be highly correlated, at least in some of the subperiods. This raises concerns about potential multicollinearity. We check for multicollinearity via variance inflation factors (VIFs), which are calculated for each estimated model and each variable:

$$\mathrm{VIF}_j = \frac{1}{1 - R_j^2},$$

where VIF_j denotes the VIF for variable j, and R_j^2 is the R^2 obtained by regressing variable j on all other variables in the model.

2.2 Detection of structural breaks

The economic events that occurred during our sample period (global financial crisis 2007-2008, European sovereign debt crisis, SNB's minimum exchange rate policy) suggest possible changes in drivers of the EUR/CHF exchange rate over time. This raises the question of how to divide the sample period into subperiods. In principle, this can be done in either of the following ways: (1) discretionary choice of breakpoints separating subperiods based on a subjective assessment of economic events and their likelihood of causing structural changes, (2) detection of such breakpoints based on statistical methods.

Regarding the SNB's minimum exchange rate policy, approach (1) could be easily followed as the starting and ending dates are exactly known. Since these dates are in-between our monthly observations, the only question is how to treat the starting and ending month since only parts of these months are affected. For the financial crisis, there is no such "official starting date," and hence, approach (2) is useful in detecting if and when the crisis led to structural changes in our data. If the statistical methods used for breakpoint detection work well, we expect them to also detect the starting/ending dates of the peg period. Correct identification of these dates thus can be seen as an additional test for the validity of these methods. Hence, in a first step, we detect breakpoints using statistical methods. In a second step we check these breakpoints for plausibility against the timeline of economic events.

In the framework of least-squares regression there exist various approaches for testing, monitoring and dating structural breaks (see, e.g., Chow, 1960, Hansen, 2001, Kleiber et al., 2002, Bai & Perron, 2003, Zeileis, 2005). These methods detect potential structural breaks in relations between variables based on changes in regression coefficients, their significance, and related statistics. Preliminary calculations showed that the observed changes in the exchange rate volatility (see Fig. 1) lead to corresponding changes in the error variance. Hence, we prefer an approach to detect structural breaks that explicitly incorporates the error variance. Zeileis et al. (2010) provide such an approach in which penalty functions based on either BIC or LWZ (Liu et al., 2007) criteria play an important role regarding the number of breakpoints that are estimated for a given dataset. They apply it to detect the structural breakpoints in the times series of the USD/CNY exchange rate.

The approach consists of three parts:

1. Testing for structural change, i.e. testing the null hypothesis that model parameters are constant in a given subperiod $i = 1,...,n$ (between structural breaks).
2. Monitoring whether the parameters of the model found in the first step remain stable when adding additional observations $i > n$. Instability is detected when an error measure exceeds a pre-specified boundary.
3. Dating the final breakpoints by optimizing a segmented objective function over all conceivable partitions. Model selection is based on the BIC criterion.

To limit the number of models to evaluate, the maximum number of breakpoints and/or a minimum length of the subperiods/regimes can be specified.

3 Data

Data on the EUR/CHF exchange rate, equity, and associated volatility indices (daily closing values) are obtained from Refinitiv. For equities, these include the European stock indices DAX and Swiss Market Index (SMI), together with their volatility indices VDAX-NEW[1] and VSMI. The interest rate data are obtained from Bloomberg. Short-term interest rates are proxied by one-month LIBOR rates in the USD, EUR, and CHF. Long-term interest rates are proxied by 30-year generic government bond yields for the USA, Germany (as a proxy for euro-denominated bonds), and Switzerland.[2] Term structure slopes are proxied by the difference between 10-year and 2-year government bond yields. All interest rate data are daily closing/last values. Data on the SNB's Foreign Currency Investments (FCIs) are taken from the SNB's balance sheet. FCI data are only available monthly, which provides an upper bound for the data frequency to use if FCI is to be included in the set of potential drivers. The Swiss Real Effective Exchange rate (REER), which will be used for a robustness check, is obtained via the SNB data portal. The sample period is January 2000–December 2020.

Regarding FCI, we note that this variable is only an imperfect proxy for the SNB's interventions because changes in FCI occur for two reasons: (1) purchases and sales of foreign assets and (2) changes in the value of foreign assets on the SNB's balance sheet. A breakdown of the SNB's foreign assets by asset class and currency would allow us to better separate these two effects and focus on the first one. Unfortunately, this additional information is only available at a quarterly frequency, which would

[1] The VDAX-NEW has been available since April 18, 2005. Its predecessor, the VDAX, was calculated following a different methodology. Historical data for the VDAX-NEW are provided by Deutsche Börse on a daily basis back to 1992.

[2] In the literature, 10-year rates are used more often. Whereas 30-year rates are detected as significant drivers in Sect. 4.2, replacing them by 10-year rates in the set of candidate drivers $\mathcal{J}$ leads to insignificant results.

reduce the number of observations in our regressions by two thirds. For this reason, we use the available monthly FCI data, but we are aware of their limitations.

FCI and REER are provided as end-of-month values. For both series, we use monthly log returns in the regressions. For the variables that are available at a daily frequency, we reduce the noise associated with daily data following Molodtsova and Papell (2009) who suggest aggregating them to monthly averages and assigning them to the end of each month. For exchange rate, index, and volatility values, we compute log returns from these monthly averages (the time index t indicates months):

$$r_{I,t} = \ln \bar{I}_t - \ln \bar{I}_{t-1}, \tag{2}$$

where I is a generic variable for any of the exchange rates or indices, and $\bar{I}_t$ is the arithmetic average of observed daily closing values of I in the time interval $(t-1, t]$.

For both short- and long-term interest rates, we have to slightly adapt this procedure because some of the observations are negative. After taking the log of $1 + \bar{i}_t^{c,\tau}$, where $\bar{i}_t^{c,\tau}$ is the arithmetic average of the (long- or short-term) interest rates for maturity τ interest rates in currency c in the time interval $(t-1, t]$, we compute interest rate differentials at time t from these values. For example, for the CHFUSD1m interest rate differential, we get

$$\mathrm{CHFUSD1m_t} = \ln \frac{1 + \bar{\mathrm{i}}_\mathrm{t}^{\mathrm{CHF,1m}}}{1 + \bar{\mathrm{i}}_\mathrm{t}^{\mathrm{USD,1m}}}. \tag{3}$$

Then, we take first differences to achieve stationarity:

$$\Delta\mathrm{CHFUSD1m_t} = \mathrm{CHFUSD1m_t} - \mathrm{CHFUSD1m_{t-1}}. \tag{4}$$

