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The De-Pegging of the EUR/CHF Minimum Exchange Rate in January 2015: Was it Expected?

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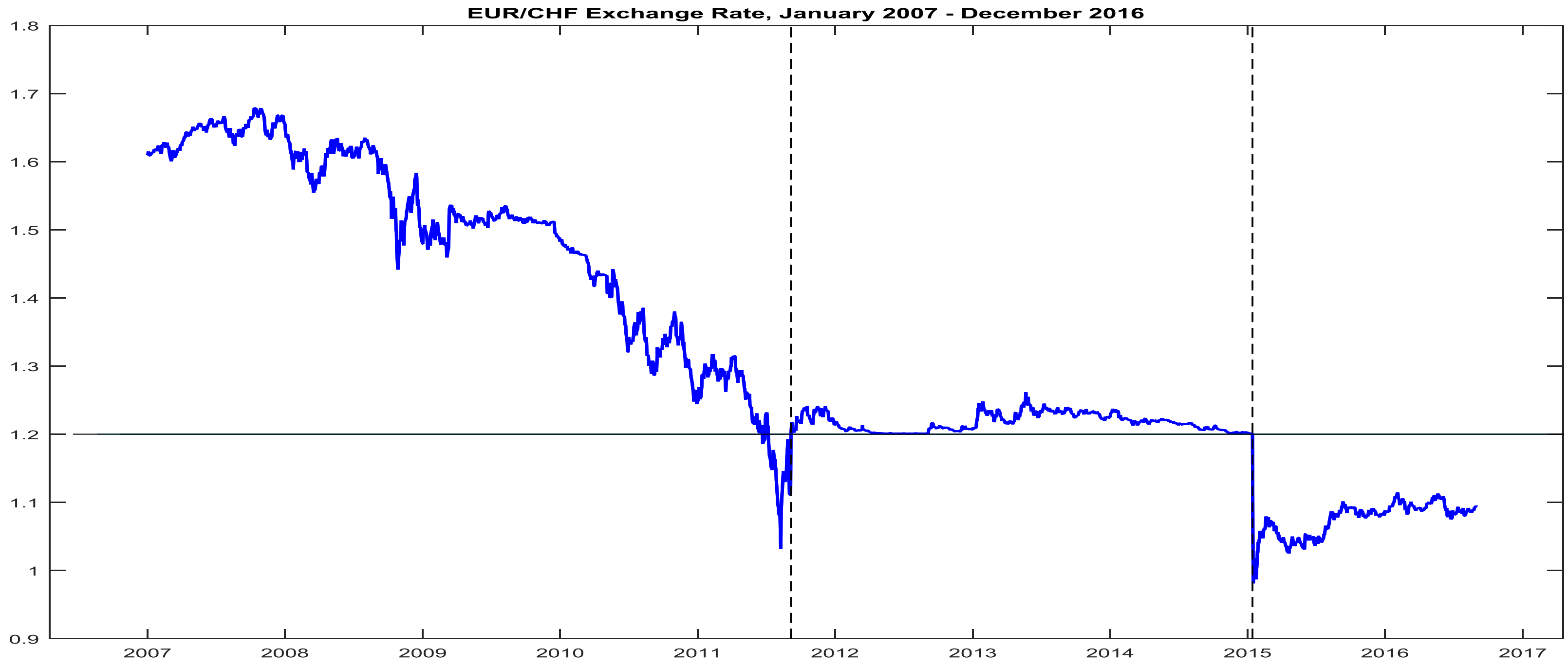
Motivation

- Due to the Financial- and Euro Crisis, the Swiss Franc appreciated against the Euro between 2007 to 2011.
- To avoid further appreciation Swiss National Bank (SNB) imposed a one sided peg of a minimum of 1.2 CHF per EURO at 6 September 2011.
- Abandoned on 15 January 2015, causing large appreciation of the Swiss Franc against the Euro.



Motivation

- Economic reasoning: Protecting domestic currency from appreciation is always credible, central bank can print unlimited amounts of its own currency.
- But: Costly, when the appreciation pressure is large plus danger of possible balance sheet losses due to foreign currency devaluation in case of termination.
- Given the termination of the peg four years after the implementation, credibility question arises.

→ We use Over-the-Counter (OTC) market options on CHF/EUR exchange rate to calculate forward looking option implied probability density functions (PDF).

→ PDFs allow to calculate the market beliefs regarding future existence of the peg, to investigate its credibility.

→ In addition, investigation of forecasting performance of those market beliefs.

Contents

1. Motivation
2. Related Literature
3. Derivation of Option Implied Densities
4. Market Expectations and Credibility
5. Forecating Ability
6. Conclusion

Related Literature: CHF/EUR Floor

- **Hertrich and Zimmermann (2015):** Break probability from an option pricing model, which imposes an hypothetical exchange rate for the case the peg is abandoned. → Not fully credible (break probability up to 50%).
- **Jermann (2015) and Hanke et al. (2015):** Break probability from an option pricing model, where a latent CHF/EUR spot rate without floor is modeled. → Large credibility (break probability most of the time around 10%-20%).
- **Mirkov et al. (2016):** Estimate model based option implied densities for CHF/EUR and test how verbal interventions have changed market views. → Verbal interventions of SNB increased credibility of the peg.
- Contribution:

  → Estimating a term structure of market beliefs.
  → Analysis of break probabilities and higher order moments.
  → Testing whether forward looking PDFs can be used for accurate forecasting during the peg.

Call Option Prices: Market Conventions

- In OTC markets prices of FX call options are quoted in terms of their Black-Scholes implied volatility, σ_t.
- Moneyness: Difference between strike price, X, and actual market price S_t:

→ At-the-money (ATM) call (put): $S_t = X$.
→ Out-of-the-money (OTM) call (put): $S_t < X$ ($S_t > X$).
→ In-the-Money (ITM) call (put): vice versa to OTM.

- For FX options, moneyness is measured by the call options delta, with domestic and foreign interest rates r_t and r_t^* and time to maturity τ:

$$\delta_{Call} \equiv \frac{\partial C_{BS}}{\partial S_t} = e^{r_t^* \tau} \Phi \left[\frac{\ln\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* + \frac{\sigma_t}{2}\right)\tau}{\sigma_t \sqrt{\tau}} \right] \in [0,1]$$

- Put-call parity: $\delta_{put} = 1 - \delta_{call}$, hence $\sigma_{25\delta p,t} = \sigma_{75\delta c,t}$
- ATM options have $\delta_{Call}=\delta_{put} = 0.5$, OTM options have $\delta_{Call} < 0.5$ and $\delta_{put} > 0.5$
- The further an option is OTM the larger is its implied volatility

→ volatility smile, $\sigma_t(\delta)$, for $\delta \equiv \delta_{call}$.

