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Abstract

We ask whether the markets expected the Swiss National Bank (SNB) to discontinue the 1.20 cap on the Swiss franc against the euro in January 2015. In the run-up to the SNB announcement, neither options on the euro/Swiss franc nor FX liquidity indicated a significant shift in market expectations. Furthermore, we find that the SNB's verbal interventions during the period of cap enforcement reduced the uncertainty of future euro/Swiss franc rate significantly and therefore reinforced the perceived continuation of the policy.

Keywords: Swiss franc; risk-neutral distribution; FX liquidity; verbal interventions

JEL Classifications: E58, E44, G12

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1 Introduction

On September 6, 2011, the Swiss National Bank (SNB) set a cap on the Swiss franc's exchange rate against the euro to avert the risk of deflation resulting from a "massive overvaluation of the Swiss franc," see SNB (2011). The franc had appreciated significantly against the euro and the US dollar in the months prior to the announcement amid the intensifying euro area crisis. The appreciation posed a threat to the small open Swiss economy. With the policy rate already being at zero, the SNB decided to announce a minimum euro/Swiss Franc exchange rate by promising to buy foreign currency in unlimited quantities if necessary.

In principle, a commitment to keeping the domestic currency low is always credible because a central bank can print unlimited amount of its own currency to buy foreign exchange.[1] However, as the balance sheet of the central bank grows in size and becomes increasingly volatile, the central bank becomes exposed to various financial risks. Excessive volatility could lead to significant balance sheet losses and even to negative equity positions. As noted by Danthine (2012) and Jordan (2011), this is not a problem in the short term but could generate doubts regarding credibility in the long term.

In this paper, we ask two questions. First, did exchange rate markets understand these risks and expect the removal of the Swiss franc cap? Second, have the SNB's verbal interventions reinforced the cap by lowering the market-perceived uncertainty regarding the future euro/Swiss franc exchange rate?

To answer the first question, we analyze option price data on the euro/Swiss franc exchange rate and spot market data of various currency pairs with the Swiss franc in the run up to the SNB's announcement to remove the Swiss franc cap. Using option price data, we estimate the risk-neutral distribution of future euro/Swiss franc exchange and extract measures of market uncertainty and skewness of the risk-neutral distribution. Using spot data, we study market liquidity from the bid-ask spreads. The empirical evidence we present shows no dramatic shift in market expectations in the run up to the SNB's announcement indicating that removal of the Swiss franc cap was anticipated.

[1] Which is different from a situation in which the central bank is buying its own currency and selling foreign exchange in a hope that its reserves will not deplete before the goal is achieved.

We study the second question by regressing our measure of market uncertainty during the period of cap enforcement on the SNB's verbal interventions and a variety of financial market indicators. We consider a verbal intervention to be a speech made by a member of the SNB Governing Board that contained the wording "utmost determination" and/or "unlimited quantities" when discussing the Swiss franc cap. We show that these verbal interventions significantly reduced uncertainty of the future euro/Swiss franc rate and therefore underpinned the perceived continuation of the policy.

Several other papers study the SNB's exchange rate policy over this period. Hertrich and Zimmermann (forthcoming 2017) explore the credibility of the Swiss franc cap and find that the cap was never perfectly credible, as the estimated probability of the euro/Swiss franc exchange rate being below 1.20 was high. Hanke et al. (2015) and Jermann (forthcoming 2017) report increasingly lower estimates of the break probability and conclude that the market's confidence in the SNB's commitment increased over time, especially from late-2012 until the end of their samples. We contribute to this literature by providing evidence on *(a)* whether the option-implied distributions can be explained by central bank actions and measures of financial market uncertainty, and *(b)* the liquidity patterns around the discontinuation of the cap.

Our study also touches upon a large literature on central banks' verbal interventions in the foreign exchange market. Beine et al. (2009) show that issuing commentary statements during foreign exchange interventions tends to reduce exchange rate volatility. Fratzscher (2008) finds that communication policies by the central banks of the US, euro area and Japan have generally constituted an effective policy tool in influencing exchange rates in the desired direction. More specifically, Burkhard and Fischer (2009) find that SNB's repeated references of non-sterilized interventions during the period 2002 – 2005 depreciated the domestic currency and proved to be a useful communication tool. Janssen and Studer (2014a) employ the Krugman (1991) model to show that market expectations that the SNB will intervene on the foreign exchange market, if the euro/Swiss franc exchange rate surpasses the announced bounds, was most of the time sufficient to stabilize the rate during the cap enforcement. Jansen and De Haan (2005) study the reaction of the conditional mean and volatility of the euro/US dollar exchange rate to statements by European

Central Bank (ECB) officials and conclude that those statements mainly influenced the conditional volatility.

The reminder of the paper is organized as follows. In Section 2, we introduce the dataset. Section 3 lays out the methodology, and Section 4 reports our findings.

2 Data

The section begins by illustrating the option data we use to extract the risk-neutral distribution of the future euro/Swiss franc exchange rate. The second part of the section introduces the spot market data we use in our analysis of bid-ask spreads. Finally, the third part illustrates our dataset of the SNB's verbal interventions together with other financial market variables we control for in the analysis.

2.1 Option data

The option data are from Bloomberg and comprise five implied volatilities on the following instruments: delta-neutral straddle, 25-delta risk reversal, 25-delta butterfly, 10-delta risk reversal and 10-delta butterfly. We use composite indicative quotes calculated daily at 17:00 New York time. The maturities in the sample are 3, 6 and 12 months. The sample period runs from the beginning of September 2011 until the end of April 2015.

These instruments can be used to back out implied volatilities and option prices for five different call options (see Malz (2014) and Wystup (2006)), which are used together with the forward price in the estimation. Forward prices at respective horizons are taken from Bloomberg. Risk-free rates are proxied by euro and Swiss franc LIBOR rates of the same maturity as the options.

Figure 1 illustrates the available strike prices in the data set. The span of strike prices changes over time, being considerably high in mid-2012 and fairly modest in mid-2014. The option market is organized in such a way that a higher perceived uncertainty about the future euro/Swiss franc exchange rate leads to a wider span of strike prices. Interestingly, there is almost always one strike price below 1.20, with the exception of the 3-month horizon during mid/late 2013. Analysis of the trading costs (not reported) suggests that the liquidity of these instruments was good during the sample period.

The prices of the options are best illustrated by the implied volatilities, obtained by inverting the Black-Scholes formula. Figure 2 shows the implied volatilities for the 3-month horizon for each of the five strike prices. The average (across the five options/strike prices) can be thought of as a the general market uncertainty—and appears to be strongly linked to the span of the strike prices in Figure 1. We are going to explore this stylized fact in our estimation method.

Figure 2 also provides a rough indicator of the "skewness" of the market's subjective distribution. If the implied volatility of the option with the lowest (highest) strike price is high, then that means that the market is willing to pay a high price for options that pay off at low (high) exchange rates. In mid-2012, the implied volatility was much higher for the option with the lowest strike price than for the option with the highest. This asymmetry indicated that the market perceived lower euro/Swiss franc exchange rate with higher probability. In mid-2013, we observe exactly the opposite. Toward the end of the sample, we again see the lowest-strike implied volatility rising above the one of the highest strike, but in a less dramatic way relative to 2012. We present more precise methods of measuring uncertainty and skewness in the following section, as they play key roles in our analysis of market expectations and the effect of verbal interventions.

We also study the morning of January 15, 2015, which is the day when the SNB discontinued the Swiss franc cap, by using 15-minute observations between 8:30 and 12:30.

2.2 Spot market data

Our analysis of the bid-ask spreads uses bid and ask spot quotes of the 9 most traded currency pairs against the Swiss franc: AUD, CAD, NZD, GBP, JPY, USD, NOK, SEK, DKK. Similar to option data, we use the composite indicative quotes from Bloomberg obtained at 17:00 New York time. The high-frequency analysis features

Bloomberg bid and ask quotes of the same currency pairs snapped at 30-minute intervals.

