Accepted manuscript
Bäurle, G. and Kaufmann, D. (2018), Measuring Exchange Rate, Price, and Output Dynamics at the Effective Lower Bound. Oxf Bull Econ Stat, 80: 1243-1266. doi:10.1111/obes.12260

Download publication from https://doi.org/10.1111/obes.12260

Measuring Exchange Rate, Price, and Output Dynamics at the Effective Lower Bound*

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13 August, 2018

Abstract

New Keynesian models with sticky prices make stark predictions about how the economy responds to shocks under different monetary policy regimes when short-term interest rates are constrained by an effective lower bound. We use the Swiss case as a laboratory to find evidence in favour of these predictions. We propose a Bayesian VAR to estimate impulse responses to risk shocks for short periods with a binding effective lower bound and with a publicly announced minimum exchange rate. In line with predictions from theory, we find that with a binding effective lower bound, the responses of the exchange rate, prices, and output become more persistent. However, the minimum exchange rate attenuates this adverse impact.

JEL classification: C11, C32, E31, E52, E58, F31

Keywords: Effective lower bound on short-term interest rates; Nonconventional monetary policy; Exchange rate targets; Bayesian SVAR.

*We thank two anonymous referees, Christiane Baumeister, Luca Benati, Fabio Canetg, Nicolas Cuche-Curti, Harris Dellas, Alain Galli, Sylvia Kaufmann, Miles Kimball, Leo Krippner, Mariano Kulish, Stefan Leist, Carlos Lenz, Matthias Lutz, James Morley, Alexander Rathke, Alex Perruchoud, Barbara Rudolf, Jonas Stulz, Rodney Strachan, Dominik Studer, Cédric Tille, as well as seminar participants at the University of Bern, the Swiss National Bank, the Bank of Lithuania, the Bank of Canada, and seminar participants at the SSES Annual Meeting, the SNB-BIS-Dallas Fed-CEPR conference on "Inflation Dynamics in a Post-Crisis Globalized Economy", the Jahrestagung of the Verein für Socialpolitik, the EABCN conference on "Inflation Developments after the Great Recession", the RBNZ conference on "Monetary Policy in Open Economies", the AEA annual meeting, for helpful comments and discussions. The views expressed in this paper are those of the authors and not necessarily those of the Swiss National Bank. A previous version of this paper has circulated as SNB Working Paper titled "Exchange Rate and Price Dynamics in a Small Open Economy – The Role of the Zero Lower Bound and Monetary Policy Regimes".

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1 Introduction

New Keynesian models with sticky prices make stark predictions about how the economy responds to shocks when the central bank faces an effective lower bound (ELB) on nominal interest rates (see e.g. Krugman, 1998, Eggertsson and Woodford, 2003, Adam and Billi, 2007, Kiley, 2016).[1] After a contractionary shock, agents expect prices to fall. Therefore, the real interest rate increases for a given nominal interest rate stuck at the ELB, which exacerbates the initial impact of the shock. An open economy additionally suffers from a strong and immediate real and nominal appreciation of the currency because the real interest rate increases relative to the real interest rate abroad (see Cook and Devereux, 2013, 2016).

Although the theoretical predictions are bleak under standard Taylor-type policy rules and inflation targeting, it is well known that there exist alternative commitments – such as history-dependent policy rules, as well as setting a price-level or exchange-rate target – that ameliorate the adverse impact of the ELB (see Reifschneider and Williams, 2000, Svensson, 2001, Eggertsson and Woodford, 2003, McCallum, 2006, Fujiwara et al., 2013). The power of such commitments is controversial, however, and has been called into question in theoretical work by Del Negro et al. (2012), McKay et al. (2016), Carlstrom et al. (2015) and Levin et al. (2010). Moreover, empirical work by Garìn et al. (2018) raises doubt about key implications of the New Keynesian model when the ELB is binding.[2]

Ultimately, whether these theoretical predictions are accurate is an empirical question. However, such an assessment is hampered by the fact that episodes with a binding ELB are intermingled with additional nonconventional monetary policy

[1] As long as it is possible to hold currency that earns a zero nominal interest rate, there is an effective lower bound on nominal interest rates, which is – due to storage costs, transaction costs or legal impediments to holding large amounts of currency – potentially lower than zero. As Swanson and Williams (2014b) emphasize, this effective lower bound can also be positive for institutional reasons.