Call Option Prices and Risk Neutral Densities

- Under the assumption of risk neutral pricing **Breeden and Litzenberger (1978)** derive the option implied density for a continuum of strike prices X:

$$c(t,X,T) = e^{-r_t\tau}\int_0^{+\infty}(S_T - X)\pi_t^{\tau}(S_T)dS_T$$

$$\rightarrow \frac{\partial^2 c(t,X,T)}{\partial X^2} = e^{-r_t\tau}\pi_t^{\tau}(X)$$

$$\leftrightarrow \pi_t^{\tau}\ (X) = e^{r_t\tau}\frac{\partial^2 c(t,X,T)}{\partial X^2}.$$

- r_t domestic risk free interest rate, τ time to maturity, T expiration date and S_T exchange rate at expiration date.
- Due to possible risk aversion risk neutral PDFs are different from real world PDFs, but:
  - → **Hanke et al. (2015)** and **Mirkov et al. (2016):** For FX markets risk neutral and real world probabilities and confidence bands are almost the same.
- Calibration of real world PDFs later on, after presentation of risk neutral PDFs.

Parametric Density Calculation I

- To apply **Breeden and Litzenberger (1978)** one would need a continuum of strike prices, which in reality does not exist.

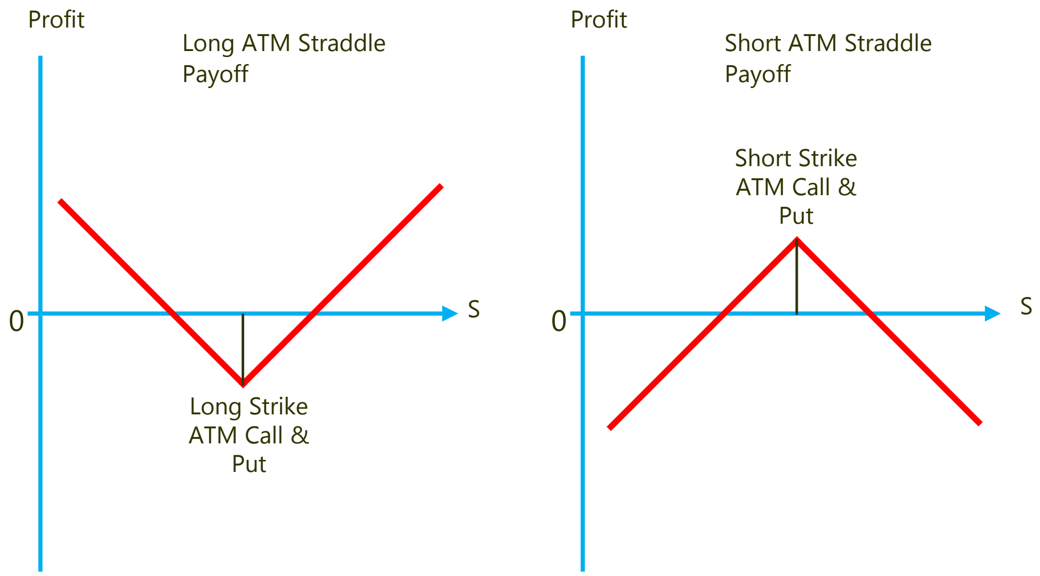
- **Malz (1997):** Quadratic approximation of the volatility smile in σ-δ space and conversion to σ-X space to get continuum of X.

- For approximation using three option bundles that characterize the shape of the volatility smile and the PDF:

ATM-Straddle:	$atm_t = \sigma_{50\delta c,t} + \sigma_{50\delta p,t}$	→ level
25δ Risk Reversal:	$rr_{25\delta,t} = \sigma_{25\delta c,t} - \sigma_{25\delta p,t}$	→ symmetry
25δ Butterfly:	$bf_{25\delta,t} = \frac{\sigma_{25\delta c,t}+\sigma_{25\delta p,t}}{2} - atm_t$	→ curvature

Parametric Density Calculation II

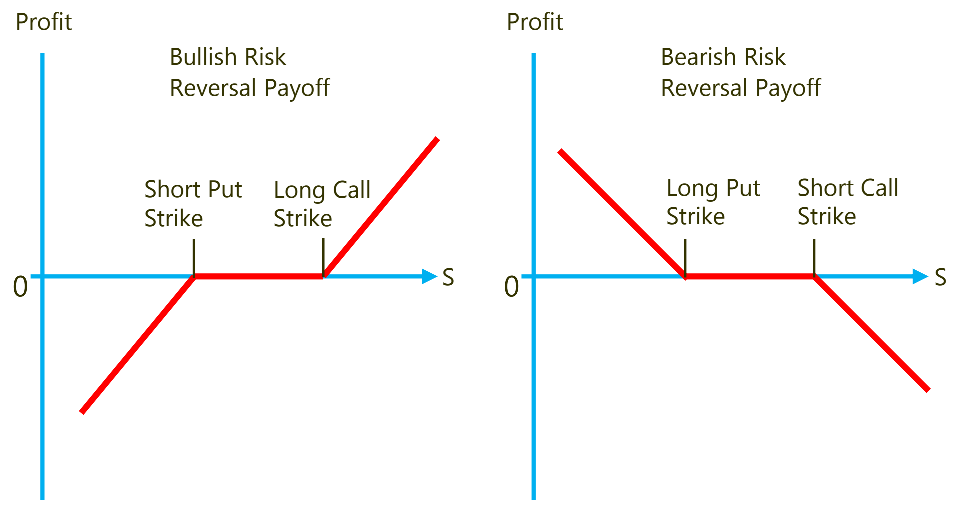
- ATM-Straddle: $atm_t = \sigma_{50\delta c,t} + \sigma_{50\delta p,t}$



- Becomes profitable, whenever the exchange rate moves in any direction.
- $atm_t \uparrow \rightarrow$ higher level of volatility smile and larger variance of PDF.