2.3 SNB's verbal interventions and control variables

Announcing the decision to impose a cap on the Swiss Franc against the euro, the SNB pledged to "enforce this minimum rate with the utmost determination and [...] buy foreign currency in unlimited quantities." The same wording was subsequently used in a variety of speeches by the members of the SNB Governing Board. In particular, there were 27 speeches during the period from September 6, 2011, to January 14, 2015, that contained the wording "utmost determination" and/or "unlimited quantities"; see Table 1. Most of these verbal interventions were delivered by Thomas Jordan, four of them by Fritz Zurbrügg, three of them by Jean-Pierre Danthine, and one of them by Philipp Hildebrand.

Our dataset also includes a number of financial market variables that we control for when regressing market beliefs on SNB's verbal interventions. First, we collect major announcements and regular policy decisions by the ECB that might have considerably affected the option market for the euro/Swiss franc rate, see Table 1. In addition, our dataset includes VIX (an option-based volatility index on S&P 500) published by CBOE, the TED spread (a spread between a USD Libor rate and a T-bill rate) published by St.Louis Federal Reserve, the 5-year European sovereign CDS spread from Bloomberg and the 10-year US term premium of Kim and Wright (2005) available from the Federal Reserve's official website.

Finally, the SNB intervened frequently on the spot market during the cap enforcement, see for example Hertrich (2016). As already noticed in the introduction, verbal interventions during the periods of foreign exchange interventions are found to reduce exchange rate volatility according to Beine et al. (2009). We therefore control for the actual interventions of the SNB by using daily data on the total amount of sight deposits that private banks in Switzerland hold by the SNB. However, given the sensitivity of the data, we report all the results without sight deposits as a control variable and acknowledge that excluding this control variable does not alter our results significantly.[2]

3 Extracting risk-neutral distribution from options

Our goal is to extract the risk neutral distribution of the future euro/Swiss franc exchange rates in a flexible way. The section starts by explaining the method we use. Next, we illustrate a few examples of fitted risk-neutral distributions and provide an overview of how we calculate measures of uncertainty and skewness from the fitted distribution. Finally, we discuss the details of the estimation approach.

3.1 The method

The price of an option is driven primarily by the market's belief regarding whether the option will pay off at maturity – and if so, by how much. For instance, a European call option with a strike price of 1.30 only pays off if the exchange rate at maturity is above 1.30. If this option is trading at a non-zero price, then an exchange rate above 1.30 is considered a possibility. Our paper extends this logic by using a cross section of options with different strike prices to recover the shape of the market-perceived distribution of the future euro/Swiss franc exchange rate.

Option pricing theory holds that, if the market beliefs regarding the logarithm of the future exchange rate are well-described by a normal distribution with mean μ and variance σ^2, option prices can be expressed in terms of the Black-Scholes formula. For the subsequent analysis, we let $G(\mu, \sigma^2, X)$ denote the Black-Scholes price of a call option with strike price X.

To allow for a flexible distribution, e.g. one that exhibits skewness or fat tails, we assume instead that the distribution of future euro/Swiss franc exchange rate can be approximated by a mixture of two lognormal distributions as in Ritchey (1990).

[2] All the regression results including sight deposits as a control variable are available on request.

In this case, the price of a European call option C can be shown to be

$$C(\alpha, \mu_1, \sigma_1^2, \mu_2, \sigma_2^2, X) = \alpha G(\mu_1, \sigma_1^2, X) + (1 - \alpha) G(\mu_2, \sigma_2^2, X), \tag{1}$$

where α is the weight on the first lognormal distribution with mean μ_1 and variance σ_1^2. Similarly, $1 - \alpha$ is the weight on the second lognormal distribution (with mean μ_2 and variance σ_2^2). Clearly, the Black-Scholes model is a special case.

For each trade time and horizon, we fit the five parameters $(\mu_1, \sigma_1^2, \mu_2, \sigma_2^2, \alpha)$ by minimizing the sum of weighted squared pricing errors, trade price $C(X_i)$ minus model price, for the options and the forward (which can be seen as an option with a zero strike price). That is, we minimize

$$\sum_{i=1}^{6} w_i [C(X_i) - C(\alpha, \mu_1, \sigma_1^2, \mu_2, \sigma_2^2, X_i)]^2, \tag{2}$$

where X_i are the six different strike prices (which is zero for the forward). The weights w_i of the options are the inverse of the (Black-Scholes) vegas, and thus, we effectively minimize the sum of fitted errors of the implied volatilities (see Carr and Wu (2007)). The weight of the forward price is the same as for the most important option. This approach is repeated for each trading day/time and for each maturity (3, 6 and 12 months).

The five parameters $(\mu_1, \sigma_1^2, \mu_2, \sigma_2^2, \alpha)$ completely characterize the risk-neutral distribution. It corresponds to market's subjective beliefs in a case in which the euro/Swiss franc embeds no risk premium.

We find that adjusting the results for risk premia have only minor effects, except possibly for a few days after January 15, 2015. In particular, we regress ex post risk premia of the exchange rate on key risk drivers 2002:01–2011:08 and use the coefficients to approximate the dynamic path of risk premia 2011:09–2015:04. Replacing the ex post premia with ex ante premia using survey data from Consensus Economics gives even more muted results, see Appendix B for details. The rest of the paper will therefore use the risk-neutral distributions without any adjustments.

3.2 Examples of fitted distributions

Figure 3 shows a few examples of the fitted risk-neutral probability density functions (pdf) for the 3-month horizon. The left subplot highlights how the distribution changed between early and mid-January 2013. On January 4, 2013, the distribution was concentrated around 1.20 with a somewhat extended upper tail. Eleven days later, the distribution had shifted upwards and was considerably more dispersed (higher uncertainty) and had an even more extended upper tail (higher skewness). Similarly, the right subplot compares the distributions on January 14 and 15, 2015. On 14 January, the distribution was concentrated around 1.20, but on the day after the distribution had shifted dramatically downwards and was much more dispersed.

3.3 Uncertainty and skewness

Once we have fitted distributions for each trading day and horizon, we compute measures of uncertainty (u) and skewness (s) for day t and horizon h as

$$\begin{aligned} u_{t,h} &= \frac{P90_{t,h} - P10_{t,h}}{2.56} \\ s_{t,h} &= \frac{(P90_{t,h} - S_{t,h}) + (P10_{t,h} - S_{t,h})}{P90_{t,h} - P10_{t,h}} \end{aligned} \tag{3}$$

where $P10$ and $P90$ denote the 10th and 90th percentiles of the fitted distribution, S denotes the spot exchange rate, and the value of 2.56 in the denominator of (3) normalizes the inter-decile range such that $u_{t,h}$ equals the standard deviation of S_t, if S_t follows a Gaussian distribution. Measures in (3) are considered to be robust measures of the standard deviation and the skewness, see Hinkley (1975). In fact, we find that they are more stable than the traditional central second and third moments of the estimated distributions. We get very similar results if we instead use the 25th and 75th percentiles.[3]

[3]For instance, on the 3-month horizon, the 10th and 25th percentiles have a correlation of 0.99 in levels and also in first-differences. For the 75th and 90th percentiles, the correlations are 0.97 and 0.94 respectively.

