Exchange rate floor and central bank balance sheets: Simple spillover tests of the Swiss franc[1]

Adrien Alvero and Andreas M. Fischer
Columbia Business School; Swiss National Bank

This paper examines spillover and spillback effects of unconventional monetary policies conducted by the European Central Bank (ECB) and Swiss National Bank (SNB) on the exchange rate's distribution. The empirical setup examines the price response of EURCHF risk reversal to a change in ECB and SNB balance sheets, with a distinction for the period of the minimum exchange rate (floor). The analysis finds only weak evidence of spillover effects from the ECB, while the spillback effect from the SNB balance sheet is robust during the floor period.

JEL codes: E52, E58, F31, G15
Key words: central bank balance sheets, spillovers and spillbacks, risk reversals, OLS regression

1 Introduction

In response to the financial crisis, central banks have introduced numerous unconventional monetary policies. The aim of these policies has been to sustain financial intermediation, foster the flow of credit to enterprises and households, support the monetary policy transmission mechanism, and mitigate deflationary risks. Although many of these policies were geared for the domestic economy, several studies argue that they generated international spillover effects, which are best captured in asset prices. For example, Neely (2015), Bauer and Neely (2014), and Gilchrist et al. (2014) find that unconventional monetary policy announcements by the Federal Reserve substantially reduced international long-term bond yields. Similarly, Diez and Presno (2013), Glick and Leduc (2012), and Neely (2015) find that unconventional monetary policies by the Federal Reserve also affected exchange rates and commodity prices.

A contentious issue in the spillover literature is the identification of unconventional monetary policies. Central banks undertook various unconventional policies that coincided or overlapped in time. Similarly, some central banks introduced multiple unconventional policies at the same time.[2] In limited cases, central

1 This paper is an abridged version of Alvero and Fischer (2015). Without implicating them, we have benefited from comments by Christian Grisse, Christoph Meyer, Thomas Moser, Thomas Nitschka, and David Pham. The views expressed in this paper are those of the authors and are not necessarily reflective of views at the Swiss National Bank. Any errors or omissions are the responsibility of the authors.

2 Amstad and Martin (2011) argue that the timing of the unconventional monetary policies of the Federal Reserve, the European Central Bank, the Bank of England, and the Swiss National Bank overlapped with each other.

banks introduced unconventional policies in response to external shocks. These developments make the identification of spillover effects of a specific program difficult. However, as noted in Amstad and Martin (2011), a common feature of unconventional monetary policies is the rapid expansion of central bank balance sheets of advanced economies. Several studies, such as Carpenter et al. (2012) and Ihrig et al. (2012), argue that central banks' balance sheets are a valid gauge to proxy the accommodation of unconventional monetary policies.[3]

The objective of this paper is to test for international spillover effects using a broad comparative measure, i.e. central bank balance sheets, that takes account of the accommodative stance of monetary policy in the home country affected by the spillover effect. Two types of spillover effects are considered: 1) the *direct* spillover effect, stemming from changes in foreign central bank balance sheets; and 2) the *relative* spillover effects, capturing the relative effect of foreign balance sheet versus domestic balance sheet changes. This case is pertinent when the domestic and the foreign central bank are each conducting unconventional monetary policies, since it allows to capture both spillovers from the foreign central bank balance sheet and spillbacks from the domestic central bank balance sheet.

These spillover effects are analyzed for a country that also undertook unconventional measures for two periods of exchange rate rigidity: a period when exchange rate movements are restricted by a minimum exchange rate; and a period when no minimum exchange rate is imposed. The empirical analysis examines spillover effects of the European Central Bank (ECB) balance sheet for the Swiss franc for a period in which the Swiss National Bank (SNB) balance sheet was expanding rapidly because of foreign exchange purchases beginning in March 2009.[4]

More specifically, our research question becomes: Are ECB spillover effects on the Swiss franc identified even controlling for SNB accommodation? The period of the Swiss minimum exchange rate (hereafter the "floor") from September 2011 to January 2015, in which the Swiss franc was bounded by a minimum rate of 1.2 against the euro, allows us to test whether ECB spillover effects are intensified when exchange rate movements are bounded.[5,6] Under the assumption that the floor is credible and the SNB does not change its monetary stance, our prior is that the spillover effect of ECB balance sheets is stronger under the floor regime.

3 An alternative view is offered by Filardo and Yetman (2012). They argue that expanding balance sheets signal policy risks linked to inflation, market distortion, and governance.

4 See SNB Press statement from 19 March 2009.

5 In this paper, the financial convention is used whereby EURCHF denotes units of Swiss franc per unit of euro.

6 The floor was introduced because the Swiss franc was viewed by the SNB to be massively overvalued and because of the need to mitigate deflationary risks (see SNB Press release from 6 September 2011).