Parametric Density Calculation III

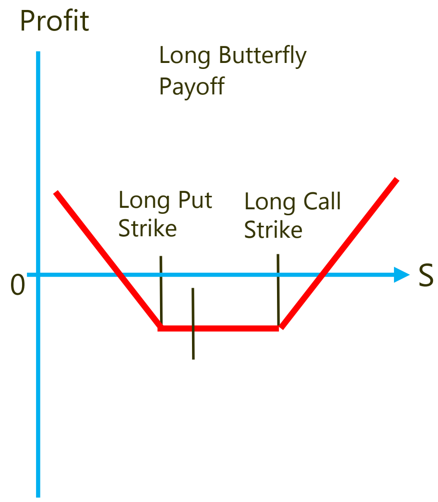
- 25δ Risk Reversal: $$rr_{25\delta,t} = \sigma_{25\delta c,t} - \sigma_{25\delta p,t}$$

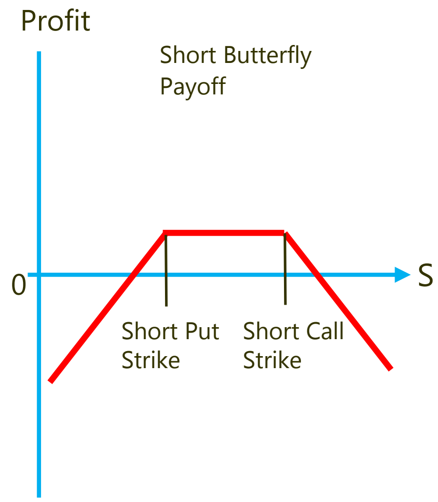


- Becomes profitable, whenever the exchange rate moves in a specific direction.
- $rr_{25\delta,t}$>0 (<0)→ positive (negative) skewness of volatility smile and PDF.

Parametric Density Calculation IV

- 25δ Butterfly: $$bf_{25\delta,t} = \frac{\sigma_{25\delta c,t} + \sigma_{25\delta p,t}}{2} - atm_t$$





- Becomes profitable, whenever there is a large move of the exchange rate in any direction.
- $bf_{25\delta,t} > 0 \rightarrow$ Volatility smile with larger curvature and leptokurtotic PDF.

Parametric Density Calculation V

- Quadratic approximation of the volatility smile:

$$\sigma_{25\delta,t}(\delta) = b_0 atm_t + b_1 rr_{25\delta,t}(\delta - 0.5) + b_2 bf_{25\delta,t}(\delta - 0.5)^2$$

$\rightarrow (b_0, b_1, b_2) = (1, -2, 16)$

- Resulting system of equations:

$$\sigma_{25\delta,t}(\delta) = b_0 atm_t + b_1 rr_{25\delta,t}(\delta - 0.5) + b_2 bf_{25\delta,t}(\delta - 0.5)^2$$

$$\delta = e^{r_t^* \tau} \Phi \left[\frac{\ln\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* + \frac{\sigma_{25\delta,t}}{2}\right)\tau}{\sigma_{25\delta,t}\sqrt{\tau}} \right]$$

- Two equations with two unknowns: X and $\sigma_{25\delta,t}(\delta)$

- Solving the system nurmerically $\Rightarrow \sigma_{25\delta,t}(X)$

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Parametric Density Calculation VI

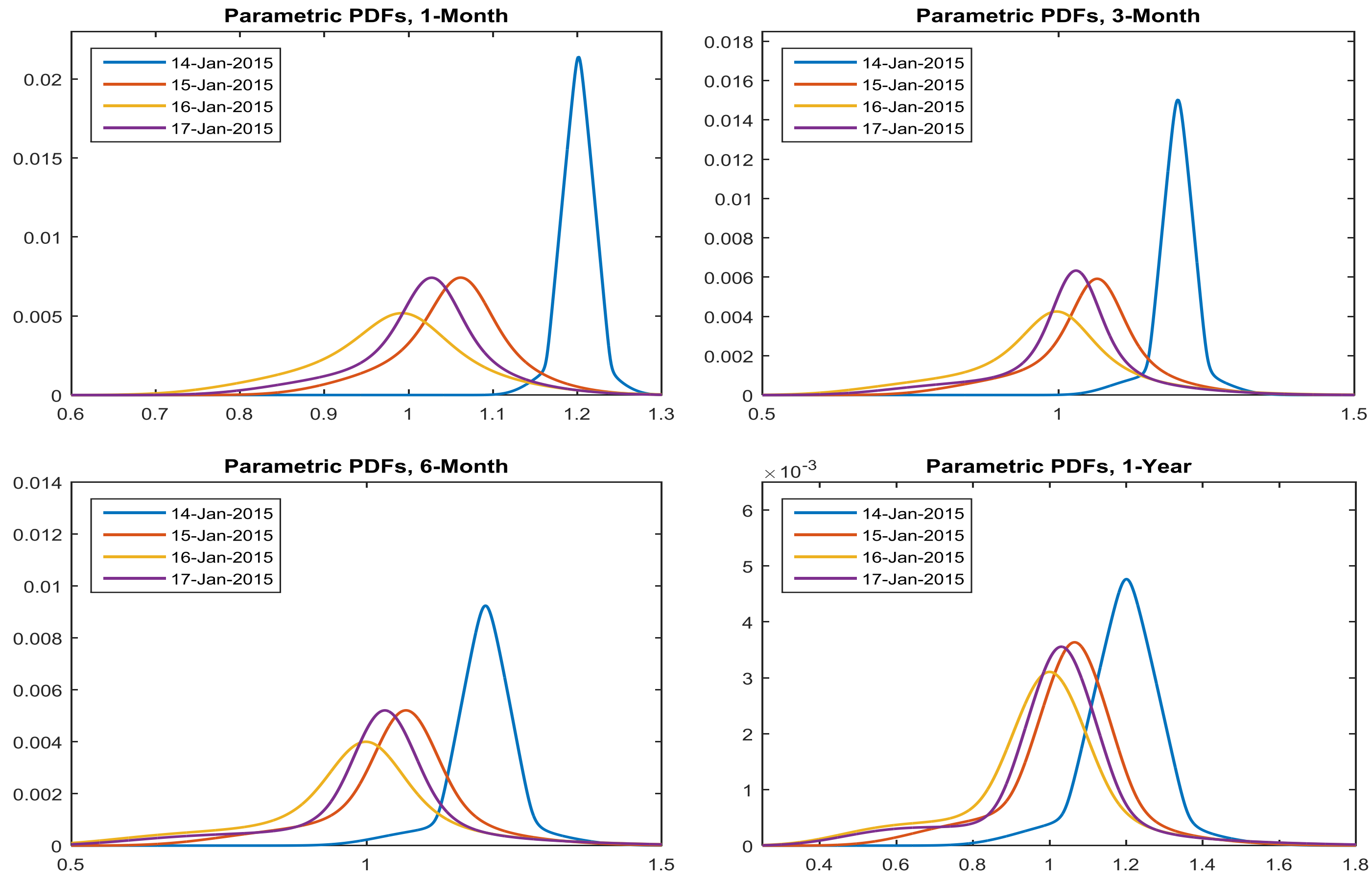
- Calculate risk neutral density, for a given τ :

  Second derivative of $C_{BS,t}\left(\sigma_{25\delta,t}(X)\right) \equiv C_{BS,t}(X)$.
- Approximate the second derivative by the second order difference quotient:

$$\frac{\partial^2 C_{BS}(t,X,T)}{\partial X^2} \approx \frac{C_{BS,t}(X+h) + C_{BS,t}(X-h) - 2C_{BS,t}(X)}{h^2}$$

$$\rightarrow \ \pi_t^\tau\ (X) \approx \ e^{r_t \tau} \frac{C_{BS,t}(X+h) + C_{BS,t}(X-h) - 2C_{BS,t}(X)}{h^2}$$

Forward Looking Parametric Densities



Non-Parametric Density Calculation I

- Parametric approach: Approximate volatility smile as quadratic function of δ.

