

The impact of SNB monetary policy on the Swiss franc and longer-term interest rates

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1 Introduction

Economic theory suggests that an increase in the policy rate appreciates the currency in the short and long run. This result is explained by two economic principles, namely, interest rate parity and purchasing power parity. Identifying the effects of policy rate changes on exchange rates is challenging due to endogeneity and simultaneity. Exchange rate and interest rate movements reflect not just monetary policy but also other drivers such as safe-haven flows into the Swiss franc.¹ For example, a negative risk shock tends to result in *lower* interest rates and a *stronger* Swiss franc because of safe-haven flows into the Swiss franc and an expected loosening of monetary policy in response to a Swiss franc appreciation. This holds particularly true for a small open economy such as Switzerland, for which the exchange rate is an important determinant of monetary policy transmission and hence for the monetary policy decision-making process.² In contrast, a negative domestic economic shock tends to induce *lower* interest rates and a *weaker* Swiss franc, both due to an expected loosening of monetary policy. Hence, the naively observed relation between interest rates and exchange rates will depend on the type of shock that dominates in a given sample period.

This paper investigates the short-term impact of monetary policy rate changes made by the Swiss National Bank (SNB) on the Swiss franc exchange rates and on the Swiss yield curve. We identify the causal effects of policy rate changes on a daily level using the identification-through-heteroskedasticity (IH) methodology following Rigobon (2003) and Rigobon and Sack (2004). The approach allows for simultaneous (intraday) feedback between interest rates and exchange rates and imposes weaker identifying assumptions than event study-based approaches.

The IH methodology is based on the fact that the variance of the interest rate shocks is higher on days of monetary policy announcements than on other days. To estimate the effects of unexpected policy rate changes, we consider the historical time frame spanning from January 1, 2000 to August 31, 2011. During this time, the 3-month CHF LIBOR was the SNB's main policy instrument. Our sample includes two policy rate cycles, covering 56 SNB monetary policy announcements and 26 changes in the 3-month CHF LIBOR target range.

The main findings can be summarized as follows. First, an unexpected policy rate hike leads to a nominal appreciation of the Swiss franc on the same day. The null hypothesis that a policy rate change does not affect the exchange value of the Swiss franc is clearly rejected. Our finding that policy rate changes made by the SNB are highly relevant for the exchange rate of the Swiss franc

¹The safe-haven characteristics of the Swiss franc have been established by numerous contributions. See Fink et al. (2019) for an overview.

²Nitschka and Mirkov (2016) estimate Taylor rules for Switzerland, augmented by an effective nominal Swiss franc exchange rate. They find that the estimated effect of Swiss franc appreciation on the 3-month LIBOR target rate is highly significant and negative, reflecting the stabilizing effect of the Swiss National Bank policy. Importantly, Nitschka and Mirkov (2016) report that professional survey expectations anticipate a response of the central bank.

is robust to the use of alternative specifications. Second, we provide empirical evidence that simple econometric methods yield biased and typically nonsignificant results. Not adequately identifying the causal effects may lead to the incorrect conclusion that policy rate changes do not impact the Swiss franc. Third, an unexpected policy rate change impacts the expected average future short-term interest rates and thereby the Swiss yield curve. Unexpected policy rate changes impact medium- to longer-term policy rate expectations, which in turn affect the exchange rate.

Our paper contributes to the literature as follows. First, we extend the rather scant empirical literature on Switzerland. In particular, we discuss how to adequately identify causal effects, which is particularly relevant for the Swiss case. Moreover, we contribute to the understanding of transmission by estimating the effects on the expected average future short-term interest rates derived using the Adrian et al. (2013) methodology. Second, with regards to the IH literature that builds on the seminal contributions of Rigobon (2003) and Rigobon and Sack (2004), we advance the estimation methodology by *jointly* estimating the effects on the EURCHF and USDCHF exchange rates using the generalized method of moments (GMM). Joint estimation is more efficient and facilitates additional robustness tests.

The analysis is structured as follows. Section 2 summarizes the relevant literature, focusing on evidence for Switzerland. Section 3 outlines the simultaneity issue and our identification approach. Section 4 describes the data. Section 5.1 presents the results on the exchange rate response to a monetary policy shock in the form of an unexpected policy rate change. In section 5.2, we discuss the effects on the expected average future short-term interest rates. Section 6 concludes.

2 Related literature

A large body of the empirical literature investigates the effects of monetary policy surprises on asset prices. As highlighted by Rigobon and Sack (2004), this relation is not only important for financial market participants but also for central banks because asset prices play an important role in monetary policy transmission.

Our contribution relates to the strand of this literature that seeks to identify the effects on exchange rates seen in daily or intraday data. Causal effects are mostly identified using event studies and by means of instrumental variables or, as in our paper, IH. This strand is distinct from an alternative strand that estimates the effects evident in lower frequency data, typically using SVARs.

With regards to the impact of unexpected monetary policy shocks on exchange rates, the international literature reports highly significant and immediate effects (e.g., Ferrari et al. (2017)),

Kerssenfischer (2019), Rosa (2011), Kearns and Manners (2006)). The point estimates roughly range from 0.3% to 1.5% nominal appreciation in response to a contractionary 25 bp interest rate shock. Specifically, considering a panel of seven major central banks, Ferrari et al. (2017) find that an unexpected policy rate hike of 25 bp causes an immediate appreciation from 1 to 1.5% for most of the central banks considered. Focusing on the ECB, Kerssenfischer (2019) reports that the EURCHF exchange rate rises by 0.95% in response to a contractionary 25 bp ECB monetary policy shock. Rosa (2011) shows that the surprise components of both the Fed’s monetary policy actions and statements have economically important and highly significant effects on the exchange rate of the U.S. dollar. An unanticipated 25 bp cut in the federal funds target rate is associated on average with a 0.5% depreciation of the exchange value of the U.S.-dollar, also towards the Swiss franc. Kearns and Manners (2006) investigate the impact of monetary policy on the exchange rate using an event study with intraday data for four countries. An unanticipated tightening of 25 bp leads to a rapid appreciation of approximately 0.35% from 1993–2004.

In line with international evidence, a rather small literature on effects of SNB policy rate changes confirms that the Swiss franc significantly appreciates in response to unexpected policy rate hikes. The magnitude of the point estimates is rather broad, however, ranging from less than 0.2% to more than 6% appreciation in response to a 25 bp policy rate hike.

The lower bound of this range is set by Ranaldo and Rossi (2010). Using an event study approach to identify the intraday effects of SNB monetary policy decisions, the authors find that an unexpected 25 bp increase in the 3-month CHF LIBOR caused the Swiss franc to appreciate by 0.17% towards the U.S.-dollar from 2000 to 2005. The upper bound is given by the estimates of Ferrari et al. (2017), who report that an SNB policy announcement that generates a 25 bp increase in the 1-month CHF OIS rate caused the Swiss franc to appreciate by 6.25% towards the U.S.-dollar from September 2010 to September 2015. The magnitude of this effect exceeds what they find for most other central banks, and they note that the findings for Switzerland should be interpreted with care due to the short sample period.

The recent results of Kugler (2020) and Grisse (2020) fall within this range. Similar to our contribution, both papers consider the period 2000-2011. Using an instrumental variable approach and daily data, Kugler (2020) reports that the Swiss franc appreciates by 0.93% in response to an unexpected 25 bp increase in the 3-month CHF LIBOR. Grisse (2020) estimates the effects using a weekly SVAR and identifies monetary policy shocks based on the comovement of interest rates and stock prices. Grisse (2020) finds that a contractionary 25 bp shock causes the Swiss franc to appreciate by 1.0% against the euro and by 0.75% against the U.S. dollar in the same week.³

³Related research confirms the relevance of policy rates for the Swiss franc. Lenz and Savioz (2009) analyze the determinants of the Swiss franc exchange rate against the euro. They find that Swiss monetary policy contributed

3 Empirical model

This section describes first the simultaneity problem when analyzing the effect of monetary policy rate changes on exchange rates. This section then presents the model, the identification strategy and the estimation methodology.

3.1 Model

When modeling the response of exchange rates to interest rates, we need to take into account the simultaneous effect that a change in the exchange rate may have on the interest rate. Today's exchange rate depends among other factors on the expected path of the interest rate, which determines the relative attractiveness of investments in Swiss franc. However, the interest rate is impacted by the expected monetary policy response to exchange rate variations. For a small open economy such as Switzerland, market participants anticipate that the exchange rate is an important factor in the monetary policy decision-making process. The latter is in line with the augmented Taylor rule estimates in Nitschka and Mirkov (2016).