This is because the spot exchange rate during the floor period has less flexibility to absorb the external shock and potential spillover effects must manifest themselves through other channels.

To account for the lack of exchange rate flexibility in the spot rate during the floor period, we use risk reversal prices as our measure to identify the spillover effect. We show that the volatility of the EURCHF risk reversal is higher during the floor period than in the previous period. Risk reversals are therefore a suitable measure to identify spillover effects under different exchange rate regimes. Risk reversals are a standard financial instrument in which the price is defined as the difference between a call and a put option. With this asset price, the empirical analysis tests two hypotheses. The spillover hypothesis says that persistent increases in the ECB balance sheet lead to a fall in the options price of the EURCHF risk reversal.[7] Similarly, the spillback hypothesis says increases in the SNB balance sheet lead to an increase in risk reversal prices. The relative spillover is simply the joint effect considering the influence of ECB and SNB balance sheets on risk reversals.

Spillover effects generally operate through two channels: the signalling and the portfolio channel. In our setup, it is assumed that the latter channel matters for spillover effects of central bank balance sheets. The rapid expansion of central bank balance sheets represents an increase in riskier assets and thus an increase in the risk premium. This increase in the risk premium impacts international assets directly through their purchase of specific assets or indirectly through the exchange rate. The signalling channel, which operates through the change in expectations for assets prices, is not captured in central bank balance sheets. This is because the balance sheets do not capture forward-looking announcement effects of a specific policy.

The empirical results are twofold. In a first step, the evidence shows that the impact of the SNB balance sheet on risk reversals is robust for different lag lengths. This spillback finding supports the view that movements in central bank balance sheets contain important information for options prices when the exchange rate is bounded by the floor. In a second step, the analysis finds limited evidence that increases in ECB bank balance sheets lead to a fall in the price of the EURCHF risk reversal, however the evidence for relative spillover effects is more supportive. The spillover effects from central bank balance sheets are most pronounced for the floor period.

7 Jermann (2014) analyzes the probability of the floor's survival using options pricing. Our study differs in that we use options pricing to study the spillover effect from the change in central bank balance sheets during the floor period.

The evidence of balance sheet spillovers contributes to two literatures: those concerned with international spillover effects, and those concerned with the zero bound in an open economy. For the rapidly growing spillover literature, the paper's empirical findings are especially relevant in that it is the first study to examine the impact of simultaneous unconventional monetary policies by different central banks for a single asset price. For this, we use the relative change in two central bank balance sheets. Previous studies examined spillover effects by a single central bank (often for a single program) on foreign asset prices without considering the degree of monetary policy accommodation of the domestic central bank.

With respect to the second contribution to the open economy literature at the zero bound, our evidence shows that exchange rate strategies designed to safeguard against the liquidity traps or deflation are more complex than has been previously documented. SVENSSON (2000, 2003) and others, for example, argue that the foolproof way to avoid deflation is to follow a three-step plan: 1) set an inflation target above the current price level; 2) depreciate the currency and set an exchange rate floor to be defended by unlimited foreign exchange interventions, and 3) define an exit strategy for when the inflation target is reached. The Swiss experience shows that potential spillover effects need to be considered when the central bank of the cross currency of the minimum exchange rate (i.e. the ECB) is also independently pursuing an unconventional monetary policy.

The paper is organized as follows. A descriptive analysis motivating the timing of changes in balance sheets and risk reversals is offered in Section 2. The empirical framework and hypotheses tests are presented in Section 3. The empirical analysis of the impact of central bank balance sheets on risk reversals is presented in Section 4. Conclusions are discussed in Section 5.

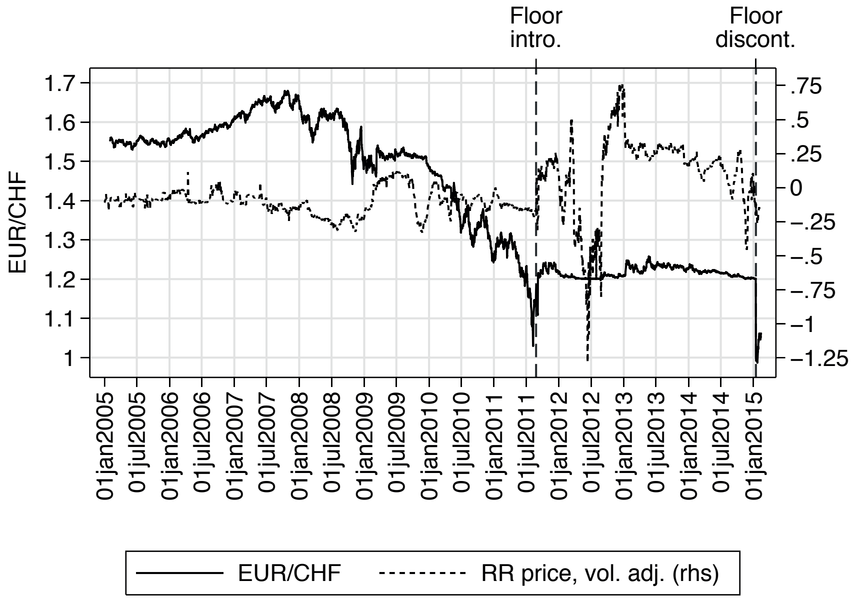
2 Motivating Spillover Effects of Foreign Balance Sheets

