The response of long-term yields to negative interest rates: evidence from Switzerland

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Abstract

This paper studies the transmission of changes in short-term interest rates to longer-term government bond yields when short-term rates are at very low levels or negative. We focus on Switzerland, where short-term interest rates have been at zero since late 2008, and negative since the beginning of 2015. The expectations hypothesis of the term structure implies that as nominal interest rates approach their lower bound, the effect of short-term rates on longer term yields should decline; and positive short rate changes should have larger absolute effects than negative short rate changes. Contrary to studies of other countries, we find no evidence for a decline in the average effect of short rate changes on long yields using Swiss data. However, we find strong evidence of the asymmetric effect for the Swiss term structure when short-term rates are close to zero. The asymmetric effect of short-term to long-term interest rates normalized again under negative interest rates. The results suggest hence that the transmission of short rate cuts to longer term yields works in negative territory.

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1 Introduction

In the past couple of years, a number of European central banks have moved their policy rates into negative territory. Denmark at first introduced a moderately negative deposit rate of –0.05% in 2012.[1] The European Central Bank reduced its deposit rate into negative territory gradually starting in 2014, leading to a deposit rate of –0.40% in March 2016. The Swiss National Bank introduced negative interest rates on sight deposit account balances of –0.75% in January 2015 and thus pioneered by cutting policy rates much deeper into the negative territory. Denmark and Sweden since followed suit with similar sized cuts. After more than seven years of holding short-term interest rates at zero, the Bank of Japan cut its main policy rate to –0.1% in January 2016.

Bech and Malkhozov (2016) analyze the rate cuts into negative territory by the four European central banks and find that the transmission from modestly negative policy rates to money market rates works the same way as with positive interest rates. In normal times, interest rate policy transmits to the real economy through its effect on longer-term interest rates and asset prices.[2] This paper investigates how changes in short-term interest rates transmit to longer-term interest rates when the policy rate is at very low levels or negative. For this empirical analysis, data on Swiss franc short and long-term interest rates are used. Swiss interest rates serve as an excellent case to study, as the policy rate had remained close to zero for a long time and was lowered to a negative level, which was never seen before.

We take an empirical approach similar to that of Ruge-Murcia (2006) and Grisse (2015). Ruge-Murcia (2006) shows in a simple term structure that when nominal interest rates are constrained by a lower bound, not only the impact of short-term interest rate on long-term interest rates declines, but also the impact becomes increasingly asymmetric, i.e. positive change in short-term interest rates have a higher impact on long-term interest rates than negative changes in short-term interest rates. The effect works through market expectations of future short term interest rates. The closeness to the lower bound influences the distribution of likely possible future changes in the policy rate, and hence, the long-term interest rate. Because market participants anticipate that future short rate shocks are constrained by the lower bound on nominal interest rates, expected future short rates and hence the yield curve is effected even when short rates are still above the lower bound. When short rates are closer to the lower bound, a short rate decline will produce a smaller downward shift in expected future short rates, and hence also a smaller effect on long-term yields.

The results can be summarized as follows. In the pre-crisis sample, which lasts until the movement of the lower bound of SNB's target range for the Swiss franc 3-month Libor to zero, we find no statistically significant difference between the impact of negative and positive short rate changes on long-term interest rates. But as short rates turn lower, the effect of short rate increases rises, while that of short rate cuts remains stable. The differences between these effects

[1]The Swedish central bank introduced negative interest rates on its deposit facility in 2009 for a short time period, which was not binding for money markets.

[2]It also transmits through the effect on interest differentials and exchange rate reactions.

becomes statistically significant, as predicted by the Ruge-Murcia (2006) model. But the Swiss data confirms the theory only partially. The increase in the effect of positive short rate changes is so strong that the average effect of short-term rates increases compared to the pre-crisis period, contrary to what theory predicts. This finding also contrasts with the results reported by Grisse (2015) which studies the transmission of US dollar interest rates and finds evidence for a decline in the average effect of short rate changes on longer term yields, but not for asymmetric effects. At times of negative interest rates the effect of positive changes in short-term interest rates declines again, while the impact of negative changes slightly increases. Hence, impact of short-term interest rates on long-term interest rates becomes less asymmetric than at times when the policy rate was at the zero lower bound. This suggests that market participants changed their beliefs about the level of the effective lower bound, and do not consider the effective lower bound to have been reached yet. While the previous literature has found that the transmission to longer term interest rates is impaired when the policy rate is close to its perceived lower bound, we find that this has not been the case in Swiss data.

Our findings have important policy implications for the use of negative interest rates as a monetary policy tool. First, the empirical results suggest that a move of policy interest rates into the negative territory not only transmits well to money market interest rates but also to longer-term interest rates such as government bond yields . This in turn suggests that the monetary transmission to the real economy works normally when policy rates are negative. Second, the results are consistent with the asymmetric effects of positive and negative short-rate changes that are predicted by the Ruge-Murcia (2006) model. As short rates are normalized after a period close to the lower bound, positive changes in short-term may have unusually strong effects and long-term interest rates may adjust very quickly to changes in the policy rate.

The remainder of this paper is structured as follows. The next section presents a summary of the Ruge-Murcia (2006) model that motivates the empirical analysis. Section 3 summarizes the developments of the Swiss monetary policy implementation since the global financial crisis. Section 4 presents the empirical analysis of the effects of Swiss franc short-term on long-term interest rates, section 5 provides several robustness checks of the analysis. Finally, section 6 concludes.

2 Theoretical motivation

We use the model derived in Ruge-Murcia (2006) as a theoretical framework for analyzing the transmission of short-term interest rates to longer-term rates. This is a simple term structure model consisting of three equations: nominal interest rates are constrained by a lower bound;[3] the (shadow) short-term interest rate follows an autoregressive process; and longer-term yields are equal to average expected future short rates (the expectations hypothesis), plus a term/liquidity premium.

[3] Grisse et al. (2016) generalize Ruge-Murcia's version of the model by allowing for a varying and possibly non-zero lower bound on the short-term nominal interest rate. This allows them to study the effects of changes in the market-perceived lower bound.

The model shows that when nominal interest rates are constrained by a lower bound, the expectations hypothesis of the term structure implies a nonlinear relationship between changes in short-term interest rates and changes in longer term yields. As short rates approach the perceived lower bound, (1) the effect of changes in short-term interest rates on changes in long-term interest rates declines; and (2) the effect of changes in short-term interest rates on changes long-term interest rates becomes increasingly asymmetric, i.e. positive changes in short-term interest rate exhibit a larger absolute impact than negative changes in short-term interest rate.