We assume that the change in the policy rate Δi_t and the change in the nominal exchange rate Δs_t are described by the following simultaneous equation system:

$$\begin{array}{ll} \text{Exchange rate response function} & \Delta s_t = \alpha \Delta i_t + \gamma_s z_t + \eta_t, \end{array} \quad (1)$$

$$\begin{array}{ll} \text{Interest rate response function} & \Delta i_t = \beta \Delta s_t + \gamma_i z_t + \varepsilon_t, \end{array} \quad (2)$$

where z_t are exogeneous variables that affect both interest rates and exchange rates. The nominal exchange rate s_t is defined as the units of Swiss franc per unit of a foreign currency. Thus, if s_t declines, the Swiss franc appreciates in nominal terms. The structural innovations (η_t, ε_t) are interpreted as an exchange rate and a monetary policy shock, respectively. The structural shocks are assumed to have a mean of zero and be uncorrelated with each other and with the exogeneous variables z_t . Our interest lies in identifying the parameter α in the exchange rate response function given by equation (1).

Empirically, we only observe equilibria of exchange rates and interest rates simultaneously, which makes it impossible to identify the response function of the exchange rates to interest rate changes with standard regression techniques. The naively observed relation will depend on the type of shock that hits the system. For example, a positive economic shock likely induces

between 7% and 15% to variations of the exchange rate from 1981 to 2007. Rudolf and Zurlinden (2014) find an impact of approximately 0.2% in an estimated DSGE model for the period 1983-2013. Based on a calibrated DSGE model of the Swiss economy, the results of Cuche-Curti et al. (2009) point towards 0.25% appreciation for a restrictive 25 bp policy rate shock in the period 1975 to 2006. Canetg and Kaufmann (2019) analyze the impact of SNB's debt security auctions from 2008 to 2011 on financial market variables. They identify a money market as well as an expectation shock and find that the two shocks explain up to 80% of the forecast-error variance of the Swiss franc.

higher interest rates and a stronger Swiss franc, both due to the expected tightening of monetary policy. A negative risk shock will induce lower interest rates and a stronger Swiss franc, both due to the resulting safe-haven flows.

In fact, the rolling 6-month correlation of the 3-month CHF LIBOR in first differences and the EURCHF log return shown in Figure 1 is rather erratic due to the different type of shocks that affect both the exchange rate and the interest rate.

Figure 1: Rolling window correlation for EURCHF and the 3-month CHF LIBOR.



Notes: The chart shows the 6-month rolling window correlation between Δ_s^{EURCHF} and $\Delta_i^{\text{3M-LIBOR}}$ from January 1, 2000 to August 31, 2011. The exchange rate is transformed by using the first difference of the log and the interest rate is transformed by the first difference.

It is therefore important to adequately account for the feedback between interest rates and exchange rates. Using basic regression methods will result in biased estimates. To robustly infer the causal impact of policy rate changes on exchange rates, we employ the identification-through-heteroskedasticity approach of Rigobon (2003) and Rigobon and Sack (2004). This approach is outlined in the next section.

3.2 Identification-through-heteroskedasticity methodology

Assume that the changes in the policy rate Δi_t and the exchange rate Δs_t are described by the above system of equations (1) and (2), respectively. The simultaneous causality between Δi_t and Δs_t means that not all the parameters are exactly identified. The reduced form of the equation system, derived in Appendix B.1, has more unknown parameters than there are coefficients in the reduced form. Rigobon (2003) and Rigobon and Sack (2004) suggest a way to identify the exchange rate response α to a monetary policy shock based on the heteroskedasticity of the monetary policy shock. The idea is to look at the differences in the covariance structure of Δi_t and Δs_t for days with a monetary policy announcement (MPA) and days with no policy announcement.

We follow Rigobon and Sack (2004) in assuming that the monetary policy shock on days of MPAs of the SNB is relatively more important:

$$\begin{aligned}\sigma_{\varepsilon,P}^2 &> \sigma_{\varepsilon,\tilde{P}}^2, \\ \sigma_{\eta,P}^2 &= \sigma_{\eta,\tilde{P}}^2\end{aligned}$$

Consequently, we split the data in two subsets that are assumed to differ only in terms of the variance of the monetary policy shock. Let P and \tilde{P} denote the two subsamples. P is the set of days with an MPA, while \tilde{P} contains non-MPA days. We assign the day before the MPA to the subsample \tilde{P} to reduce unpredictable influences from other economic shocks with respect to monetary policy actions. The key assumption is that the monetary policy innovations in the two sets have different variances, and the structural parameters and the variance of the exchange rate innovations are unchanged.

Clearly, identification is complicated by the fact that interest rates and exchange rates are affected by a common set of exogenous variables z_t . An important benefit of the IH methodology is that potentially confounding variables need not be explicitly considered in order to identify α . As shown by Rigobon and Sack (2004), it is sufficient to impose the assumption that the variance of the exogenous shocks does not differ across the two subsamples:

$$\sigma_{z,P}^2 = \sigma_{z,\tilde{P}}^2.$$

Given these assumptions, it can be shown that the difference between the covariance on MPA days and the covariance on non-MPA days is given by (see Appendix B.1 for a derivation):

$$\Delta\Omega = \lambda \begin{bmatrix} 1 & \alpha \\ \alpha & \alpha^2 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ \alpha \end{bmatrix} \begin{bmatrix} 1 & \alpha \end{bmatrix},$$

where

$$\lambda = \frac{\sigma_{\eta,P}^2 - \sigma_{\eta,\tilde{P}}^2}{(1 - \alpha\beta)^2}. \quad (3)$$

That is, by examining the change in the covariance, we can isolate the policy impact parameter α and purge all other influences that are assumed to have an equal covariance structure on MPA and non-MPA days.

We can extend the model by introducing an additional exchange rate equation that allows us to analyze the policy effect on EURCHF and USDCHF in a single system. In this case, the change in the covariance is given by (see Appendix B.2 for a derivation):

$$\Delta\Omega = \lambda \begin{bmatrix} 1 & \alpha_1 & \alpha_2 \\ \alpha_1 & \alpha_1^2 & \alpha_1\alpha_2 \\ \alpha_2 & \alpha_1\alpha_2 & \alpha_2^2 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ \alpha_1 \\ \alpha_2 \end{bmatrix} \begin{bmatrix} 1 & \alpha_1 & \alpha_2 \end{bmatrix},$$

with

$$\lambda = \frac{\sigma_{\eta,P}^2 - \sigma_{\eta,\tilde{P}}^2}{(1 - \alpha_1\beta_1 - \alpha_2\beta_2)^2}.$$

The next section outlines our estimation approach.

3.3 Estimation methods

Rigobon and Sack (2004) show that there are two ways to implement the estimation: using instrumental variables (IV) or using the generalized method of moments (GMM). In what follows, we focus on the GMM approach. To check robustness, we also implement the IV estimator, with consistent findings presented in Appendix C.

The GMM approach matches the model implied variances and covariances with their empirical counterparts. For the single exchange rate case, we obtain 3 moment conditions in 2 unknown parameters (see Appendix B.1 for a derivation):

$$g(\lambda, \alpha) = \begin{bmatrix} \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t^2 - \lambda \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_t - \lambda \alpha \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_t^2 - \lambda \alpha^2 \end{bmatrix}$$

In a system with two exchange rates, we obtain two additional terms for the variance of the second exchange rate and its covariance with the interest rate change. On top of that, we obtain another moment condition corresponding to the covariance between the two exchange rates.⁴ This results in 6 moment conditions in 3 unknown parameters (see Appendix B.2 for a derivation):

$$g(\lambda, \alpha_1, \alpha_2) = \begin{bmatrix} \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t^2 - \lambda \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_{1t} - \lambda \alpha_1 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{1t}^2 - \lambda \alpha_1^2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_{2t} - \lambda \alpha_2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{2t}^2 - \lambda \alpha_2^2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{1t} s_{2t} - \lambda \alpha_1 \alpha_2 \end{bmatrix}.$$

The system with two exchange rates allows us to test for the equality of the impact coefficients α_1 and α_2 . Given that the null hypothesis of the equality of the effects cannot be rejected, we estimate a constrained model with $\alpha = \alpha_1 = \alpha_2$. Note that we expect equal effects on the EURCHF and USDCHF exchange rate because it seems implausible that the EURUSD

⁴Rigobon and Sack (2004) also use GMM to estimate across a class of financial variables at once. They report to “stack the three moment conditions b_t [with our notation $g(\lambda, \alpha)$] for all variables”. However, note that doing so means that the moment condition derived from the variance of the interest rate is added twice. It is also unclear if they make use of the additional moment conditions derived from the covariance between the financial variables.