Our interest in spillover effects of foreign central bank balance sheets at the time of the floor is motivated with the help of two simple graphs. The descriptive analysis begins with Figure 1, which shows the evolution of the EURCHF exchange rate and the price of its corresponding risk reversal at a daily frequency. The sample is from 1 March 2005 to 31 March 2015. After a prolonged period in which the EURCHF exchange rate appreciated from 1.68 on 1 July 2007 to 1.03 on 31 August 2011, the Swiss franc experienced a period of stability under the floor regime from 6 September 2011 to 14 January 2015. During the floor's 40-month history, the EURCHF was always near to but above the 1.2 minimum rate. A notable episode was from January 2013 to July 2014, when the Swiss franc was able to gain distance from the 1.2 minimum rate. During much of this time, the Swiss franc was around 1.23 against the euro.

Together with the exchange rate, Figure 1 shows the risk reversal price defined for a 25% delta with a one-month duration.[8] The risk reversal for the EURCHF is simply the difference between the implied volatility of a call and a put option, adjusted by the volatility of an at-the-money option. Positive risk reversal prices signal that the market's perception is skewed towards a depreciation of the Swiss franc against the euro. Similarly, negative risk reversals signal that the market's perception is skewed towards an appreciation of the Swiss franc against the euro.

In Figure 1, the risk reversal shows considerable volatility during the floor. The daily standard deviation of the risk reversal is 0.30 during the floor compared to a standard deviation of 0.12 during the 40-month period prior to the floor's introduction.[9] In other words, a low variance of the EURCHF exchange rate did not coincide with a low variance of its corresponding risk reversal during the floor.

Figure 1: Exchange rate and risk reversals evolution

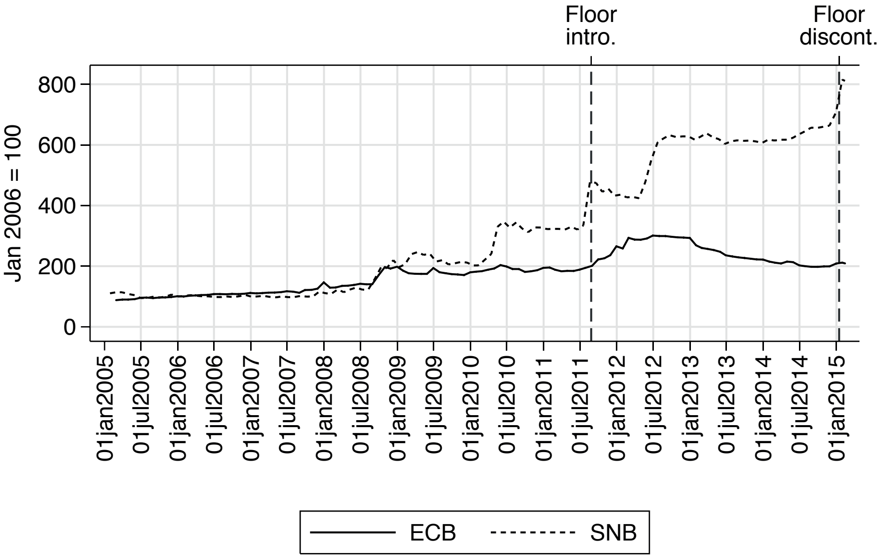


8 The Appendix offers a more concise definition of the pricing of risk reversal options and the volatility adjustment.

9 The unit of the numbers is, respectively, 30% and 12%, respectively, of the implied volatility of an at the money option.

Next, Figure 2 shows the monthly balance sheet of the ECB and the SNB normalized to 100 in January 2006, where both balance sheets are measured in euros. The figure shows two developments. The first is that the two central banks expanded their balance sheets almost in locksteps from January 2006 to December 2012. However, it should be noted that the volatility of the SNB balance sheet was considerably greater than that of the ECB balance sheet. The second development is the period of balance sheet divergence from January 2013 to July 2014. The ECB's balance sheet fell by 26%, while the SNB balance sheet remained relatively stable.

Figure 2: ECB and SNB balance sheets (normalized to 100 at 2006:1)



Note: Both balance sheets are measured in euros.