These nonlinearities work through market expectations of future short-term interest rates. The intuition for these results is similar to that for the "honeymoon" effect (the nonlinear relationship between the exchange rate and its fundamentals) in Krugman's (1991) target zone model. Suppose that market participants think that future positive and negative interest rate shocks are equally likely. Suppose also that short-term rates are at 0.5%, with a lower bound of zero. Then a future shock to the shadow short rate of +1 percentage points would raise short rates to +1.5%, while a shock of −1 percentage points would only lower short rates to zero. Because market participants anticipate that future short rate shocks are constrained by the lower bound on nominal interest rates in this way, expected future short rates and hence the yield curve is affected even when short rates are still above the lower bound. When short rates are closer to the lower bound, a short rate decline will produce a smaller downward shift in expected future short rates, and hence also a smaller effect on long-term yields.

Ruge-Murcia (2006) takes his model to the data for Japanese interest rates, and other studies have more recently looked at US data (e.g. Grisse, 2015). These studies have all assumed a fixed lower bound on nominal rates of zero, finding the transmission of cuts in the short-term policy rates to the rest of the term structure to be stunted around zero. There are no previous studies using negative nominal rates, notably because sufficiently long time series with negative policy rates have not previously been available. The recent Swiss experience with negative nominal policy rates since January 2015 provides us with new data with sufficiently long time series below zero to conduct such a study.

3 Swiss monetary policy implementation

The cornerstone of Swiss monetary policy strategy is an announced target band for the level of the market-determined 3-month Swiss franc interbank interest rate, the 3-month Libor. The announced target band is chosen so as to be consistent with an outlook for the medium term inflation rate of below two percent. We consider this 3-month Swiss franc Libor the best candidate short-term interest rate to reflect the policy rate for the empirical investigations below. Before the financial crisis, the SNB implemented its strategy using as its main tool the interest rate on one-week repo liquidity providing operations with its counterparties, to steer short-term money market interest rates toward the announced target band. The one-week repo rate was adjusted frequently in order to keep the 3-month Libor rate close to the middle of its announced target band. Monetary policy implementation changed as Switzerland was adversely affected by the global financial crisis in 2008-2009. Due to adverse financial as well as real shocks, and an unprecedented appreciation of the Swiss franc linked to its safe haven status (see Figure 1), the outlook for Swiss economic activity and inflation worsened abruptly.

[Figure 1 about here]

As a response, the SNB lowered its mid-point for the target band for the 3-month Libor gradually starting the second half of 2008, reaching 0.50 percent in the first half of 2009 (see Figure 2). In 2009 the SNB introduced new and unconventional monetary policy instruments. In March 2009, a small asset purchase program was announced and carried out. Moreover, an implicit ceiling for the strength of the Swiss franc against the euro was announced and enforced through foreign exchange interventions.[4] The continuing persistent pressure on the Swiss franc culminated in a series of liquidity expansions akin to quantitative easing in August 2011 and the introduction of a minimum exchange rate against the euro in September 2011.[5] The minimum exchange rate policy was in place until January 2015.

[Figure 2 about here]

Through these various unconventional measures, the resulting liquidity surplus of the SNB counterparties grew immensely between 2009 and 2015. As a result, the liquidity in the Swiss money market, especially in the unsecured market, fell dramatically during those years, as banks became satiated in liquidity (see Guggenheim et al. 2011). The SNB's liquidity providing repo operations were suspended for roughly a year in May 2010 and finally discontinued in April 2012.[6] Thus, the time series for the weekly (liquidity providing) repo rate has not been available on a continuous basis after Mai 2010. Despite the low money market liquidity, however, the 3-month Swiss franc Libor has continued to be quoted daily and it has remained an important rate for signalling the Swiss monetary policy stance, and as a reference rate for financial market contracts such as mortgage and derivatives contract.[7]

The SNB's tools for monetary policy implementation during the March 2009 to January 2015 period, namely liquidity providing asset purchases and foreign exchange interventions, affected long-term interest rates mainly through term and risk premiums (Christensen and Krogstrup, 2015), and less through the expected path of short-term interest rates that we are focusing on here. The measures did, however, also succeed in affecting the 3-month Swiss franc Libor rate within its target band, and this variation is what we take advantage of in our empirical analysis. Notably, the unprecedented liquidity expansions of August 2011 succeeded in pushing it, along with other money market interest rates, to near zero, reflecting the easing effect of the

[4] See Kettemann and Krogstrup (2014) for an overview of these new measures and an analysis of the SNB's covered bond purchase program in 2009-2010.

[5] See Christensen and Krogstrup (2015) for an analysis of the impact of these measures on interest rates.

[6] To absorb the liquidity created in the foreign exchange interventions, SNB conducted liquidity absorbing repo operations between July 2010 and August 2011. With the introduction of the minimum exchange rate, SNB again conducted minor liquidity providing repo operations between until April 2012.

[7] According to the Swiss franc market participant group on reforming interest rate benchmarks the notional volume of outstanding financial contracts indexed to CHF-LIBOR is estimated to be greater than 6.5 TN [USD]. The main types of contracts indexed to CHF-LIBOR include Over-the-Counter (OTC) and exchange traded derivatives, corporate loans, retail mortgages, floating rate bonds and securitized products." (FSB, 2014)

measures taken. We hence consider it reasonable to use the 3-month Libor rate as a baseline policy rate measure for our empirical analysis also for this period. The low activity in money markets, moreover, calls for considering alternative measures of the short-term interest rate. We hence also check robustness of our results to using different short-term interest rates such as rates derived from interest rate swaps.

Inflation perspectives worsened anew in Europe stating in mid-2014, resulting in further loosening of the ECB's monetary policy stance, and renewed pressures on the Swiss franc. In December 18, 2015, the SNB announced a lowering of the target range for 3-month Libor into negative territory to -0.75% to 0.25%. This was the first time that the mid-point of SNB's target range for the 3-month Swiss franc Libor has turned negative. To achieve this lowering of short-term money market rates into negative territory, the SNB introduced negative interest on banks' sight deposits held with the SNB (the equivalent of central bank reserves), and simultaneously announced that it would be set at -0.25%. The change was only to come into effect on January 22, 2015, because of a required change in the terms of business with the SNB's counterparties. On the 15th of January 2015, however, simultaneously to the announcement of the exit from the minimum exchange rate regime, interest rates on sight deposits were further lowered to -0.75%, again taking effect on January 22 2015. The target range for the 3-month Libor was further lowered to -1.5% to -0.25%. From January 2015 onward, the SNB's main tool for monetary policy implementation was therefore again a short-term interest rate.

