The Impact of SNB Monetary Policy on the Swiss Franc and Longer-Term Interest Rates*

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We estimate the impact of monetary policy announcements by the Swiss National Bank on the Swiss franc and on the expected path of future short-term interest rates. Monetary policy announcement effects are identified using the identification-through-heteroskedasticity approach. The approach accounts for the simultaneous relation of exchange rates and interest rates. We find that from 2000–11, an announcement of a monetary policy tightening appreciated the nominal Swiss franc on the same day. Importantly, the results indicate that simple methods that do not adequately account for simultaneity between exchange rates and interest rates yield biased and typically non-significant estimates. Our findings further suggest that monetary policy announcements affect medium- to longer-term expectations, which in turn influence the Swiss franc.

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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 decisionmaking 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 announcements made by the Swiss National Bank (SNB) on the Swiss franc exchange rates and on the Swiss yield curve. A monetary policy announcement includes a monetary policy decision about its policy rate and a conditional inflation forecast.[3] Furthermore, a forecast for the Swiss economy is provided. Thus, the monetary policy shock we identify reflects these two components: the

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[1]The safe-haven characteristics of the Swiss franc have been established by numerous contributions. See Fink, Frei, and Gloede (2022) for an overview.

[2]Nitschka 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 three-month LIBOR (London interbank offered rate) 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.

[3]The forecast is based on the assumption that the policy rate set when the forecast is published will remain constant over the entire three-year forecast horizon.

change of monetary policy and the change of the outlook of the Swiss economy. We identify the causal effect 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 monetary policy announcements, we consider the historical time frame spanning from January 1, 2000 to August 31, 2011. During this time, the three-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 three-month CHF LIBOR target range.

The main findings can be summarized as follows. First, a monetary policy announcement shock which increases the policy rate leads to a nominal appreciation of the Swiss franc on the same day. The null hypothesis that monetary policy announcement shocks that change the policy rate do not affect the exchange value of the Swiss franc is clearly rejected. Our finding that monetary policy announcement shocks by the SNB are highly relevant for the exchange rate of the Swiss franc is robust to the use of alternative specifications. Second, we provide empirical evidence that simple econometric methods yield biased and typically non-significant results. Not adequately identifying the causal effects may lead to the incorrect conclusion that monetary policy announcements do not affect the Swiss franc. Third, monetary policy announcements affect the curve of expected average future short-term interest rates, which in turn influence the valuation of the Swiss franc.

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, Crump, and Moench (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 EUR/CHF and USD/CHF exchange rates using the generalized method of moments (GMM).[4] 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 announcement shock. 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 structural vector autoregressions (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., Kearns and Manners 2006; Rosa 2011; Ferrari, Kearns, and Schrimpf 2017; Kerssenfischer 2019). The point estimates roughly range from 0.3 percent to 1.5 percent nominal appreciation in response to a contractionary 25 basis point

[4]Exchange rates are quoted in relation to another currency. In this paper we follow market conventions to quote exchange rates, i.e., the first currency is the base currency and the second currency is the price currency. Thus, if you purchase USD/CHF, you would receive one unit of the U.S. dollar in exchange for a payment of Swiss franc.

(bp) interest rate shock. Specifically, considering a panel of seven major central banks, Ferrari, Kearns, and Schrimpf (2017) find that an unexpected policy rate hike of 25 bp causes an immediate appreciation from 1 to 1.5 percent for most of the central banks considered. Focusing on the European Central Bank (ECB), Kerssenfischer (2019) reports that the EUR/CHF exchange rate rises by 0.95 percent in response to a contractionary 25 bp ECB monetary policy shock. Rosa (2011) shows that the surprise components of both the Federal Reserve's (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 percent 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 percent from 1993 to 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 contractionary monetary policy shocks. The magnitude of the point estimates is rather broad, however, ranging from less than 0.2 percent to more than 6 percent appreciation in response to a monetary policy announcement of a 25 bp interest rate increase.

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 three-month CHF LIBOR caused the Swiss franc to appreciate by 0.17 percent towards the U.S. dollar from 2000 to 2005. The upper bound is given by the estimates of Ferrari, Kearns, and Schrimpf (2017), who report that an SNB policy announcement that generates a 25 bp increase in the one-month CHF overnight index swap (OIS) rate caused the Swiss franc to appreciate by 6.25 percent 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 Grisse (2020) and Kugler (2020) fall within this range. Similar to our contribution, both papers consider the period 2000–11. Using an instrumental-variable approach and daily data, Kugler (2020) reports that the Swiss franc appreciates by 0.93 percent in response to an unexpected 25 bp increase in the three-month CHF LIBOR. Grisse (2020) estimates the effects using a weekly SVAR and identifies monetary policy shocks based on the co-movement of interest rates and stock prices: A contractionary 25 bp shock causes the Swiss franc to appreciate by 1.0 percent against the euro and by 0.75 percent against the U.S. dollar in the same week.[5]

3. Empirical Model

This section describes first the simultaneity problem when analyzing the effect of monetary policy 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 affected by the expected monetary policy response to exchange rate variations. For