  → Main disadvantage: Approximates volatility smile with only 3 data points.
  → Nowadays option prices with more delta values other than 25% available.

- Non-parametric approach of **Malz (2014)** uses a clamped cubic spline to interpolate as many points as desired.
- A clamped cubic spline function interpolates a set of data points, $\{(x_1, y_1), \dots, (x_n, y_n)\}$, such that the resulting function is continuously differentiable at the nodes.

$$y(x) = \begin{cases} x_1 \; for \;\; x < x_1 \\ f(x) \quad for \;\; x_1 \leq x < x_n \\ x_n \; for \;\; x \geq x_n \end{cases}$$

Non-Parametric Density Calculation II

- Seven data points are interpolated: atm_t, 10%, 25% and 35% delta put and call implied volatilities:

$$\sigma_{x\delta c,t} = atm_t + bf_{x\delta,t} + 0.5rr_{x\delta,t}$$
$$\sigma_{x\delta p,t} = atm_t + bf_{x\delta,t} - 0.5rr_{x\delta,t}$$

- Spline function interpolates between deltas of 10% and 90%, hence extrapolation has to be done to calculate the entire volatility smile.

- To avoid no arbitrage violations the interpolated function is assumed to have a derivative of zero at the boundary points $(10\%, \sigma_{10\%\ \delta c,t})$ and $(90\%, \sigma_{10\%\ \delta p,t})$.

- Result: non-parametric function, $\sigma_t(\delta)$, representing the volatility smile.

Non-Parametric Density Calculation III

- Substitute $\sigma_t(\delta)$ into the call-delta function:

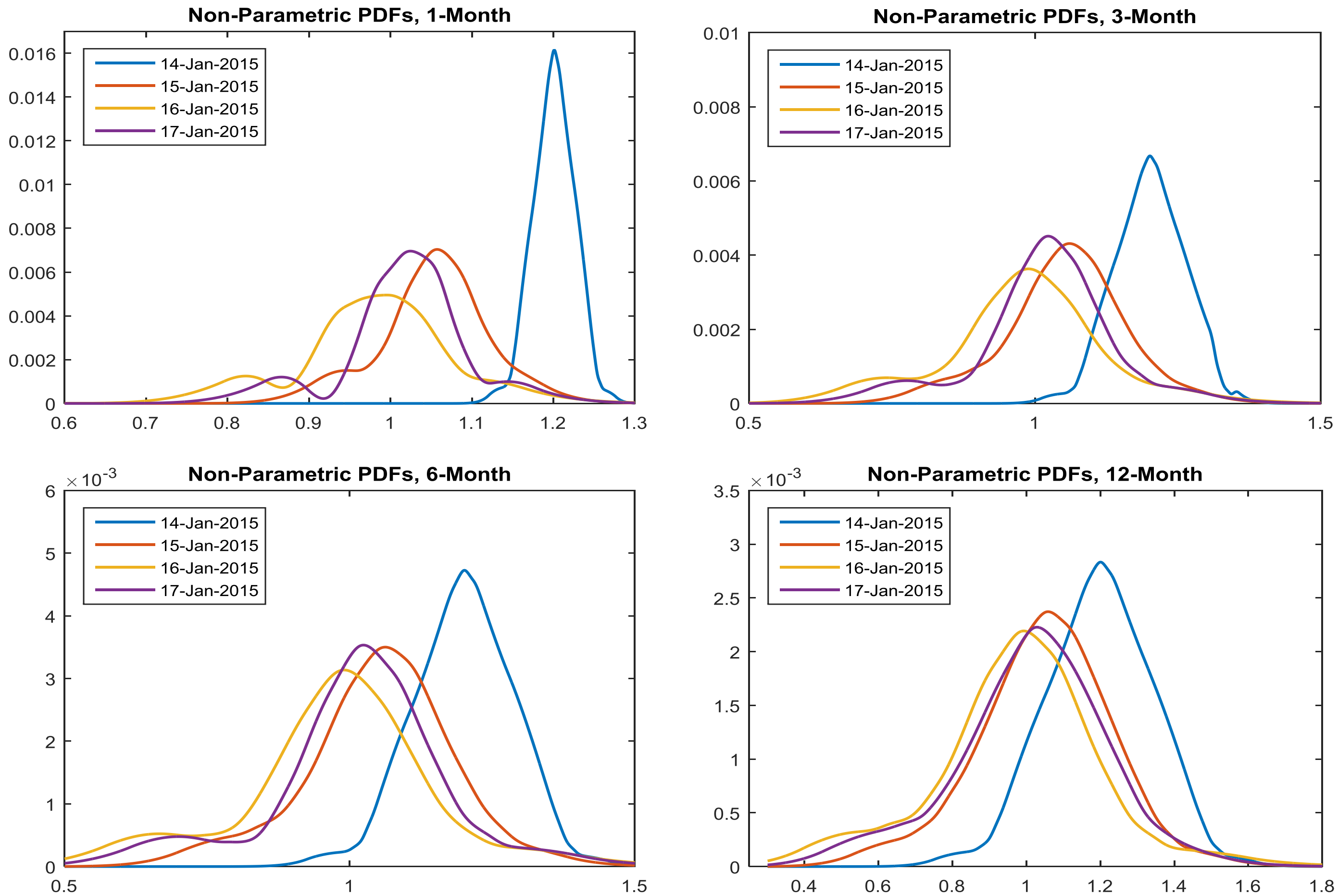
$$\delta = e^{r_t^* \tau} \Phi \left[\frac{\ln\left(\frac{S_t}{X}\right) + \left(r_t - r_t^* + \frac{\sigma_t(\delta)}{2}\right)\tau}{\sigma_t \sqrt{\tau}} \right] \qquad (3)$$