Swiss franc money market rates reacted significantly to the reaction of negative interest rates. The response of the 3-month Swiss franc Libor to the announced lowering into negative of the target band was immediate, as can be seen from Figure 3. Also the future contracts on the 3-month Swiss franc Libor as well as the SARON, the overnight rate for secured Swiss franc liquidity and the 3-month treasury bill reacted consistently and since then lie within SNB's target range. Thus, the transmission of the change in the policy rate to money market interest rates worked well. Long term interest rates reacted immediately to the two announcements. Especially on January 15, long-term interest rates fell within a few minutes by 20 to 30 basis points (see Figure 4). Swiss government bond yields of horizons up to 10 years turned negative in January 2015, with 5-year yields falling to -1% and 10-year yields falling as far as -0.3% (see Figure 5), suggesting a strong transmission to long-term yields. The cause of the reaction of long-term yields at exactly this event is hard to interpret, however. The announcements of rate cuts into negative territory likely moved market perceptions of where the lower bound on interest rates is located, as well as simultaneously lowering the policy rate. Moreover, the simultaneous discontinuation of the minimum exchange rate policy resulted in strong upheaval in global financial markets. Long term interest rates may have responded to all of these factors at that event. As we wish to separately identify the effect of the policy rate, we hence dummy these particular events out in the time series regressions below.

[Figure 5 about here]

4 Empirical results

In the following we investigate empirically whether the transmission of interest rate cuts changes when interest rates are close to zero or negative. The experience with negative policy rates in recent years in Switzerland lends itself particularly well to investigating these effects. Interest rates in Switzerland have been close to zero for a substantial period of time, and have been negative since late 2014. This makes Switzerland an ideal case study for detecting the non-linearities predicted by the Ruge-Murcia (2006) model. Moreover, to the best of our knowledge Swiss data are previously unexplored for these purposes.

The empirical approach we take is an adaptation of the time series approach of Ruge-Murcia (2006) and Grisse (2015) to the specific Swiss circumstances. Using time series regression techniques, we assess the association between the Swiss short-term interest rate, as a measure of the policy rate, and long-term interest rates. To capture the nonlinearities predicted by the model, we allow this association to depend on the level of the short-term interest rate – in the baseline specifications, this is achieved by splitting the sample into different subsamples (pre-zero lower bound (ZLB), ZLB and negative interest rate (NIR) period) – and we allow it to differ depending on whether the short-term interest rate is increasing or declining.

4.1 Baseline time series regressions

Our empirical approach follows the work by Ruge-Murcia (2006) for Japanese bond yields (1995-2001), and by Grisse (2015) for the US term structure (1990-2014). Our baseline regression is

$$\Delta R_t = \beta_0 + \beta_{pos}\mathbb{1}(\Delta r_t > 0)\Delta r_t + \beta_{neg}\mathbb{1}(\Delta r_t < 0)\Delta r_t + \epsilon_t \quad (1)$$

Here ΔR_t denotes changes in long-term interest rates, Δr_t changes in short-term interest rates and $\mathbb{1}(\cdot)$ is an indicator function to differentiate between positive and negative changes in the short-term interest rate. According to the model, both β_{pos} and β_{neg} are expected to be positive. However, approaching the lower bound, the average size of both β_{pos} and β_{neg} should decline while β_{pos} is expected to become increasingly larger than β_{neg}.

We use the 3-month Swiss franc Libor as the main explanatory variable in the baseline regression.[8] As outlined above, the 3-month Swiss franc Libor forms the cornerstone of Swiss monetary policy strategy as the SNB announces a target band for the level of this interest rate and it is used as a reference rate in a number of contracts (see FSB, 2014). Moreover, the 3-month Swiss franc Libor incorporates the expected outcome of the SNB' s next monetary policy assessment, as policy meetings regularly take place four times a year. In contrast to very short-term money market rates, the 3-mont Libor is not driven by short-term liquidity management considerations by banks, as is the case for overnight and one-week interest rates.

As long-term interest rates we use Swiss government bond yields, also referred to as Swiss Confederation bond yields. Currently, outstanding Swiss government bonds are worth CHF

[8] Libor rates are calculated based on submissions of a panel of banks by 11am London time. The 11 am London fixing of both rates are available on Bloomberg a daily basis.

85 bn which accounts to roughly 45% of Switzerland's GDP. The Swiss confederation has the highest credit rating, and yields on their bonds can be considered a good proxy for nearly risk-free long-term interest rates. We use yields of bonds with a constant time to maturity of 2, 5, 7, 10, 15 and 20 years, available on Bloomberg on an end-of-day basis (6 pm Central European Time, CET).

The time of observation of the dependent and independent variables differ, in that due to data availability reasons, we use data collected at noon for short-term Libor rate while we use end-of-day data for the long-term yield. Since we are assessing the reaction of long yields to short yields, this time discrepancy allows the long-yields to react on changes in short-term yields, and we hence do not expect it to hamper our results. It might, however, lead to a slight risk of underestimating the effects, if the impact of short rates on long rates is instant.

Swanson and Williams (2014) and Grisse (2015) use 1990-2000 as their reference sample. Because of limited data availability and because of changes in the Swiss National Bank's monetary policy framework between 1999 and 2000, our reference sample runs from 1 January 2000 to 10 December 2008. On 11 December 2008 SNB reduced the target range for the 3-month Swiss franc Libor by 50 basis points to 0–1%. We take this event as the starting point for the ZLB sample, which lasts until 17 December 2014. On 18 December 2014 the SNB announced a lowering of the target range for the 3-month Swiss franc Libor into negative territory. This event starts the NIR sample period, which lasts until 30 March 2016.

4.2 Results

[Table 1 to 3 about here]

Table 1 to 3 show the results for the baseline regression for the three sample periods. The results can be summarized as follows. For the reference period, both coefficients β_{pos} and β_{neg} are positive as expected. The longer the maturity of the dependent variable the higher the values of the coefficients. Hence, short-term interest rates have a higher impact on shorter term government bond yields, which is consistent with the findings for US data in Grisse (2015). The null hypothesis that β_{pos} and β_{neg} are equal cannot be rejected. In fact, β_{neg} is slightly larger than β_{pos}.