Proxies for differences in the changes in the slopes of term structures are derived in a similar way. A commonly used measure is the "ten-minus-two" spread.[3] The slope difference for the EURUSD currency pair is calculated as

$$\begin{aligned}\mathrm{EURUSD10y2y_t} = &\ln\left(1 + \bar{i}_t^{\mathrm{EUR,10y}}\right) - \ln\left(1 + \bar{i}_t^{\mathrm{EUR,2y}}\right) \\ &- \ln\left(1 + \bar{i}_t^{\mathrm{USD,10y}}\right) + \ln\left(1 + \bar{i}_t^{\mathrm{USD,2y}}\right),\end{aligned} \tag{5}$$

followed by taking first differences to achieve stationarity:

$$\Delta\mathrm{EURUSD10y2y_t} = \mathrm{EURUSD10y2y_t} - \mathrm{EURUSD10y2y_{t-1}}. \tag{6}$$

The set of candidate explanatory variables or potential drivers, $\mathcal{J}$, is given by $\mathcal{J}$ = {FCI, DAX, SMI, VDAX, VSMI, EURUSD1m, CHFUSD1m, CHFEUR1m, EURUSD30y, CHFUSD30y, CHFEUR30y, EURUSD10y2y, CHFUSD10y2y, CHFEUR10y2y}. Starting from the set $\mathcal{J}$, the forward selection procedure discussed in Sect. 2.1 is run to determine different subsets $\mathcal{J}_0$ of explanatory variables for each of the subperiods.

4 Empirical results

This section reports the results of our analysis. When presenting our results, Sect. 4.1 starts with a description of the best set of breakpoints that could be identified. Afterward, Sect. 4.2 presents the most important drivers selected for each subperiod, including details of the estimated regression models. In Sect. 4.3, this is followed by a robustness check based on a comparison of our selection of drivers to the drivers selected using the same method, but for the real effective exchange rate as the dependent variable. We expect some similarities between the drivers of the observed and real exchange rates. Moreover, we compare our selected drivers to those chosen by other established variable selection procedures. While our selection procedure should lead to sparser models, we expect a significant overlap between our drivers and those selected by alternative variable selection methods.

4.1 Breakpoints and subperiods

As described in Sect. 2.2, we follow a statistical approach to identify different exchange rate regimes and the breakpoints separating them. The results of this approach are then checked for plausibility against the timeline of economic events. If the statistical models work well, they should correctly identify the starting and ending dates of the SNB's minimum exchange rate policy.

In a first step, we formulate numerous regression models as described in Eq. (1), imposing a restriction to use at most one variable from each of the categories described in Sect. 3 (e.g., only one stock index, only one volatility index, etc.). This avoids potential multicollinearity issues that could arise from the high correlation between the variables within each category. In the next step, we estimate different sets of breakpoints with restrictions on the maximum number of breakpoints and on the minimal length of the resulting subperiods. As parameter estimation in very short subperiods would suffer from a low number of observations, we set the minimum subperiod length to 20 months. From the timeline of economic events, we would expect at least two breakpoints at the beginning and the end of the peg period, plus probably another one related to the Global Financial Crisis, so we focus on models with a maximum of three breakpoints. Table 1 provides an overview of the breakpoint estimates resulting from those 76 models (combinations of explanatory variables) that

[3] See e.g., https://fred.stlouisfed.org/series/T10Y2Y.

Table 1 Breakpoints estimated using the following parameters: minimal subperiod size of 20 months, maximum number of breakpoints: three

	1st Breakpoint	2nd Breakpoint	3rd Breakpoint
Estimated dates	09-2007 (28) 10-2007 (18) 12-2007 (30)	08-2011 (10) 10-2011 (43) 11-2012 (5) 01-2013 (15) 06-2013 (2) 08-2013 (1)	10-2014 (12) 12-2014 (41) 02-2015 (13) 04-2015 (10)

Values in brackets indicate the number of models in which a certain date has been identified as a breakpoint

actually detected three breakpoints. It shows how often a certain breakpoint has been detected.

The first breakpoint estimates occur around the onset of the global financial crisis, while the second and third breakpoints lie near the beginning/end of the SNB's minimum exchange rate policy (the "peg period"). Combining statistical results and the timeline of economic events, we conclude that the second and third breaks most likely occurred in September 2011 and January 2015. Since we use monthly averages for the exchange rate and both the beginning and the end of the peg period fall roughly halfway into the respective months, we decide to drop these breakpoint months from the respective subperiods. This averaging may actually be one reason why our statistical methods detect adjacent months, but not directly the beginning/end of the peg policy. For the first breakpoint, our procedure returns three months in the second half of 2007 as breakpoint candidates. To break the tie between these candidates, we use the overall R^2 (for the entire sample period) achievable from selecting optimal variables for each subperiod according to Eq. (1). We select December 2007 as the first breakpoint, which yields an overall (adjusted) R^2 of 31.41% (23.34%), compared to the alternatives of 30.10% (21.87%) (October 2007) and 30.13% (21.91%) (September 2007). Similarly to the peg period, we exclude December 2007 from the first two subsamples. To summarize, our breakpoints analysis results in the following subperiods: January 2000–November 2007 (pre-financial crisis), January 2008–August 2011 (financial crisis until the beginning of the peg), October 2011–December 2014 (peg period), February 2015–December 2020 (post-peg period).

For the peg period, we conduct our calculations not only for the observed exchange rate, but also for the latent exchange rate calculated according to Hanke et al. (2019). Using an approach that is based on option pricing theory, their resulting latent exchange rate is an estimate of where the exchange rate would have been in the absence of the SNB's peg policy. Table 9 provides descriptive statistics for all variables and subperiods. Figure 3 shows rolling window correlations between all explanatory variables and the EUR/CHF exchange rate for a window size of 18 months.

4.2 Drivers of the EUR/CHF exchange rate

For each of the subperiods estimated by the breakpoints from the previous section, we run our regression in Eq. (1) in a step-forward approach. As described in Sect. 2.1, we incrementally select the best performing subset of drivers, $\mathcal{J}_0$, from the set of candidate drivers, $\mathcal{J}$, based on the Newey–West adjusted p values. Given that a number of candidate drivers show non-negligible correlations with other drivers, a higher number of variables increases the risk of multicollinearity issues which are addressed by using Mallows's C_p as a stopping criterion. In addition, we check the variance inflation factor (VIF) for each parameter.

In the regression results tables, all independent variables have been standardized to zero mean and unit standard deviation. This allows for a simple interpretation that is independent of the magnitude of the variable values. All coefficients can be interpreted as follows: a one-standard deviation increase in the corresponding driver leads to a change of beta in the dependent variable. The dependent variable has been multiplied by 100 and represents percentage changes for notational convenience in exhibition.