The two graphs suggest a possible interdependence between the ECB balance sheet and the risk reversal price evolution. Consider the period from January 2013 (or slightly earlier) to July 2014. This period matches the episodes of Swiss franc stability and SNB balance sheet stability to the episode of positive risk reversals and a contracting ECB balance sheet. In other words, the descriptive evidence suggests that the behavior of foreign central banks could have had both positive and negative spillover effects for the Swiss franc and the floor. The positive spillover is visible in the positive risk reversal during the January 2013 to July 2014 episode. In contrast, negative spillovers are visible from September 2011 to December 2012. The risk reversal was negative as the ECB balance sheet grew strongly. In the next section, we seek to determine whether the correlations between risk reversals and the SNB and ECB balance sheets are statistically robust.

3 Testing the Impact of Balance Sheets

The graphical information in the previous section showed an increase in the volatility of the risk reversal with diverging behavior in SNB and ECB balance sheets during the floor. From this information, it is unclear whether ECB policy contributed to the increased volatility in the risk reversal. To test for spillover effects from the ECB and SNB balance sheets on the risk reversal, the following regression is specified:

$$\Delta RR_t = \alpha + \Sigma_{i=1}^{p} \beta_{0i} \Delta bs_{t-i}^{ECB} + \Sigma_{i=1}^{p} \beta_{1i} D^{floor} \Delta bs_{t-i}^{ECB} + \Sigma_{i=1}^{p} \delta_{0i} \Delta bs_{t-i}^{SNB} + \Sigma_{i=1}^{p} \delta_{1i} D^{floor} \Delta bs_{t-i}^{SNB} + \theta' X_t + \mu_t \quad (3.1)$$

where the dependent variable, ΔRR_t, is the change in the risk reversal with a 25% delta and duration of one month. The variables of interest are the change in log ECB total assets, Δbs_{t-i}^{ECB}, and the change in log SNB total assets, Δbs_{t-i}^{SNB}. The balance sheet variables are lagged to reflect the persistence of the portfolio effect.[10] To determine whether the balance sheet effects were stronger during the floor, the balance sheet variables are interacted with a floor dummy, D^{floor}. This dummy variable is +1 from September 2011 to January 2015 and zero otherwise. The vector of control variables, X_t, includes the change in Swiss and euro interest rates, the change in the log spot EURCHF exchange rate, and lagged risk reversals. The constant term is denoted by α and the error term is denoted by μ_t.

Equation (3.1) allows us to test hypotheses on the impact of the ECB and the SNB on the risk reversal price. The first hypothesis test of the direct spillover effect is $\beta_1 + \beta_0 < \beta_0 < 0$. The risk reversal, which is a profitable strategy when the Swiss franc depreciates, becomes less expensive when the ECB balance sheet expands. This spillover effect implies that increases in the ECB's balance sheet have a negative effect on risk reversals during normal times and the effect is stronger during the floor period. The assumption is that the magnitude of the spillover effect is partially absorbed by changes in the exchange rate when the Swiss franc is not bounded by the floor.

10 The Swiss National Bank releases its balance sheet one month after the end of the reference month. The ECB publishes its balance sheet on a weekly basis with a one-week lag.

The second hypothesis test of spillbacks is $\delta_1 + \delta_0 > \delta_0 > 0$. The positive coefficient implies that it becomes more expensive to implement a strategy benefiting from a depreciation of the Swiss franc (i.e. buying a risk reversal) when the SNB's balance sheet expands. For completeness, the second part of the hypothesis of $\delta_1 + \delta_0 > \delta_0$ tests whether SNB actions have a stronger impact under the floor regime. A priori, it is unclear whether this condition holds for SNB spillbacks during the floor period. This is because the exchange rate during the floor is not bounded by a spillback effect.

The third hypothesis of relative spillovers says that the monthly change of the log-normalized ratio of the SNB balance sheet over the ECB balance sheet, $\Delta bs^{SNB/ECB}$, impacts the risk reversal. In terms of equation (3.1), the new specification:

$$\Delta RR_t = \alpha + \Sigma_{i=1}^{p} \beta_0' \Delta bs_{t-i}^{SNB/ECB} + \Sigma_{i=1}^{p} \beta_1' D^{floor} \Delta bs_{t-i}^{SNB/ECB} + \theta' X_t + \mu_t, \tag{3.2}$$

would test whether β_0' and β_1' are positive or negative. Positive values would be consistent with the hypothesis that the SNB (ECB) pushes the price of risk reversal up (down).

The empirical strategy assumes that changes in foreign and domestic balance sheets are a valid proxy for unconventional monetary policies. Balance sheet changes represent a broad view of monetary policy accommodation, however it should be noted that they also suffer from certain limitations. For example, announcement or signalling effects that operate through changes in expectations and their effects on assets prices are not captured in our measure of balance sheets. More importantly, we assume that balance sheet changes capture portfolio effects, which in turn are associated with purchases of riskier assets. These riskier assets may include foreign currency or asset-backed securities. The increase of central bank balance sheets should influence the risk premium and thereby the exchange rate.