For the ZLB sample period, β_{pos} increases, while β_{neg} remains roughly unchanged. With the exception of the 20-year yield regressions, the difference $\beta_{pos} - \beta_{neg}$ is now statistically significantly different from zero, in line with the predictions of Ruge-Murcia (2006). The average effect increases, contrary to the predictions of Ruge-Murcia (2006) and the findings of Grisse (2015) for the US. However, the average effect is mainly driven by β_{pos}. Finally, the increasing effect of positive interest rate changes on longer term government bond yields vanishes, indicating that the whole interest rate curve is affected simultaneously by (positive) movements in short-term interest rates.

In the NIR sample period, β_{pos} declines compared to the ZLB period, while β_{neg} increases (shorter term government bond yields) or remain broadly unchanged (longer term government bond yields). The increase in the level and in the significance of β_{neg} can indicate two effects.

On the one hand, market participants might have changed the perception of the effective lower bound. That is, market participants expect short-term interest rates not to have reached the effective lower bound, which is in line with occasionally very negative 3-month Swiss franc Libor futures (as low as $-1,2\%$) after the introduction of negative interest rates. On the other hand, market participants might also have changed their expectations about how long interest rates will stay at low levels. For regressions considering government bond yields with a maturity longer than seven years, the difference between β_{pos} and β_{neg} turns statistically insignificant. The transmission of short-term to longer term interest rates thus seems to work better than during the ZLB period. Moreover, the negative relationship between the maturity of the dependent variable and the size of the coefficients holds again. That is, shorter term government bond yields react more to changes in short-term rates than longer ones.

Overall, the results of Ruge-Murica (2006) can only partly be confirmed: $\partial R_t/\partial r_t$ is rather decreasing in r_t and $|\Delta R_t|$ is larger if $\Delta r_t > 0$ only holds in the ZLB period. The results indicate that the transmission from short to long-term interest rates was impaired during the ZLB period. Negative changes in short-term interest had hardly any impact on long-term interest rates. Instead, positive changes had an exceptionally large effect on long-term rates. After the introduction of negative interest rates, the relationship between short and long-term interest rates normalized. Although the average effect is still higher than in the baseline period, the impact of negative changes becomes statistically significant again. Furthermore, positive and negative changes in short-term rates are more balanced. The findings shows that the transmission of short- to long-term interest rates also works when short-term interest rates are in the negative territory. Not only have we found a statistical significant effect of changes in short-term interest rates on long-term yields but also a significant effect of negative changes in short-term rates. The increasing impact of negative changes in short-term on long-term interest rates suggests that market participants believe that the lower bound has not have been reached yet . The move of policy interest rates into the negative territory thus has not only transmitted well to money market interest rates but also to longer-term interest rates such as government bond yields.

5 Robustness

5.1 Alternative measures for short- and long-term interest rates

The overview of recent changes in Swiss monetary policy implementation in section 3 suggests a number of necessary robustness checks. In particular, we want to make sure the results are not driven by additional factors that could be correlated with monetary policy, and that the results are robust to the choice of short-term interest rate. We try three alternative measures of short-term interest rates, in place of 3-month Libor in the baseline specification: the 6-month Libor, which also serves as basis for several derivative contracts; the fixed leg of one year interest rate swaps, as a measure for a one year interest rate; and the fixed leg of 3-month overnight indexed swaps, which can be seen as a measure for the risk free interest rate of a maturity of three months. To control for policy changes, we include the change in the level of central bank reserves as an additional control variable. Short-term interest rates can spike at month ends or at the end of a minimum reserve requirement (mire) period as banks require short-term funding on such dates. To control for such effects, indicator variables for days at the end of a month and the end of a minimum reserve requirement period are included. Additionally, dummies for dates of monetary policy decisions are included in order to control for expected monetary policy changes. Finally, we control for measures of global financial market risk aversion, using the VIX index, to pick up risk premium movements. Global risk aversion is likely to affect Swiss term premia through safe haven demand (negative) as well as through risk premiums directly (positive), and we do not know a priori what sign to expect. Finally, we use the fixed legs from interest rates swaps for different maturities as dependent variables, in place of government bond yields, as an alternative measure of long-term yields.

[Table 4 to 6 about here]

Tables 4 to 6 present an overview of these robustness tests. With a few exceptions, the results from the baseline regression are robust to different specifications: in the baseline period, β_{pos} and β_{neg} are positive and in most cases statistically significant but not significantly different from each other. The impact of changes in short-term rates decreases with the maturity of the long-term interest rates. During the ZLB period β_{pos} generally increases, while the coefficients for negative changes in short-term interest rates either remain unchanged, only increase slightly or even turn statistically insignificant when controlling for additional variables. Consequently, the difference between the two coefficients are significantly different from each other. The overall average effect of changes in short-term rates on changes in long-term rates increases. In the NIR period, β_{pos} decrease again but are still elevated compared to the levels in the baseline period. β_{neg} slightly increase to a the level above the baseline and ZLB period and turn statistically significant. The difference between β_{pos} and β_{neg} in most cases is not statistically significant anymore.

Tables 7 to 9 in the appendix show the results with the additional control variables and reveal that these additional control variables are rarely statistically significant, and that the baseline results are robust to these inclusions. Changes in the amount of SNB sight deposits show a significant although very small negative impact in the NIR period. An increase in sight deposits thus leads to a slight decrease in long-term interest rates with a maturity of up to 5 years. Balance sheet increases, notably due to foreign policy interventions or liquidity expansions, are thus associated with a decrease in long-term yields, which is also consistent with a term premium effect of such measures as identified in Christensen and Krogstrup (2016). Furthermore, the coefficient for policy rate decreases exhibits a positive significant coefficient in the reference period, indicating an additional decrease in long-term interest rates when the policy rate was cut. The VIX Index has a statistically significant, but economically very small effect, and only in the NIR period for two maturities.

5.2 An alternative specification

The Ruge-Murcia (2006) model predicts that longer-term yields respond more strongly to positive than to negative short rate changes, *at a given interest rate level*. Our baseline regressions, following the earlier empirical literature, tried to capture this effect by considering subsamples such that within each sample short-term interest rates are either well above zero (where lower bound effects would not be expected to matter much anyway) or exhibit only small changes at low levels.