[5]Related 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 between 7 percent and 15 percent to variations of the exchange rate from 1981 to 2007. Rudolf and Zurlinden (2014) find an impact of approximately 0.2 percent in an estimated DSGE model for the period 1983–2013. Based on a calibrated dynamic stochastic general equilibrium (DSGE) model of the Swiss economy, the results of Cuche-Curti, Dellas, and Natal (2009) point towards 0.25 percent 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 percent of the forecast-error variance of the Swiss franc.

a small open economy such as Switzerland, market participants anticipate that the exchange rate is an important factor in the monetary policy decisionmaking 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:

$$\textit{Exchange rate response function} \quad \Delta s_t = \alpha \Delta i_t + \gamma_s z_t + \eta_t, \tag{1}$$

$$\textit{Interest rate response function} \quad \Delta i_t = \beta \Delta s_t + \gamma_i z_t + \varepsilon_t, \tag{2}$$

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 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 six-month correlation of the three-month CHF LIBOR in first differences and the EUR/CHF 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.

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 IH approach of Rigobon (2003) and Rigobon and Sack (2004). This approach is outlined in the next section.

Figure 1. Rolling Window Correlation for EUR/CHF and the Three-Month CHF LIBOR

Note: The chart shows the six-month rolling window correlation between $\Delta s^{\mathrm{EURCHF}}$ and $\Delta i^{\mathrm{3M\text{-}LIBOR}}$ 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.

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 announcement shock based on the heteroskedasticity of the 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:

$$\sigma^2_{\varepsilon,P} > \sigma^2_{\varepsilon,\tilde{P}},$$
$$\sigma^2_{\eta,P} = \sigma^2_{\eta,\tilde{P}}.$$

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. Following Rigobon and Sack (2004), 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. We assess the robustness of this choice in Appendix C.5. Since Switzerland is a small open economy and highly economically connected to Europe, monetary policy from other major economies affects Swiss exchange rates. We believe that focusing only on two days in the whole sample (non-policy sample with previous days' values and policy sample with MPA days) is therefore an advantage to isolate Swiss monetary policy surprises from other shocks (e.g., monetary policy surprises by the ECB). 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.[6] A monetary policy announcement by the SNB includes a monetary policy decision about its policy rate and a conditional inflation forecast. Furthermore, a forecast of Swiss real economic activity is provided. Since we identify monetary policy shocks based on monetary policy announcements, our identified shock reflects both components—the change of monetary policy and the change of the outlook of the Swiss economy.

Clearly, identification is complicated by the fact that interest rates and exchange rates are affected by a common set of exogeneous 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 exogeneous shocks does not differ across the two subsamples:

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

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

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

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

[6] A recent paper by Jarocinski and Karadi (2020) deconstructs monetary policy surprises into information about the future stance of monetary policy and the economic outlook using high-frequency data. This is a relevant decomposition from which we have to abstract because we use daily data and the assumption about a switch in variances to identify monetary policy shocks.

EUR/CHF and USD/CHF 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

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

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 three moment conditions in two 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. This results in six moment conditions in three 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 EUR/CHF and USD/CHF exchange rate because it seems implausible that the EUR/USD exchange rate is affected by SNB policy rate decisions. In the constrained model, we have six moment conditions in two unknown parameters.

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

4. Data

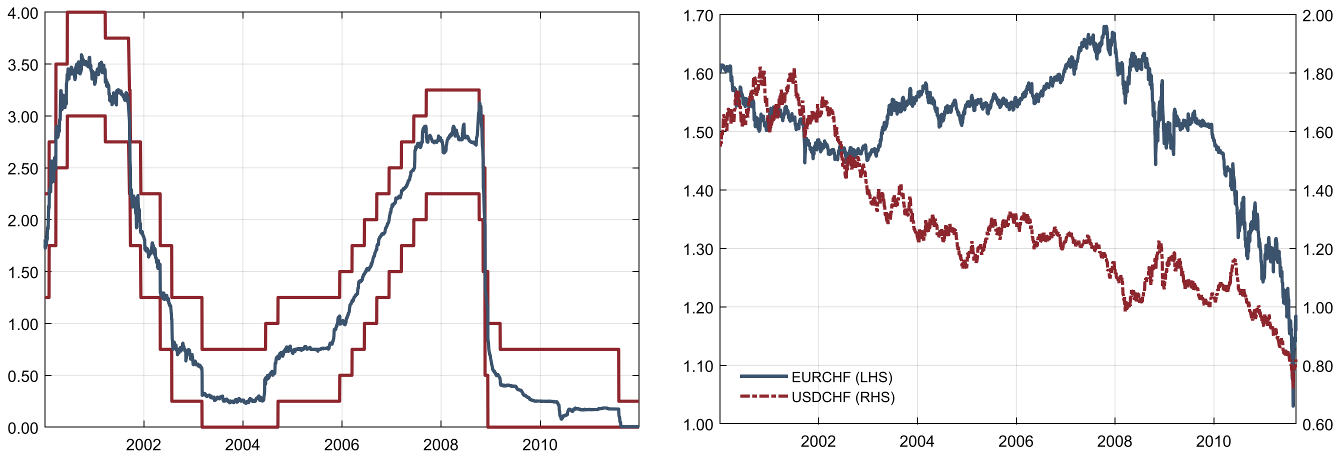
Policy rates have been relatively stable internationally and in particular in Switzerland after having reached a lower bound in the aftermath of the global financial crisis. Therefore, we have to resort to historical monetary policy cycles spanning from January 1, 2000 to August 31, 2011 at daily frequency. The sample begins after the SNB changed its monetary policy concept in December 1999. After 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 percent. The second element was a conditional inflation forecast that is published on a quarterly basis. The forecast is based on the assumption that the policy rate set when the forecast is published will remain constant over the entire three-year forecast horizon. The third element was an operational target range for the three-month CHF LIBOR.[7] The SNB began to announce a target band for the three-month CHF LIBOR, which was chosen to be consistent with a medium-term inflation rate of below 2 percent. The sample ends prior to the EUR/CHF minimum exchange rate regime, which was introduced on September 6, 2011. This event was the beginning of a significant regime change of SNB's monetary policy, where besides negative policy rates FX interventions became the second pillar of SNB's monetary policy tools.[8] In the sample, the SNB implemented its monetary policy mainly using one-week repurchase agreement operations to control the three-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 three-month CHF LIBOR, and the Swiss exchange rates in the left and right panels, respectively.