Endogeneity issues are also a concern. No assumptions are made about whether the SNB's purchases of foreign assets were triggered by movements in the spot exchange rate, risk reversals, or even the ECB balance sheet. The empirical analysis seeks to determine if movements in risk reversals coincide with movements in central bank balance sheets and if the correlation is strongest during the floor period.

Finally, we also want to raise the issue of data quality for the risk reversal prices. These are quoted prices from Bloomberg, which by definition are informative and cannot always be attributed to traded prices. This problem is reduced, however, by taking monthly averages of the daily data. Moreover, in the presence of the EURCHF floor, it is likely that risk reversal prices were downward biased. Hedging a put option must have been more expensive than hedging a call option due to the higher uncertainty in the exchange rate distribution below 1.20. In other words, part of the put option price was simply reflecting the anticipated cost of maintaining a replication portfolio in the presence of higher market frictions and erratic price movements.

4 Evidence on Balance Sheet Spillovers[11]

Regression results based on equations (3.1) and (3.2) are presented in this section. The monthly sample is from February 2005 to February 2015, with a total of 121 observations.[12] All regressions are for risk reversals with a 25% delta and a one-month maturity.[13] Table 1 exhibits the descriptive statistics of the data set.

Table 1: Descriptive statistics

	Mean	SD	Min.	Max.
$RR_{\delta=25\%,month=1}$	-0.037	0.204	-0.757	0.661
ECB total assets (bn EUR)	1850.924	618.879	906.928	3102.227
SNB total assets (bn EUR)	213.714	144.929	62.530	537.297
EUR:CHF	1.406	0.176	1.054	1.671
$Libor_{CHF,month=1}$	0.689	0.941	-0.922	2.702
$Libor_{EUR,month=1}$	1.610	1.575	-0.008	4.815
Observations	121			

11 In ALVERO and FISCHER (2015), we offer further tests and econometric methods to mea- sure spillover effects, using Bayesian model averaging for instance. We also broaden the discussion by also looking at the Federal Reserve balance sheet and other control variables.

12 Daily exchange and interest rates are from Thomson and Reuters, and risk reversal prices are from Bloomberg. Weekly and monthly data on balance sheets of the ECB and SNB are directly taken from the respective central bank databases. To match the monthly balance sheet frequency of the SNB, the financial variables are averaged over the month, and the last week of the month is used for the ECB balance sheet.

13 Between the alternative maturities (i.e. three and six months), the risk reversal with one-month maturity showed the least amount of persistence. In terms of matching the dynamics with the balance sheets, this does not bias the results in our favor.

All risk reversal prices correspond to monthly averages and are adjusted by the implied volatility. For instance, risk reversal with a 25% delta and one-month maturity yields -3.7% of the EURCHF implied volatility for the period 2005-2015. The 3.7% corresponds to the average volatility premium that investors are willing to pay to take a directional bet on an appreciation of the Swiss franc against the euro.

4.1 Spillovers and spillbacks

The empirical findings suggest only weak evidence of spillover effects of the ECB balance sheet on risk reversals. The coefficient estimates of the ECB are not consistently correctly signed throughout the tests. In other words, it is not clear whether increases in foreign balance sheets reduce the price of a risk reversal. The impact of the change of the SNB balance sheet on the risk reversal, however, is found to be correctly signed and statistically significant. Different specifications of equation (3.1) reveal that lagged increases in the SNB balance sheet are linked to increases in risk reversal prices. This evidence suggests that SNB purchases of foreign assets were able to influence the skewness of the expected future EURCHF spot rate distribution. The effect of the SNB balance sheet is most pronounced during the floor, suggesting that the size of the spillback effect is conditional on the exchange rate regime.

Table 2 shows two sets of regressions of equation (3.1) in which the balance sheet variables enter separately with and without control variables. The lag order for the change of the balance sheets is one and two months, respectively, to reflect the timing at which they were made public (see footnote 9). The balance sheet variable is also interacted with the floor dummy. The spillover effect, defined by the coefficient values of the ECB balance sheet, is wrongly signed but not statistically different from zero. From this test, we are not able to conclude that unconventional monetary policies by the ECB captured by balance sheet movements for a single month generated spillover effects in risk reversal prices.