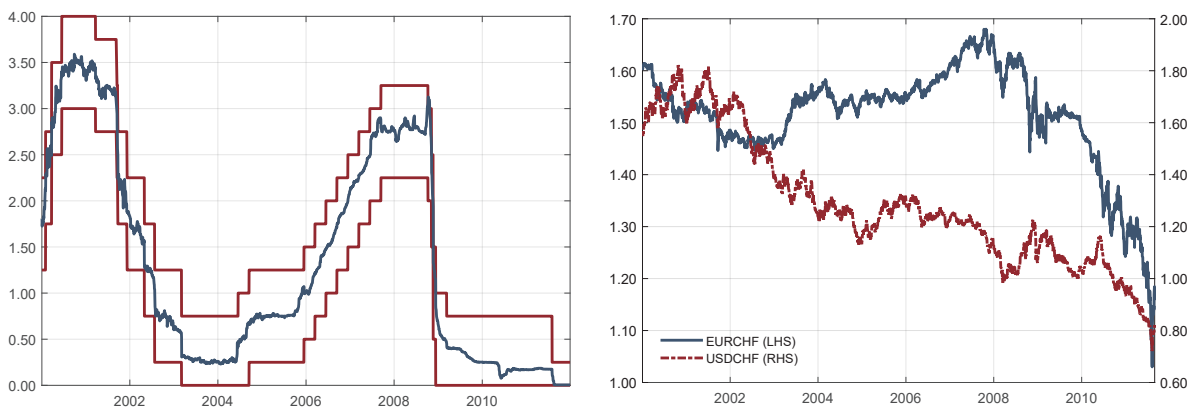
exchange rate is affected by SNB policy rate decisions. In the constrained model, we have 6 moment conditions in 2 unknown parameters.

We estimate the unknown parameters by iterated efficient nonlinear GMM, as detailed in Appendix B.3.

4 Data

Our analysis is based on daily data from January 1, 2000 to August 31, 2011. The sample begins after the SNB changed its monetary policy concept in December 1999.⁵ Back then, the SNB began to announce a target band for the 3-month CHF LIBOR, which was chosen to be consistent with a medium-term inflation rate of below 2%. The sample ends prior to the EURCHF minimum exchange rate regime, which was introduced on September 6, 2011. In the sample, the SNB implemented its monetary policy mainly using one-week repurchase agreement operations to control the 3-month CHF LIBOR. Typically, the SNB aimed to keep the reference rate in the middle of the target range. Figure 2 shows the SNB target range, the 3-month CHF LIBOR and the Swiss exchange rates in the left and right panels, respectively.

Figure 2: SNB target range, 3-month CHF LIBOR and Swiss franc exchange rates



Notes: The chart shows the SNB target range for the 3-month CHF LIBOR, the 3-month CHF LIBOR and Swiss franc exchange rates on a daily basis from January 1, 2000 to August 31, 2011.

MPA days

The IH methodology requires the sample to be split into MPA and non-MPA days to identify the slope of the exchange rate response function. Our time frame covers 56 monetary policy

⁵After 25 years of monetary targeting, the SNB implemented a new monetary policy concept in December 1999. The new concept built on three elements. The first element was considering price stability to be compatible with annual CPI inflation of less than 2%. The second element was an inflation forecast that is published on a quarterly basis. The third element was an operational target range for the 3-month CHF LIBOR. Note that on 13 June 2019, the target range for the 3-month CHF LIBOR was replaced by the SNB policy rate.

decisions made by the SNB. At 26 policy meetings, the target range of the 3-month CHF LIBOR was changed. Furthermore, 9 out of the 56 policy meetings were unscheduled special meetings. Table A-6 provides a detailed overview of the monetary policy announcement meetings.

Measuring policy rate changes

We use the daily change in the 3-month CHF LIBOR to measure the policy rate changes Δi_t . Since the SNB targeted the 3-month CHF LIBOR, the rate directly incorporates policy rate expectations between day t and $t + 90$. Hence, absent other shocks, the 3-month CHF LIBOR will change only on MPA day t if the markets are surprised by the outcome of the SNB's monetary policy decision.⁶

Measuring the expectations component in longer-term interest rates

We decompose the Swiss government bond yield curve into two components: the expected average future short-term interest rates and the term premium. For this purpose, we use the term structure model and estimation procedure of Adrian et al. (2013). For each maturity, we calculate the expected component as the expected average future 1-year interest rate. For decomposing the response of long-term expectations about future short-term interest rates, we use Swiss government bonds prices sampled at their end-of-day value.

Exchange rates

As exchange rate variables we use both the EURCHF and USDCHF exchange rate. As outlined above, these exchange rates measure the units of Swiss franc per unit of euro and U.S. dollar, respectively. Thus, if the exchange rate declines, the Swiss franc appreciates in nominal terms. The exchange rates are sampled at the same points in time as the interest rate variable. For the 3-month CHF LIBOR, the relevant time of day is 11 a.m. London time, when the LIBOR is approximately fixed. For every day in our sample, we retrieve the best bid and offer prices on the interbank market at the respective point in London time. We then compute the daily exchange rate return as the difference in the logarithm of the mid-price. Table 1 provides an overview on the source and transformations of the interest rate and exchange rate variables.

Descriptive statistics

The descriptive statistics for the subsamples P and \tilde{P} are reported in Table 2. Note that the standard deviation of the 3-month CHF LIBOR significantly increases by a factor larger than two on MPA days compared to the standard deviation on non-MPA days. The standard deviations

⁶Note that for approximately 50% of the MPAs, we use the 3-month CHF LIBOR change between t and $t + 1$ to measure unexpected policy rate changes. The reason for this is that the 3-month CHF LIBOR is fixed at approximately 11:00 a.m. London time (12:00/13:00 Zurich daylight savings / standard time), whereas the monetary policy decisions were alternately announced before and after the LIBOR fixing. Between 2000 and 2010, the SNB policy announcements took place at 9:30 a.m. Zurich time in June and December (we use the 3-month CHF LIBOR change $t - 1$ to t) and at 14:00 p.m. Zurich time in March and September (we use the 3-month CHF LIBOR change t to $t + 1$). Unscheduled announcements were released at approximately 13:00 p.m. (we use the 3-month CHF LIBOR change t to $t + 1$).

Table 1: Overview of the financial variables

Name	Description	Transformation	Unit
$\Delta i^{3M-LIBOR}$	3-month LIBOR rate for CHF deposits	First difference	Ppts
Δs^{EURCHF}	EURCHF exchange rate	Log return	Pct
Δs^{USDCHF}	USDCHF exchange rate	Log return	Pct
Δi^{2Y}	2-year Swiss government bond yield		Pct
Δi^{3Y}	3-year Swiss government bond yield		Pct
Δi^{5Y}	5-year Swiss government bond yield		Pct
Δi^{7Y}	7-year Swiss government bond yield		Pct
Δi^{10Y}	10-year Swiss government bond yield		Pct

Notes: The table provides details of the variables used for estimation. The data source for the 3-month CHF LIBOR and the Swiss government bond yields is Bloomberg L.P., whereas for the exchange rates we rely on EBS Data Mine data.

of the CHF exchange rate returns increase as well, but the magnitude is much smaller. Thus, as expected, the descriptive statistics support the assumption that the variance of the monetary policy shock on MPA days relatively increases.

Table 2: Descriptive statistics

	Mean	Median	Minimum	Maximum	SD
MPA Days					
$\Delta i^{3M-LIBOR}$	-0.037	-0.005	-0.612	0.282	0.122
Δs^{EURCHF}	0.135	0.095	-1.221	3.511	0.666
Δs^{USDCHF}	-0.012	-0.012	-1.833	2.629	0.914
Non-MPA Days					
$\Delta i^{3M-LIBOR}$	-0.002	0.000	-0.135	0.070	0.029
Δs^{EURCHF}	-0.130	-0.051	-2.968	0.850	0.552
Δs^{USDCHF}	-0.267	-0.246	-4.684	1.191	0.892

Notes: The table provides the descriptive statistics for the exchange rates and the policy rate variable for both subsamples. The sample size for each subsample is 56, according to the number of monetary policy announcements by the SNB from January 1, 2000 to August 31, 2011.