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 decisions made by the SNB. At 26 policy meetings, the target range of the three-month CHF LIBOR was changed. Monetary policy decisions are made on a quarterly basis by the SNB Governing Board at its monetary policy assessment. The monetary policy decision is announced in a press release. At the June and December monetary policy assessments, the members of the Governing Board also explain the monetary policy decision at a press conference. A monetary policy assessment consists of a monetary policy decision about the policy rate and a conditional inflation forecast. Furthermore, a forecast of real economic activity is provided. From 2003 until 2011, every regularly scheduled monetary policy meeting contains the conditional forecast for inflation over the next three years as well as the forecast for real economic activity. For June and December meetings, the detailed chart about conditional inflation

[7]Note that on June 13, 2019, the target range for the three-month CHF LIBOR was replaced by the SNB policy rate.

[8]The SNB announced that the minimum exchange rate is enforced with the utmost determination via buying foreign currency in unlimited quantities. The policy rate did not change during the minimum exchange rate regime and the volatility of the EUR/CHF exchange rate was low, which makes our identification approach not applicable in this time period.

Figure 2. SNB Target Range, Three-Month CHF LIBOR, and Swiss Franc Exchange Rates



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

is presented in the press release "Introductory Remarks, News Conference," whereas for March and September meetings the chart is presented in the press release "Monetary Policy Assessment." The reason for this is that the June and December meetings have a press conference shortly after the official announcement, whereas March and September meetings do not have a press conference. Importantly, inflation and economic outlook forecasts are provided each meeting.[9] Furthermore, 9 out of the 56 policy meetings were unscheduled special meetings. Table A.1 in Appendix A provides a detailed overview of the monetary policy announcement meetings.[10]

Policy Rate. We use the daily change in the three-month CHF LIBOR to measure the policy rate changes Δi_t, because it is the monetary policy instrument that is controlled by the SNB. While longer-term interest rates are also relevant for exchange rate dynamics, our analysis takes the perspective of a policymaker that is interested in the impact its monetary policy decision. Since the SNB targeted the three-month CHF LIBOR, the rate directly incorporates policy rate expectations between day t and $t + 90$. Hence, absent other shocks, the three-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.[11]

[9]To check whether it is appropriate to combine MPAs with and without press conference, we analyzed the uncertainty around SNB policy meetings in high frequency, using the spread between the best bid and offer price of EUR/CHF and USD/CHF as a proxy for the arrival of new information. Typically, spreads increase during the arrival of new information, since uncertainty is large and market participants do not want to be on the wrong side of a transaction. As market participants interpret and digest the new information, spreads typically decrease to their normal levels. For the SNB policy meetings, we see a widening of the spread over the initial release, but not during the press conference (which is usually 30 minutes after the release). We conclude that the latter does not include substantial additional information and therefore we do not differentiate further between MPAs with and without a press conference. To compute the spread, we resample best bid and offer prices at a one-minute frequency over a window from 100 minutes before to 100 minutes after an announcement.

[10]The non-MPA sample contains two days where the ECB and the Fed held monetary policy announcement meetings (ECB: December 6, 2001; Fed: February 2, 2000). Excluding these days does not alter the results.

[11]Note that for approximately 50 percent of the MPAs, we use the three-month CHF LIBOR change between t and $t + 1$ to measure unexpected policy rate changes. The reason for this is that the three-month CHF LIBOR is fixed at approximately 11:00 a.m. London time (12:00/13:00 Zurich daylight

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, Crump, and Moench (2013). For each maturity, we calculate the expected component as the expected average future one-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 EUR/CHF and USD/CHF 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 three-month CHF LIBOR, the relevant time of day is 11:00 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 three-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 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.

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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 three-month CHF LIBOR change $t-1$ to t) and at 14:00 p.m. Zurich time in March and September (we use the three-month CHF LIBOR change t to $t+1$). Unscheduled announcements were released at approximately 13:00 p.m. (we use the three-month CHF LIBOR change t to $t+1$).