To obtain reliable results, we impose two conditions on the parameters: that σ_1 and σ_2 do not differ too much and that μ_1 and μ_2 are not too far from the forward price. This mitigates the effects of (a) having only six data points in each cross section (five options and the forward rate); and (b) sometimes noisy data. Fitting without any restrictions gives similar medium- and long-run movements in the 10th and 90th percentiles, but "noisier" day-to-day changes.[4]

3.4 Discussion of the estimation method

There are several advantages of assuming a mixture of lognormal distributions. First, it excludes negative probabilities and produces relatively stable estimates unlike non-parametric methods. Second, the mixture of lognormals gives closed form solutions for the option prices, which facilitate estimation and allow us to impose restrictions that make the estimation more stable. Third, the approach facilitates a systematic discussion of the role of risk premia. Fourth, and perhaps most important, the method is fairly flexible and can be estimated also on data sets with few options.

There are also some disadvantages of using a mixture of lognormals. To begin with, our estimation method is parametric and its output exhibits estimation errors. Nevertheless, our method produces very small estimation errors, because there is only one degree of freedom — 5 parameters and 6 data points. The median absolute error for the implied volatilities is 0.03% to 0.05% depending on the horizon, whereas the implied volatilities are typically around 5% to 10%, see Figure 2. Moreover, we compare our uncertainty proxy to the model-free implied variance calculated along the lines of Jiang and Tian (2005). We find a correlation of 0.94–0.96 between the two series depending on the option time to expiry, which suggests that estimation errors have very small impact on the uncertainty estimates.

In addition, our method fits a smooth distribution to the data and therefore tends to overestimate the probability mass below a threshold, e.g. 1.20, when there are

[4]Specifically, we impose $3/4 < \sigma_1/\sigma_2 < 4/3$ and $4/5 < \mu_i/F < 5/4$, where F is the forward price. On the 3-month horizon, the two estimation methods give similar mean absolute deviations (mad) of the levels of the 10th and 90th percentiles, but the method without restrictions gives a 50% higher mad in first-differences. The percentiles of the two estimation methods have correlations of 0.99 in levels 0.85 in first-differences.

no put options below that threshold. Nevertheless, there are few such instances in the sample, see Figure 1 of the data section. Moreover, we use a real-life example from May 17, 2013 to show that our measures of uncertainty and skewness in those instances change negligibly, when we assume a truncated distribution instead of the mixed lognormal.

More specifically, we take the truncated distribution calibrated to market data to be "true" and use it to calculate consistent option prices for the available strike prices. We then apply our estimation approach to this artificial data, see Figure 4. Clearly, the estimated distribution implies some probability mass below 1.20. Nevertheless, the 10th percentile is very similar in the two distributions (1.215 and 1.213) and the same holds for the 90th percentile (1.308 and 1.306). Consequently, the measures of uncertainty and skewness are almost identical, which means that our method provide robust results and can handle a variety of scenarios.

One last side note: pooling the data across the horizons (3, 6 and 12 months) could potentially help with augmenting the cross-section, but empirical results suggest that straightforward cross-horizon restrictions do not hold in our sample. In particular, the variances do not scale with the horizon. On several important occasions, the 3-month distribution changes much more significantly than the 12-month distribution.

4 Results

The first part of our results analyzes daily data, and specifically the option market data and the spot market data, toward the discontinuation of the Swiss franc cap. In the second part of the section, we zoom-in on January 15, 2015, and look at high-frequency data from options and spot markets around the announcement by the SNB to discontinue the Swiss franc cap.

4.1 Evidence from daily option market data

This subsection is structured as follows. First, we illustrate the evolution of uncertainty and skewness toward the SNB's decision to discontinue the Swiss franc cap. Second, we relate the measures of uncertainty and skewness implied by the estimated distribution to the speeches by SNB officials intended to reinforce the cap and ask whether these verbal interventions significantly affected the estimated measures. Third, we show how the effect of the SNB's verbal interventions propagated over time.

4.1.1 Toward the discontinuation of the Swiss franc cap

In the weeks prior to the SNB announcement to discontinue the Swiss franc cap, we observe no significant changes in uncertainty or skewness of the risk-neutral distribution, see Figure 5. The closest significant change in uncertainty before January 15, 2015 was a drop observed on December 1, 2014, which was the first trading day after the so-called "Save our Swiss Gold" initiative was rejected at the referendum held on Sunday November, 30, 2014. Before that, uncertainty increased significantly on October 6, 2014 amid weak industrial production data from Germany. Around these times, skewness displayed no significant changes. Consequently, we find no dramatic shift in market expectations in the run up to the SNB's announcement which would indicate that discontinuation of the Swiss franc cap was anticipated.

There is a considerable variation in our measures over time. Uncertainty dropped significantly in the months after the cap was introduced. Although it displayed several significant spikes, uncertainty was gradually decreasing throughout the period of cap enforcement. This result is in line with Hertrich and Zimmermann (forthcoming 2017), who find that the "break probability", i.e. the probability that the SNB would discontinue the cap within the option expiration, was high at the inception of the Swiss franc cap, and that it dropped considerably over time. In autumn 2014, uncertainty started to rise steadily, but remained relatively low in magnitude.

Changes in skewness during the period of cap enforcement are interesting in their own right. Since the mid-2012 and presumably after the famous "whatever-it-takes" speech by the ECB's president Mario Draghi, skewness trended upwards (toward franc depreciation) for several months and remained high throughout 2013. On 5th December 2013, skewness estimated from 3-month options collapsed to zero. On that very same day, the ECB decided to keep its policy rates unchanged, but reiterated its forward guidance that key ECB rates are expected to remain low "for an extended period of time." For the rest of the sample, skewness hovered around zero and moved significantly on two occasions in May 2014, once toward the Swiss franc depreciation and one toward its appreciation.

Finally, one can think about the joint dynamics of uncertainty and skewness during this period. The spike in uncertainty in early May 2012 and a less-pronounced one at the end of 2014 are short-lived and come down within a month—they are also associated with drops in the skewness (lower panel of Figure 5) towards a neutral value. This means that these movements were "non-directional." In contrast, the increases in uncertainty in January and April 2013 are much more persistent and are associated with high (and with a lag, further increasing) skewness. This means that these movements were "directional" where investors adjusted their beliefs towards franc depreciation—and were rather slow to dispose with them.

4.1.2 The SNB's verbal interventions and uncertainty

In this section, we explore whether the SNB's verbal interventions reinforced the continuation of the Swiss franc cap by lowering the market-perceived uncertainty regarding the future euro/Swiss franc exchange rate. Our preliminary analysis showed that those interventions had no significant effect on the estimated skewness of risk-neutral distribution.[5] Therefore, we focus entirely on analyzing the effect of verbal interventions on uncertainty. A verbal intervention is considered to be a speech made by a member of the SNB Governing Board that used the words "utmost determination" and/or "unlimited quantities", see Section 2.3 and Table 1.

We run the following regression

[5] We find that the only variable that significantly co-moves with our skewness measure are changes in VIX. In particular, increases in VIX are associated with a drop in skewness indicating Swiss franc appreciation.

$$u_{t,h} - u_{t-1,h} = \alpha + \beta d_t + \gamma' \left(X_t - X_{t-1} \right) + \varepsilon_t, \tag{4}$$

where u_t is our uncertainty measure estimated on either 3-month, 6-month or 12-month options, d_t is a dummy variable that takes the value of one on the day of the verbal intervention and zero otherwise, and X_t is a vector of control variables. Beside all the variables mentioned in Section 2.3, X_t also includes the spot euro/Swiss franc exchange rate to account for level-dependency of uncertainty. We estimate the regression in first-differences instead of levels in order to avoid issues of multicollinearity among the right-hand side variables and serial correlation in the error term. We apply the Newey-West standard errors when producing t-statistics to account for any remaining autocorrelation.