[2] Moreover, Keen et al. (2017) show that the effectiveness of forward guidance differs in a nonlinear model.

actions. Because these nonconventional actions influence expectations about the future behaviour of the central bank, constant-parameter models are subject to the Lucas critique (see also Weale and Wieladek, 2016). Regrettably, from a strictly empirical point of view, episodes with a binding ELB but without nonconventional policy actions are rare and of short duration. Central banks usually take additional measures once their interest rate instruments approach the ELB.[3] To the extent that those interventions (explicitly or implicitly) shape expectations on the future evolution of the short-term interest rate, most episodes are not informative about the behaviour of the economy at the ELB under an unchanged monetary regime.

To disentangle the impact of the ELB from nonconventional policy actions, Switzerland proves to be an interesting case to study. We can identify two short episodes with a binding ELB and little nonconventional policy (i.e., no level target, no expectations management, and no permanent balance sheet expansions). Moreover, we observe an unexpected regime change when the SNB introduced an explicit minimum level for the CHF/EUR exchange rate in September 2011. Therefore, we can measure the dynamics of the Swiss economy with a binding ELB in addition to a publicly announced nominal level target.

We estimate a structural vector autoregressive model (SVAR) and show how the impulse responses to contractionary risk shocks, i.e., shocks that increase uncertainty in Switzerland's main trading partners, differ among the regimes. To tackle the small number of observations with binding ELB, we propose using Bayesian shrinkage methods. During normal times, we employ a noninformative prior. For the other two regimes we implement a prior centred on the posterior of the parameters at the effective lower bound. Following Giannone et al. (2015) we treat the weight given to

[3]We find many examples of a binding ELB and simultaneous nonconventional actions. Most of the large-scale asset purchases and forward guidance by the Federal Reserve were introduced at the same time as interest rates were close to zero. Moreover, the Swiss National Bank (SNB) conducted large-scale exchange rate interventions simultaneously with corporate bond purchases, while its policy instrument was effectively constrained. Similarly, the Czech National Bank adopted a commitment to maintain the exchange rate close to koruna 27 to the euro in autumn 2013, after short-term interest rates fell technically to zero at the end of 2012.

this prior as an additional hyperparameter to be estimated. This is a conservative choice because our prior implies no change in the parameters between the regimes.

We find that when the ELB is binding, the dynamics of the exchange rate, imported consumer prices, and output differ from normal times: the responses of those variables to a temporary risk shock become more persistent. We find a smaller difference relative to normal times after the SNB introduced an explicit minimum exchange rate. The responses of the macroeconomic variables become less persistent. This speaks to the success of a nominal level target to mitigate the adverse impact of the ELB. The findings are robust with respect to alternative identification schemes that lead to an appreciation of the Swiss franc. The impact of the ELB arises independently of the exact nature of the contractionary shock. We provide thus empirical support for the theoretical argument that a stable exchange rate is beneficial in an ELB environment when another commitment mechanism is lacking (see Svensson, 2001, Fujiwara et al., 2013, Cook and Devereux, 2016).

Our model has several advantages over existing approaches to estimate impulse response at the ELB. First, because of the sudden introduction of the minimum exchange rate, it is inappropriate to treat the entire Swiss ELB episode as one monetary regime with unchanged parameters as in Japan (see Miyao, 2002, Iwata and Wu, 2006, Schenkelberg and Watzka, 2013), or in the US (see Weale and Wieladek, 2016).[4] Second, against the backdrop of our particularly short samples, the Bayesian shrinkage approach allows a relatively rich model in terms of the lag length and number of variables while still letting the data speak about possible parameter changes (in contrast to more restrictive Minnesota-type priors). Finally, our approach is closely related to a time-varying parameter VAR (TVP-VAR) as used by Primiceri (2005), Baumeister and Benati (2013), and Debortoli et al. (2018). In typical TVP-VARs, however, coefficients change every period, which increases the degrees

[4]This does not necessarily imply that constant-parameter VARs are inappropriate for analysing the Japanese or US cases. Wu and Xia (2016) find no significant changes in VAR coefficients when the ELB started to be binding in the US.

of freedom substantially. This requires restricting the size of the possible parameter changes. Consequently, this approach yields many, albeit small, regime changes that are a priori independent of the state of the economy and, therefore, it is not tailored to capture the sudden and large regime changes that we observe for Switzerland.