Table 1. Overview of the Financial Variables

Name	Description	Transformation	Unit
$\Delta i^{\text{3M-LIBOR}}$	3-Month LIBOR Rate for CHF Deposits	First Difference	Ppts
Δs^{EURCHF}	EUR/CHF Exchange Rate	Log Return	Pct
Δs^{USDCHF}	USD/CHF 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

Note: The table provides details of the variables used for estimation. The data source for the three-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.

Table 2. Descriptive Statistics

	Mean	Median	Minimum	Maximum	SD
A. MPA Days					
$\Delta i^{\text{3M-LIBOR}}$	−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
B. Non-MPA Days					
$\Delta i^{\text{3M-LIBOR}}$	−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

Note: The table provides 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 a Monetary Policy Shock

This section discusses the main result of the present analysis, namely, the estimated response of exchange rates to a monetary policy shock (i.e., parameter α in Equation (1)).

Exchange Rate Response. Table 3 shows the IH-GMM-estimation results. Our baseline specifications use the three-month CHF LIBOR as the policy variable. The two left-most columns show the results of estimating two separate equations for EUR/CHF and USD/CHF. The significance tests and standard deviations are asymptotic. In response to a 100 bp increase in the three-month LIBOR, the point estimates suggest that the Swiss franc appreciates by 2.1 percent and 1.9 percent on the same day against the euro and the U.S. dollar, respectively.[12] The third and fourth columns show that consistent estimates result when estimating the joint system that includes both EUR/CHF and USD/CHF. 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 EUR/CHF and USD/CHF 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 monetary policy announcements made by the SNB are able to move the EUR/USD exchange rate.

As the null hypothesis of equality cannot be rejected, we restrict the impact coefficients in the EUR/CHF and USD/CHF 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 three-month CHF LIBOR, the Swiss franc appreciates by 2.0

[12]Table A.1 in Appendix A reports the change of the three-month CHF LIBOR (in bp) for each monetary policy announcement day. For example, on November 6, 2008, the SNB decided to decrease the lower as well as the upper bound of the target range by 50 bp. The three-month CHF LIBOR decreased by 25 bp. On average, the absolute change of the three-month CHF LIBOR of monetary policy announcements dates is 7 bp.

Table 3. IH-GMM Estimates of the Exchange Rate Response

	Separate Equations		Joint Estimation		Restricted $\alpha_1 = \alpha_2$
	EUR/CHF	**USD/CHF**	**EUR/CHF**	**USD/CHF**	**EUR/CHF USD/CHF**
$\hat{\alpha}$	−2.1***	−1.9*	−2.0***	−1.8**	−2.0***
	(0.46)	(1.0)	(0.32)	(1.0)	(0.3)
$\hat{\lambda}$	0.015**	0.015**	0.015**		0.015***
	(0.0072)	(0.0072)	(0.0071)		(0.0048)
Wald $H_0 : \alpha_1 = \alpha_2$			0.038		
p-value			0.84		
J-statistic	0.066	0.032	0.18		0.22
p-value	0.8	0.86	0.98		0.99
No. Moment Conditions	3	3	6		6
No. Parameters	2	2	3		2

Note: The table shows the IH-GMM estimates. The policy rate variable is the three-month CHF LIBOR. The J-statistic reports the results of testing the null hypothesis regarding the validity of overidentifying restrictions. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively. The numbers in parentheses are standard deviations.

percent against the euro and the U.S. dollar, with the 95 percent confidence interval spanning from 1.4 percent to 2.5 percent.

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.

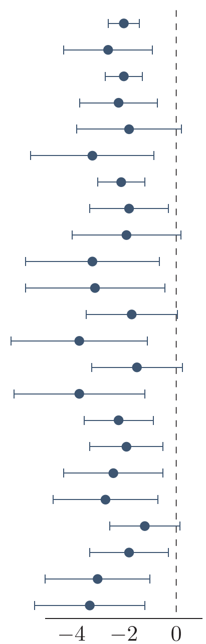
The magnitude of our benchmark result for the exchange rate response lies within the range of effects reported in the literature and are similar to the findings of Grisse (2020) and Kugler (2020).

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 ordinary least squares (OLS) results. The OLS estimate for EUR/CHF is not significantly different from zero, while the USD/CHF 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.

Robustness Checks. Table 4 and Appendix C include four 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 three-month CHF LIBOR is fixed (11:00 a.m. London time) (see Appendix C.3). Third, we use estimates of the three-month constant maturity rate inferred from three-month CHF LIBOR futures as the policy rate (see Appendix C.4). The ICE LIBOR (intercontinental exchange London interbank offered rate) futures data as well as exchange rates are sampled at the close of the

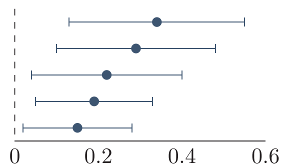
Table 4. Estimates of $\hat{\alpha}$ from Alternative Specifications