- Only unknown X solve (3) numerically for $\sigma \rightarrow \sigma_t(X)$.
- For given τ, $\sigma_t(X)$ can be substituted into the Black-Scholes call price formula, $C_{BS,t}\big(\sigma_t(X)\big) \equiv C_{BS,t}(X)$.
- Numerical differentiation by second order difference quotient to obtain the τ -months forward looking risk neutral non-parametric density:

$$\frac{\partial^2 C_{BS}(t, X, T)}{\partial X^2} \approx \frac{C_{BS,t}(X+h) + C_{BS,t}(X-h) - 2C_{BS,t}(X)}{h^2}$$

$$\rightarrow \pi_t^\tau\,(X) \approx \; e^{r_t \tau} \frac{C_{BS,t}(X+h) + C_{BS,t}(X-h) - 2C_{BS,t}(X)}{h^2}$$

Forward Looking Non-Parametric Densities



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Real World Densities I

- **Jackwerth (2000):** Risk neutral probability is equal to the real world probability times a risk aversion adjustment.
- To model the relationship between risk-neutral densities (RNDs, $\pi_t^\tau(X)$) and real-world densities (RWDs, $q_t^\tau(X)$) one can make assumptions about risk preferences.
- **Bliss and Panigirtzoglou (2004)** use CRRA utility function with relative risk aversion parameter ρ:

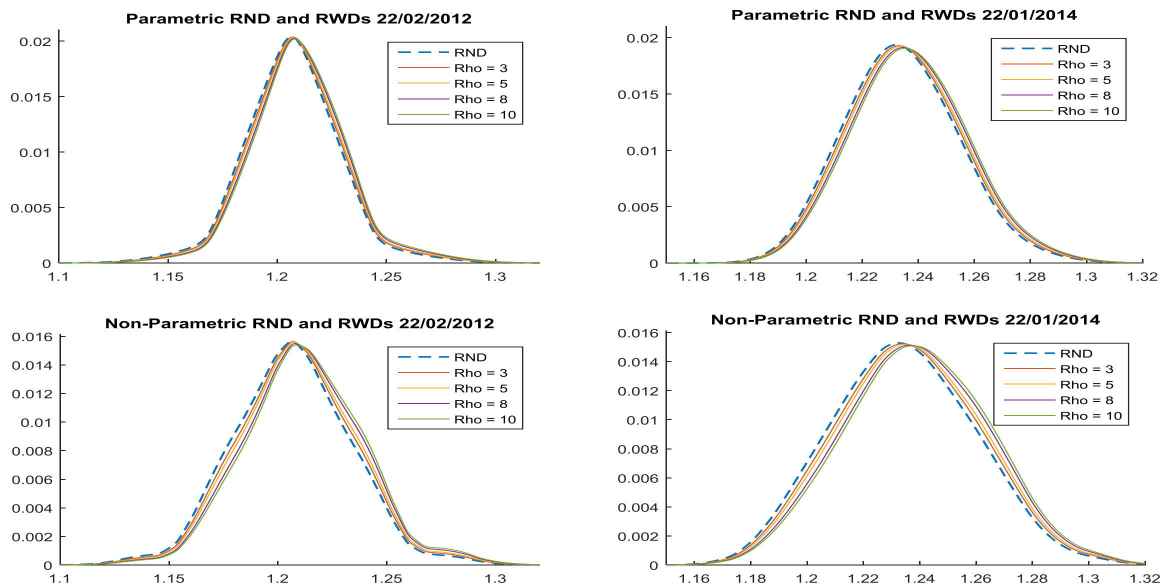
$$u(x) = \frac{x^{1-\rho}-1}{1-\rho} \qquad (4)$$

- General relationship between $q_t^\tau(x)$ and $\pi_t^\tau(x)$, derived by **Ait-Sahalia and Lo (2000)** with application of CRRA utility function by **Bliss and Panigirtzoglou (2004)** :

$$q_t^\tau(x) = \frac{\frac{\pi_t^\tau(x)}{u'(x)}}{\int_0^\infty \frac{\pi_t^\tau(y)}{u'(y)} dy} = \frac{x^\rho \pi_t^\tau(x)}{\int_0^\infty y^\rho \pi_t^\tau(y) dy} \qquad (5)$$

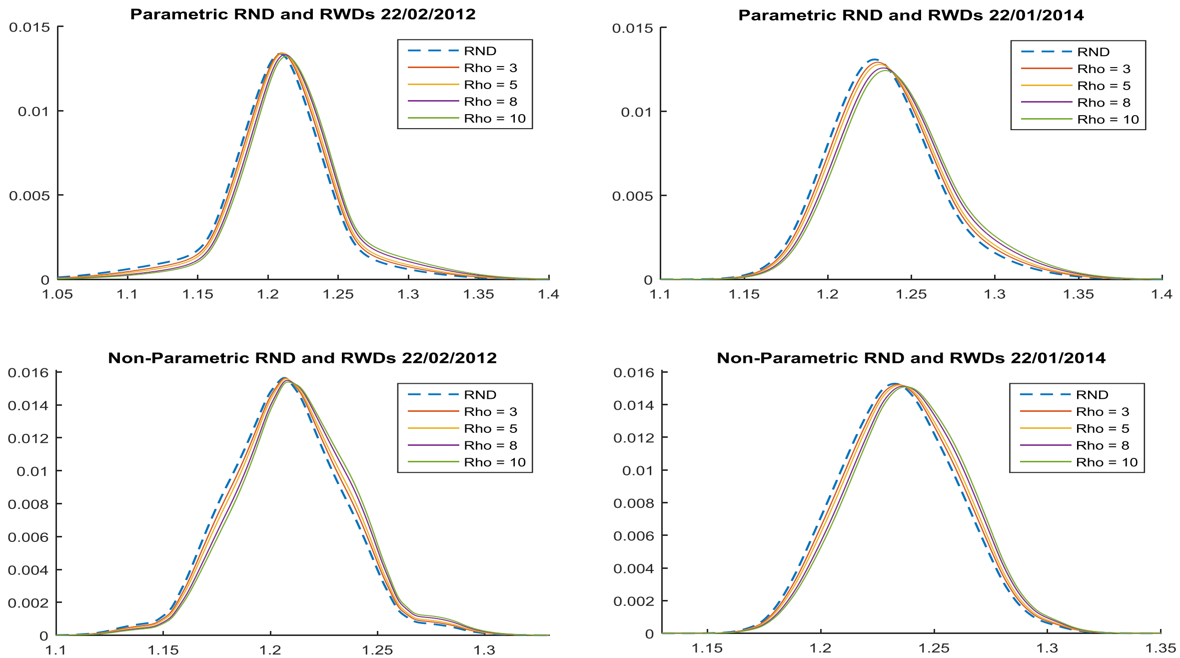
Real World Densities II

- A plausible assumption is that the relative risk aversion parameter is in the range of $3 < \rho < 10$.
- **Bliss and Panigirtzoglou (2004)** and **Liu et al. (2007):** $2 < \rho < 4$.
- **Mehra and Prescott (1985)** imposed an upper bound of $\rho = 10$.
- One Month ahead parametric and non-parametric RNDs and RWDs for different parameters:



Real World Densities III

- 3 Months ahead parametric and non-parametric RNDs and RWDs for different parameters:



Credibility Analysis: Break Probabilities

- Since RNDs and RWDs are close to each other, RNDs are a reasonable proxy for market sentiment.