We start by a presentation of the results for each subperiod. This is followed by a summary of the selected variables and a comparison of the drivers we find to those chosen by alternative variable selection procedures, which serves as a robustness check.

4.2.1 Pre-crisis period (January 2000–November 2007)

Table 2 shows the results for the pre-financial crisis period, January 2000–November 2007. The first selected driver is the DAX, and the resulting regression model is shown in column (1). Before the financial crisis, decreases in the DAX lead to a strengthening of the Swiss franc relative to the euro. The safe-haven property of the Swiss franc, which has been documented in the literature, is in line with the sign of this dependence (Ranaldo & Söderlind, 2010, Hossfeld & MacDonald, 2015). The second variable that is selected by the step-forward procedure is the CHFUSD1m interest rate differential, and the augmented model is shown in column (2). Out of all interest rate differentials in the CHF–EUR–USD currency triangle, the CHFEUR differentials should be expected to have the most direct effect on the EUR/CHF exchange rate.

Table 2 OLS regression results for the pre-crisis period (January 2000–November 2007)

	Pre-crisis period (January 2000–November 2007)		
	Dependent variable: **EUR/CHF**		
	(1)	**(2)**	**(3)**
Constant	0.027	0.027	0.027
	(0.765)	(0.762)	(0.753)
CHFUSD1m		− 0.150*	− 0.170*
		(0.093)	(0.068)
		VIF = 1.015	VIF = 1.062
DAX	0.106*	0.124**	0.263***
	(0.056)	(0.014)	(0.004)
		VIF = 1.015	VIF = 3.297
SMI			− 0.166**
			(0.017)
			VIF = 3.247
Observations	93	93	93
Mallows's C_p	1.16	− 0.48	0.12
Selected model		X	
R^2	0.020	0.060	0.075
Adjusted R^2	0.009	0.039	0.044

In this table, we show results from regressing the EUR/CHF exchange rate onto an increasing set $\mathcal{J}_0$ of variables that are determined by the stepwise forward selection method described in Sect. 2.1. *p* values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis. Variance inflation factors are shown underneath each variable to indicate potential multicollinearity. The selected model in column (2) minimizes Mallows's C_p

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

While the CHFEUR interest rate differentials are indeed frequently selected as drivers by our models, for the pre-crisis period the CHFUSD1m differential is given preference by our variable selection. In the pre-crisis period, the correlation between CHFEUR1m and CHFUSD1m is 53%, which is quite high and may explain why the choice between the two variables may not be obvious. In the light of this information, the sign of the coefficient is negative as expected: If interest rates in the Swiss franc rise more (fall less) compared to those in the US dollar (and, by the high correlation, the euro), this leads to a strengthening of the Swiss franc relative to the euro.

The model in column (2) of Table 2 shows the lowest Mallows's C_p statistic and is therefore selected. The next selected driver would have been the SMI. The resulting values in column (3) indicate why this model is considered to be inferior according to Mallows's C_p: DAX and SMI have a high positive correlation in this time period. The SMI enters with a negative sign, and the difference in the coefficients of DAX and SMI in model (3) is close to the coefficient of the DAX in model (2), while the VIFs of these two drivers are markedly higher in model (3) compared to that of the DAX in model (2). Although the (adjusted) R^2 increases, the associated increase in Mallows's C_p from model (2) to model (3) indicates that the third variable should not be included. We note that the explanatory power of the selected drivers in the pre-crisis period is low with an adjusted R^2 of only 3.9% (Table 2).

4.2.2 Financial crisis period (January 2008–August 2011)

Between the financial crisis and the peg period, from January 2008 to August 2011, the slope difference between the Swiss franc and the US dollar yield curve, CHFUSD10y2y, is selected as the most important driver of the EUR/CHF exchange rate (Table 3). Adding the VSMI and the DAX improves the model fit according to Mallows's C_p. Including further variables, while beneficial for the (adjusted) R^2, would worsen (i.e. increase) the C_p statistic.

For one particular country or currency area, a positive 10y2y spread is viewed as a predictor of positive economic development, while a negative 10y2y spread predicts an economic downturn or even a recession. When comparing two countries/currency areas, a change in the difference in 10y2y spreads may be interpreted as a change in their relative economic prospects: the currency of the country whose 10y2y spread shows a relative increase should be expected to strengthen relative to the other (see, e.g., Ang & Chen, 2010). The results from model (1) imply that an increase in Switzerland's 10y2y spread relative to the USD leads to a strengthening of the Swiss franc relative to the euro (similar to the pre-crisis period, the model chooses the CHFUSD10y2y variable over the CHFEUR10y2y). The next selected variable, VSMI, can be viewed as a crisis indicator. Equity volatilities in developed countries are usually highly correlated—higher uncertainty in a global economy ultimately affects all countries. The sign of the coefficient matches the safe-haven properties of the Swiss franc as documented by Ranaldo and Söderlind (2010); Grisse and Nitschka (2015); Fatum and Yamamoto (2016); Lee (2017): Higher equity volatility leads to a strengthening of the Swiss franc. For model (3), the DAX is also included as a driver. Compared to Table 2, however, the sign of its coefficient changes to negative, which seems hard to interpret at first sight. Such a regime dependence in the relation between the DAX and the EUR/CHF (USD/CHF) exchange rate has been documented in previous literature, e.g., Leutert (2018) (Ranaldo & Söderlind, 2007, Fig. 4). A comparison of the VSMI coefficients between models (2) and (3) shows that this effect may be, at least

Table 3 OLS regression results for the financial crisis period (January 2008–August 2011)

	Financial crisis period (January 2008–August 2011)				
	Dependent variable: **EUR/CHF**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Constant	− 0.859***	− 0.859***	− 0.859***	− 0.859***	− 0.859***
	(0.004)	(0.002)	(0.001)	(0.0002)	(0.0001)
CHFEUR10y2y				0.408**	0.322**
				(0.021)	(0.035)
				VIF = 2.477	VIF = 2.569
CHFUSD10y2y	− 0.544***	− 0.561***	− 0.608***	− 0.920***	− 0.984***
	(0.001)	(0.001)	(0.004)	(0.004)	(0.001)
		VIF = 1.002	VIF = 1.008	VIF = 2.452	VIF = 2.503
DAX			− 0.918***	− 0.919**	− 0.937***
			(0.009)	(0.012)	(0.008)
			VIF = 2.072	VIF = 2.072	VIF = 2.076
VSMI		− 0.355**	− 1.016***	− 1.082***	− 1.125***
		(0.038)	(0.00003)	(0.0003)	(0.001)
		VIF = 1.002	VIF = 2.077	VIF = 2.141	VIF = 2.164
EURUSD1m					− 0.319
					(0.101)
					VIF = 1.262
Observations	43	43	43	43	43
Mallows's C_p	− 0.85	− 0.49	− 3.79	− 2.67	− 1.73
Selected model			X		
R^2	0.092	0.131	0.257	0.278	0.303
Adjusted R^2	0.070	0.087	0.200	0.202	0.209