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	EUR/CHF	Sync		–2.0	0.3	(–2.6 to –1.3)
Joint	LIBOR	EUR/CHF	End		–2.2	0.8	(–3.7 to –0.7)
Joint	LIBOR	USD/CHF	Sync		–1.8	1.0	(–3.7 to +0.2)
Joint	LIBOR	USD/CHF	End		–3.2	1.2	(–5.5 to –0.9)
Sep	LIBOR	EUR/CHF	Sync		–2.1	0.5	(–2.9 to –1.2)
Sep	LIBOR	EUR/CHF	End		–1.8	0.8	(–3.4 to –0.3)
Sep	LIBOR	USD/CHF	Sync		–1.9	1.0	(–3.9 to +0.2)
Sep	LIBOR	USD/CHF	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	EUR/CHF	Sync		–1.7	0.9	(–3.5 to +0.0)
Joint	Future	USD/CHF	Sync		–3.7	1.3	(–6.2 to –1.1)
Sep	Future	EUR/CHF	Sync		–1.5	0.9	(–3.2 to +0.2)
Sep	Future	USD/CHF	Sync		–3.7	1.3	(–6.2 to –1.2)
IV	LIBOR	EUR/CHF	Sync		–2.2	0.7	(–3.4 to –0.9)
IV	LIBOR	EUR/CHF	End		–1.9	0.7	(–3.3 to –0.5)
IV	LIBOR	USD/CHF	Sync		–2.4	1.0	(–4.3 to –0.5)
IV	LIBOR	USD/CHF	End		–2.7	1.0	(–4.6 to –0.7)
IV	Future	EUR/CHF	Sync		–1.2	0.7	(–2.6 to +0.1)
IV	Future	EUR/CHF	End		–1.8	0.8	(–3.3 to –0.3)
IV	Future	USD/CHF	Sync		–3.0	1.0	(–4.9 to –1.0)
IV	Future	USD/CHF	End		–3.3	1.1	(–5.4 to –1.2)



Note: "Rest": restricted GMM. "Joint": joint GMM. "Sep": separate GMM. "Samp.": exchange rate sampling. "Sync": synchronized to policy variable (i.e., 11:00 a.m. London for LIBOR; 6:00 p.m. London for futures). "End": closing rate (i.e., 5:00 p.m. New York).

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)

Note: 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 six parameters. $\hat{\lambda} = 0.009^{**}(0.0045)$. J-statistic for validity of overidentifying restrictions: 2.41 with a p-value of 0.99. The expected average short-term interest rates are generated variables and therefore the confidence intervals may be biased.

day (6:00 p.m. London time). Fourth, we investigated the robustness of our results with respect to the choice of the non-policy sample.

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 percent significance level. At the 10 percent 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 the Swiss franc is very robust.

5.2 Yield Curve Response to a Monetary Policy Shock

In this section, we analyze the impact of a monetary policy shock 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, Crump, and Moench (2013). The interest rate expectation component is the financial market's best forecast of short-term yields over the lifetime of the bond. This analysis will shed light on how an unexpected change in the three-month CHF LIBOR affects the expectation of the expected average future short-term interest rates.

Table 5 shows the IH-GMM joint model estimates of the response of the expected average future short-term interest rate to a monetary policy shock that changes the policy rate by 100 bp. The estimates reveal that expected average future short-term rates are affected by monetary policy shocks. For the two-year maturity, we find that a 100 bp increase in the three-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.[13] 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 the identified monetary policy shock significantly affects medium- to longer-term policy rate expectations, which in turn affects the exchange rate.

6. Conclusions

This paper identifies the short-term impact of monetary policy announcements made by the SNB on the Swiss franc exchange rates and on the Swiss yield curve. Our results robustly show that a monetary policy announcement that increases the policy rate appreciates the nominal Swiss franc on the same day. The null hypothesis that monetary policy announcement shocks do 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 non-significant results. This may lead to the incorrect conclusion that monetary policy changes do not affect the Swiss franc.

Moreover, we find that our identified monetary policy announcement shock affects the expected path of future short-term interest rates, which in turn influence the valuation of the Swiss franc.

[13]We also estimated the impact of a monetary policy shock on the term premium at different maturities. We find that an increase in the policy rate typically leads to a small effect (0.05 percentage point for a 100 bp increase) in the term premium for short- and medium-term maturities. For longer maturities, this effect decreases. The pattern of small increases at shorter- to medium-term and the decrease for longer-term maturities is in line with the results of Soederlind (2010).

The magnitude of the benchmark results lies within the range of estimates in the literature. In this study we use data on two conventional monetary policy cycles in the historical sample from 2000 to 2011. However, recent contributions have suggested that in an environment of 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 and longer-term interest rates 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.

Appendix A. SNB Monetary Policy Announcements

Table A.1 provides details of the MPA days of the SNB from January 1, 2000 to August 31, 2011.