Apart from affecting contemporaneous changes in uncertainty, the SNB speeches might have also affected the following-day changes in uncertainty. Therefore, we also run the following regression

$$u_{t+1,h} - u_{t,h} = \alpha + \beta d_t + \gamma' \left(X_{t+1} - X_t \right) + \varepsilon_{t+1}. \tag{5}$$

Table 2 shows the results of regressions (4) and (5). We find that SNB's verbal interventions significantly reduced the estimated uncertainty regarding the future value of the euro/Swiss franc exchange rate. They were especially effective in lowering uncertainty on the day following the day of the speech. In particular, a verbal intervention on day t lowered uncertainty on day $t+1$ by 13 to 21 pips, depending on the option expiry. Meanwhile, a verbal intervention on day t resulted in significantly lower uncertainty on the same day only if the uncertainty measure is extracted from 12-month options.

When it comes to control variables, the announcements made by the ECB tend to increase uncertainty of the future euro/Swiss franc rate, but the coefficient is significant only in the regression with 3-month uncertainty. The troubles in the euro zone measured by the average CDS spread across EU countries, as well as stock market volatility in the US measured by VIX, increased uncertainty, although the effect is relatively small. The stronger the signs of global economic recovery measured by the 10-year US term premium, the lower is the uncertainty. Finally, the lower the spot rate, the lower the uncertainty.

4.1.3 Propagation of the SNB's verbal interventions over time

We have seen that the speeches by the members of the SNB Governing Board reduced the market uncertainty both on the day of the speech and on the day after. In fact, the impact might have persisted even after the next day and it would be interesting to trace its propagation. We do so by means of regression and by conducting an event study.

To begin with, we run the following regression

$$u_{t+k,h} - u_{t,h} = \alpha + \beta d_t + \gamma' \left(X_{t+k} - X_t\right) + \varepsilon_{t+k}, \tag{6}$$

where we set $k = [1, 5]$. In other words, we measure the effect of SNB's verbal interventions at t on k-day difference in uncertainty at $t + k$. We find that these SNB speeches resulted in a significant decline of uncertainty for several subsequent days, see Table 3. In particular, the cumulative effects seem to be the highest around the fourth day after the speech amounting to as much as 40 pips reduction in uncertainty.

We conduct an event study of the daily changes in uncertainty along the lines of Fama et al. (1969). First, we define the "normal" change as that prevailing on average over day $t - 45$ to day $t - 1$, where t is the day of a speech (similar to (Brown and Warner, 1980)).[6] If two speeches are less than 45 days apart, then we reduce the estimation window to avoid overlap. Second, the "abnormal" change on day t is the actual change minus the "normal" change. Finally, we use the standard deviation on days $t-45$ to $t-1$ (or in the shorter interval as above) to test whether the abnormal change is statistically significant.

[6] We have ascertained that changing the estimation window (for instance, to 22 days) has a negligible impact on the results.

Figure 6 shows average (across speeches) *cumulative changes* in uncertainty at different days after a speech, as well as the lower part of a 95% confidence interval around zero. In line with the previous findings, we see that the first day's change in uncertainty is negative and marginally significant. During the next three days, the uncertainty continues to decline significantly, and it is the fourth and fifth day after a speech on which uncertainty stabilizes around a lower level relative to the day before the speech. The effect is pronounced at all considered horizons.

4.1.4 Choice of wording

The wording "utmost determination" was used repeatedly by SNB officials and was often quoted in the media. This section studies whether other phrases played an important role in affecting market uncertainty.

To address this question, we (1) filter the words pronounced in each speech according to the standard text analytics rules, (2) aggregate some of them into groups based on their topic (e.g. "export" and "import"; see Table 6 in the Appendix), (3) record frequencies of occurrence of words within each group across speeches.

To overcome the problem with many possible word groups, we repeatedly draw random samples of 3 word groups and substitute them for the dummy variable in model (5)—and then record the t-statistics. The result is that the group related to "utmost determination" has the most significant coefficient on average, followed by the group "global".

Table 4 reports the average $t-$ statistics for the "utmost determination." It shows that this particular word group remains highly significant also when entering the regression together with other groups.

4.2 Evidence from daily spot market data

Speculations that the Swiss franc cap was going to be removed would have forced liquidity providers to protect their positions against sudden market changes. Therefore, if they had anticipated the removal, we would most likely have observed a draining of liquidity on the market and a surge in bid-ask spreads.

In order to explore market liquidity in the run-up to the SNB's announcement, we look beyond the euro/Swiss franc currency pair and build a weighted average bid-ask spread across the exchange rates of 9 currencies against the Swiss franc.[7] We report this average bid-ask spread in Figure 7 after demeaning it and deseasonalizing it.

The average bid-ask spread remained remarkably stable until the SNB announced the discontinuation of its policy. Moreover, the upper border of the confidence interval around the 20-day moving average was most of the time below the post-event level with two exceptions: the early 2012 and mid 2013. These two periods were also characterized by relatively high uncertainty, see Figure 5. Immediately after the announcement, both the level and the standard deviation of the mean spread jumped significantly. Consequently, we observe no major shift in expectations regarding the SNB policy that took place immediately before 15 January.

4.3 Zooming-in on January 15, 2015

This section studies the hours surrounding the removal of the cap. Similarly to the previous section regarding the results from the daily data, we consider both option and spot market data.

4.3.1 Option market

The results from using high-frequency option data for 8:30 to 12:30 on January 15, 2015, shows that between 10:30 and 10:45 uncertainty quadrupled from around 200 pips to above 900pips. Then, it increased even further to around 1100 pips by 12:30. The skewness changed somewhat slowly, drifting from around zero at 08:30 to -0.05

[7]The weight for each currency pair is the share of its base currency in global foreign exchange market turnover in 2013 as taken from the BIS Triennial Central Bank Survey (http://www.bis.org/publ/rpfx13.htm). For instance, the share of all USDXXX pairs is 87%, that of all JPYXXX pairs is 23%, and so forth. We normalize the weights such that they sum up to one.

around the lunch time. It seems as the option market had not anticipated the timing of the policy change.

4.3.2 Spot market

Using high-frequency bid-ask spot market data we find further support for the claim that the market did not expect the cap to be removed on 15 January. We report the average weighted bid-ask spread of the major currency pairs, demeaned and deseasonalized with hourly dummies, see Figure 8. During the week of the event (Monday, January 12 to Friday, January 16) it was about zero pips and remarkably stable, rarely moving out of the ±1 pip confidence interval. It jumped immediately after the removal of the cap. Similar to the conclusions drawn before, this speaks in favor of no apparent shift in market expectations before the SNB's announcement.

5 Conclusion

We examine option prices and spot rates of the Swiss franc around the decision of the Swiss National Bank (SNB) to discontinue the 1.20 cap on the exchange rate against the euro in January 2015. The market-perceived uncertainty estimated from option prices was broadly stable prior to the decision and considerably higher thereafter. Similarly, we find no evidence from the spot market that the liquidity exhibited abnormal behavior prior to the SNB's decision. Our study also shows that the SNB's verbal interventions during the period of cap enforcement reduced the uncertainty regarding the future euro/Swiss franc rate significantly and therefore reinforced the continuation of the policy perceived by the markets.

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Tables and Figures

Table 1: **List of the SNB's verbal interventions and ECB announcements.** The table reports the speeches by the members of the SNB's Governing Board used to create the dummy variable d_t in the equations (4) and (5). It also reports the regular monetary policy decisions by the ECB and several key policy announcements.