In this table, we show results from regressing the EUR/CHF exchange rate onto an increasing set $\mathcal{J}_0$ of variables that are determined by the stepwise forward selection method described in Sect. 2.1. p values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis. Variance inflation factors are shown underneath each variable to indicate potential multicollinearity. The selected model in column (3) minimizes Mallows's C_p

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

partly, due to the correlation between the DAX and the VSMI: Adding the DAX leads to a marked increase in the magnitude of the VSMI coefficient, and the VIF of VSMI also increases considerably. While inclusion of the DAX is recommended by the C_p statistic nonetheless, this does not hold for the next candidate variable, CHFEUR10y2y. Here, the compensatory effect with CHFUSD10y2y becomes obvious from a comparison of their coefficients between models (3) and (4), and the marked increase in the VIF of CHFUSD10y2y confirms it. The explanatory power of the selected drivers in the crisis period is markedly higher than in the pre-crisis period, with an adjusted R^2 of 20%.

4.2.3 Peg period (October 2011–December 2014)

Table 4 shows that for the peg period, the short-term interest rate differential between the Swiss franc and the euro is the only significant driver of the EUR/CHF exchange rate. The sign of this dependence in column (1) is as expected: Higher interest rate increases in the Swiss franc lead to its strengthening against the euro. Adding the term structure slope difference in column (2) increases the R^2, but it also increases Mallows's C_p. The positive sign of its coefficient seems puzzling at first sight, but it is, first, not significantly different from zero at conventional levels, and second, its inclusion also changes the magnitude of the CHFEUR1m interest rate differential already included in model (1).

Columns (3) and (4) are not the result of our variable selection procedure. The reason we show them is that a number of alternative selection procedures, which are based on correlation instead of p values, suggest including VSMI as a driver already at the first step (see

Table 4 OLS regression results for the peg period (October 2011–December 2014)

	Peg period (October 2011–December 2014)			
	Dependent variable: **EUR/CHF**			
	(1)	**(2)**	**(3)**	**(4)**
Constant	− 0.060	− 0.060	− 0.060	− 0.060
	(0.455)	(0.446)	(0.491)	(0.446)
CHFEUR1m	− 0.114***	− 0.089**		− 0.081**
	(0.009)	(0.025)		(0.024)
		VIF = 1.049		VIF = − 3.315
CHFEUR10y2y		0.118		
		(0.165)		
		VIF = 1.049		
VSMI			0.150	0.129
			(0.212)	(0.264)
			VIF = 0.705	VIF = 0.489
Observations	38	38	38	38
Mallows's Cp	1.44	1.85	0.31	1.57
Selected model	X			
R^2	0.042	0.085	0.073	0.093
Adjusted R^2	0.016	0.033	0.047	0.041

Columns (1) and (2) show results from regressing the EUR/CHF exchange rate onto an increasing set $\mathcal{J}_0$ of variables that are determined by the stepwise forward selection method described in Sect. 2.1. *p* values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis. Variance inflation factors are shown underneath each variable to indicate potential multicollinearity. The selected model in column (1) minimizes Mallows's C_p. Due to the fact that alternative variable selection methods choose VSMI as the first variable, columns (3) and (4) show for comparison results from a two-step selection using VSMI (rather than CHFEUR1m) as the first chosen variable

$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Sect. 4.3). Column (3) shows what happens when we include VSMI as the first variable for the peg period: The regression has a better R^2 compared to the regression in column (1) with CHFEUR1m as the first driver, but VSMI's coefficient is insignificant. CHFEUR1m would then be selected as the second driver, showing a coefficient and *p* value that are very similar to the regression in column (2). This illustrates the different goals of variable selection methods based on *p* values (our approach) and those based on correlations: the latter typically result in higher R^2, but at the "risk"/expense of insignificant coefficients.

Interestingly, foreign currency investments (FCI) are not selected as a driver during this period by any of the models. We explain this by the low variability in the observed exchange rate, which was almost flat during Q2-Q3 2012, and the strong effect that the SNB's announcement to defend this lower bound had on the market. From Fig. 1, we can spot two major intervention

Table 5 OLS regression results for the peg period (October 2011–December 2014)

	Peg period (October 2011–December 2014)				
	Dependent variable: **Latent EUR/CHF**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Constant	− 0.101	− 0.101	− 0.101	− 0.101	− 0.101
	(0.835)	(0.823)	(0.815)	(0.816)	(0.810)
CHFEUR1m	− 0.308	− 0.582**	− 0.571**	− 0.465	− 0.468
	(0.133)	(0.024)	(0.022)	(0.103)	(0.123)
		VIF = 1.120	VIF = 1.127	VIF = 1.179	VIF = 1.179
CHFEUR10y2y				0.480*	0.181
				(0.065)	(0.558)
				VIF = 1.084	VIF = 1.279
CHFEUR30y			− 0.162	− 0.261	− 0.252
			(0.752)	(0.588)	(0.655)
			VIF = 1.437	VIF = 1.484	VIF = 1.484
DAX		0.840	0.748*	0.708*	1.252**
		(0.118)	(0.079)	(0.083)	(0.033)
		VIF = 1.120	VIF = 1.588	VIF = 1.595	VIF = 2.238
VSMI					0.934
					(0.148)
					VIF = 1.893
Observations	38	38	38	38	38
Mallows's Cp	2.53	1.42	3.33	4.28	4.01
Selected model		X			
R^2	0.013	0.097	0.099	0.128	0.189
Adjusted R^2	− 0.015	0.045	0.020	0.022	0.062

In this table, we show results from regressing the latent EUR/CHF exchange rate from Hanke et al. (2019) onto an increasing set $\mathcal{J}_0$ of variables that are determined by the stepwise forward selection method described in Sect. 2.1. *p* values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis. Variance inflation factors are shown underneath each variable to indicate potential multicollinearity. The selected model in column (2) minimizes Mallows's C_p

$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

periods in the third quarter of 2011 and the second quarter of 2012 when FCI increased sharply. For the rest of the peg period, the level of FCI was relatively stable. However, we cannot detect a significant influence of FCI during the peg period.