Table A.1. SNB Monetary Policy Announcement Dates

Year	Day	Comment	Δi	Δs^E	Δs^U
2000	20 Jan	R: Unchanged	3.3	–0.17	–0.53
	03 Feb	S: $\Delta\underline{B} = 50$ (1.75), $\Delta\overline{B} = 50$ (2.75)	14.7	–0.25	–1.63
	23 Mar	R: $\Delta\underline{B} = 75$ (2.50), $\Delta\overline{B} = 75$ (3.50)	28.2	–0.60	–1.69
	15 Jun	R: $\Delta\underline{B} = 50$ (3.00), $\Delta\overline{B} = 50$ (4.00)	1.3	–0.20	0.08
	14 Sep	R: Unchanged	–4.8	0.71	0.15
	08 Dec	R: Unchanged	–2.0	–0.04	0.06
2001	22 Mar	R: $\Delta\underline{B} = -25$ (2.75), $\Delta\overline{B} = -25$ (3.75)	–11.2	–0.11	0.74
	14 Jun	R: Unchanged	13.2	–0.10	–0.95
	17 Sep	R: $\Delta\underline{B} = -50$ (2.25), $\Delta\overline{B} = -50$ (3.25)	–15.7	–2.16	–5.11
	24 Sep	S: $\Delta\underline{B} = -50$ (1.75), $\Delta\overline{B} = -50$ (2.75)	–25.2	1.29	1.15
	07 Dec	R: $\Delta\underline{B} = -50$ (1.25), $\Delta\overline{B} = -50$ (2.25)	–7.3	0.09	0.64
2002	21 Mar	R: Unchanged	–0.7	–0.24	0.17
	02 May	S: $\Delta\underline{B} = -50$ (0.75), $\Delta\overline{B} = -50$ (1.75)	–19.8	0.07	0.42
	14 Jun	R: Unchanged	–0.8	0.13	–0.16
	26 Jul	S: $\Delta\underline{B} = -50$ (0.25), $\Delta\overline{B} = -50$ (1.25)	–19.2	–0.03	1.76
	19 Sep	R: Unchanged	0.0	–0.40	–1.32
	13 Dec	R: Unchanged	2.7	–0.01	–0.53
2003	06 Mar	S: $\Delta\underline{B} = -25$ (0.00), $\Delta\overline{B} = -50$ (0.75)	–21.5	0.40	0.41
	20 Mar	R: Unchanged	–0.4	0.00	–0.45
	13 Jun	R: Unchanged	–0.7	–0.25	–1.15
	18 Sep	R: Unchanged	0.0	0.13	0.39
	12 Dec	R: Unchanged	–0.3	0.02	–0.40
2004	18 Mar	R: Unchanged	–0.2	–0.32	–1.55
	17 Jun	R: Unchanged $\Delta\underline{B}$, $\Delta\overline{B} = 25$ (1.00)	6.2	–0.76	–1.13
	16 Sep	R: $\Delta\underline{B} = 25$ (0.25), $\Delta\overline{B} = 25$ (1.25)	–0.8	0.17	–0.09
	16 Dec	R: Unchanged	–3.2	0.29	1.43
2005	17 Mar	R: Unchanged	–0.8	0.08	0.36

(*continued*)

Table A.1. (Continued)

Year	Day	Comment	Δi	Δs^{E}	Δs^{U}
	16 Jun	R: Unchanged	0.0	0.01	0.09
	15 Sep	R: Unchanged	–0.7	0.27	0.78
	15 Dec	R: $\Delta\underline{B} = 25$ (0.50), $\Delta\overline{B} = 25$ (1.50)	–6.7	0.37	0.55
2006	16 Mar	R: $\Delta\underline{B} = 25$ (0.75), $\Delta\overline{B} = 25$ (1.75)	–1.4	0.46	–0.47
	15 Jun	R: $\Delta\underline{B} = 25$ (1.00), $\Delta\overline{B} = 25$ (2.00)	0.5	0.26	–0.07
	14 Sep	R: $\Delta\underline{B} = 25$ (1.25), $\Delta\overline{B} = 25$ (2.25)	2.7	0.32	0.04
	14 Dec	R: $\Delta\underline{B} = 25$ (1.50), $\Delta\overline{B} = 25$ (2.50)	1.0	0.17	0.70
2007	15 Mar	R: $\Delta\underline{B} = 25$ (1.75), $\Delta\overline{B} = 25$ (2.75)	–0.5	0.19	0.07
	14 Jun	R: $\Delta\underline{B} = 25$ (2.00), $\Delta\overline{B} = 25$ (3.00)	0.1	0.15	0.13
	13 Sep	R: $\Delta\underline{B} = 25$ (2.25), $\Delta\overline{B} = 25$ (3.25)	–9.2	–0.05	0.09
	13 Dec	R: Unchanged	1.3	0.07	0.57
2008	13 Mar	R: Unchanged	–1.5	0.05	–0.53
	19 Jun	R: Unchanged	–6.4	0.69	0.90
	18 Sep	R: Unchanged	1.3	0.30	0.15
	08 Oct	S: $\Delta\underline{B} = -25$ (2.00), $\Delta\overline{B} = -25$ (3.00)	1.3	–0.68	–1.14
	06 Nov	S: $\Delta\underline{B} = -50$ (1.50), $\Delta\overline{B} = -50$ (2.50)	–25.3	–0.14	1.71
	20 Nov	S: $\Delta\underline{B} = -100$ (0.50), $\Delta\overline{B} = -100$ (1.50)	–61.2	0.59	0.89
	11 Dec	S: $\Delta\underline{B} = -50$ (0.00), $\Delta\overline{B} = -50$ (1.00)	–27.3	1.28	–1.25
2009	12 Mar	R: Unchanged $\Delta\underline{B}$, $\Delta\overline{B} = -25$ (0.75)	–3.8	3.30	2.75
	18 Jun	R: Unchanged	0.0	0.28	0.60
	17 Sep	R: Unchanged	–0.3	–0.13	–0.38
	10 Dec	R: Unchanged	0.0	–0.03	–0.07
2010	11 Mar	R: Unchanged	0.0	0.04	–0.16
	17 Jun	R: Unchanged	0.7	–1.07	–1.70
	16 Sep	R: Unchanged	–0.7	1.76	1.23
	16 Dec	R: Unchanged	–0.1	–0.15	–0.38
2011	17 Mar	R: Unchanged	0.0	–0.17	–1.07
	16 Jun	R: Unchanged	0.0	–0.43	–0.64
	03 Aug	S: Unchanged $\Delta\underline{B}$, $\Delta\overline{B} = -50$ (0.25)	–3.7	1.89	1.07