5 Results

5.1 Exchange rate response to an unexpected policy rate change

This section discusses the main result of the present analysis, namely, the estimated response of exchange rates to an unexpected policy rate change (i.e., parameter α in equation (1)).

Exchange rate response

Table 3 shows the IH-GMM-estimation results. Our baseline specifications use the 3-month CHF LIBOR as the policy variable. The two left-most columns show the results of estimating two separate equations for EURCHF and USDCHF. In response to an 100 bp increase in the

3-month LIBOR, the point estimates suggest that the Swiss franc appreciates by 2.1% and 1.9% on the same day against the euro and the U.S. dollar, respectively. The third and fourth columns show that consistent estimates result when estimating the joint system that includes both EURCHF and USDCHF. While the point estimates are fairly similar, using all available information reduces the standard error of the estimation.

Next, we test the null hypothesis that the effects are the same for both the EURCHF and USDCHF exchange rates. The results for the corresponding Wald test are shown in Table 3. The null hypothesis regarding the equality of the effects cannot be rejected. This result is sensible from an economic perspective because differing effects would imply that the policy announcements made by the SNB are able to move the EURUSD exchange rate.

As the null hypothesis of equality cannot be rejected, we restrict the impact coefficients in the EURCHF and USDCHF equations to be equal. The results shown in the last column of Table 3 indicate that this further improves the precision of the estimates. The point estimate for α suggests that in response to a 100 bp increase in the 3-month CHF LIBOR, the Swiss franc appreciates by 2.0% against the euro and U.S. dollar, with the 95% confidence interval spanning from 1.4% to 2.5%.

The GMM table includes the estimates of the parameter λ , which represents the change in the variance of ϵ_t between MPA and non-MPA dates divided by a determinant. The IH-approach works only if a change in the variance is present. The estimates indicate that this is indeed the case for all the specifications.

The remaining rows of Table 3 show the tests for the validity of the overidentifying restrictions. The null hypothesis regarding the validity of the restrictions cannot be rejected for any of the different specifications. Finally, the last row shows the number of iterations needed for the convergence of iterated efficient GMM. The results show that convergence is achieved fairly quickly.

The magnitude of our benchmark result for the exchange rate response lies within the range of effects reported in the literature and are similar to the recent findings of Grisse (2020) and Kugler (2020).

Relevance of accounting for simultaneity

Accounting for simultaneity is important. Using simple regression methods that do not disentangle the feedback between interest rates and exchange rates results in biased estimates. Regressing exchange rate returns on interest rate changes yields estimates significantly different from the IH-estimates. Appendix C.1 presents the biased OLS results. The OLS estimate for EURCHF is not significantly different from zero, while the USDCHF coefficient has the opposite sign. We conclude that with standard regressions (or event studies at the daily level), one cannot

correctly identify the causal impact of interest rates on exchange rates. As outlined in Section 3.1, this occurs because interest rates and foreign exchange rates react to each other during the day.

Table 3: IH-GMM estimates of the exchange rate response

	Separate equations		Joint estimation		Restricted $\alpha_1 = \alpha_2$
	EURCHF	USDCHF	EURCHF	USDCHF	EURCHF USDCHF
$\hat{\alpha}$	-2.1*** (0.46)	-1.9* (1.0)	-2.0*** (0.32)	-1.8** (1.0)	-2.0*** (0.3)
$\hat{\lambda}$	0.015** (0.0072)	0.015** (0.0072)	0.015** (0.0071)		0.015*** (0.0048)
Wald $H_0 : \alpha_1 = \alpha_2$			0.038		
p-value			0.84		
J-stat	0.066	0.032	0.18		0.22
p-value	0.8	0.86	0.98		0.99
# moment conditions	3	3	6		6
# parameters	2	2	3		2
# iterations	3	3	3		3

The table shows the identification-through-heteroscedasticity GMM estimates. The policy rate variable is the 3-month CHF LIBOR. We use the iterated efficient nonlinear GMM for the estimation of α and λ . The first two columns report the results estimated separately for EURCHF and USDCHF. The third and fourth column contain the results for the estimated joint system and the result of a Wald test of the equality of α_1 and α_2 , respectively. The rightmost column shows the result of estimating a joint system with the restriction $\alpha_1 = \alpha_2$. The J-statistic reports the results of testing the null hypothesis regarding the validity of overidentifying restrictions. The last row contains the number of iterations needed for convergence. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

Robustness checks

Table 4 and Appendix C include three robustness checks: First, we use the IH-IV estimator instead of the GMM (see Appendix C.2). Second, we sample exchange rates at the end of the day (5:00 p.m. New York time) rather than at the points in time when the 3-month CHF LIBOR is fixed (11:00 a.m. London time) (see Appendix C.3). Third, we use estimates of the 3-month constant maturity rate inferred from 3-month CHF LIBOR futures as the policy rate (see Appendix C.4). The ICE LIBOR futures data as well as exchange rates are sampled at the close of the day (6:00 p.m. London time).

Table 4 visually shows that our benchmark results (in the first row) are supported by alternative specifications. The confidence intervals can become larger for a few alternative specifications consistent with even more pronounced effects than our benchmark results suggest. For 18 out of 23 specifications, the point estimates are significantly different from zero at the 5% significance level. At the 10% level, all point estimates are significantly different from zero. We conclude that our key result that an unexpected increase in the policy rate leads to an appreciation of

Table 4: Alternative specifications

Model*	Policy†	Rate‡	Samp§		$\hat{\alpha}$	SE	95% CI
Rest	Libor	CHF	Sync		-2.0	0.3	(-2.5 to -1.4)
Rest	Libor	CHF	End		-2.6	0.8	(-4.2 to -0.9)
Joint	Libor	EURCHF	Sync		-2.0	0.3	(-2.6 to -1.3)
Joint	Libor	EURCHF	End		-2.2	0.8	(-3.7 to -0.7)
Joint	Libor	USDCHF	Sync		-1.8	1.0	(-3.7 to +0.2)
Joint	Libor	USDCHF	End		-3.2	1.2	(-5.5 to -0.9)
Sep	Libor	EURCHF	Sync		-2.1	0.5	(-2.9 to -1.2)
Sep	Libor	EURCHF	End		-1.8	0.8	(-3.4 to -0.3)
Sep	Libor	USDCHF	Sync		-1.9	1.0	(-3.9 to +0.2)
Sep	Libor	USDCHF	End		-3.2	1.3	(-5.7 to -0.7)
Rest	Future	CHF	Sync		-3.1	1.3	(-5.7 to -0.4)
Joint	Future	EURCHF	Sync		-1.7	0.9	(-3.5 to +0.0)
Joint	Future	USDCHF	Sync		-3.7	1.3	(-6.2 to -1.1)
Sep	Future	EURCHF	Sync		-1.5	0.9	(-3.2 to +0.2)
Sep	Future	USDCHF	Sync		-3.7	1.3	(-6.2 to -1.2)
IV	Libor	EURCHF	Sync		-2.2	0.7	(-3.4 to -0.9)
IV	Libor	EURCHF	End		-1.9	0.7	(-3.3 to -0.5)
IV	Libor	USDCHF	Sync		-2.4	1.0	(-4.3 to -0.5)
IV	Libor	USDCHF	End		-2.7	1.0	(-4.6 to -0.7)
IV	Future	EURCHF	Sync		-1.2	0.7	(-2.6 to +0.1)
IV	Future	EURCHF	End		-1.8	0.8	(-3.3 to -0.3)
IV	Future	USDCHF	Sync		-3.0	1.0	(-4.9 to -1.0)
IV	Future	USDCHF	End		-3.3	1.1	(-5.4 to -1.2)

The table lists coefficient estimates $\hat{\alpha}$ for various alternative specifications. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days.

* “Model” refers to the model used for estimation. “Rest”: GMM model with $\alpha_1 = \alpha_2$ imposed. “Joint”: joint GMM estimation for EURCHF and USDCHF. “Sep”: separate GMM estimation for EURCHF and USDCHF. “IV”: instrumental variable estimation.

† “Policy” refers to the policy variable used. “LIBOR”: 3M LIBOR rate. “Future”: 3M LIBOR futures.

‡ “Rate” is the exchange rate used. “CHF”: restricted EURCHF and USDCHF model.

§ “Samp” refers to the point in time for sampling the exchange rate. “Sync”: synchronized to the policy variable (i.e., 11 a.m. London for 3-month CHF LIBOR; 6 p.m. London for futures). “End”: closing rate (i.e., 5 p.m. New York).

the Swiss franc is very robust.