The explanatory power of the (only) selected driver in the peg period is very low, and the adjusted R^2 is merely 1.6%. This may be due to the large influence of the SNB's policy actions during this period. Table 5 provides the results of our step-forward regressions for the peg period when using the latent exchange rate from Hanke et al. (2019) as the dependent variable. For this case, CHFEUR1m enters first, followed by the DAX. Including the other CHFEUR interest rate and yield curve slope differentials would increase the R^2, but is not recommended by Mallows's C_p. The signs of both variables in the best model in column (2) are as expected and previously interpreted: Higher interest rate increases in the Swiss franc lead to its strengthening, and similar to the pre-crisis period, decreases in the DAX strengthen the Swiss franc relative to the euro. Comparing the coefficients of CHFEUR1m in Tables 4 and 5, we find that the effects of this short-term interest rate differential were significantly dampened by the SNB's minimum exchange rate policy.

4.2.4 Post-peg period (February 2015–December 2020)

The subperiod after the peg shows the highest number of significant drivers of the EUR/CHF exchange rate. FCI enters the list of selected drivers in this subperiod for the first time, and at very high levels of significance. One possible explanation for this is that during the peg period, the SNB's official commitment to maintain the lower bound of 1.20 required only moderate FCI, mainly to intervene when this commitment was tested by the market. Once this commitment was lifted and the SNB no longer communicated any target rate, it had to intervene in the FX market more strongly by purchasing substantial amounts of euro-dominated assets. This resulted in an increase in FCI by more than 50% in the post-peg period. The positive sign of its coefficient shows that FCI worked as expected, as an increase in FCI resulted in a weakening of the Swiss franc.

The second selected variable is the SMI. Increases in the Swiss market index show a positive impact on the Swiss franc, for which increased demand via the portfolio channel may be a possible explanation. Adding the long-term Swiss franc–euro interest rate differential, CHFEUR30y, further improves the model in column (3), with the expected negative sign already explained above. Including also the EURUSD1m interest rate differential does not further improve Mallows's C_p, and the next variables that would be selected turn out to be insignificant, see column (5). Between those models that only contain significant coefficients, we select model (3) over model (4) for sparsity. During this period, the adjusted R^2 of this model is quite high at 23.6%. Even model (1), which contains only FCI as a driver, already shows an adjusted R^2 of 16.7%.

4.2.5 Summary of regression results

Table 7 summarizes the results for the best models selected for the EUR/CHF exchange rate per subperiod (in the columns). Due to the standardization of the variables within each subperiod, larger coefficients (in absolute terms) indicate a higher impact of the respective independent variable. The largest coefficients of individual drivers of the observed exchange rate occur in those periods when the R^2 is the highest, i.e. in the crisis and post-peg periods. In the pre-crisis and the peg periods, both the impact of individual drivers and the resulting explanatory power are markedly lower.

Overall, we find different drivers from various categories whose importance varies across subperiods. Sometimes, their impact even changes sign from one subperiod to the next. These findings are in line with previous literature: Ranaldo & Söderlind (2007, Fig. 4) find time variation and changes in sign in correlations between the USD/CHF exchange rate and the S&P 500 and Treasury futures returns. Leutert (2018) documents regime dependence of the relation between equity indices and the EUR/CHF exchange rate with the correlation changing from positive before 1999 to highly negative

Table 6 OLS regression results for the post-peg period (February 2015–December 2020)

	Post-peg period (February 2015–December 2020)				
	***Dependent variable:* EUR/CHF**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Constant	0.025	0.025	0.025	0.025	0.025
	(0.851)	(0.854)	(0.847)	(0.840)	(0.823)
FCI	0.427***	0.457***	0.511***	0.516***	0.543***
	(0.00002)	(0.00000)	(0.00000)	(0.00000)	(0.00000)
			VIF = 1.081	VIF = 1.082	VIF = 1.099
EURUSD1m				− 0.180*	− 0.262*
				(0.090)	(0.085)
				VIF = 1.100	VIF = 1.258
EURUSD30y					0.241
					(0.189)
					VIF = 1.376
CHFEUR30y			− 0.240**	− 0.224**	− 0.129
			(0.012)	(0.019)	(0.340)
			VIF = 1.162	VIF = 1.169	VIF = 1.387
SMI		− 0.206*	− 0.285***	− 0.333***	− 0.300***
		(0.076)	(0.008)	(0.002)	(0.002)
			VIF = 1.151	VIF = 1.228	VIF = 1.254
Observations	70	70	70	70	70
Mallows's C_p	− 9.39	− 10.20	− 11.56	− 11.56	− 12.42
Selected model			X		
R^2	0.180	0.220	0.269	0.298	0.339
Adjusted R^2	0.167	0.197	0.236	0.255	0.288

In this table, we show results from regressing the EUR/CHF exchange rate onto an increasing set $\mathcal{J}_0$ of variables that are determined by the stepwise forward selection method described in Sect. 2.1. p values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis. Variance inflation factors are shown underneath each variable to indicate potential multicollinearity. The models in columns (3) and (4) minimize Mallows's C_p, the tie is broken in favor of the sparser model

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 7 In this table, we summarize the OLS regression results for the best models from Tables 2, 3, 4, 5, 6 for each subperiod

	Best models per subperiod				
Dependent variable:	**EUR/CHF**	**EUR/CHF**	**EUR/CHF**	**Latent**	**EUR/CHF**
Subperiod	**pre-crisis**	**crisis**	**peg**	**peg**	**post-peg**
Constant	0.027	− 0.859***	− 0.060	− 0.101	0.025
	(0.762)	(0.001)	(0.455)	(0.823)	(0.847)
FCI					0.511***
					(0.00000)
CHFEUR1m			− 0.114***	− 0.582**	
			(0.009)	(0.024)	
CHFEUR30y					− 0.240**
					(0.012)
CHFUSD1m	− 0.150*				
	(0.093)				
CHFUSD10y2y		− 0.608***			
		(0.004)			
DAX	0.124**	− 0.918***		0.840	
	(0.014)	(0.009)		(0.118)	
SMI					− 0.285***
					(0.008)
VSMI		− 1.016***			
		(0.00003)			
Observations	93	43	38	38	70
R^2	0.060	0.257	0.042	0.097	0.269
Adjusted R^2	0.039	0.200	0.016	0.045	0.236

p values (in parentheses) and corresponding significance stars are based on Newey–West adjusted standard errors with 6 lags, where the lag order was determined based on a full-sample analysis

$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

after 1999. Hossfeld and MacDonald (2015) find major differences in correlations between currency returns and global stock market returns conditional on the level of financial stress. Andrews et al. (2022) find the so-called slope carry risk premium to be slightly negative (strongly positive) in the pre-(post-)2008 period. Similar to other papers in this strand of the literature, our approach in the present paper is descriptive and does not model economic chains of cause and effect, in particular, why and how the effects of certain drivers amplify or attenuate each other. Explaining why a certain variable is significant in one subperiod but not in others, or why one particular driver shows a positive impact in one subperiod but a negative impact in another, would require a different modeling approach and is beyond the scope of this paper.