We contribute to a recent literature that examines the adverse impact of the ELB and the effectiveness of alternative commitments and forward guidance.[5] In line with our results, Caggiano et al. (2017) find that the ELB exacerbates the impact of risk shocks on real activity. Garìn et al. (2018), however, argue that a key implication of the New Keynesian model is at odds with the data because positive technology shocks are still expansionary when the ELB is binding. As one possibility for their finding, and in line with our results, they mention that the basic New Keynesian model does not take into account nonconventional policy measures that ameliorate the ELB constraint. Debortoli et al. (2018) find that, for the US, the impulse responses of a time-varying parameter VAR do not change at the ELB. They also suggest that this is because conventional monetary policy can be substituted with nonconventional measures. Other studies rely on structural models to account for changes in the policy regime implied by, for example, forward guidance. Gust et al. (2017) showed that the ELB indeed exacerbated the economic slump in the US estimating a non-linear DSGE model using Bayesian methods. Moreover, Plante et al. (2016) showed that the ELB contributed to higher uncertainty and consequently higher volatility of real activity. Finally, the effectiveness of forward guidance in the US has been explored by Campbell et al. (2016) and Christiano et al. (2015).

The remainder of this paper is organized as follows. We first identify separate

[5]The term forward guidance is also used to describe that some central banks publish a forecast of their policy interest rate. For some central banks this was common practice even before the financial crisis and away from the ELB. However, this represents a commitment conditional on an unchanged policy regime. In theory, such commitments are less powerful than introducing, for example, a nominal level target at the ELB. Our study therefore differs from Kool and Thornton (2015) who measure the effectiveness of forward guidance in terms of improved market participant's ability to forecast short-term interest rates and Svensson (2015) who empirically examined the predictability and credibility of policy rate forecasts.

episodes when the Swiss National Bank's operational interest rate target was effectively constrained and when additional nonconventional policy actions were taken. Then, we propose a Bayesian SVAR to estimate the impulse responses to a risk shock under different regimes with a small number of observations and discuss its properties relative to alternative approaches. Finally, we present the results before offering some concluding remarks.

2 The ELB and monetary policy in Switzerland

Following Wu and Xia (2016) we can formally identify whether the ELB was binding using a shadow-short rate (SSR) and compare it with the SNB's reference rate – the 3M-Libor. The SSR is calculated using the approach by Krippner (2013).[6] A negative SSR combined with a positive 3M-Libor suggests that the policy instrument was constrained by the ELB.[7] The SSR fell below 0% from December 2002 until April 2004 and again in December 2008. In December 2014, however, the SNB announced to introduce negative interest rates on sight deposits and lowered its target range for the 3M-Libor to $[-0.75\%, 0.25\%]$.[8]Therefore, we assume that the ELB was binding only from December 2002 to April 2004 and from December 2008 to November 2014 (see shaded areas in Figure 1, panel A).