5.2 Yield curve response to an unexpected policy rate change

In this section, we analyze the impact of an unexpected change in the 3-month CHF LIBOR on the yield curve of Swiss government bonds. The expected average future 1-year interest rate is computed for 2-, 3-, 5-, 7-, and 10-year terms using the approach of Adrian et al. (2013). The interest rate expectation component is the financial markets best forecast of short-term yields over the lifetime of the bond. This analysis will shed light on how an unexpected change in the 3-month CHF LIBOR affects the expectation of the expected average future short-term interest rates.

Figure 5 shows the IH-GMM joint model estimates of the response of the expected average future short-term interest rate to an unexpected policy rate change by 100bp. The estimates

reveal that expected average future short-term rates are impacted by unexpected changes in the 3-month CHF LIBOR. For the 2-year maturity, we find that a 100 bp increase in the 3-month CHF LIBOR increases the expected average short-term rate by 34 bp. The effect declines to 15 bp for the 10-year ahead expected short-term rate. Importantly, the null hypothesis of no effect can be clearly rejected at all maturities. The findings are in line with Grisse and Schumacher (2018), who also report that short-term and longer-term interest rates tend to move in the same direction but not one-for-one.

We conclude that unexpected policy rate changes significantly impact medium- to longer-term policy rate expectations, which in turn affect the exchange rate.

Table 5: Term structure response

Parameter	$\hat{\alpha}$	SE		95% CI
2Y	0.34	0.11		(+0.13 to +0.55)
3Y	0.29	0.10		(+0.09 to +0.48)
5Y	0.22	0.09		(+0.42 to +0.40)
7Y	0.19	0.75		(+0.41 to +0.33)
10Y	0.15	0.07		(+0.01 to +0.28)

IH-GMM estimation of the response of the expected average short-term interest rate to an unexpected policy rate change by 100 bp. Joint GMM estimation with 21 moment conditions for 6 parameters. $\hat{\lambda} = 0.009^{**}(0.0045)$. J-stat for validity of overidentifying restrictions: 2.41 with a p-value of 0.99. Convergence achieved after 4 iterations. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days.

6 Conclusions

Our results robustly show that an unexpected policy rate hike made by the Swiss National Bank appreciates the nominal Swiss franc. The null hypothesis that a policy rate change does not affect the exchange value of the Swiss franc is clearly rejected.

Importantly, we also show that simple methods that do not adequately account for the simultaneous relation of exchange rates and interest rates yield biased and typically nonsignificant results. This may lead to the incorrect conclusion that policy rate changes do not impact the Swiss franc.

Moreover, we find that an unexpected policy rate change impacts the expected path of future short-term interest rates. The implied change in monetary policy expectations in turn affects the exchange rate.

The magnitude of the benchmark results lies within the range of estimates in the literature. While we use data on two conventional monetary policy cycles in the historical sample from 2000 to 2011, recent contributions have suggested that due to low interest rates, markets might have become more sensitive to restrictive monetary policy shifts. It would be interesting to

analyze the effects on the Swiss franc resulting from changes in the monetary policy stances of other central banks such as the ECB or Fed. All these possible extensions are, however, left for future research.

Appendices

A SNB monetary policy announcements

Table A-6: Dates of the Monetary policy announcements made by the Swiss National Bank

Year	Day	Comment	$\Delta i^{3M-LIBOR}$	Δ_s^{EURCHF}	Δ_s^{USDCHF}
2000	20 Jan	R: No change in LIBOR target range.	3.3	-0.17	-0.53
	03 Feb	S: $\Delta LB = 50$ bp (1.75%). $\Delta UB = 50$ bp (2.75%).	14.7	-0.25	-1.63
	23 Mar	R: $\Delta LB = 75$ bp (2.50%). $\Delta UB = 75$ bp (3.50%).	28.2	-0.60	-1.69
	15 Jun	R: $\Delta LB = 50$ bp (3.00%). $\Delta UB = 50$ bp (4.00%).	1.3	-0.20	0.08
	14 Sep	R: No change in Libor target range.	-4.8	0.71	0.15
2001	08 Dec	R: No change in LIBOR target range.	-2.0	-0.04	0.06
	22 Mar	R: $\Delta LB = -25$ bp (2.75%). $\Delta UB = -25$ bp (3.75%).	-11.2	-0.11	0.74
	14 Jun	R: No change in LIBOR target range.	13.2	-0.10	-0.95
	17 Sep	R: $\Delta LB = -50$ bp (2.25%). $\Delta UB = -50$ bp (3.25%).	-15.7	-2.16	-5.11
	24 Sep	S: $\Delta LB = -50$ bp (1.75%). $\Delta UB = -50$ bp (2.75%).	-25.2	1.29	1.15
2002	07 Dec	R: $\Delta LB = -50$ bp (1.25%). $\Delta UB = -50$ bp (2.25%).	-7.3	0.09	0.64
	21 Mar	R: No change in LIBOR target range.	-0.7	-0.24	0.17
	02 May	S: $\Delta LB = -50$ bp (0.75%). $\Delta UB = -50$ bp (1.75%).	-19.8	0.07	0.42
	14 Jun	R: No change in LIBOR target range.	-0.8	0.13	-0.16
	26 Jul	S: $\Delta LB = -50$ bp (0.25%). $\Delta UB = -50$ bp (1.25%).	-19.2	-0.03	1.76
2003	19 Sep	R: No change in LIBOR target range.	0.0	-0.40	-1.32
	13 Dec	R: No change in LIBOR target range.	2.7	-0.01	-0.53
	06 Mar	S: $\Delta LB = -25$ bp (0.00%). $\Delta UB = -50$ bp (0.75%).	-21.5	0.40	0.41
	20 Mar	R: No change in LIBOR target range.	-0.4	0.00	-0.45
	13 Jun	R: No change in LIBOR target range.	-0.7	-0.25	-1.15
2004	18 Sep	R: No change in LIBOR target range.	0.0	0.13	0.39
	12 Dec	R: No change in LIBOR target range.	-0.3	0.02	-0.40
	18 Mar	R: No change in LIBOR target range.	-0.2	-0.32	-1.55
	17 Jun	R: No change in lower LIBOR bound. $\Delta UB = 25$ bp (1.00%).	6.2	-0.76	-1.13
	16 Sep	R: $\Delta LB = 25$ bp (0.25%). $\Delta UB = 25$ bp (1.25%).	-0.8	0.17	-0.09
2005	16 Dec	R: No change in LIBOR target range.	-3.2	0.29	1.43
	17 Mar	R: No change in LIBOR target range.	-0.8	0.08	0.36
	16 Jun	R: No change in LIBOR target range.	0.0	0.01	0.09
	15 Sep	R: No change in LIBOR target range.	-0.7	0.27	0.78
	15 Dec	R: $\Delta LB = 25$ bp (0.50%). $\Delta UB = 25$ bp (1.50%).	-6.7	0.37	0.55
2006	16 Mar	R: $\Delta LB = 25$ bp (0.75%). $\Delta UB = 25$ bp (1.75%).	-1.4	0.46	-0.47
	15 Jun	R: $\Delta LB = 25$ bp (1.00%). $\Delta UB = 25$ bp (2.00%).	0.5	0.26	-0.07
	14 Sep	R: $\Delta LB = 25$ bp (1.25%). $\Delta UB = 25$ bp (2.25%).	2.7	0.32	0.04
	14 Dec	R: $\Delta LB = 25$ bp (1.50%). $\Delta UB = 25$ bp (2.50%).	1.0	0.17	0.70
	2007	15 Mar	R: $\Delta LB = 25$ bp (1.75%). $\Delta UB = 25$ bp (2.75%).	-0.5	0.19
14 Jun		R: $\Delta LB = 25$ bp (2.00%). $\Delta UB = 25$ bp (3.00%).	0.1	0.15	0.13
13 Sep		R: $\Delta LB = 25$ bp (2.25%). $\Delta UB = 25$ bp (3.25%).	-9.2	-0.05	0.09
13 Dec		R: No change in LIBOR target range.	1.3	0.07	0.57
2008		13 Mar	R: No change in LIBOR target range.	-1.5	0.05
	19 Jun	R: No change in LIBOR target range.	-6.4	0.69	0.90
	18 Sep	R: No change in LIBOR target range.	1.3	0.30	0.15
	08 Oct	S: $\Delta LB = -25$ bp (2.00%). $\Delta UB = -25$ bp (3.00%).	1.3	-0.68	-1.14
	06 Nov	S: $\Delta LB = -50$ bp (1.50%). $\Delta UB = -50$ bp (2.50%).	-25.3	-0.14	1.71
2009	20 Nov	S: $\Delta LB = -100$ bp (0.50%). $\Delta UB = -100$ bp (1.50%).	-61.2	0.59	0.89
	11 Dec	R: $\Delta LB = -50$ bp (0.00%). $\Delta UB = -50$ bp (1.00%).	-27.3	1.28	-1.25
	12 Mar	R: No change in lower LIBOR bound. $\Delta UB = -25$ bp (0.75%).	-3.8	3.30	2.75
	18 Jun	R: No change in LIBOR target range.	0.0	0.28	0.60
	17 Sep	R: No change in LIBOR target range.	-0.3	-0.13	-0.38
2010	10 Dec	R: No change in LIBOR target range.	0.0	-0.03	-0.07
	11 Mar	R: No change in LIBOR target range.	0.0	0.04	-0.16
	17 Jun	R: No change in LIBOR target range.	0.7	-1.07	-1.70
	16 Sep	R: No change in LIBOR target range.	-0.7	1.76	1.23
	16 Dec	R: No change in LIBOR target range.	-0.1	-0.15	-0.38
2011	17 Mar	R: No change in LIBOR target range.	0.0	-0.17	-1.07
	16 Jun	R: No change in LIBOR target range.	0.0	-0.43	-0.64
	03 Aug	S: No change in lower LIBOR bound. $\Delta UB = -50$ bp (0.25%).	-3.7	1.89	1.07