4.3 Robustness checks: Drivers of the REER and alternative variable selection procedures

As a robustness check for our methodology, we repeat the analysis for the Swiss real effective exchange rate (REER) and compare the drivers by subperiod to those found for the observed exchange rate. The best models found for the REER are shown in Table 10 in Appendix. Table 8 compares the resulting drivers of the REER in the respective subperiods to those selected for the observed exchange rate. As an additional robustness check, we also show the sets of drivers selected by the several alternative variable selection procedures described in Sect. 2.1.

Table 8 shows some similarities in the sets of relevant drivers between the REER and the observed exchange rate (top panel and middle panel with entries labeled "*p* values"), with approximately half of the drivers identical for both dependent variables. Detailed results for the regression models with REER as the dependent variable are provided in Table 10. Compared to Table 7, the changes in sign of the estimated beta coefficients are due to the REER calculation/notation. An appreciation of the Swiss franc against major trading partners results in an appreciation of the REER, whereas due to market conventions, an appreciation relative to the euro corresponds to a decrease in the EUR/CHF rate.

Table 8 Drivers for each subperiod in their order of selection by the respective method

Subperiods	January 2000–November 2007	January 2008–August 2011	October 2011–December 2014	February 2015–December 2020
p values (REER)	DAX, VSMI	EURUSD1m, CHFUSD10y2y	CHFUSD1m, SMI, CHFUSD10y2y	CHFEUR1m, FCI, SMI, VDAX
p values (EUR/CHF)	CHFUSD1m, DAX	CHFUSD10y2y, VSMI, DAX	CHFEUR1m	FCI, SMI, CHFEUR30y, (EURUSD1m)
lars/stepwise	CHFUSD1m, DAX, EURUSD30y	CHFUSD10y2y, VSMI, DAX	VSMI	FCI, EURUSD30y, EURUSD1m, SMI, VSMI
lars/lar	CHFUSD1m, DAX, EURUSD30y, EURUSD1m, EURUSD10y2y	CHFUSD10y2y, VSMI, CHFEUR1m, DAX, CHFEUR30y, EURUSD10y2y, EURUSD1m	–	FCI, EURUSD30y, SMI, EURUSD1m, CHFEUR30y, DAX, VSMI
lars/lasso	CHFUSD1m, DAX, EURUSD30y, EURUSD1m, EURUSD10y2y	CHFUSD10y2y, VSMI, CHFEUR1m, DAX, CHFEUR30y, EURUSD10y2y, EURUSD1m, CHFUSD30y	–	FCI, EURUSD30y, SMI, EURUSD1m, CHFEUR30y, DAX, VSMI
lars/stagewise.forward	CHFUSD1m, DAX, EURUSD30y, EURUSD1m, EURUSD10y2y	CHFUSD10y2y, VSMI, CHFEUR1m, DAX, CHFEUR30y, EURUSD10y2y, EURUSD1m, CHFUSD30y	–	FCI, EURUSD30y, SMI, EURUSD1m, CHFEUR30y, DAX, VSMI, CHFUSD10y2y, EURUSD10y2y
Fivefold 15times CV (C_p):	CHFUSD30y, CHFUSD1m	VSMI	VSMI	VSMI, CHFEUR30y, FCI
Fivefold 15times CV (R^2):	CHFUSD30y, CHFUSD1m, EURUSD30y, EURUSD10y2y	VSMI, DAX, VDAX, CHFUSD10y2y	VSMI	VSMI, CHFEUR30y, FCI, CHFUSD1m, EURUSD10y2y

Top panel (first row): Drivers for the real effective exchange rate selected according to the method described in Sect. 2.1. Middle panel (second row): Drivers for the observed exchange rate selected according to the method described in Sect. 2.1. Bottom panel (remaining rows): Drivers for the observed exchange rate selected by different methods from the lars package and by two variants of cross-validation

A comparison of our approach to selecting drivers for the observed exchange rate (middle panel of Table 8) to alternative approaches (bottom panel), we find that all methods largely agree on the first few drivers in all regimes except for the peg period. In many cases, even the order in which they are selected is identical. The main difference is that our approach leads to sparser models. In the peg period, some alternative approaches choose VSMI as the first and only driver, whereas our approach based on *p* values selects CHFEUR1m. The difference between selecting these variables has been illustrated in Sect. 4.2.3.

5 Conclusion

Based on 21 years of exchange rate data, we investigated drivers of the EUR/CHF exchange rate. The sample covers different subperiods, which represent different exchange rate environments or regimes: pre-financial crisis, financial crisis until the introduction of the peg, the peg period itself, and the time after the peg. Breakpoints between these subperiods were selected using a combination of statistical techniques and economic events. Candidate drivers were chosen based on the literature and include interest rate and yield curve slope differentials, equity indices and their associated volatility indices, as well as foreign currency investments by the SNB. For each of the subperiods, we have found different combinations of drivers. A comparison of the regressions for the observed and the latent EUR/CHF rates during the peg period revealed that although one of the detected drivers was the same, its effect on the observed exchange rate was significantly dampened by the SNB's policy during this period. Interestingly, foreign currency investments themselves became a significant driver only after the peg period when there was no longer a communicated target rate. As robustness tests, we have shown that there are similarities between the drivers we find for the observed EUR/CHF exchange rate and the Swiss franc's real effective exchange rate and that variables selected by our approach as drivers of the observed exchange rate are very similar to drivers selected by other established variable selection methods.

Appendix

See Tables 9, 10 and Figs. 3, 4.