An empirical approach that perhaps more accurately captures the effects predicted by the theory is to introduce interaction terms with the (lagged) interest rate level – as a measure as the extent to which the lower bound is binding – and short rate changes. We consider the following regression specification as an alternative to the baseline specification:

$$\begin{aligned} \Delta R_t = \beta_0 + \beta_1 \mathbb{1}(\Delta r_t > 0)\Delta r_t + \beta_2 \mathbb{1}(\Delta r_t < 0)\Delta r_t + \beta_3 r_{t-1} \\ + \beta_4 \mathbb{1}(\Delta r_t > 0)\Delta r_t * r_{t-1} + \beta_5 \mathbb{1}(\Delta r_t < 0)\Delta r_t * r_{t-1} + \epsilon_t \end{aligned} \quad (2)$$

We estimate this specification over the whole sample period. Again β_1 and β_2 are expected to be positive. According to the model, β_4 and β_5 should be positive as well, i.e. the effect of short-term on long-term interest rates should be increasing in the level of the interest rates.

[Table 10 about here]

Changes in Swiss government bond yields are regressed on changes in 3-month Swiss franc Libor rates, i.e. using the same data as in the baseline specification. Table 10 shows the results for different maturities of government bond yields, which are in line with the previous findings. Both β_1 and β_2 are positive and decreasing with the maturity of the dependent variable. The impact of positive changes in short-term interest rates tends to be bigger than the one of negative changes, the difference between β_1 and β_3 decreases however with the maturity. The coefficients for the interaction terms, β_4 and β_5 are negative and significant: the effect of short-term interest rates on long-term interest rates is decreasing in the level of the rates. This is in line with the baseline results, but at odds with the theory. Note that these results are also robust to using alternative short- and long-term interest rates as well as additional control variables used above.[9]

6 Conclusion

This paper studies the transmission of changes in short-term interest rates to longer-term government bond yields when short-term rates are close to the zero lower bound or negative, focusing on Switzerland.

We find no evidence for a decline in the average effect of short rate changes on long term interest rates. During the period where short-term interest rates are close to zero, the transmission of short-term interest rates becomes asymmetric – positive changes in short-term interest

[9]Details are available from the authors upon request.

rates have a much bigger impact on long-term interest rates than negative changes in short-term interest rates. Since the SNB has implemented negative interest rates on sight deposits, the strength of this asymmetry has decreased again, suggesting that the transmission from short to long-term interest rates improved.

These findings have important policy implications for the use of negative interest rates as a monetary policy tool. First, the transmission of short rate cuts to longer term yields works in negative territory. Second, as short rates are normalized after a period close to the lower bound, positive changes in short-term interest rates may have unusually strong effects and long-term interest rates may adjust very quickly to changes in the policy rate.

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Tables and figures

Table 1: Baseline, sample: 01/10/2000 - 12/10/2008

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.472***	0.366***	0.292***	0.224***	0.186***	0.205***
	(5.26)	(6.11)	(5.92)	(4.71)	(3.90)	(5.00)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.324***	0.160	0.125	0.128*	0.166**	0.101**
	(3.38)	(1.31)	(1.65)	(2.58)	(3.08)	(2.78)
Constant	-0.001	-0.002	-0.001	-0.001	-0.001	-0.001
	(-1.07)	(-1.49)	(-1.51)	(-1.45)	(-0.96)	(-1.60)
Number of observations	1782	1783	1783	1783	1776	1646
R^2	0.052	0.043	0.029	0.021	0.018	0.016
H0: p-value	0.289	0.170	0.090	0.188	0.798	0.068

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor

Table 2: Baseline, sample: 12/11/2008 - 12/17/2014

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.633**	1.987**	2.992***	2.460**	2.365**	2.111**
	(2.71)	(2.95)	(3.85)	(3.02)	(2.80)	(2.94)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.369***	0.233	0.271*	0.333*	0.355**	1.960**
	(4.88)	(1.93)	(2.44)	(2.37)	(2.62)	(3.11)
Constant	-0.000	-0.001	-0.001	-0.001	-0.001	0.000
	(-0.55)	(-1.46)	(-1.48)	(-1.38)	(-1.24)	(0.05)
Number of observations	1187	1190	1111	1180	1173	1142
R^2	0.021	0.010	0.019	0.016	0.016	0.035
H0: p-value	0.038	0.010	0.001	0.010	0.019	0.881

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor

Table 3: Baseline, sample: 12/18/2014 - 03/30/2016

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.798***	1.520***	1.254***	0.479*	0.662**	0.782**
	(3.92)	(7.59)	(5.64)	(2.43)	(3.00)	(2.65)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.806***	0.740**	0.566***	0.444***	0.375*	0.302
	(4.81)	(3.03)	(4.31)	(5.24)	(2.46)	(1.40)
Constant	-0.002	-0.003	-0.002	-0.000	-0.000	-0.001
	(-0.68)	(-1.31)	(-0.87)	(-0.21)	(-0.21)	(-0.54)
Number of observations	255	255	255	255	255	255
R^2	0.322	0.358	0.259	0.098	0.081	0.070
H0: p-value	0.046	0.020	0.010	0.874	0.295	0.203

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor

Table 4: Robustness checks with alternative variables, sample: 01/10/2000 - 12/10/2008

Δr_t:	3M Libor (Baseline)	6M Libor	1Y IRS	3M OIS	3M Libor with add. control variables
$\Delta R_{i,t}$: 5-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.366***	0.480***	0.381***	0.318***	0.355***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.16	0.208	0.382***	0.329**	0.129
R^2	0.043	0.072	0.217	0.081	0.074
H0: p-value	0.17	0.143	0.988	0.944	0.094
$\Delta R_{i,t}$: 10-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.224	0.295***	0.283***	0.190*	0.224***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.224***	0.165*	0.350***	0.227***	0.116**
R^2	0.021	0.035	0.167	0.039	0.036
H0: p-value	0.188	0.161	0.389	0.736	0.109
$\Delta R_{i,t}$: 5-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.348***	0.464***	0.483***	0.354***	0.471***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.229***	0.281***	0.513***	0.418***	0.233***
R^2	0.05	0.081	0.353	0.114	0.117
H0: p-value	0.142	0.085	0.797	0.652	0.012
$\Delta R_{i,t}$: 10-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.193***	0.252***	0.352***	0.234**	0.258***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.166***	0.191***	0.428***	0.285***	0.166***
R^2	0.021	0.031	0.232	0.056	0.045
H0: p-value	0.631	0.333	0.423	0.672	0.0135