SNB		ECB	
8-Nov-11	Jordan	8-Sep-11	regular
15-Dec-11	Hildebrand	6-Oct-11	regular
24-Jan-12	Danthine	3-Nov-11	regular
7-Feb-12	Jordan	8-Dec-11	LTRO
15-Mar-12	Jordan	12-Jan-12	regular
22-Mar-12	Danthine	9-Feb-12	regular
10-Apr-12	Jordan	8-Mar-12	regular
27-Apr-12	Jordan	4-Apr-12	regular
31-May-12	Danthine	3-May-12	regular
14-Jun-12	Jordan	6-Jun-12	regular
3-Sep-12	Jordan	5-Jul-12	regular
8-Nov-12	Zurbrügg	26-Jul-12	"whatever it takes"
16-Nov-12	Jordan	2-Aug-12	OMT
28-Nov-12	Jordan	6-Sep-12	regular
13-Dec-12	Jordan	4-Oct-12	regular
19-Feb-13	Jordan	8-Nov-12	regular
26-Apr-13	Jordan	6-Dec-12	regular
20-Jun-13	Jordan	10-Jan-13	regular
8-Oct-13	Jordan	7-Feb-13	regular
21-Nov-13	Zurbrügg	7-Mar-13	regular
12-Dec-13	Jordan	4-Apr-13	regular
27-Mar-14	Zurbrügg	2-May-13	regular
25-Apr-14	Jordan	6-Jun-13	regular
19-Jun-14	Jordan	4-Jul-13	regular
20-Nov-14	Zurbrügg	2-Aug-13	regular
11-Dec-14	Jordan	5-Sep-13	regular
18-Dec-14	Jordan	2-Oct-13	regular
		7-Nov-13	regular
		5-Dec-13	regular
		9-Jan-14	regular
		6-Feb-14	regular
		6-Mar-14	regular
		3-Apr-14	regular
		8-May-14	regular
		5-Jun-14	negative depo rate & TLTRO
		3-Jul-14	regular
		7-Aug-14	regular
		4-Sep-14	regular
		2-Oct-14	regular
		6-Nov-14	regular
		4-Dec-14	regular

Table 2: **The SNB's verbal interventions and market uncertainty.** The table reports estimated coefficients of equations (4) and (5) and t-stats (in parentheses, estimated using the Newey and West (1987) procedure with 1 lag). The dependent variables are uncertainty measures estimated from options with 3-month, 6-moth and 12-month expiries. The right-hand variables are (from top to bottom) a constant, the dummy for the SNB speeches, a dummy for the ECB key policy decisions, TED spread, European sovereign CDS spread, the S&P 500 option-implied volatility index, 10-year term premium on US Treasuries and the spot euro/Swiss franc exchange rate. The Durbin-Watson statistic and the adjusted R-squared of the regression are reported at the bottom of the table. The sample goes from September 6, 2011 to February 14, 2015.

	Contemporaneous (4)			Following-day (5)		
	3m	6m	12m	3m	6m	12m
c	-1.65	-0.99	-1.39	-0.04	-1.30	-1.45
	(-0.94)	(-0.54)	(-0.64)	(-0.02)	(-0.71)	(-0.68)
$\boldsymbol{d_t}$	**-10.56**	**-11.11**	**-21.33**	**-20.75**	**-12.57**	**-20.11**
	(-1.01)	**(-1.16)**	**(-1.77)**	**(-2.76)**	**(-1.80)**	**(-1.98)**
ECB	18.34	0.74	2.03	-6.91	8.01	2.83
	(2.00)	(0.09)	(0.25)	(-0.79)	(1.09)	(0.39)
TED spread	59.46	-199.32	95.57	58.80	-196.03	97.25
	(0.42)	(-1.24)	(0.60)	(0.41)	(-1.22)	(0.61)
EU CDS	0.72	0.64	0.97	0.70	0.61	0.93
	(1.88)	(1.66)	(1.50)	(1.88)	(1.63)	(1.47)
VIX	3.25	5.82	5.45	3.13	5.95	5.57
	(1.68)	(3.22)	(2.72)	(1.61)	(3.30)	(2.80)
10Y US TP	-105.53	-56.88	-2.28	-107.74	-61.75	-9.68
	(-2.16)	(-1.24)	(-0.04)	(-2.21)	(-1.34)	(-0.16)
Spot	67.14	67.69	72.01	67.75	68.28	73.15
	(6.09)	(5.94)	(6.06)	(6.19)	(5.98)	(6.02)
DW stat	2.07	1.94	2.02	2.07	1.94	2.03
adj. R^2	0.13	0.14	0.12	0.13	0.14	0.12

Table 3: **Propagation of SNB's verbal interventions.** The table shows the coefficient estimates on the dummy variable d_t in the equation (6) for $k = [1, 5]$ together with coefficients' t-stats (in brackets, robust as above). The sample goes from September 6, 2011 to February 14, 2015.

	3m	6m	12m
$k = 1$	-20.75	-12.57	-20.11
	(-2.76)	(-1.80)	(-1.98)
$k = 2$	-23.01	-17.07	-30.23
	(-2.33)	(-1.59)	(-2.51)
$k = 3$	-37.62	-32.82	-42.12
	(-2.75)	(-2.18)	(-2.42)
$k = 4$	-27.07	-34.02	-39.20
	(-1.70)	(-1.74)	(-1.76)
$k = 5$	-30.42	-27.90	-35.56
	(-1.43)	(-1.17)	(-1.26)

Table 4: **Average t-statistics of the "utmost determination" word group**. This table is the result of a text analytics Monte Carlo exercise with 10000 iterations. Each iteration a sample of 3 word groups was drawn, and model (5) estimated. Columns depict cases of different choice of the left-hand side variable: cumulative changes in uncertainty over the next 1, 2, 3 or 4 days are considered. Sample means of t-statistics for the group in question are reported.

horizon \lag of response	1	2	3	4
3M	-0.59	-2.68	-2.73	-4.18
6M	-1.32	-3.35	-2.71	-5.46
12M	-1.11	-2.41	-1.44	-3.11

Figure 1: **Strike prices of the currency options.** The figure shows strike prices for which there are option prices available for the 3-month, 6-month and 12-month horizons. The sample period goes from the beginning of September 2011 to the end of April 2015.

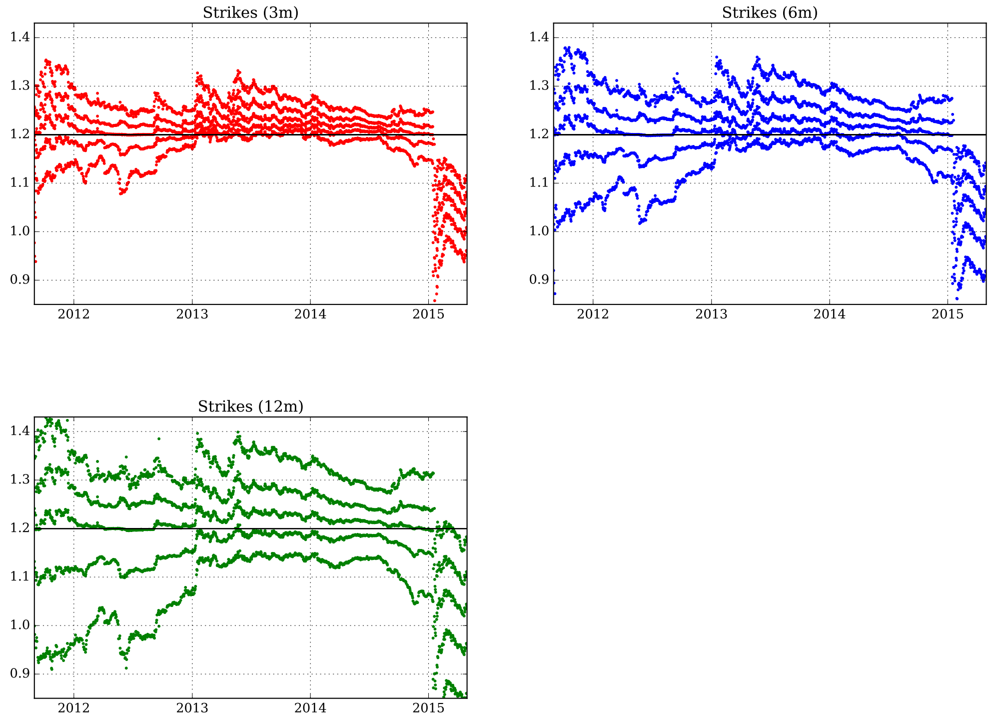


Figure 2: **Implied volatilities of the currency options.** The figure shows implied volatilities of the 3-month options. The sample period goes from the beginning of September 2011 to the end of April 2015.