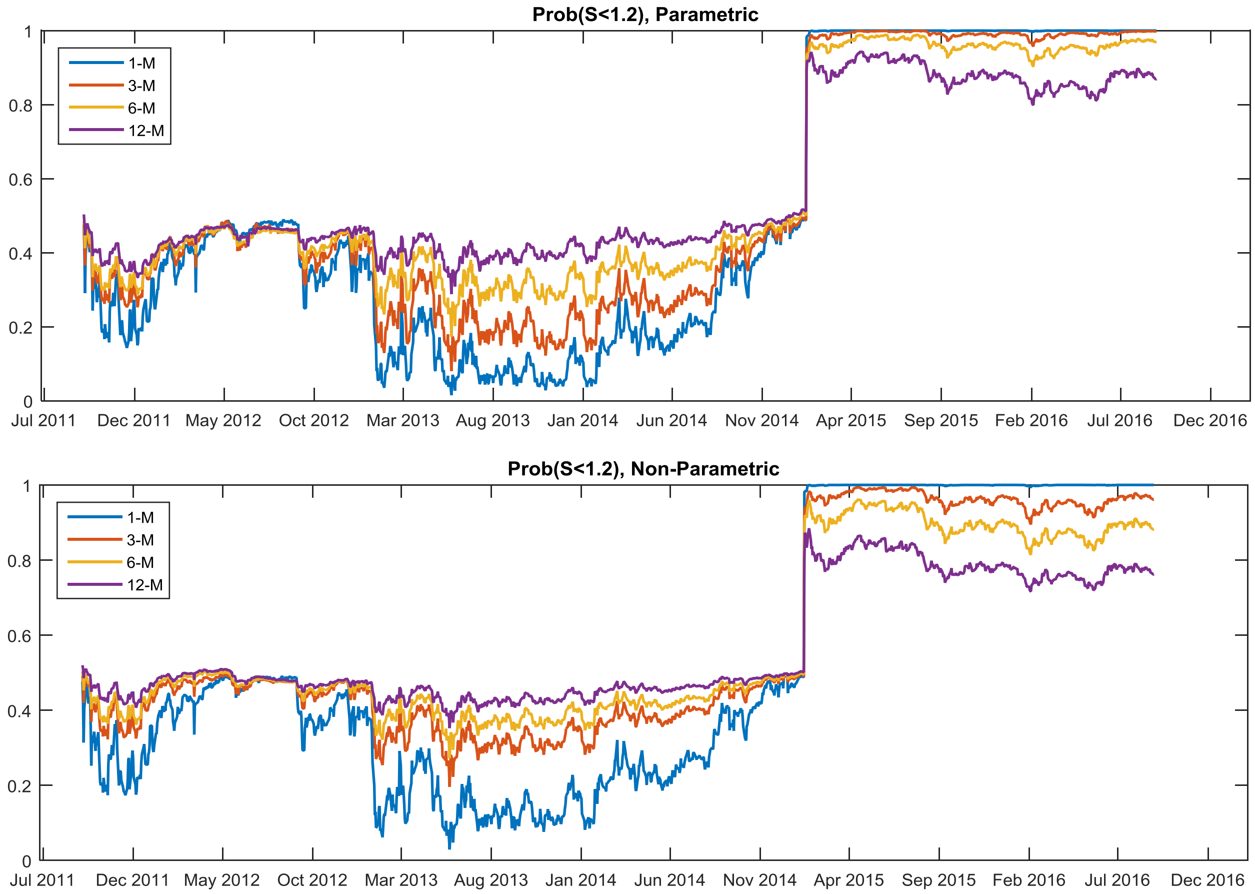
- Each days expected probability of going below 1.20 CHF per Euro within the next τ-months is calculated:

$$P_t^\tau(S_t < 1.2) = \int_0^{1.2} \pi_t^\tau(S_t) dS_t$$

- When break probability is significantly above 50%, the Swiss Franc Floor is incredible.

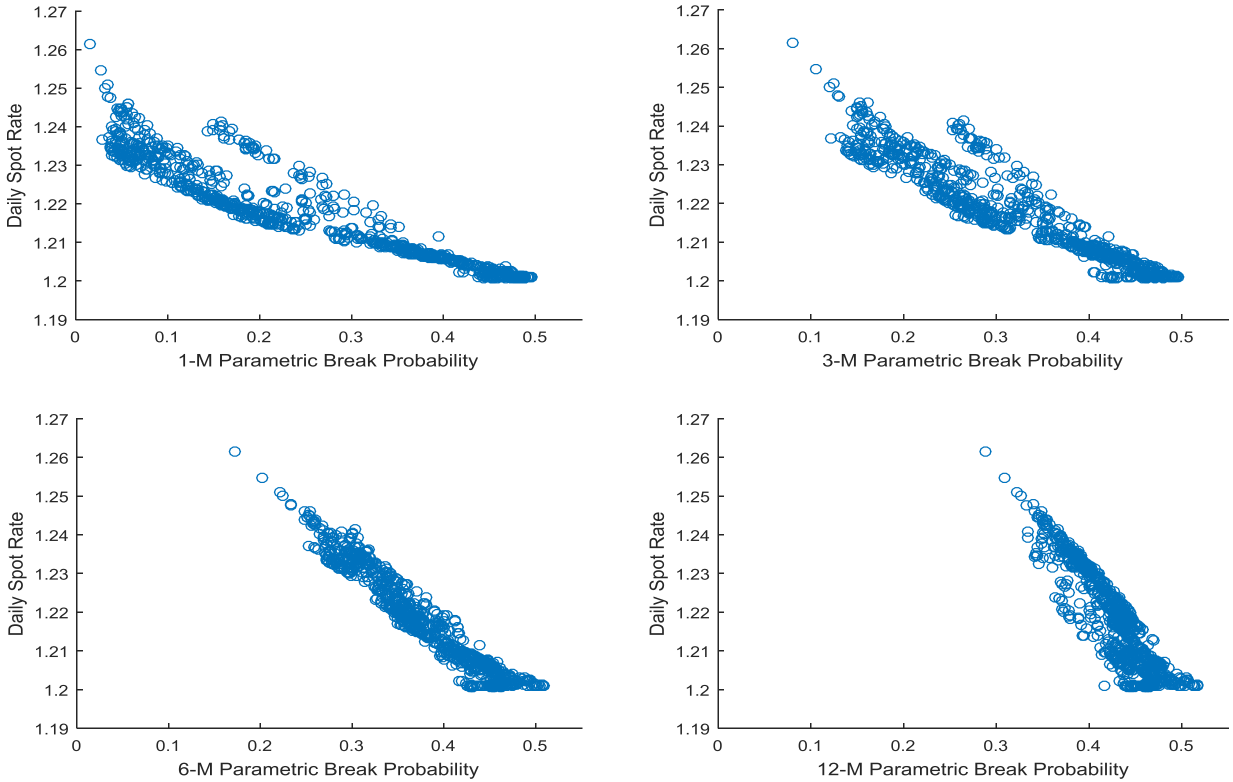
- When break probability is around or close to 50%, there are doubts about future existence.