Table 9 Descriptive statistics for all variables by subperiod

	January 2000–November 2007				January 2008–August 2011				October 2011–December 2014				February 2014–December 2020			
Variable	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**
Obs. EUR/CHF	0.0002	0.0074	− 0.0198	0.0188	− 0.0089	0.0179	− 0.0490	0.0273	0.0000	0.0068	− 0.0139	0.0242	− 0.0002	0.0107	− 0.0324	0.0299
Lat. EUR/CHF									− 0.0013	0.0271	− 0.0664	0.0954				
REER	− 0.0004	0.0095	− 0.0212	0.0206	0.0072	0.0166	− 0.0210	0.0482	− 0.0020	0.0085	− 0.0267	0.0196	− 0.0002	0.0103	− 0.0217	0.0256
FCI	0.0001	0.0319	− 0.1472	0.0611	0.0390	0.1141	− 0.0521	0.4413	0.0132	0.0558	− 0.1536	0.2138	0.0082	0.0175	− 0.0392	0.0424
CHFEUR1m	− 0.0000	0.0012	− 0.0036	0.0040	0.0001	0.0019	− 0.0059	0.0061	0.0003	0.0008	− 0.0008	0.0029	0.0000	0.0006	− 0.0044	0.0008
CHFUSD1m	0.0002	0.0018	− 0.0034	0.0078	0.0005	0.0024	− 0.0057	0.0094	0.0000	0.0001	− 0.0003	0.0005	− 0.0000	0.0014	− 0.0045	0.0064
EURUSD1m	0.0002	0.0016	− 0.0023	0.0063	0.0003	0.0030	− 0.0070	0.0118	− 0.0003	0.0007	− 0.0029	0.0008	− 0.0001	0.0013	− 0.0020	0.0072
CHFEUR30y	0.0000	0.0010	− 0.0022	0.0031	− 0.0000	0.0010	− 0.0025	0.0018	0.0002	0.0006	− 0.0013	0.0018	0.0001	0.0009	− 0.0036	0.0026
CHFUSD30y	0.0001	0.0014	− 0.0045	0.0036	− 0.0002	0.0018	− 0.0053	0.0049	− 0.0000	0.0009	− 0.0021	0.0017	− 0.0000	0.0012	− 0.0030	0.0057
EURUSD30y	0.0000	0.0010	− 0.0035	0.0020	− 0.0001	0.0017	− 0.0052	0.0053	− 0.0002	0.0009	− 0.0018	0.0020	− 0.0001	0.0011	− 0.0030	0.0031
EURUSD10y2y	− 0.0001	0.0013	− 0.0043	0.0034	− 0.0000	0.0018	− 0.0034	0.0059	− 0.0001	0.0009	− 0.0019	0.0023	0.0000	0.0007	− 0.0020	0.0017
CHFUSD10y2y	− 0.0001	0.0014	− 0.0041	0.0027	− 0.0002	0.0025	− 0.0062	0.0114	− 0.0001	0.0012	− 0.0021	0.0039	0.0000	0.0008	− 0.0020	0.0017
CHFEUR10y2y	0.0001	0.0013	− 0.0039	0.0046	− 0.0002	0.0022	− 0.0083	0.0065	0.0001	0.0011	− 0.0029	0.0026	− 0.0000	0.0007	− 0.0025	0.0022
VDAX	− 0.0032	0.1359	− 0.2177	0.5753	0.0176	0.2143	− 0.2676	0.7730	− 0.0198	0.1169	− 0.2198	0.2487	0.0001	0.2051	− 0.3077	1.1363
VSMI	0.0004	0.1610	− 0.2663	0.5912	0.0131	0.2081	− 0.2580	0.7032	− 0.0206	0.1236	− 0.2966	0.3022	− 0.0026	0.2195	− 0.3772	1.1837
DAX	0.0012	0.0539	− 0.2181	0.1135	− 0.0067	0.0647	− 0.2153	0.1298	0.0153	0.0375	− 0.0706	0.0833	0.0040	0.0511	− 0.2841	0.1134
SMI	0.0017	0.0394	− 0.1347	0.0919	− 0.0112	0.0491	− 0.1389	0.0852	0.0130	0.0273	− 0.0629	0.0510	0.0028	0.0328	− 0.1823	0.0514

Subperiods are separated by structural breaks identified via the statistical techniques described in Sect. 2. The construction of the variables is described in Sect. 3

Table 10 Optimal OLS regression results across all subperiods

	Dependent variable:			
	REER_CHF			
	(1)	**(2)**	**(3)**	**(4)**
Constant	− 0.033	0.676***	− 0.140	− 0.041
	(0.695)	(0.004)	(0.133)	(0.710)
FCI				− 0.449***
				(0.00001)
CHFEUR1m				0.208***
				(0.000)
CHFUSD1m			0.150***	
			(0.005)	
CHFUSD10y2y		0.440**	− 0.201*	
		(0.020)	(0.076)	
EURUSD1m		0.500***		
		(0.003)		
DAX	− 0.286***			
	(0.004)			
SMI			0.223***	0.717***
			(0.005)	(0.00000)
VDAX				0.566***
				(0.003)
VSMI	− 0.203**			
	(0.020)			
Observations	93	43	38	67
R^2	0.047	0.098	0.250	0.392
Adjusted R^2	0.025	0.053	0.183	0.353

In this table, we show results from regressing the real effective exchange rate (REER) onto an incremental number of variables that are selected by the multicollinearity-aware forward selection described in Sect. 2. p values (in parenthesis) and corresponding significance stars are based on Newey–West adjusted standard errors with 5 lags which were determined based on a full-sample analysis. We additionally take into account variance inflation factors shown underneath each variable to account for multicollinearity. We also show Mallows's C_p (ultimate model selection criterion) in each table