Note: The table provides details of the MPA days of the SNB from January 1, 2000 to August 31, 2011. $\Delta\underline{B}$ ($\Delta\overline{B}$) indicates the change in lower (upper) bound of the three-month CHF LIBOR target range (in bp). The level is in parentheses (in pct). R (S) stands for regular (special) MPAs. Δi, Δs^{E}, and Δs^{U} are the change in the three-month CHF LIBOR (in bp) and the return of the EUR/CHF and USD/CHF exchange rate (in pct) on the MPA day, respectively.

Appendix 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 non-monetary-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

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

where

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

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):

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

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

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

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

where

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

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

$$\begin{aligned} \Delta\hat{\Omega} &= \hat{\Omega}_P - \hat{\Omega}_{\tilde{P}} \\ &= \frac{1}{T_P}\sum_{t=1}^{T} \delta_t^P \Delta x_t \Delta x_t' - \frac{1}{T_{\tilde{P}}}\sum_{t=1}^{T} \delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \\ &= \sum_{t=1}^{T} \frac{1}{T_P}\delta_t^P \Delta x_t \Delta x_t' - \sum_{t=1}^{T} \frac{1}{T_{\tilde{P}}}\delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \end{aligned} \tag{B.2}$$

$$= \sum_{t=1}^{T} \left[\frac{1}{T_P} \delta_t^P \Delta x_t \Delta x_t' - \frac{1}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \Delta x_t \Delta x_t' \right]$$

$$= \sum_{t=1}^{T} \left[\left(\frac{1}{T_P} \delta_t^P - \frac{1}{T_{\tilde{P}}} \delta_t^{\tilde{P}} \right) \Delta x_t \Delta x_t' \right]. \tag{B.3}$$

We find the moment conditions by matching the variances and covariances in (B.1) with their empirical counterparts in (B.3). This result provides three moment conditions for the two unknown parameters, corresponding to the two 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, which allows us to analyze both the EUR/CHF and USD/CHF 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 non-policy 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 EUR/CHF exchange rate, and Δs_{2t} is the difference in the logarithm of the USD/CHF 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

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

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

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

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 six moment conditions in three 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 six equations in three unknown parameters. 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.[14] 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

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

[14]The notations in this section loosely follow Zivot and Wang (2007, Section 21.6).

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

$$\hat{\theta}(\hat{S}_{HC}^{-1}) \xrightarrow{p} \theta$$

$$\text{avar}(\hat{\theta}(\hat{S}_{HC}^{-1})) = (\hat{G}'\hat{S}_{HC}^{-1}\hat{G})^{-1}$$

$$\hat{G} = \frac{1}{T}\sum_{t=1}^{T} \frac{\partial g(\hat{\theta}(\hat{W}))}{\partial \theta'}.$$

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 one degree of freedom.

Appendix C. Robustness

C.1 Results with OLS Estimator

We regress the exchange rate returns on three-month CHF LIBOR rate changes. The results are shown in Table C.2. The estimation results suggest that the estimates significantly differ from the IH estimates for EUR/CHF (point estimate: −0.4, standard error: 0.3) and USD/CHF (point estimate: 2.5, standard error: 0.5). The OLS estimates are not significantly different from zero, except for the estimates for USD/CHF. For USD/CHF, however, the OLS estimate is positive.

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 $(\Delta i, \Delta s)$

$$w_i \equiv \begin{bmatrix} \Delta i_P \\ -\Delta i_{\tilde{P}} \end{bmatrix}, \quad \Delta i \equiv \begin{bmatrix} \Delta i_P \\ \Delta i_{\tilde{P}} \end{bmatrix}, \quad w_s \equiv \begin{bmatrix} \Delta s_P \\ -\Delta s_{\tilde{P}} \end{bmatrix}, \quad \Delta s \equiv \begin{bmatrix} \Delta s_P \\ \Delta s_{\tilde{P}} \end{bmatrix}. \tag{C.1}$$

Table C.1. GMM Estimates with End-of-Day Exchange Rates

	Separate Equations		Joint Estimation		Restricted $\boldsymbol{\alpha_1 = \alpha_2}$
	EUR/CHF	**USD/CHF**	**EUR/CHF**	**USD/CHF**	**EUR/CHF USD/CHF**
$\hat{\alpha}$	–1.8**	–3.2**	–2.2***	–3.2***	–2.6***
	(0.78)	(1.3)	(0.77)	(1.2)	(0.84)
$\hat{\lambda}$	0.015**	0.014**	0.015**		0.013*
	(0.0072)	(0.0071)	(0.007)		(0.0069)
Wald $H_0 : \alpha_1 = \alpha_2$			0.67		
p-value			0.41		
J-statistic	0.28	0.99	1.1		1.7
p-value	0.59	0.32	0.78		0.79
No. Moment Conditions	3	3	6		6
No. Parameters	2	2	3		2

Note: The exchange rate variables are sampled at the close of the day (5:00 p.m. NY time). Please see notes of Table 3 for a detailed table description.