Credibility Analysis: Break Probabilities



Credibility Analysis: Spot Rate vs. Break Probabilities I

- Sample period: 06/09/2011 to 14/01/2015.



Credibility Analysis: Spot Rate vs. Break Probabilities II

	1-M Prob	*3-M Prob*	*6-M Prob*	*12-M Prob*
Coefficient	-0.0814	-0.1137	-0.1900	-0.3054
P-Value	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.8809	0.8871	0.9413	0.8280

- OLS estimates of slope coefficient of: $S_t = \alpha + \beta\, x_t^\tau + \epsilon_t$
- S_t is the time t spot exchange rate and x_t^τ is the τ-month forward looking parametric break probability.
- Sample period: 06/09/2011 to 14/01/2015.

Credibility Analysis: Skewness and Excess Kurtosis

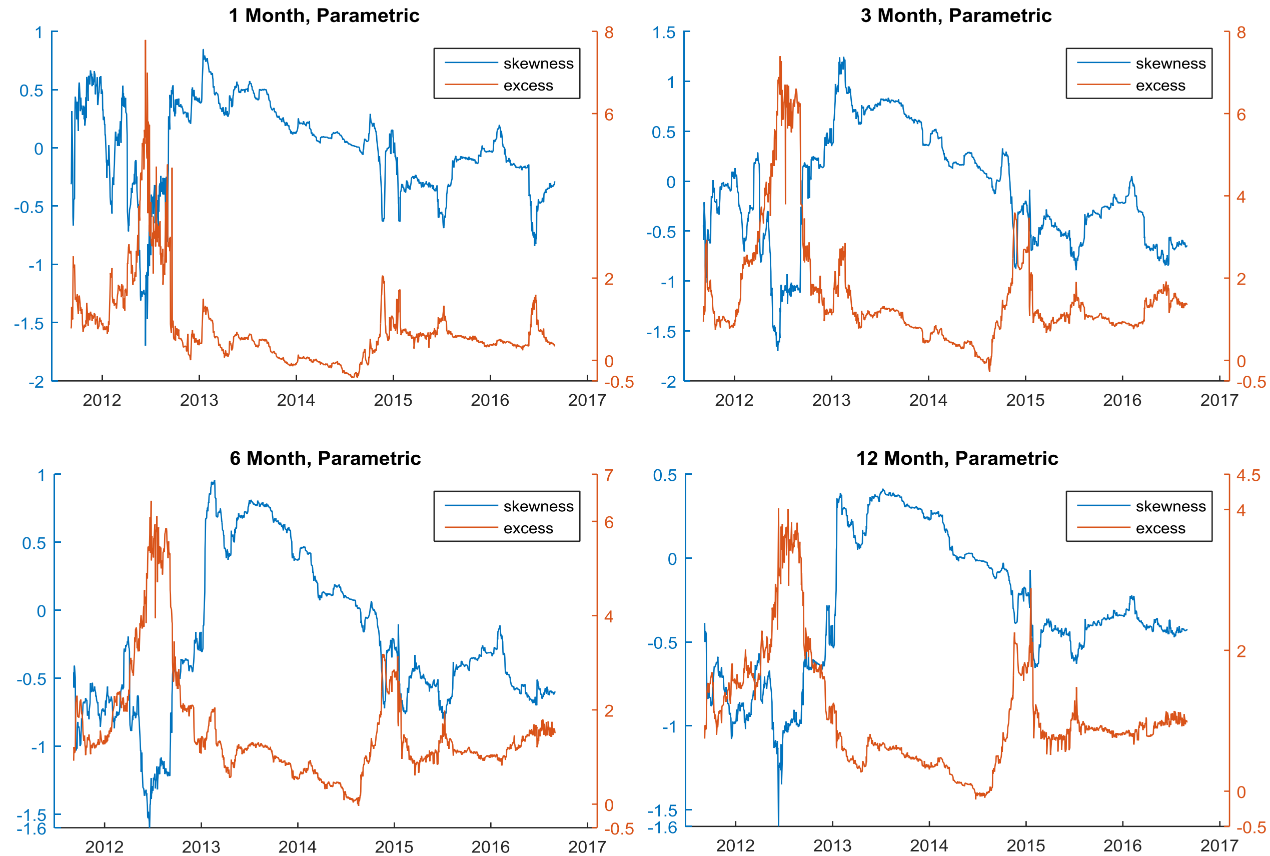
- To get a deeper understanding of how market views regarding credibility have evolved over time each days expected skewness and excess kurtosis are calculated:

$$sk_t^\tau = E\left[\left(\frac{X - E[X]}{\sigma}\right)^3\right] = \int_0^{+\infty} \frac{\left(x - E(X)\right)^3}{\sigma^3} \pi_t^\tau(x) dx$$

$$ex_t^\tau = E\left[\left(\frac{X - E[X]}{\sigma}\right)^4\right] - 3 = \left(\int_0^{+\infty} \frac{\left(x - E(X)\right)^4}{\sigma^4} \pi_t^\tau(x) dx\right) - 3$$

- Positive (negative) skewness: Market considers further depreciation (appreciation) of CHF against EUR as more possible.
- Larger excess kurtosis: Market considers large moves in both directions as more possible.
- Together:
  $\rightarrow sk_t^\tau \ll 0$ and $ex_t^\tau \gg 0$: Large appreciation is considered as more possible than large depreciation.

Credibility Analysis: Skewness and Excess Kurtosis



Forecasting Setup and Evaluation: Introduction

- Investigation whether option variables can outperform the naive random walk in terms of point forecasting.
- Conducting **point forecast** evaluation by MSE superiority tests and encompassing tests in the style of **Clark and McCracken(2001)**.
- Testing **directional forecasting** ability by test procedure of **Pesaran and Timmermann (1992).**
- Interpreting the parametric and non-parametric PDFs as **density forecasts**.
- Testing density forecasts by applying test procedure of **Berkowitz(2001)**.