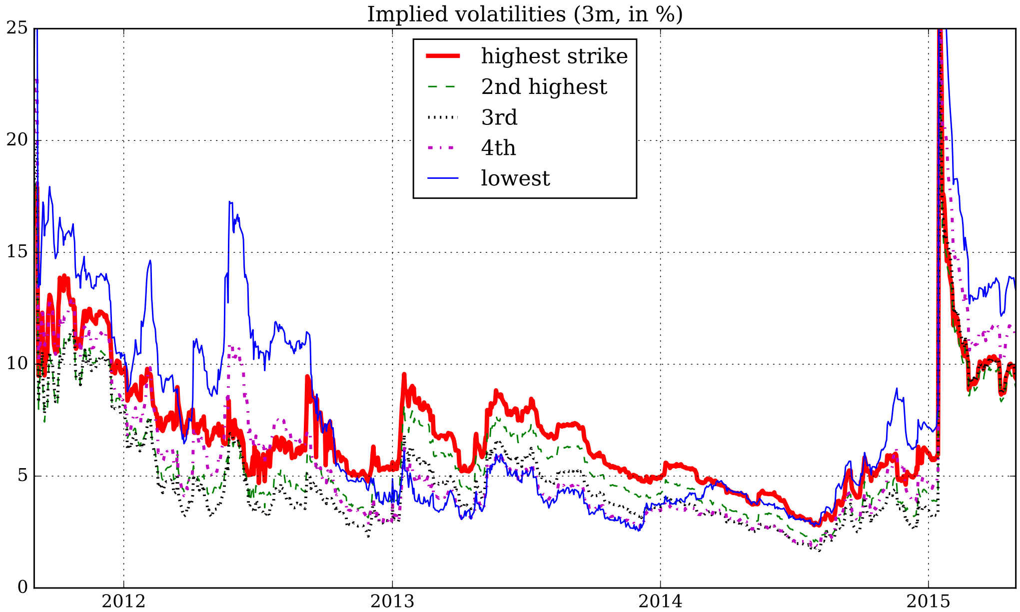


Figure 3: **Estimated probability density functions for selected dates.** The figure shows estimated pdfs for the 3-month horizon.

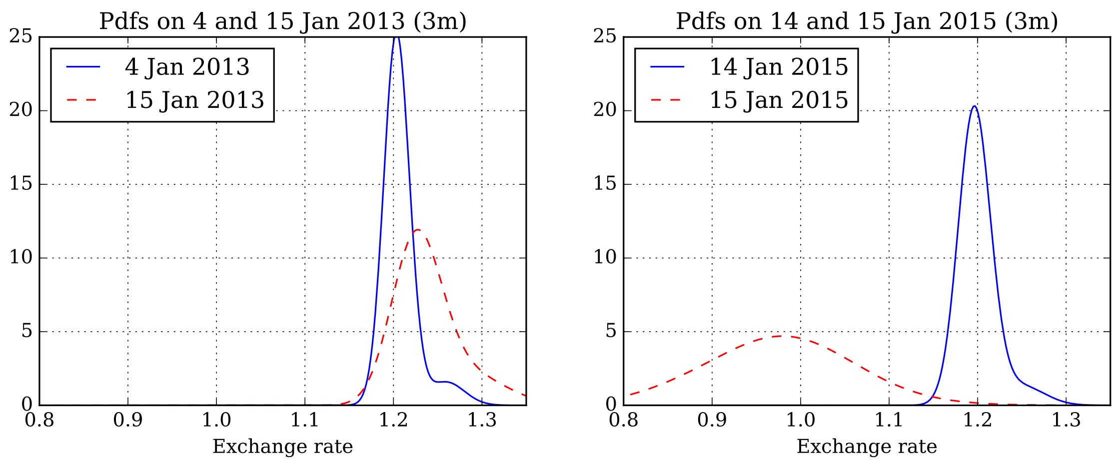


Figure 4: **A hypothetical truncated distribution and the resulting estimate.** The figure shows a hypothetical distribution with zero probability mass, the available strike prices and the result from estimating a mixture of two lognormals.

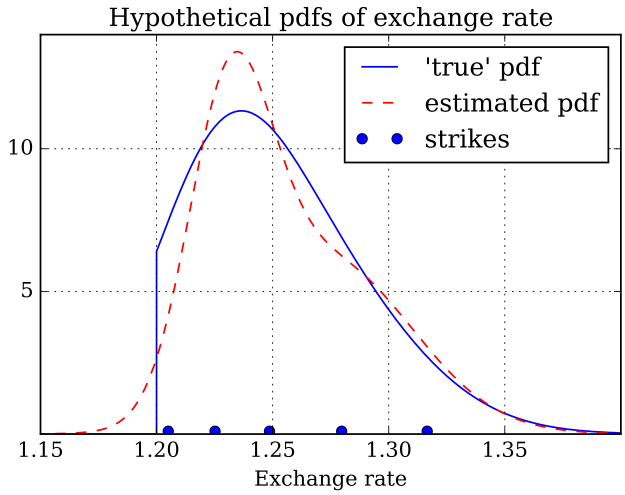


Figure 5: **Estimated uncertainty and skewness.** The figure illustrates our measures of uncertainty (upper panel) and skewness (lower panel) of the estimated risk-neutral distribution for 3, 6, and 12-month horizons, see equation 3. The figure also indicates (with red circles) when the day-to-day changes for the 3-month horizon are outside a 1% confidence band. The confidence band is obtained by combining the sampling variability of implied volatilities (see Figure 2) over the period of the cap with the near linearity in the mapping from average implied volatility to uncertainty (a delta method approach) and from risk reversals to skewness. The sample period goes from the beginning of September 2011 to the end of April 2015.