Table C.2. OLS and IV Estimates of the Exchange Rate Response

	$\Delta s^{\mathbf{EURCHF}}$	$\Delta s^{\mathbf{USDCHF}}$
OLS Estimates		
$\Delta i^{\text{3M-LIBOR}}$	–0.4 (0.30)	2.5*** (0.50)
IH-IV Estimates		
$\Delta i^{\text{3M-LIBOR}}$	–2.2*** (0.65)	–2.4** (0.96)
IH-IV Estimates with End-of-Day Exchange Rates		
$\Delta i^{\text{3M-LIBOR}}$	–1.9*** (0.71)	–2.7*** (1.0)
IH-IV Estimates with LIBOR Futures		
Δi^{M90}	–1.2* (0.7)	–3.0*** (0.97)

Note: The table shows the OLS estimates. The policy rate variable is the three-month CHF LIBOR. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively. The numbers in parentheses are standard deviations.

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

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 5:00 p.m. New York time. The IV-IH results are shown in Table C.2, whereas IH-GMM is displayed in Table C.1.

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 6:00 p.m. London time. The IV-IH results are shown in Table C.2, whereas IH-GMM is displayed in Table C.3.

Table C.3. GMM Estimates with LIBOR Futures

	Separate Equations		Joint Estimation		Restricted $\alpha_1 = \alpha_2$
	EUR/CHF	USD/CHF	EUR/CHF	USD/CHF	EUR/CHF USD/CHF
$\hat{\alpha}$	–1.5*	–3.7***	–1.7*	–3.7***	–3.1**
	(0.88)	(1.3)	(0.91)	(1.3)	(1.3)
$\hat{\lambda}$	0.012**	0.012*	0.011*		0.0082
	(0.006)	(0.006)	(0.006)		(0.0059)
Wald $H_0 : \alpha_1 = \alpha_2$			2.4		
p-value			0.12		
J-statistic	0.84	1.3	1.5		4.0
p-value	0.36	0.25	0.68		0.41
No. Moment Conditions	3	3	6		6
No. Parameters	2	2	3		3
No. Iterations	3	3	3		3

Note: 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 (6:00 p.m. London time). Please see notes of Table 3 for a detailed table description.

Table C.4. Non-policy Dates

19-Jan-2000	25-Jul-2002	14-Sep-2005	05-Nov-2008
02-Feb-2000	18-Sep-2002	14-Dec-2005	19-Nov-2008
22-Mar-2000	12-Dec-2002	15-Mar-2006	10-Dec-2008
14-Jun-2000	05-Mar-2003	14-Jun-2006	11-Mar-2009
13-Sep-2000	19-Mar-2003	13-Sep-2006	17-Jun-2009
07-Dec-2000	12-Jun-2003	13-Dec-2006	16-Sep-2009
21-Mar-2001	17-Sep-2003	14-Mar-2007	09-Dec-2009
13-Jun-2001	11-Dec-2003	13-Jun-2007	10-Mar-2010
10-Sep-2001	17-Mar-2004	12-Sep-2007	16-Jun-2010
21-Sep-2001	16-Jun-2004	12-Dec-2007	15-Sep-2010
06-Dec-2001	15-Sep-2004	12-Mar-2008	15-Dec-2010
20-Mar-2002	15-Dec-2004	18-Jun-2008	16-Mar-2011
01-May-2002	16-Mar-2005	17-Sep-2008	15-Jun-2011
13-Jun-2002	15-Jun-2005	07-Oct-2008	02-Aug-2011

Note: The table lists the non-policy sample dates. We follow Rigobon and Sack (2004) and use the previous day of the policy decision as non-policy day.

C.5 Selection of Non-policy Sample

In our benchmark model we followed Rigobon and Sack (2004) and use the previous day of the policy decision as non-policy day (see Table C.4). The previous day is a valid candidate for the non-policy sample since no information has been released, market participants are in wait-and-see mode, and SNB officials are in the blackout period, when speaking publicly is not allowed. If we move more days away from the policy date, we get in conflict with monetary policy decision meetings by the Fed, which are typically more than two days prior to an SNB policy meeting. The assumption of homoskedastic shocks is potentially violated in these cases. In a further robustness exercise, we randomly select days from the candidate set of non-policy days and estimate our benchmark model each time. We find that the results remain qualitatively robust (i.e., a policy rate increase leads to an appreciation of the currency). Quantitatively, however, we observe that the median of the simulation results are absolute smaller than our benchmark (around –1.6 percent) and estimates are less stable. This finding is in line with the robustness results reported in Rigobon and Sack (2004). It could be the case that the homoskedastic assumption, which is one of the key assumptions of the identification-through-heteroscedasticity approach, is violated because different kinds of shocks may materialize on these days.

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