The coefficient estimates for the lagged change in the SNB balance sheet are all correctly signed, and (weakly) significant for the floor period at the 10% significance level. The results suggest that only the domestic central bank is affecting the market expectation of exchange rate directions. Regarding the size of the SNB coefficients during the floor period, a 10% increase in the SNB balance sheet corresponds to a 9.3 percentage point increase of risk reversal price (in implied volatility unit). This is not negligible compared to the risk reversal average of -3.7% of implied volatility between 2005 and 2015, and a 20.4%

standard deviation (see Table 1). Nevertheless, a single month may not be enough to capture co-movements in risk reversals.

The second set of regressions includes several control variables that merit further discussion. First, the lagged risk reversal is almost zero and not significant. This result is not surprising. It simply says that the degree of persistence of risk reversals is low and that past information does not (statistically) determine the current price. The contemporaneous change in the EURCHF is positively correlated with the risk reversal and is statistically significant. In addition to exchange rates, the change in the CHF Libor and the change in the EUR Libor are considered. Both coefficient estimates of the interest rate variables are consistent with the priors, and both are statistically significant. Intuitively, when the Swiss (euro) interest rate increases, the directional bet on the depreciation of the Swiss franc becomes more (less) expensive as it gets more (less) expensive to borrow Swiss francs to hold euros.

Table 2: Regression table with HAC-robust standard errors (dependent variable is ΔRR_t)

	(1)	(2)	(3)	(4)
Δecb_{t-1}	-0.006 (0.140)		0.178 (0.129)	
Floor*Δecb_{t-1}	1.128 (0.753)		0.817 (0.770)	
Δsnb_{t-2}		0.082 (0.092)		0.142 (0.094)
Floor*Δsnb_{t-2}		0.933* (0.497)		0.841* (0.501)
$\Delta i_{chf,t}$			0.099** (0.045)	0.128*** (0.046)
$\Delta i_{eur,t}$			-0.084* (0.048)	-0.106** (0.052)
$\Delta \ln(S_{EUR:CHF,t})$			0.918** (0.415)	0.448 (0.381)
ΔRR_{t-1}			-0.012 (0.176)	-0.040 (0.172)
Constant	-0.001 (0.011)	-0.007 (0.011)	0.001 (0.012)	-0.006 (0.011)
Observations	119	118	119	118
R^2	0.046	0.108	0.075	0.135

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3 presents the accumulated impact of balance sheets for different lags of equation (3.1). Each specification includes the lagged balance sheet effect for a single central bank with control variables. Only the coefficient of the accumulated lags along with the *p* value, which tests their joint exclusion, is shown. The first column shows the accumulated coefficient for lags 1 and 2. Thereafter, each column shows the accumulated coefficient for a higher lag order. In total, Table 3 presents the results of eight distinct regressions. The coefficients for the ECB balance sheets are wrongly signed apart from during the floor period. The statistical significance is in general weak for the ECB. The opposite effect is observed for the accumulated coefficients of the SNB balance sheet. The magnitude of the positive coefficients is largest for the floor, and the statistical significance is good. This evidence suggests that (higher order) lagged changes in SNB balance sheets coincide with risk reversals, supporting the results found previously in Table 2.

Table 3: Dynamic betas for different lags, including controls, one-month risk reversal as dependent variable.

	lag 1 to 2	lag 1 to 3	lag 1 to 4	lag 1 to 5
Δecb_{t-i}	0.273 (0.266)	0.303 (0.375)	0.163 (0.737)	0.0575 (0.902)
Floor*Δecb_{t-i}	-0.403 (0.687)	-0.150 (0.877)	-0.540 (0.575)	-0.407 (0.701)
Δsnb_{t-i}	0.293** (0.033)	0.345** (0.042)	0.482** (0.045)	0.503* (0.070)
Floor*Δsnb_{t-i}	0.725 (0.139)	1.222* (0.081)	1.875** (0.019)	1.367* (0.087)

Notes: The table presents the result of eight distinct regressions. *p*-values (in parentheses) of a Wald test, H0: $\Sigma\beta=0$ * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.2 Relative spillovers

This subsection examines the relative spillover effect by estimating simultaneously the impact of the ECB and SNB balance sheets. Three regression specifications with control variables are presented. The first two specifications are taken from equation (3.1), which includes balance sheet effects for the ECB and SNB in the same regression – one for a single lag and the other for cumulative effects. The second specification is equation (3.2). In this specification, the relative balance sheet effect is the difference in the log-change of the SNB balance sheet and the log-change in the ECB balance sheet. As in the previous subsection, only the estimates of the accumulated spillover effect for various lag lengths are presented.

In Table 4, where both central banks are included in the regression, the ECB balance sheet coefficient again suggests no spillover effects on risk reversal. All ECB coefficients are positive and not different from zero according to statistical tests. The SNB balance sheet spillback effect is still correctly signed but not significant for the floor, although the standard error is smaller than that associated with the ECB coefficients.