Notes: Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$

Table 5: Robustness checks with alternative variables, sample: 12/11/2008 - 12/17/2014

Δr_t:	3M Libor (Baseline)	6M Libor	1Y IRS	3M OIS	3M Libor with add. control variables
$\Delta R_{i,t}$: 5-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.987**	4.617***	1.158***	0.04	1.906**
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.233	0.224	0.911***	0.305***	0.144
R^2	0.010	0.034	0.250	0.013	0.022
H0: p-value	0.010	0.000	0.361	0.045	0.019
$\Delta R_{i,t}$: 10-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	2.460**	4.207***	1.236***	0.067	2.357**
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.333*	0.320*	0.889***	0.503***	0.207
R^2	0.016	0.031	0.238	0.031	0.023
H0: p-value	0.010	0.000	0.247	0.022	0.029
$\Delta R_{i,t}$: 5-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	2.344***	3.530***	1.398***	0.145	2.366**
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.381*	0.348***	1.081***	0.388***	0.202
R^2	0.023	0.034	0.415	0.027	0.038
H0: p-value	0.008	0.000	0.196	0.121	0.006
$\Delta R_{i,t}$: 10-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	2.660***	3.27***	1.377***	0.077	2.573***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.226	0.198	0.968***	0.519***	0.022
R^2	0.012	0.020	0.270	0.031	0.018
H0: p-value	0.001	0.000	0.235	0.004	0.002

Notes: Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$

Table 6: Robustness checks with alternative variables, sample: 12/18/2014 - 06/30/2016

Δr_t:	3M Libor (Baseline)	6M Libor	1Y IRS	3M OIS	3M Libor with add. control variables
$\Delta R_{i,t}$: 5-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.520***	1.428***	1.454****	0.836**	1.507***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.740**	0.764**	0.742***	0.632***	0.918***
R^2	0.358	0.384	0.634	0.25	0.397
H0: p-value	0.020	0.034	0.003	0.555	0.108
$\Delta R_{i,t}$: 10-year government bond yield					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.479*	0.557***	0.897***	0.458*	0.447*
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.444***	0.635***	0.559***	0.303**	0.525**
R^2	0.098	0.308	0.342	0.082	0.103
H0: p-value	0.874	0.018	0.124	0.56	0.778
$\Delta R_{i,t}$: 5-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.971***	0.898***	1.032***	0.464*	0353***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.808***	0.873***	0.905***	0.658***	0.18***
R^2	0.388	0.44	0.738	0.251	0.089
H0: p-value	0.164	0.846	0.398	0.464	0.022
$\Delta R_{i,t}$: 10-year IRS fixed leg					
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.629***	0.628***	0.955***	0.465*	0.200***
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.584***	0.645***	0.702***	0.444*	0.140***
R^2	0.167	0.204	0.449	0.125	0.037
H0: p-value	0.728	0.897	0.317	0.946	0.301

Notes: Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$

Table 7: Robustness check with additional control variables, sample: 01/10/2000 - 12/10/2008

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	0.454***	0.355***	0.289***	0.224***	0.187***	0.204***
	(4.92)	(5.85)	(5.70)	(4.58)	(3.81)	(4.85)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.276***	0.129	0.090	0.116**	0.127*	0.094**
	(3.52)	(1.19)	(1.38)	(2.77)	(2.16)	(3.09)
ΔS_t	-0.001	0.001	0.000	0.001	-0.001	0.001
	(-0.91)	(1.38)	(0.20)	(1.30)	(-0.54)	(0.75)
$\mathbb{1}(\Delta E_t > 0)$	-0.002	-0.002	-0.003	-0.002	-0.002	-0.001
	(-0.46)	(-0.56)	(-0.91)	(-0.71)	(-0.60)	(-0.36)
$\mathbb{1}(\Delta \bar{r}_t > 0)\Delta \bar{r}_t$	0.018	-0.006	-0.012	-0.016	-0.005	-0.019
	(0.73)	(-0.43)	(-1.18)	(-1.56)	(-0.46)	(-0.84)
$\mathbb{1}(\Delta \bar{r}_t < 0)\Delta \bar{r}_t$	0.193***	0.167*	0.171*	0.100*	0.116	0.137***
	(3.38)	(2.05)	(2.36)	(2.05)	(1.69)	(3.33)
ΔV_t	0.000	-0.000	0.000	-0.000	-0.001	-0.000
	(0.33)	(-0.11)	(0.34)	(-0.49)	(-0.82)	(-0.65)
Constant	-0.001	-0.001	-0.001	-0.001	-0.000	-0.001
	(-0.71)	(-1.04)	(-0.83)	(-0.85)	(-0.39)	(-1.03)
Number of observations	1689	1690	1690	1690	1683	1561
R^2	0.073	0.074	0.065	0.036	0.036	0.038
H0: p-value	0.160	0.094	0.025	0.109	0.458	0.041

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor, ΔS_t denotes the changes in sight deposits held at the SNB, $\mathbb{1}(\Delta E_t > 0)$ is an indicator variable for days at the end of month and end of minimum reserve requirement period, $\Delta \bar{r}_t$ denotes changes in the policy rate, ΔV_t denotes the changes in the VIX index.

Table 8: Robustness check with additional control variables, sample: 12/11/2008 - 12/17/2014

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.610**	1.906**	2.891***	2.357**	2.300**	2.040**
	(2.68)	(2.84)	(3.73)	(2.88)	(2.75)	(2.79)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.132	0.144	0.025	0.207	0.216	2.364***
	(0.65)	(0.47)	(0.07)	(0.46)	(0.56)	(3.49)
ΔS_t	-0.001*	-0.000	-0.000	-0.000	-0.001	0.000
	(-2.28)	(-1.43)	(-1.22)	(-0.99)	(-1.77)	(1.21)
$\mathbb{1}(\Delta E_t > 0)$	0.005	0.006	-0.000	-0.004	-0.001	-0.005
	(1.45)	(1.14)	(-0.05)	(-1.26)	(-0.16)	(-1.41)
$\mathbb{1}(\Delta \bar{r}_t > 0)\Delta \bar{r}_t$	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
$\mathbb{1}(\Delta \bar{r}_t < 0)\Delta \bar{r}_t$	0.129	0.040	0.136	0.069	0.071	-0.316**
	(1.23)	(0.26)	(0.68)	(0.28)	(0.33)	(-3.11)
ΔV_t	-0.001	-0.001*	-0.001*	-0.001	-0.001	-0.000
	(-1.74)	(-2.40)	(-2.04)	(-1.70)	(-1.43)	(-0.32)
Constant	-0.001	-0.002*	-0.002	-0.001	-0.001	0.001
	(-1.28)	(-2.22)	(-1.69)	(-0.99)	(-1.19)	(0.51)
Number of observations	1124	1127	1051	1118	1111	1085
R^2	0.037	0.022	0.028	0.023	0.023	0.043
H0: p-value	0.022	0.019	0.001	0.029	0.030	0.759