Forecasting Setup and Evaluation: Related Literature

- Studies that examine the information content of FX option based measures on exchange rates:

  → **Campa and Chang (1996)**, **Malz (1996)**, **Haas et al. (2006)**: Option implied measures provide useful information during ERM crises of 1992.
  → **Campa et al. (1998)**: positive correlation between skewness and the spot rate for USD/DM and USD/Yen.
  → **Bates (1996)**: higher order option implied moments contain significant information for the future USD/DM exchange rate.

- For our point forecasts:

  → Focus on break probabilities, because these aggregate the properties of the density in one number.

Forecasting Setup and Evaluation: Point Forecasts

- 5 days daily data, one month has approximately 22 days.
- Recursive forecasting scheme. One step ahead out of sample random walk forecast vs. error correction forecast.
- Forecasting models take option maturity into account:

$$E_{t-22\tau}(s_t - s_{t-22\tau}) = 0 \qquad \rightarrow MSE_1$$

$$s_t - s_{t-22\tau} = \alpha + \beta(s_{t-22\tau} - \gamma_0 - \gamma_1 x_{t-22\tau}) + \epsilon_t \qquad \rightarrow MSE_2$$

- Nested models, therefore evaluation by test procedure of **Clark and McCracken(2001):**
  - → **MSE superiority:** One-sided t-test with null-hypothesis: $MSE_1 \leq MSE_2$
  - → **Encompassing:** One sided t-test with null-hypothesis: $Cov(MSE_1, (MSE_1 - MSE_2)) \leq 0$
- The tests follow non-standard limiting distributions.

Results: Point Forecasts

	ME	MAE	RMSE	MSE	MSE-F	MSE-t	ENC-F	ENC-t
1 Month								
Random Walk	0.00205	0.49413	0.75550	0.57078	----	----	----	----
Para	-0.1923	0.57418	0.78121	0.61030	-44.099	-1.958	37.617*	3.0463*
Non-Para	-0.1984	0.58024	0.79012	0.62428	-58.361	-2.609	29.506*	2.454*
3 Months								
Random Walk	0.01748	0.72141	0.93931	0.88229	----	----	----	----
Para	-0.2394	0.99949	1.17723	1.38587	-231.46	-12.930	-46.276	-5.5691
Non-Para	-0.2070	0.94647	1.13585	1.29017	-201.38	-12.399	-43.456	-5.8043

- Notes: 5%-Critical Values 1 Month (3 Months): MSE-F=0.966(1.045), MSE-t=0.241(0.268), ENC-F=3.418(3.384), ENC- t=1.386(1.392).
- In-sample period 1 Month and 3 Months: 06/10/2011 to 04/06/2012 and 07/12/2011 to 03/08/2012.
- Out-of-sample period 1 Month and 3 Months: 05/06/2012 to 14/01/2015 and 04/08/2012 to 14/01/2015.

Forecasting Setup and Evaluation: Directional Density Forecasts

- Non-parametric test of directional forecasting ability of **Pesaran and Timmermann (1992):**

  → Tests whether the sign of the τ-month return, $R_{t-22\tau} = \ln(S_t) - \ln(S_{t-22\tau})$, is predicted correctly by a variable $\Delta X_{t-22\tau}$:

$$R_{t-22\tau} = \beta \Delta X_{t-22\tau} + \epsilon_t \tag{3}$$

- Compares the fraction of right directional forecasts of (3), denoted by $\hat{P}$, with the fraction of co-movements of $R_{t-22\tau}$ and $\Delta X_{t-22\tau}$, denoted by $\hat{P}_*$.

- Under the null that $R_{t-22\tau}$ is independent from $\Delta X_{t-22\tau}$, $\hat{P}$ shouldn't differ from $\hat{P}_*$. Test-statistic:

$$PT = \frac{\hat{P} - \hat{P}_*}{var(\hat{P}) - var(\hat{P}_*)} \rightarrow N(0,1)$$

Results: Pesaran-Timmermann Test

- Pesaran/Timmermann Test,1 and 3-Months Maturity:

Parametric		**Non-Parametric**	
1 Month	3 Months	1 Month	3 Months
2.0422*	1.0538	1.3235	1.4324

Note: 5%-Critical Value: 1.96

- One month parametric break probabilities are able to predict the right sign of the one month return.
- All other specifications are not.
- All in all, directional forecasting ability is questionable

Forecasting Setup and Evaluation: Density Forecasts

- **Berkowitz (2001)** test, to evaluate quality of a density forecast.
- Probability Integral Transformation (PIT):

$$z_t = \int_0^{S_{t+22\tau}} \pi_t^{\tau}(x)dx$$

  → If density forecast is correct $y_t = \Phi^{-1}(z_t) \sim iid\ N(0,1)$.
- Estimate: $y_t - \mu = \alpha(y_{t-1} - \mu) + \epsilon_t$, $\epsilon_t \sim iid\ N(0,1)$.
- Likelihood-ratio test: $LR_3 = -2[L(0,1,0) - L(\hat{\mu}, \hat{\sigma}^2, \hat{\alpha})] \sim \chi^2_{(3)}$.
- For **Berkowitz(2001)** test the densities are not allowed to be overlapping in maturities, otherwise there would be by construction serial correlation in the z_t's.
- Hence for 1-month maturity only 39 non-overlapping densities are left during the peg. For 3-month maturity only 13 and so on.
  → Conducting **Berkowitz(2001)** test only for 1-month maturity.

Results: Berkowitz Test

- Berkowitz Test, 1-Month Maturity:

	Parametric PDF	**Non-Parametric PDF**
LR_3 *Statistic*	42.01	60.27
	(0.00)	(0.00)

Notes: $H_0: \{y_t\} \sim \text{iid } N(0,1)$; Under the validity of the null hypothesis the test statistic follows a $\chi^2(3)$ distribution; p-values are in parenthesis.

- Null is rejected, hence one month forward looking PDFs are not able to predict the full range of exchange rate realizations and corresponding probabilities correctly.
- PDFs can be used as barometer of market sentiment but not as good density forecasts.

Conclusion

- Swiss Franc floor was more credible over shorter horizons, but never fully credible as break probabilities for longer maturities as six and twelve months remain large.
- During turbulent times in 2012 and 2014 all densities indicate that markets believed a 50:50 chance of continuation.
- Over time and with longer horizons confidence in the SNB's commitment decreased.
- For the one-month parametric and non-parametric break probabilities ECM has an informational advantage over the random walk, but not for three months.
- Directional forecast test indicates that break probabilities are not really able to predict the right sign of the exchange rate movement.
- Density forecasts are not able to predict accurately. Therefore option implied PDFs can be seen as a barometer of market sentiment, but financial market prices do not incorporate additional information for the full range of exchange rate realizations.

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