Table 4: Regression table with HAC-robust standard errors (dependent variable is ΔRR_t)

	(1)	(2)
Δecb_{t-1}	0.029 (0.151)	0.222 (0.134)
Floor*Δecb_{t-1}	0.495 (0.923)	0.196 (0.926)
Δsnb_{t-2}	0.080 (0.096)	0.168 (0.109)
Floor*Δsnb_{t-2}	0.813 (0.559)	0.716 (0.557)
$\Delta i_{chf,t}$		0.136*** (0.042)
$\Delta i_{eur,t}$		-0.097** (0.045)
$\Delta \ln(S_{EUR:CHF,t})$		0.562 (0.363)
ΔRR_{t-1}		-0.041 (0.173)
Constant	-0.007 (0.011)	-0.007 (0.012)
Observations	118	118
R^2	0.177	0.144

Note: Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5 presents results on the relative spillover effects. The table shows the regression with multiple spillover effects and control variables (not shown). The accumulated impact effect of balance sheets is shown for four different lag specifications, and as opposed to Table 3, these are the result of four regressions since both ECB and SNB balance sheets are included simultaneously. The balance sheet effects are largest during the floor, where the ECB balance sheet effects are negative and thus correctly signed. The effect of SNB balance sheets is positive and statistically significant for all four lag specifications, and stronger for the floor period.

Table 5: Dynamic betas for different lags, including controls, one-month risk reversal as dependent variable.

	lag 1 to 2	lag 1 to 3	lag 1 to 4	lag 1 to 5
Δecb_{t-i}	0.132 (0.619)	0.275 (0.451)	0.138 (0.793)	0.0403 (0.928)
Floor* Δecb_{t-i}	-0.874 (0.426)	-1.070 (0.246)	-1.579 (0.137)	-1.254 (0.305)
Δsnb_{t-i}	0.256* (0.087)	0.292* (0.091)	0.402** (0.038)	0.552* (0.050)
Floor* Δsnb_{t-i}	0.717 (0.196)	1.758** (0.015)	2.076** (0.013)	1.807** (0.042)

Note: The table presents the result of four distinct regressions. *p*-values (in parentheses) of a Wald test, H0: $\Sigma\beta=0$ * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 shows the relative accumulated spillover effect for various lag specifications. The four lag specification shows the relative difference between the log-change in the SNB balance minus the log-change in the ECB balance sheet and its interaction with the floor (again, the coefficients of the control variables are not shown). The accumulated coefficients are all positive. This means that for a positive risk reversal change, the SNB balance sheet needs to grow faster than the ECB balance sheet. Similarly, for a negative risk reversal change, the ECB balance sheet needs to grow faster than the SNB balance sheet. As in the previous regressions, the balance sheet effects are strongest during the floor. The coefficients of the relative balance sheets interacted with the floor dummy are large and statistically significant for lag 1 to 4.

Table 6: Dynamic betas for different lags, including controls, one-month risk reversal as dependent variable.

	lag 1 to 2	lag 1 to 3	lag 1 to 4	lag 1 to 5
$\Delta snb_{t-i} - \Delta ecb_{t-i}$	0.214 (0.155)	0.201 (0.254)	0.314* (0.100)	0.411* (0.097)
Floor*($\Delta snb_{t-i} - \Delta ecb_{t-i}$)	0.799 (0.162)	1.155 (0.135)	1.987** (0.014)	1.490 (0.118)

Note: The table presents the result of 4 distinct regressions. *p*-values (in parentheses) of a Wald test, H0: $\Sigma\beta=0$ * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

To sum up, the empirical evidence in Tables 2 to 6 tends to confirm the view that the main driver of EUR-CHF expectations measured by the one-month RR was the SNB during the period of the floor.

5 Conclusion

The impact of unconventional monetary policy by the European Central Bank and the Swiss National Bank is identified for options pricing strategies. The change in the foreign central bank's balance sheet is used as a gauge to proxy for changes in unconventional monetary policy. Changes in SNB balance sheets are shown to have a strong impact on the price of risk reversals.

For the ECB balance sheet, two spillovers findings are uncovered. The first finding is that the coefficient estimates for the ECB balance sheet during the floor period are consistent with the spillover view, however the statistical evidence is weak. This directional result implies that an increase in balance sheets of the ECB coincides with a price decrease in the risk reversal strategy, implying appreciation pressures. The second finding is that spillover effects are strongest for the floor. This spillover result may be interpreted as weak evidence that the SNB's efforts to support the floor were partially mitigated through foreign actions in the official sector. The main finding of the analysis presented in this paper, however, suggests that competing balance sheet effects were dominated by the SNB during the floor.

References

ALVERO, A. and A. M. FISCHER (2015), Competing balance sheet spillover effects, SNB working paper, forthcoming.

AMSTAD, M. and A. MARTIN (2011), Monetary policy implementation: common goals but different practices, *Current Issues in Economics and Finance* 17 (7), 1–11.