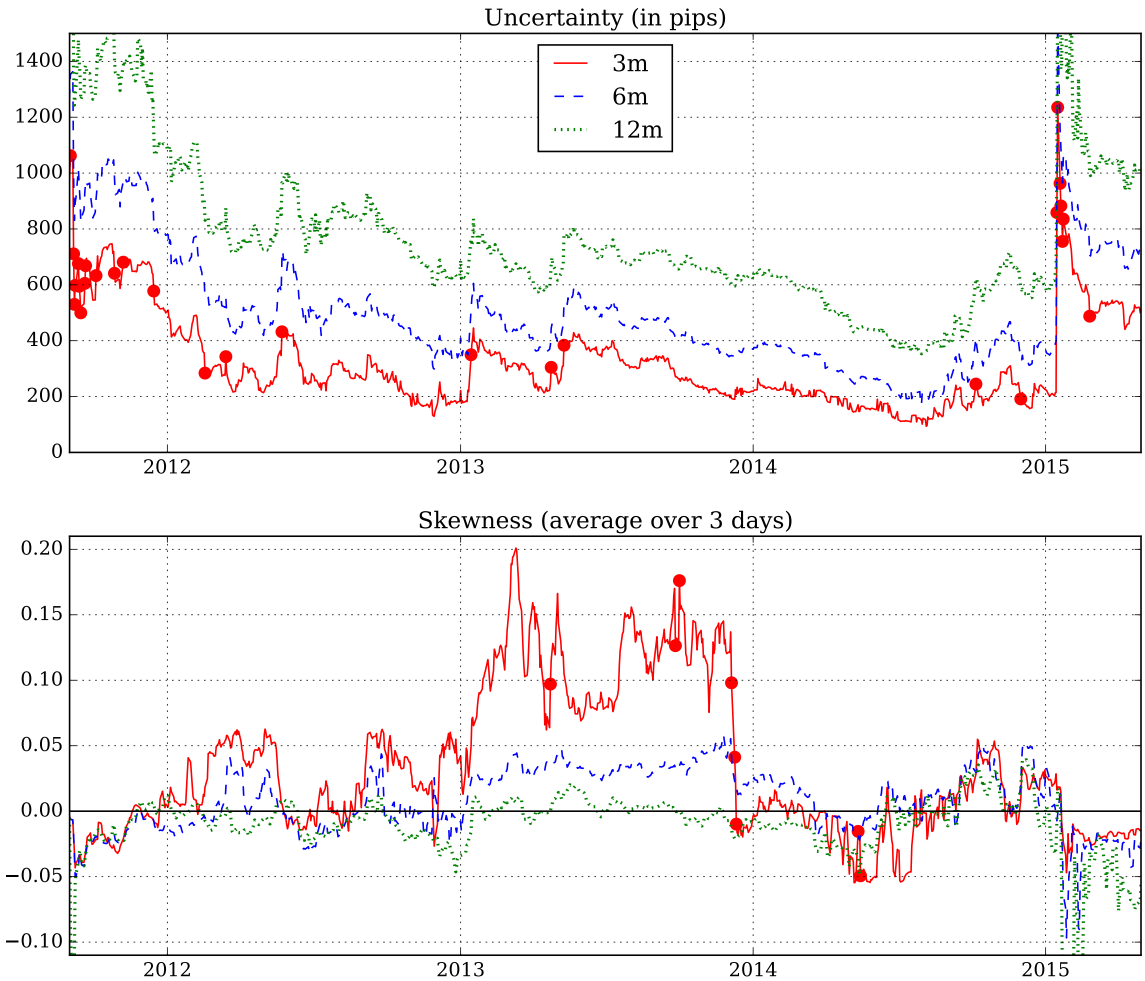


Figure 6: **Event study.** This figure shows the cumulative average difference in uncertainty (solid black line) in pips and the lower part of the 95% confidence band around zero (gray shaded area). Day 0 means the speech day. Horizons of 3, 6 and 12 months are considered. The confidence interval is calculated assuming cross-sectional and intertemporal independence of differences in uncertainty after speeches.

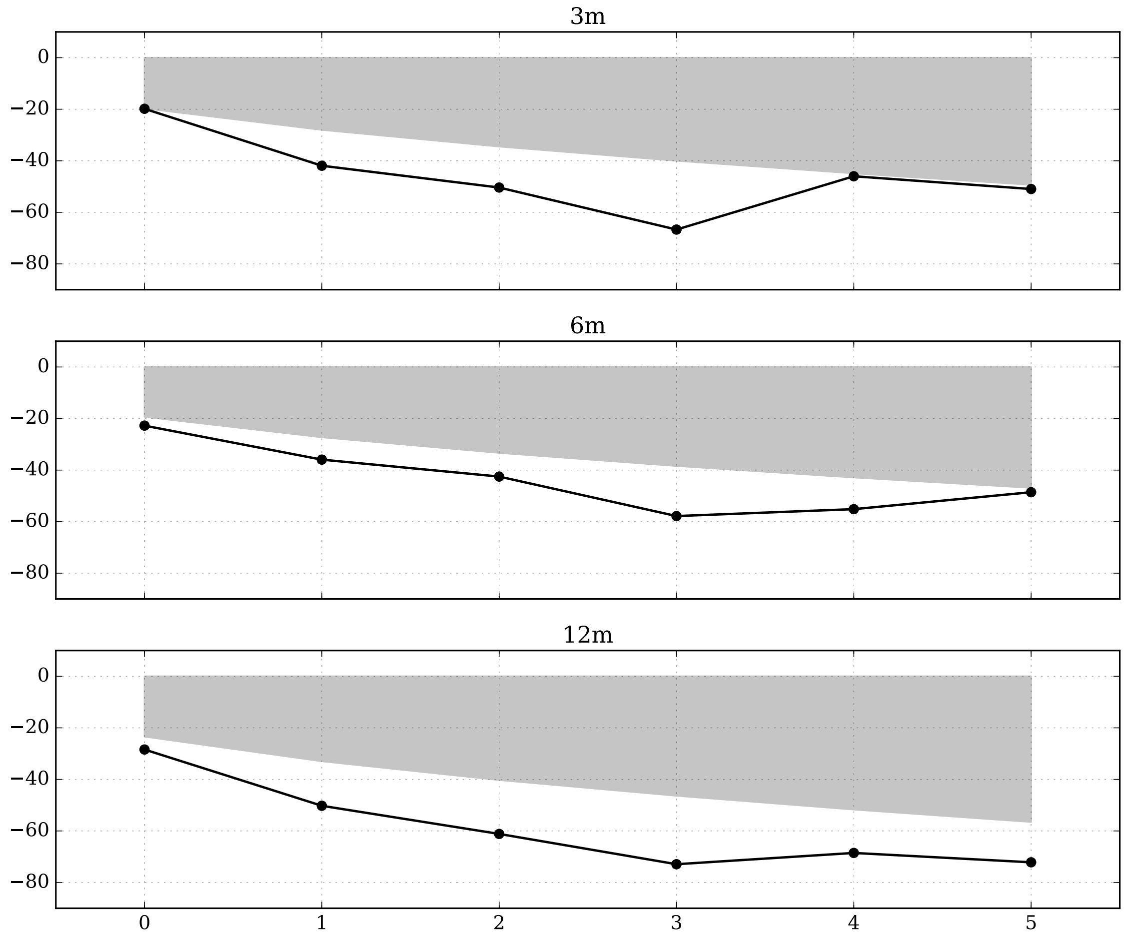


Figure 7: **Evidence from spreads.** The solid black line in this Figure shows the 20-day moving average of the mean volume-weighted bid-ask spread of 9 currencies against the Swiss franc (in pips), demeaned and deseasonalized. The dotted red line is the post-event mean spread, the gray shaded area is the 95% confidence interval calculated based on the assumption of i.i.d consecutive mean spread values. The red dot indicates the value of the mean spread on January 14, 2015. The sample period goes from the beginning of September 2011 to the end of April 2015.