The table provides details of the MPA days of the SNB from January 1, 2000 to August 31, 2011. LB indicates the lower bound of the 3-month CHF LIBOR target range whereas UB is the upper bound. R stands for regular MPAs and S for special (unscheduled) MPAs. $\Delta i^{3M-LIBOR}$, Δ_s^{EURCHF} and Δ_s^{USDCHF} are the change in the 3-month CHF LIBOR (in bp) and the return of the EURCHF and USDCHF exchange rate (in pct) on the MPA day, respectively.

B Estimation by GMM

This section details the estimation of the interest rate effect by the generalized method of moments. Section B.1 considers the case of a single exchange rate equation and derives the model implied change in the covariance matrix between monetary policy announcement days and nonmonetary policy announcement days. From this, we can deduce the moment conditions that enables us to estimate the policy effect. Section B.2 extends the system by adding an additional exchange rate equation and works out the corresponding moment conditions.

B.1 Single exchange rate equation

Let us start with the equation system given by (1) and (2). In matrix form this can be represented by

$$\begin{bmatrix} 1 & -\beta \\ -\alpha & 1 \end{bmatrix} \begin{bmatrix} \Delta i_t \\ \Delta s_t \end{bmatrix} = \begin{bmatrix} \gamma_i \\ \gamma_s \end{bmatrix} z_t + \begin{bmatrix} \epsilon_t \\ \eta_t \end{bmatrix}$$

The reduced form of the system is

$$\begin{aligned} \begin{bmatrix} \Delta i_t \\ \Delta s_t \end{bmatrix} &= \frac{1}{(1-\alpha\beta)^2} \begin{bmatrix} 1 & \beta \\ \alpha & 1 \end{bmatrix} \left(\begin{bmatrix} \gamma_i \\ \gamma_s \end{bmatrix} z_t + \begin{bmatrix} \epsilon_t \\ \eta_t \end{bmatrix} \right) \\ &= \frac{1}{(1-\alpha\beta)^2} \begin{bmatrix} (\gamma_i + \beta\gamma_s)z_t + \epsilon_t + \beta\eta_t \\ (\alpha\gamma_i + \gamma_s)z_t + \alpha\epsilon_t + \eta_t \end{bmatrix}. \end{aligned}$$

The covariance is given by

$$\Omega = \begin{bmatrix} \sigma_{\Delta i}^2 & \sigma_{\Delta i \Delta s} \\ \sigma_{\Delta i \Delta s} & \sigma_{\Delta s}^2 \end{bmatrix},$$

where

$$\begin{aligned} \sigma_{\Delta i}^2 &= \frac{1}{(1-\alpha\beta)^2} [(\gamma_i + \beta\gamma_s)^2 \sigma_z^2 + \sigma_\epsilon^2 + \beta^2 \sigma_\eta^2] \\ \sigma_{\Delta i \Delta s} &= \frac{1}{(1-\alpha\beta)^2} [(\gamma_i + \beta\gamma_s)(\alpha\gamma_i + \gamma_s) \sigma_z^2 + \alpha\sigma_\epsilon^2 + \beta\sigma_\eta^2] \\ \sigma_{\Delta s}^2 &= \frac{1}{(1-\alpha\beta)^2} [(\gamma_i + \beta\gamma_s)^2 \sigma_z^2 + \alpha^2 \sigma_\epsilon^2 + \sigma_\eta^2]. \end{aligned}$$

When calculating the difference between the covariance of policy dates and the covariance of non-policy dates, the terms with σ_z^2 and σ_η^2 will cancel out, because their variance is assumed to be the same on policy and non-policy dates. The covariance difference implied by the model reduces to (see also Rigobon and Sack 2004, equation 9):

$$\Delta\Omega = \lambda \begin{bmatrix} 1 & \alpha \\ \alpha & \alpha^2 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ \alpha \end{bmatrix} \begin{bmatrix} 1 & \alpha \end{bmatrix}, \quad (4)$$

with

$$\lambda = \frac{\sigma_{\eta,P}^2 - \sigma_{\eta,\tilde{P}}^2}{(1 - \alpha\beta)^2}.$$

The empirical equivalent to this covariance matrix difference is

$$\Delta\hat{\Omega} = \hat{\Omega}_P - \hat{\Omega}_{\tilde{P}},$$

with

$$\begin{aligned}\hat{\Omega}_P &= \frac{1}{T_P} \sum_{t=1}^T \delta_t^P \Delta x_t \Delta x_t', \\ \hat{\Omega}_{\tilde{P}} &= \frac{1}{T_{\tilde{P}}} \sum_{t=1}^T \delta_t^{\tilde{P}} \Delta x_t \Delta x_t',\end{aligned}$$

where

$$\Delta x_t = \begin{bmatrix} \Delta i_t \\ \Delta s_t \end{bmatrix}$$

and δ_t^P and $\delta_t^{\tilde{P}}$ are dummies for policy and nonpolicy dates, respectively. From this,

$$\Delta\hat{\Omega} = \hat{\Omega}_P - \hat{\Omega}_{\tilde{P}} \tag{5}$$

$$\begin{aligned}&= \frac{1}{T_P} \sum_{t=1}^T \delta_t^P \Delta x_t \Delta x_t' - \frac{1}{T_{\tilde{P}}} \sum_{t=1}^T \delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \\ &= \sum_{t=1}^T \frac{1}{T_P} \delta_t^P \Delta x_t \Delta x_t' - \sum_{t=1}^T \frac{1}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \\ &= \sum_{t=1}^T \left[\frac{1}{T_P} \delta_t^P \Delta x_t \Delta x_t' - \frac{1}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \right] \\ &= \sum_{t=1}^T \left[\left(\frac{1}{T_P} \delta_t^P - \frac{1}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta x_t \Delta x_t' \right].\end{aligned} \tag{6}$$

We find the moment conditions by matching the variances and covariances in (4) with its empirical counterparts in (6). This result provides 3 moment conditions for the 2 unknown parameters, corresponding to the 2 variance terms and the covariance term:

$$g(\lambda, \alpha) = \begin{bmatrix} \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t^2 - \lambda \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_t - \lambda \alpha \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_t^2 - \lambda \alpha^2 \end{bmatrix}$$

Identification requires that

$$E[g(\lambda, \alpha)] \neq 0 \quad \text{for} \quad \begin{bmatrix} \lambda \\ \alpha \end{bmatrix} \neq 0,$$

and

$$G = E \left[\frac{\partial g(\lambda, \alpha)}{\partial [\lambda \ \alpha]} \right] = \begin{bmatrix} -1 & 0 \\ -\alpha & -\lambda \\ -\alpha^2 & -2\lambda\alpha \end{bmatrix}$$

has full column rank 3. This requires $\lambda \neq 0$.