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor, ΔS_t denotes the changes in sight deposits held at the SNB, $\mathbb{1}(\Delta E_t > 0)$ is an indicator variable for days at the end of month and end of minimum reserve requirement period, $\Delta \bar{r}_t$ denotes changes in the policy rate, ΔV_t denotes the changes in the VIX index.

Table 9: Robustness check with additional control variables, sample: 12/18/2014 - 06/30/2016

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.833***	1.507***	1.244***	0.447*	0.638**	0.756*
	(3.95)	(6.65)	(5.19)	(2.07)	(2.65)	(2.38)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.651*	0.918***	0.763***	0.525**	0.467***	0.471*
	(2.29)	(3.42)	(4.45)	(3.28)	(3.84)	(2.08)
ΔS_t	-0.004***	-0.002*	0.002	0.001	0.000	0.001
	(-4.45)	(-2.22)	(1.80)	(1.73)	(0.14)	(0.70)
$\mathbb{1}(\Delta E_t > 0)$	-0.006	-0.006	-0.008	-0.011	-0.009	-0.014*
	(-1.02)	(-1.08)	(-1.48)	(-1.85)	(-1.48)	(-2.10)
$\mathbb{1}(\Delta \bar{r}_t > 0)\Delta \bar{r}_t$	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(.)	(.)	(.)	(.)	(.)
$\mathbb{1}(\Delta \bar{r}_t < 0)\Delta \bar{r}_t$	-0.008	-0.229	-0.112	-0.047	-0.124*	-0.165
	(-0.07)	(-1.96)	(-1.35)	(-0.75)	(-2.34)	(-1.48)
ΔV_t	-0.001	-0.002	-0.001	-0.000	-0.001	-0.001
	(-0.91)	(-1.23)	(-0.82)	(-0.27)	(-0.44)	(-0.65)
Constant	0.001	-0.000	-0.000	0.002	0.001	0.001
	(0.35)	(-0.19)	(-0.21)	(0.62)	(0.54)	(0.44)
Number of observations	239	239	239	239	239	239
R^2	0.359	0.397	0.269	0.103	0.083	0.088
H0: p-value	0.034	0.108	0.114	0.778	0.533	0.479

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
H0: $\mathbb{1}(\Delta r_t > 0)\Delta r_t = \mathbb{1}(\Delta r_t < 0)\Delta r_t$
Δr_t denotes the changes in 3-month Swiss franc Libor, ΔS_t denotes the changes in sight deposits held at the SNB, $\mathbb{1}(\Delta E_t > 0)$ is an indicator variable for days at the end of month and end of minimum reserve requirement period, $\Delta \bar{r}_t$ denotes changes in the policy rate, ΔV_t denotes the changes in the VIX index.

Table 10: Robustness check with alternative specification

ΔR_t = gov. bond yields	2-year	5-year	7-year	10-year	15-year	20-year
$\mathbb{1}(\Delta r_t > 0)\Delta r_t$	1.273***	0.989***	0.852***	0.462***	0.482***	0.565***
	(5.13)	(5.33)	(5.07)	(4.22)	(3.48)	(3.59)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t$	0.668***	0.485***	0.410***	0.376***	0.363***	0.313*
	(5.49)	(3.47)	(4.67)	(5.80)	(4.04)	(2.54)
r_{t-1}	-0.001	-0.000	-0.000	-0.000	0.000	-0.000
	(-1.29)	(-0.72)	(-0.74)	(-0.79)	(0.10)	(-0.51)
$\mathbb{1}(\Delta r_t > 0)\Delta r_t * r_{t-1}$	-0.308**	-0.239***	-0.216***	-0.092*	-0.116*	-0.140*
	(-3.27)	(-3.38)	(-3.39)	(-2.10)	(-2.26)	(-2.37)
$\mathbb{1}(\Delta r_t < 0)\Delta r_t * r_{t-1}$	-0.167***	-0.147*	-0.129***	-0.112***	-0.081*	-0.094
	(-3.30)	(-2.40)	(-3.45)	(-3.52)	(-1.97)	(-1.75)
Constant	-0.000	-0.001	-0.001	-0.001	-0.001	-0.001
	(-0.50)	(-1.70)	(-1.35)	(-0.94)	(-1.05)	(-1.25)
Number of observations	3224	3228	3149	3218	3204	3043
R^2	0.077	0.060	0.046	0.025	0.022	0.021

Notes: Robust standard errors in parentheses.
Statistical significance indicated with *** if $p < 0.001$, ** if $p < 0.01$ and * if $p < 0.05$.
Δr_t denotes the changes in 3-month Swiss franc Libor

Figure 1: EURCHF exchange rate. Event A: Lehman bankruptcy. Event B: Introduction of the EURCHF floor. Event C: Discontinuation of the EURCHF floor, introduction of negative interest rates on sight deposits with the SNB.