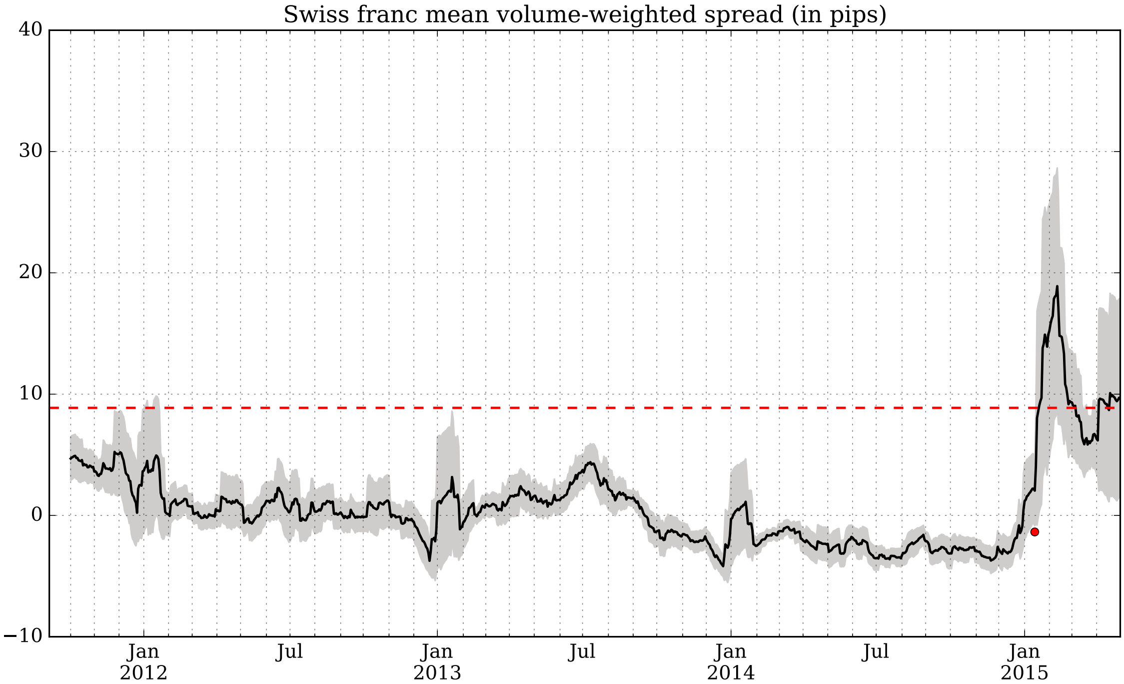
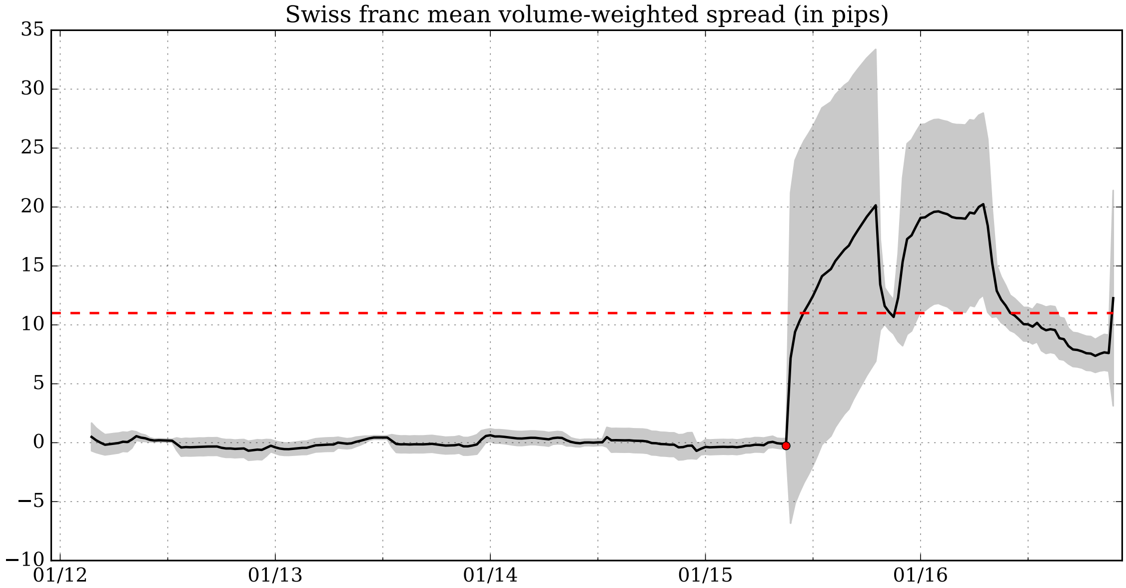


Figure 8: **Evidence from spreads in high frequency.** The solid black line in this Figure depicts the 10-hour moving average of the mean volume-weighted bid-ask spread of 9 currencies against the Swiss franc (in pips), demeaned and deseasonalized. The dotted red line is the post-event mean spread, the gray shaded area is the 95% confidence interval calculated based on the assumption of i.i.d consecutive mean spread values. The red dot indicates the value of the mean spread on January 15, 2015 at 10:00:00 CET. The plotted sample goes from January 12, 2015 at 23:00:00 CET to January 16, 2015 at 00:00:00 CET.



Appendix A: Robustness checks

We find that our regression results hold independently of whether we use all the speeches of the Governing Board members or a subsamples of them (Thomas Jordan only), or whether the dependent variable is a proxy for uncertainty, i.e. at-the-money option-implied volatility, instead of our estimated measure of uncertainty, see Table 5.

Table 5: **Robustness check.** The table shows the coefficient estimates on the dummy variable d_t in eqs. (4)-(5) and its t-statistics (in parentheses, estimated using the Newey and West (1987) procedure with 1 lag) for a different d_t (speeches by Thomas Jordan only) and for a different u_t (at-the-money option volatilities from Bloomberg).

	Contemporaneous			Following-day		
	3m	6m	12m	3m	6m	12m
Jordan only	-12.90	-18.48	-27.70	-18.49	-13.09	-20.76
	(-1.14)	(-1.62)	(-2.00)	(-1.67)	(-1.18)	(-1.54)
ATM vola	-7.65	-9.27	-8.47	-9.34	-5.55	-5.45
	(-1.54)	(-2.39)	(-2.62)	(-1.87)	(-1.42)	(-1.66)

Table 6: **Word groups.** This table presents allocation of words to semantic groups. Word frequencies within each group are counted together.

currency / exchange	eurozone / (euro area) / europe	franc
dollar	risk	inflation/ deflation/ price
balance / (balance sheet) / buffer	appreciation / depreciation / devaluation / weakening / strengthening	
target	obligation / mandate	stabilization
future / potential	crisis / recession	(central bank) / regulator
shareholder	swiss / domestic / home	uncertain / unclear / opaque / vague
debt / credit / lend	haven	export / import
liquid	house / mortgage / residential / estate	enforce / (utmost determination) / (unlimited quantities)
unchanged	minimum / floor	emerging / abroad / world / international
macro	(interest rate) / (monetary policy)	

Appendix B: The physical distribution of the euro/ Swiss franc exchange rate

Transforming a risk-neutral distribution to a physical distribution requires information about the risk premium of the exchange rate—and assumptions about how the shape of the distribution can change. This section will illustrate the (relatively minor) effect of such a transformation.

To do so, we take the following steps. First, we regress the *ex post* risk premium (current forward rate minus the spot rate 3 months ahead) on current market risk factors (implied volatility from the options discussed above, VIX and the TED spread) on daily data for 2002–2011. The results indicate, for instance, a negative 1–

3% risk premium during the height of the financial crisis. We then use the estimated coefficients together with the observed risk factors to predict risk premia for 2011:09 to 2015:04. If we instead use the *ex ante* risk premium (forward minus the 3m survey data from Consensus Economics), then we get a similar (but more muted) time series pattern.

Second, we adjust the mean of each lognormal distribution by an amount proportional to its standard deviation (assuming that more volatility causes a higher risk premium) such that the option pricing model generates the same risk premium as in the first step. This is done in the following way. The physical distribution is obtained by replacing the risk-neutral means μ_i by $\mu_i - \kappa_i$ where κ_i is the covariance of the exchange rate with the pricing kernel. We also note that the forward price is $F = \alpha \exp(\mu_1 + \sigma_1^2/2) + (1 - \alpha) \exp(\mu_2 + \sigma_2^2/2)$ and that the expected log future exchange rate is $\mathrm{E} \ln S_{3m} = \alpha(\mu_1 - \kappa_1) + (1 - \alpha)(\mu_2 - \kappa_2)$. Combining a value of the risk premium $\ln F - \mathrm{E} \ln S_{3m}$ with the assumption that $\kappa_1/\kappa_2 = \sigma_1/\sigma_2$ allows us to recover the physical distribution.

This approach leads to very small adjustments of the 10th and 90th percentiles (the correlation of the two set of results are 0.99 in levels and 0.98 in first differences), except for a few days after January 15, 2015.