B.2 Two exchange rate equations

This section augments the model by introducing another exchange rate equation, that allows us to analyze both the EURCHF and USDCHF effects. For brevity, we disregard the exogenous variables. As in the single exchange rate equation case, these variables will drop out when computing the difference in the covariance between policy and nonpolicy dates.

The equation system with two exchange rate equations is given by

$$\begin{aligned} \Delta i_t &= \beta_1 \Delta s_{1t} + \beta_2 \Delta s_{2t} + \epsilon_t \\ \Delta s_{1t} &= \alpha_1 \Delta i_t + \eta_{1t} \\ \Delta s_{2t} &= \alpha_2 \Delta i_t + \eta_{2t}, \end{aligned}$$

where Δi_t is the first difference in the interest rate, Δs_{1t} is the difference in the logarithm of the EURCHF exchange rate, and Δs_{2t} is the difference in the logarithm of the USDCHF exchange rate. In matrix form this system can be represented as

$$\begin{bmatrix} 1 & -\beta_1 & -\beta_2 \\ -\alpha_1 & 1 & 0 \\ -\alpha_2 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta i_t \\ \Delta s_{1t} \\ \Delta s_{2t} \end{bmatrix} = \begin{bmatrix} \epsilon_t \\ \eta_{1t} \\ \eta_{2t} \end{bmatrix}.$$

The reduced form is

$$\begin{bmatrix} \Delta i_t \\ \Delta s_{1t} \\ \Delta s_{2t} \end{bmatrix} = \frac{1}{1 - \alpha_1 \beta_1 - \alpha_2 \beta_2} \begin{bmatrix} 1 & \beta_1 & \beta_2 \\ \alpha_1 & 1 - \alpha_2 \beta_2 & \alpha_1 \beta_2 \\ \alpha_2 & \alpha_2 \beta_1 & 1 - \alpha_1 \beta_1 \end{bmatrix} \begin{bmatrix} \epsilon_t \\ \eta_{1t} \\ \eta_{2t} \end{bmatrix}.$$

The individual equations are thus

$$\begin{aligned} \Delta i_t &= \frac{1}{1 - \alpha_1 \beta_1 - \alpha_2 \beta_2} [\epsilon_t - \beta_1 \eta_{1t} - \beta_2 \eta_{2t}] \\ \Delta s_{1t} &= \frac{1}{1 - \alpha_1 \beta_1 - \alpha_2 \beta_2} [\alpha_1 \epsilon_t + (1 - \alpha_2 \beta_2) \eta_{1t} + \alpha_1 \beta_2 \eta_{2t}] \\ \Delta s_{2t} &= \frac{1}{1 - \alpha_1 \beta_1 - \alpha_2 \beta_2} [\alpha_2 \epsilon_t + \alpha_2 \beta_1 \eta_{2t} + (1 - \alpha_2 \beta_1) \eta_{2t}] \end{aligned}$$

From these we can compute the 3 variances and 3 covariances of the variables. As most terms will again drop out when building the difference between policy dates and nonpolicy dates, we

omit the formulas. The difference in the covariance is

$$\Delta\Omega = \lambda \begin{bmatrix} 1 & \alpha_1 & \alpha_2 \\ \alpha_1 & \alpha_1^2 & \alpha_1\alpha_2 \\ \alpha_2 & \alpha_1\alpha_2 & \alpha_2^2 \end{bmatrix} = \lambda \begin{bmatrix} 1 \\ \alpha_1 \\ \alpha_2 \end{bmatrix} \begin{bmatrix} 1 & \alpha_1 & \alpha_2 \end{bmatrix},$$

with

$$\lambda = \frac{\sigma_{\eta,P}^2 - \sigma_{\eta,\tilde{P}}^2}{(1 - \alpha_1\beta_1 - \alpha_2\beta_2)^2}.$$

The empirical equivalent to this covariance matrix difference is

$$\Delta\hat{\Omega} = \hat{\Omega}_P - \hat{\Omega}_{\tilde{P}},$$

with

$$\hat{\Omega}_P = \frac{1}{T_P} \sum_{t=1}^T \delta_t^P \Delta x_t \Delta x_t',$$

$$\hat{\Omega}_{\tilde{P}} = \frac{1}{T_{\tilde{P}}} \sum_{t=1}^T \delta_t^{\tilde{P}} \Delta x_t \Delta x_t',$$

where

$$\Delta x_t = \begin{bmatrix} \Delta i_t \\ \Delta s_{1t} \\ \Delta s_{2t} \end{bmatrix}.$$

Again matching the model implied variances and covariance with their empirical counterparts gives 6 moment conditions in 3 unknown parameters:

$$g(\lambda, \alpha_1, \alpha_2) = \begin{bmatrix} \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t^2 - \lambda \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_{1t} - \lambda \alpha_1 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{1t}^2 - \lambda \alpha_1^2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta i_t \Delta s_{2t} - \lambda \alpha_2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{2t}^2 - \lambda \alpha_2^2 \\ \left(\frac{T}{T_P} \delta_t^P - \frac{T}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta s_{1t} s_{2t} - \lambda \alpha_1 \alpha_2 \end{bmatrix}.$$

We now have 6 equations in 3 unknown. Identification requires that

$$E[g(\lambda, \alpha_1, \alpha_2)] \neq 0 \quad \text{for} \quad \begin{bmatrix} \lambda \\ \alpha_1 \\ \alpha_2 \end{bmatrix} \neq 0,$$

and

$$G = E \left[\frac{\partial g(\lambda, \alpha_1, \alpha_2)}{\partial [\lambda \ \alpha_1 \ \alpha_2]} \right] = \begin{bmatrix} -1 & 0 & 0 \\ -\alpha_1 & -\lambda & 0 \\ -\alpha_1^2 & -2\lambda\alpha_1 & 0 \\ -\alpha_2 & 0 & -\lambda \\ -\alpha_2^2 & 0 & -2\lambda\alpha_2 \\ -\alpha_1\alpha_2 & -\lambda\alpha_2 & -\lambda\alpha_1 \end{bmatrix}$$

has full column rank 3. This requires $\lambda \neq 0$.

B.3 Iterated efficient GMM

Given the moment conditions, we can estimate the parameters by iterated efficient GMM.⁷ The sample moment condition for arbitrary parameters is

$$g_T(\lambda, \alpha) = \frac{1}{T} \sum_{t=1}^T g(\Delta i_t, \Delta s_t; \lambda, \alpha).$$

The efficient GMM estimator is given by

$$\hat{\theta}(\hat{W}) = \arg \min J(\lambda, \alpha, \hat{W}) = T g_T(\lambda, \alpha)' \hat{W} g_T(\lambda, \alpha),$$

where $\theta = [\lambda \ \alpha]'$, $\hat{W} = \hat{S}^{-1}$, such that $\hat{S} \xrightarrow{p} S = \text{avar}(g_T(\lambda, \alpha))$.

Given the consistent estimates $\hat{\lambda}$ and $\hat{\alpha}$ of λ and α , respectively, a heteroskedasticity (HC) estimate of S is

$$\hat{S}_{HC} = \frac{1}{T} \sum_{t=1}^T g(\hat{\lambda}, \hat{\alpha}) g(\hat{\lambda}, \hat{\alpha})'.$$

For the efficient GMM estimator, we use $\hat{W} = \hat{S}_{HC}^{-1}$, and it can be shown that

$$\begin{aligned} \hat{\theta}(\hat{S}_{HC}^{-1}) &\xrightarrow{p} \theta \\ \text{avar}(\hat{\theta}(\hat{S}_{HC}^{-1})) &= (\hat{G}' \hat{S}_{HC}^{-1} \hat{G})^{-1} \\ \hat{G} &= \frac{1}{T} \sum_{t=1}^T \frac{\partial g(\hat{\theta}(\hat{W}))}{\partial \theta'}. \end{aligned}$$

We use the iterated efficient GMM, stopping once the change in the moment norm is smaller than 1e-12, which is usually achieved in a few iterations.

The J-statistic for the validity of the moment conditions is given by

$$J = T g_T(\hat{\theta}(\hat{S}_{HC}^{-1}))' \hat{S}_{HC}^{-1} g_T(\hat{\theta}(\hat{S}_{HC}^{-1}))$$

and has a χ^2 -distribution with 1 degree of freedom.

⁷The notations in this section loosely follow Zivot and Wang (2007, section 21.6).