BAUER, M. D. and C. J. NEELY (2014), International channels of the Fed's unconventional monetary policy, *Journal of International Money and Finance* 44, 24–46.

CARPENTER, S. B., J. E. IHRIG, E. KLEE, A. H. BOOTE and D. W. QUINN (2012), The Federal Reserve's balance sheet: a primer and projections, FEDS Working Paper No. 2012-56.

DIEZ, F. J. and I. PRESNO (2013), Domestic and foreign announcements on unconventional monetary policy and exchange rates, Public Policy Brief, Federal Reserve Bank of Boston.

FILARDO, A. J. and J. YETMAN (2012), The expansion of central bank balance sheets in emerging Asia: what are the risks?, *BIS Quarterly Review,* June.

GILCHRIST, S., V. YUE, and E. ZAKRAJSEK (2014), The response of sovereign bond yields to us monetary policy, mimeo.

Glick, R. and S. Leduc (2012), Central bank announcements of asset purchases and the impact on global financial and commodity markets, *Journal of International Money and Finance* 31 (8), 2078–2101.

Ihrig, J. E., E. Klee, C. Li, B. Schulte and M. Wei (2012), Expectations about the Federal Reserve's balance sheet and the term structure of interest rates, Federal Reserve Board Working Paper.

Jermann, U. (2014), Financial markets' views about the euro-Swiss franc floor, Wharton School of the University of Pennsylvania.

Malz, A. M. (1996), Using option prices to estimate realignment probabilities in the European monetary system: The case of sterling-mark, *Journal of International Money and Finance* 15 (5), 717–748.

Neely, C. J. (2015), Unconventional monetary policy had large international effects, *Journal of Banking and Finance* 52, 101–111.

Svensson, L. E. (2000), The zero bound in an open economy: A foolproof way of escaping from a liquidity trap, NBER Technical Report, Washington, DC.

Svensson, L. E. O. (2003), Escaping from a liquidity trap and deflation: The foolproof way and others, *Journal of Economic Perspectives* 17, 145–166.

Appendix: Conceptual issues and definitions

By looking at the price of financial contracts on exchange rates, it is possible to infer market expectations of future spot exchange rates moments. While forward contracts can be interpreted as the risk-neutral expected value (first moment) of the future spot exchange rate, the implied volatility of currency options can be interpreted as the corresponding volatility (second moment).[14] Similarly, other combinations of options provide information on higher moments of the distribution. For instance, a long position in an out-of-the-money call and a short position in the corresponding out-of-the-money put is called a risk reversal, and can be directly traded over-the-counter.[15] If investors expect a symmetrical distribution of futures spot exchange rates, the price of this strategy should be zero. In contrast, if the price of this strategy is positive (negative) – meaning that the protection against an upward (downward) move is higher – investors see the distribution of future spot rates skewed towards the right (left). The FX market quotes risk reversal (RR) prices as follows:

$$RR_{\delta} = \hat{\sigma}_{Call,\delta} - \hat{\sigma}_{Put,\delta} \qquad (1)$$

14 A complete procedure for estimating the market's perceived probability distribution of futures exchange rates from option strategies is described in Malz (1996).

15 The strike prices of the out-of-the-money call and put options should be equidistant from the spot exchange rate. In practice, this is done by taking two options with the same delta, corresponding to the option price derivative with respect to the underlying exchange rate.

where σ corresponds to the volatility implied by the Garman-Kohlhagen formula (the Black-Scholes-Merton formula adapted to exchange rates). For instance, the formula for the price of a call option is as follows:

$$Call_t(S_t, K, T, r^*, r, \sigma) = S_t e^{(-r_T^* T)} N(d_1) - K e^{-r_T T} \mathrm{N}(d_2) \qquad (2)$$

where

$$d_1 = \frac{1}{\sigma\sqrt{T}} (ln(\frac{S_t}{K}) + (r_T - r_T^* + \frac{1}{2}\,\sigma^2)T)$$

$$d_2 = d1 - \sigma\sqrt{T}$$

For a given option price C(·), spot rate S_t, exercise price K, maturity T, and domestic and foreign interest rates r and r^*, it is possible to extract the implied volatility by using the above formula. It is worth noting that both the spot rate and exercise price need to be quoted in units of domestic currency per unit of foreign currency.

Moreover, the different exercise prices are also expressed indirectly through the option's delta δ, corresponding to the price sensitivity with respect to the spot rate. There is a monotonic relation between the delta and the strike price of an option, and the strike price can be easily retrieved from (2).

Last, it is worth mentioning that this paper uses volatility-adjusted risk reversal prices. This means that the risk reversal formula above is divided by the implied volatility of an at-the-money option. This makes all risk reversals comparable across different currency pairs.