$*p < 0.1$; $**p < 0.05$; $***p < 0.01$

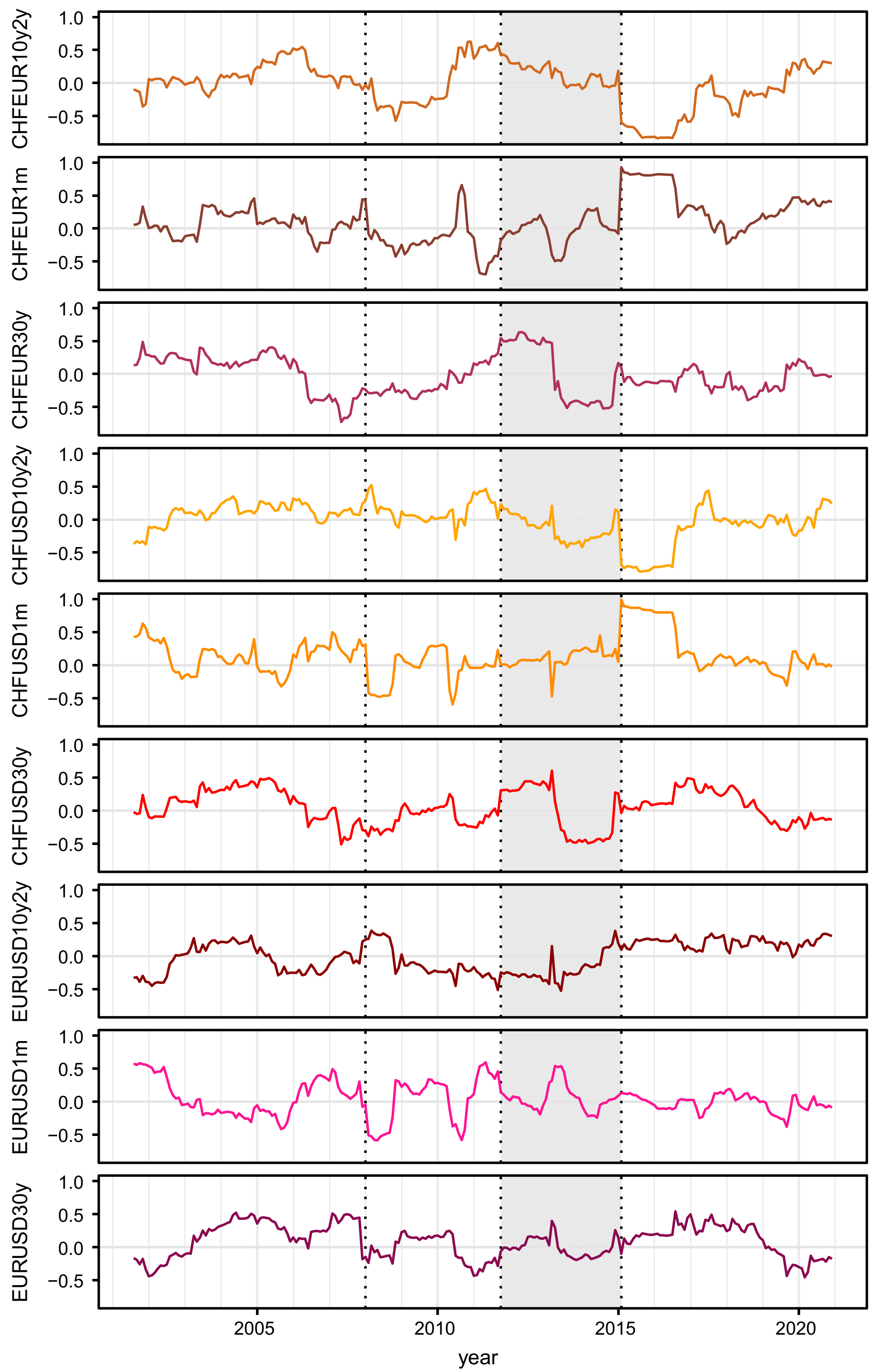

Fig. 3 Rolling window correlations (part 1) between explanatory variables and the EUR/CHF exchange rate for a window size of 18 months. Dotted lines indicate the estimated breakpoints. The shaded area marks the peg period

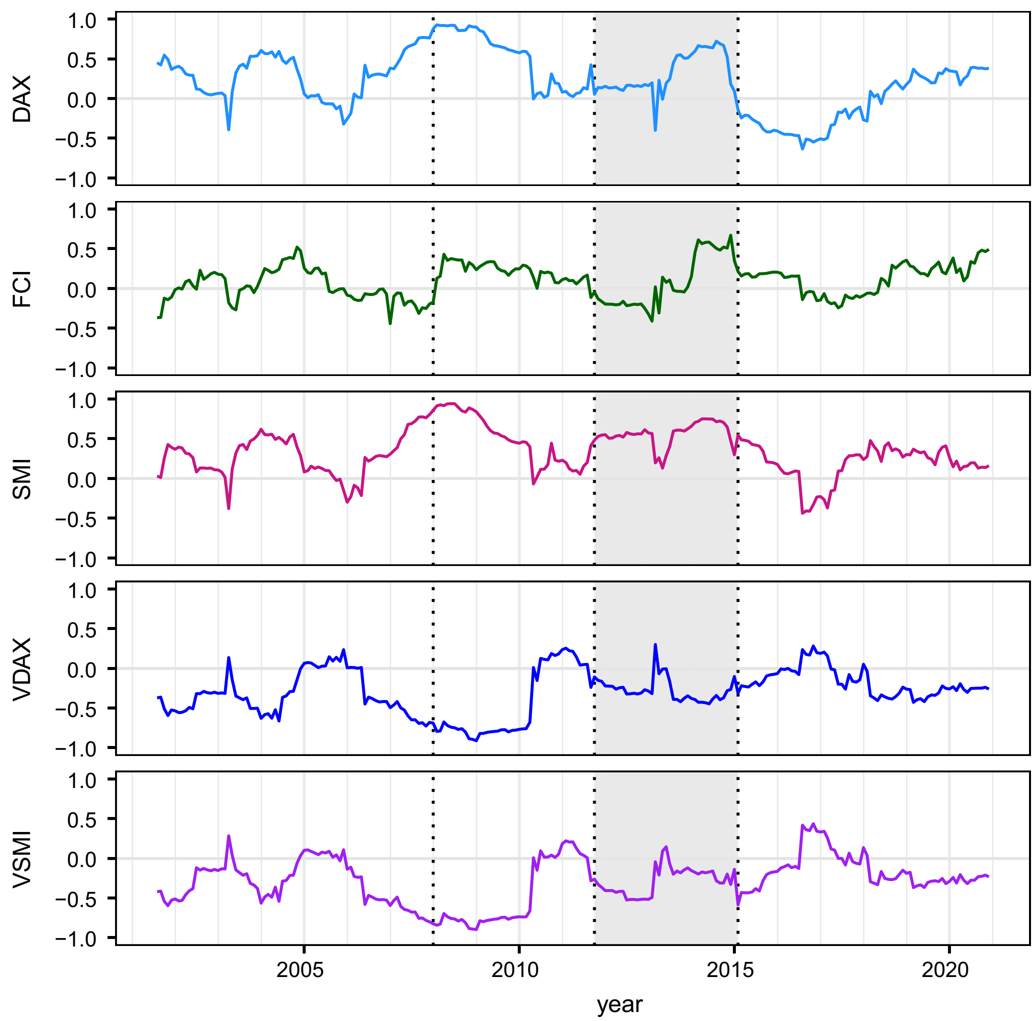

Fig. 4 Rolling window correlations (part 1) between explanatory variables and the EUR/CHF exchange rate for a window size of 18 months. Dotted lines indicate the estimated breakpoints. The shaded area marks the peg period

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Availability of data and materials
The data on Swiss National Bank Foreign Currency Investments and Real Effective Exchange Rate are publicly available from the Swiss National Bank data portal. The other data used in this paper are subject to terms and conditions of the respective data provider. We can therefore not make them available, neither publicly nor on request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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