C Robustness

C.1 Results with OLS estimator

We regress the exchange rate returns on 3-month CHF LIBOR rate changes. The estimation results suggest that the estimates significantly differ from the IH-estimates for EURCHF (point estimate: -0.4, standard error: 0.3) and USDCHF (point estimate: 2.5, standard error: 0.5). The OLS estimates are not significantly different from zero, except for the estimates for USDCHF. For USDCHF, however, the OLS estimate is positive.

Table C-1: OLS estimates of the exchange rate response

	Δs^{EURCHF}	Δs^{USDCHF}
$\Delta i^{\text{3M-LIBOR}}$	-0.4 (0.30)	2.5*** (0.50)

The table shows the OLS estimates. The policy rate variable is the 3-month CHF LIBOR. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The sample contains all days from January 1, 2000 to August 31, 2011. The numbers in parentheses are standard deviations.

C.2 Results with instrumental variable estimator

Estimation by instrumental variables following Rigobon and Sack (2004) is based on using the instruments (w_i, w_s) for the endogenous variables $(\Delta i, \Delta s)$

$$w_i \equiv \begin{bmatrix} \Delta i_P \\ -\Delta i_{\bar{P}} \end{bmatrix}, \quad \Delta i \equiv \begin{bmatrix} \Delta i_P \\ \Delta i_{\bar{P}} \end{bmatrix}, \quad w_s \equiv \begin{bmatrix} \Delta s_P \\ -\Delta s_{\bar{P}} \end{bmatrix}, \quad \Delta s \equiv \begin{bmatrix} \Delta s_P \\ \Delta s_{\bar{P}} \end{bmatrix}. \quad (7)$$

Using these instruments, we estimate the parameters using two stage least squares.

Table C-2: IH-IV estimates of the exchange rate response

	Δs^{EURCHF}	Δs^{USDCHF}
$\Delta i^{\text{3M-LIBOR}}$	-2.2*** (0.65)	-2.4** (0.96)

The table shows the identification-through-heteroscedasticity IV estimates. The policy rate variable is the 3-month CHF LIBOR. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The sample contains MPA and non-MPA days from January 1, 2000 until August 31, 2011, a total of 112 days. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

C.3 Results with end-of-day exchange rates

The end-of-day exchange rates used for a robustness check are sampled at the close of the day, i.e., at 5 p.m. New York time.

Table C-3: IV estimates with end-of-day exchange rates

	Δ_s^{EURCHF}	Δ_s^{USDCHF}
$\Delta_i^{\text{3M-LIBOR}}$	-1.9*** (0.71)	-2.7*** (1.0)

The table shows the identification-through-heteroscedasticity IV estimates. The policy rate variable is the 3-month CHF LIBOR. The exchange rate variables are sampled at the close (5 p.m. NY time). *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

Table C-4: GMM estimates with end-of-day exchange rates

	Separate equations		Joint estimation		Restricted $\alpha_1 = \alpha_2$
	EURCHF	USDCHF	EURCHF	USDCHF	EURCHF USDCHF
$\hat{\alpha}$	-1.8** (0.78)	-3.2** (1.3)	-2.2*** (0.77)	-3.2*** (1.2)	-2.6*** (0.84)
$\hat{\lambda}$	0.015** (0.0072)	0.014** (0.0071)	0.015** (0.007)		0.013* (0.0069)
Wald $H_0 : \alpha_1 = \alpha_2$			0.67		
p-value			0.41		
J-stat	0.28	0.99	1.1		1.7
p-value	0.59	0.32	0.78		0.79
# moment conditions	3	3	6		6
# parameters	2	2	3		2
# iterations	3	3	3		3

The table shows the identification-through-heteroscedasticity GMM estimates. The policy rate variable is the 3-month CHF LIBOR. The exchange rate variables are sampled at the close of the day (5 p.m. NY time). We use the iterated efficient nonlinear GMM for the estimation of α and λ . The first two columns report the results estimated separately for EURCHF and USDCHF. The third and fourth columns contain an estimated joint system and the result of a Wald test of the equality of α_1 and α_2 , respectively. The rightmost column shows the result of estimating a joint system with the restriction $\alpha_1 = \alpha_2$. The J-statistic reports the results of testing the null hypothesis of validity of overidentifying restrictions. The last row contains the number of iterations needed for convergence. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

C.4 Results with Swiss LIBOR futures

The ICE LIBOR futures data used for a robustness check is sampled at the close of the day, i.e., at 6 p.m. London time.

Table C-5: IV estimates with LIBOR futures

	Δ_s^{EURCHF}	Δ_s^{USDCHF}
Δi^{M90}	-1.2* (0.7)	-3.0*** (0.97)

The table shows the identification-through-heteroscedasticity IV estimates. The policy rate variable is the change in the 90-day constant maturity rate computed from the CHF LIBOR futures. The exchange rate variables are sampled at the close of the day for futures (6 p.m. London time). *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

Table C-6: GMM estimates with LIBOR futures

	Separate equations		Joint estimation		Restricted $\alpha_1 = \alpha_2$
	EURCHF	USDCHF	EURCHF	USDCHF	EURCHF USDCHF
$\hat{\alpha}$	-1.5* (0.88)	-3.7*** (1.3)	-1.7* (0.91)	-3.7*** (1.3)	-3.1** (1.3)
$\hat{\lambda}$	0.012** (0.006)	0.012* (0.006)	0.011* (0.006)		0.0082 (0.0059)
Wald $H_0 : \alpha_1 = \alpha_2$			2.4		
p-value			0.12		
J-stat	0.84	1.3	1.5		4.0
p-value	0.36	0.25	0.68		0.41
# moment conditions	3	3	6		6
# parameters	2	2	3		2
# iterations	3	3	3		3

The table shows the identification-through-heteroscedasticity GMM estimates. The policy rate variable is the change in the 90-day constant maturity rate computed from the CHF LIBOR futures. The exchange rate variables are sampled at the close of the day for futures (6 p.m. London time). We use the iterated efficient nonlinear GMM for the estimation of α and λ . The first two columns report the results estimated separately for EURCHF and USDCHF. The third and fourth columns contain the results for estimating a joint system and the result of a Wald test of the equality of α_1 and α_2 , respectively. The rightmost column shows the result of estimating a joint system with the restriction $\alpha_1 = \alpha_2$. The J-statistic reports the results of testing the null hypothesis of validity of overidentifying restrictions. The last row contains the number of iterations needed for convergence. The sample contains MPA and non-MPA days from January 1, 2000 to August 31, 2011, a total of 112 days. *, **, and *** denote significance at the 10, 5 and 1 percent levels, respectively. The numbers in parentheses are standard deviations. The significance tests and standard deviations are asymptotic.

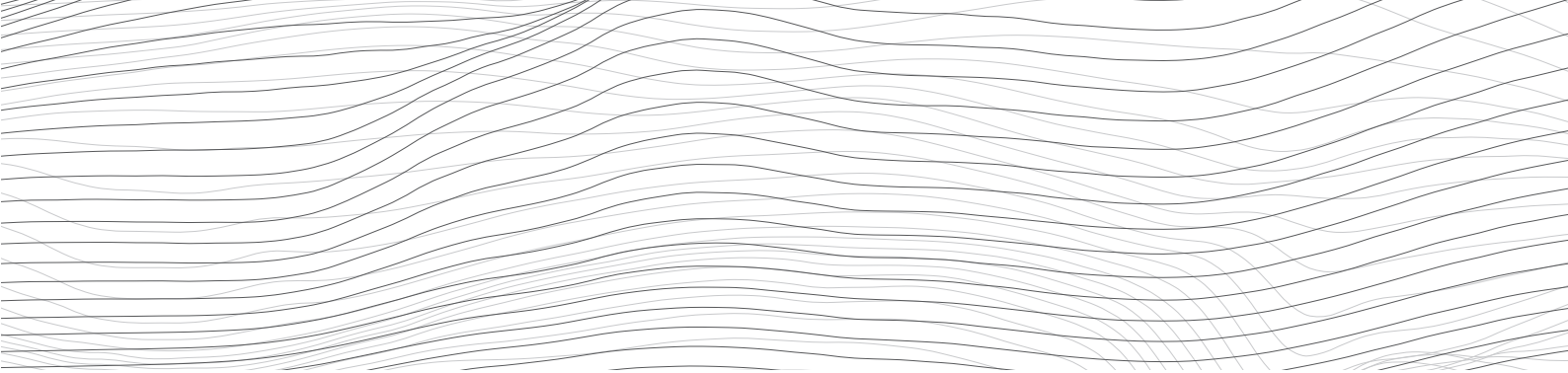
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