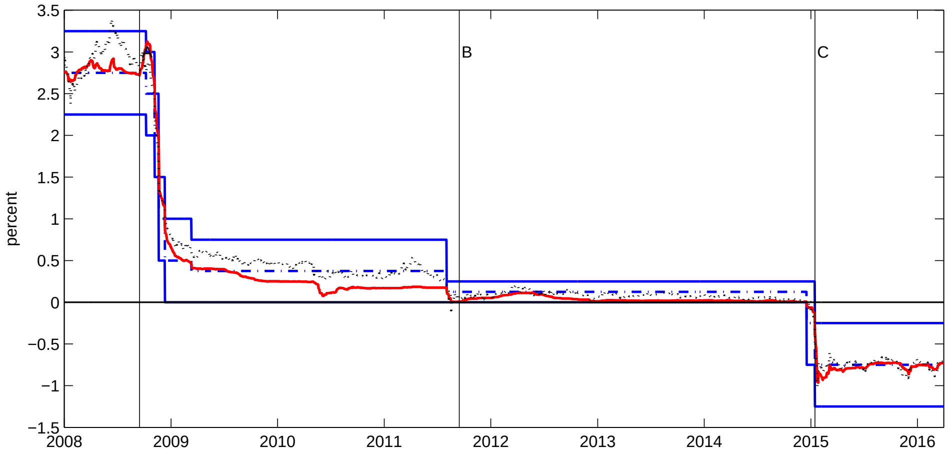

Figure 2: Swiss franc 3-month Libor (red solid line), 1-year interest rates swap rates (black dotted line, SNB target range (blue line) and middle of SNB target range (blue dashed line). Event A: Lehman bankruptcy. Event B: Introduction of the EURCHF floor. Event C: Discontinuation of the EURCHF floor, introduction of negative interest rates on sight deposits with the SNB.

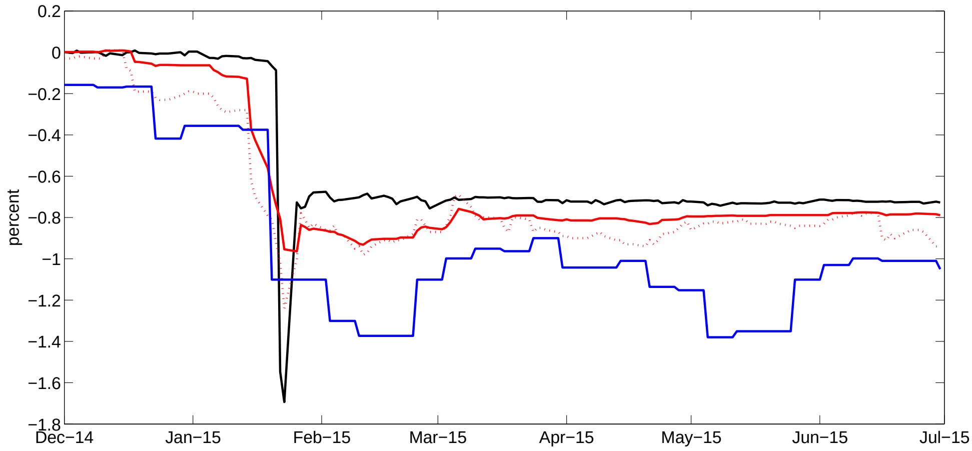

Figure 3: CHF money market interest rates after the announcement (15 January 2015) and introduction of negative interest rates (22 January 2015). The black line shows SARON, the red line the 3-month Swiss franc Libor, the red dotted line the first Future contract on the 3-month Swiss franc Libor and the blue line the yield of the 3-month Swiss government debt register claim auction.

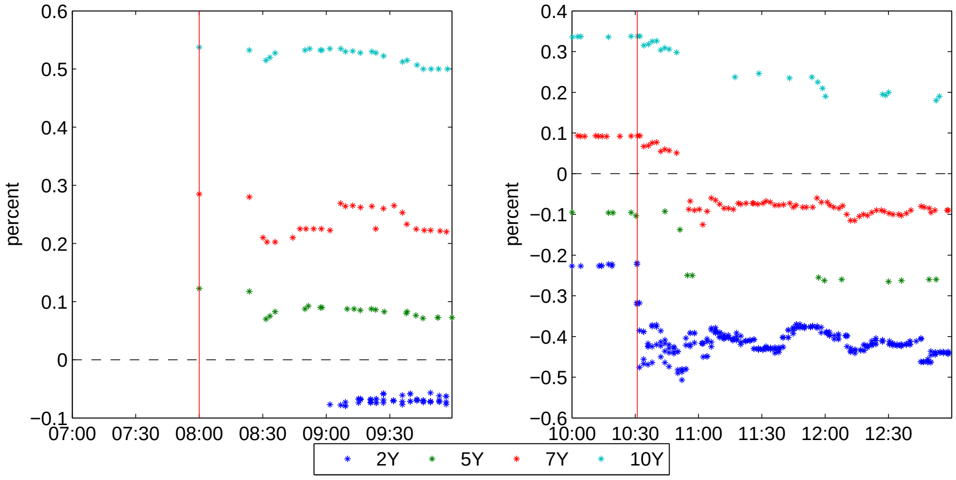

Figure 4: Left panel: intraday reaction of interest rate swap rates after the announcement of the introduction of negative interest rates of -0.25% on SNB sight deposit accounts on 18 December 2014; right panel: intraday reaction of interest rate swap rates after announcement of lowering the negative interest rates on SNB sight deposit accounts to -0.75% on 15 January 2015; the red lines indicate the time of the announcements.

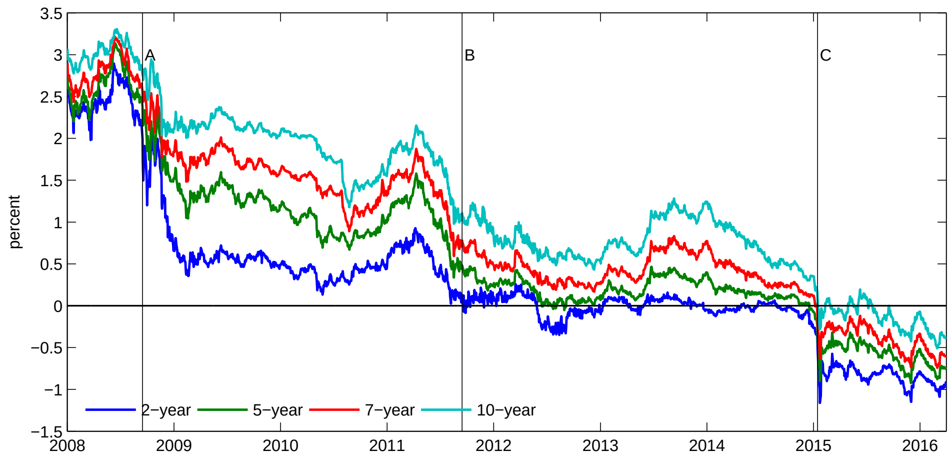

Figure 5: Swiss government bond yields, constant maturity. Event A: Lehman bankruptcy. Event B: Introduction of the EURCHF floor. Event C: Discontinuation of the EURCHF floor, introduction of negative interest rates on sight deposits with the SNB.