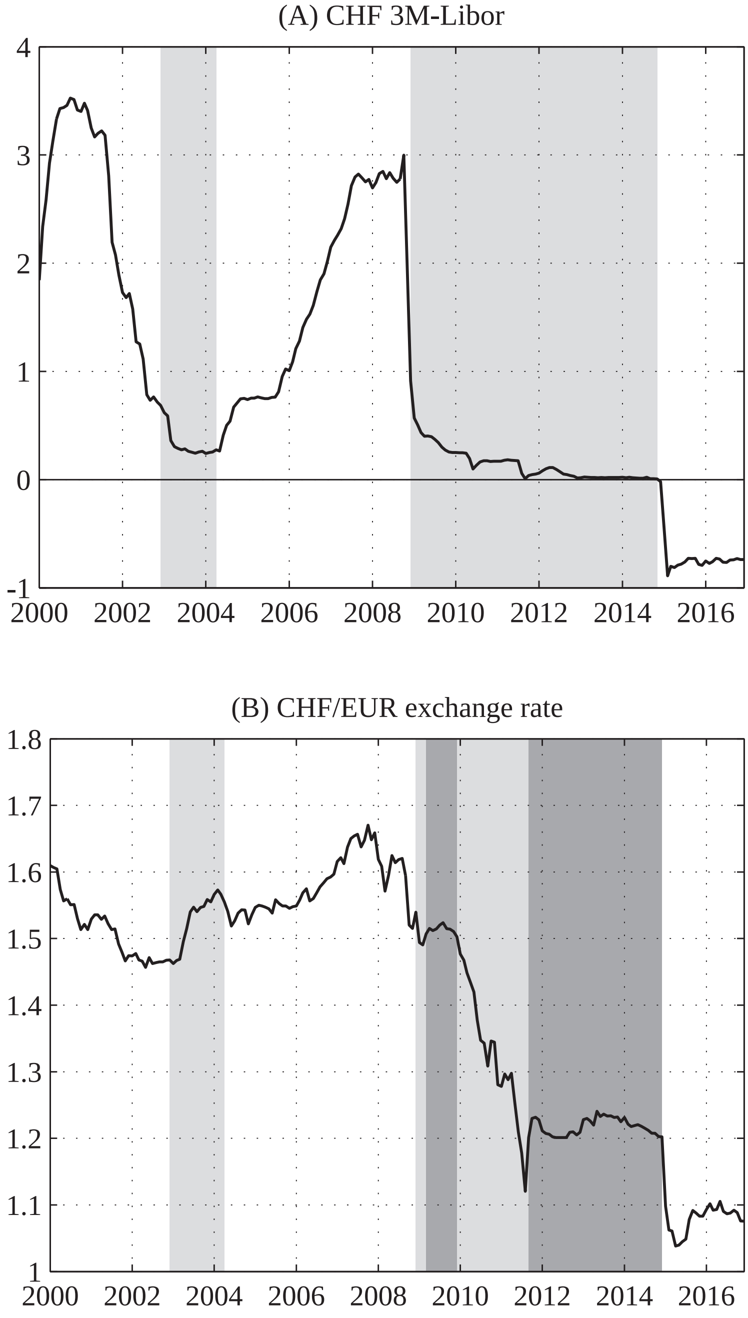
This is supported by narrative evidence from the SNB's press releases. The SNB usually announces a 100 basis points target range for the 3M-Libor point and aims at targeting the centre of this range. However, on an unscheduled monetary policy assessment in March 2003, the Swiss National Bank narrowed the target range to 75 basis points (0%-0.75%) because of "technical factors" (see SNB, 2003) and announced to target a 3M-Libor of 25 basis points. The truncated range suggests that

[6]We are grateful to Leo Krippner for sharing the data for Switzerland.

[7]Our definition of the ELB highlights that, although it may have been technically possible to reduce the policy rate further, the SNB refrained from doing so in practice.

[8]Negative interest rates on sight deposits were charged starting on 22 January, although the 3M-Libor declined immediately on the announcement.

Figure 1: Episodes at the effective lower bound



Note: The upper panel shows the CHF 3M-Libor (in percent). The lower panel shows the CHF/EUR exchange rate defined as the price of the euro in Swiss francs; i.e., a decrease is an appreciation of the Swiss franc. Light grey areas denote episodes with a binding ELB. Dark grey areas denote episodes with implicit or explicit minimum exchange rates against the euro.

policy-makers did not consider the possibility of a negative 3M-Libor. Moreover, in the wake of the global financial crisis, the target range was truncated at zero on 12 March 2009 “due to the fact that a negative Libor is not technically possible” (see SNB, 2009). After the SNB introduced negative interest on reserves in December 2014, and therefore showed the possibility and willingness to let the 3M-Libor move to negative territory, it widened the range again to 100 basis points.

A first glance at the data supports the theory by Cook and Devereux (2016) that ELB episodes are accompanied with an appreciation of the Swiss franc. The lower panel of Figure 1 shows CHF/EUR exchange rate defined as the price of one euro in Swiss francs; i.e. a decrease is an appreciation of the Swiss franc. We observe a strong appreciation of the Swiss franc between December 2009 and August 2011, when the Swiss franc gained 25%. Interestingly, with gains of 24% against the US dollar, and 11% against the yen, the Swiss franc also appreciated against other typical safe haven currencies.[9] During the ELB episode starting in December 2002, the Swiss franc also appreciated by about 10% but against the US dollar. The narrative evidence from speeches of the governing board suggests that this appreciation worried policy-makers (see Burkhard and Fischer, 2009).[10] This is supported by Table 1 showing that all interest rate cuts in 2002 and 2003 were taken at unscheduled exceptional meetings and were justified by the strengthening of the Swiss franc against major currencies.

So far, we only examined whether the short-term interest rate was constrained by the ELB. This does not imply, however, that the SNB refrained from nonconventional policy actions. The negative SSR may indicate that nonconventional policy measures pushed long-term interest rates lower. Swanson and Williams (2014a), for example, find that long-term yields respond to macroeconomic news even though

[9]Ranaldo and Söderlind (2010) document similar safe haven properties of the yen and the Swiss franc with data from 1993 to 2008.

[10]This is also in line with the experience in the late 1970s (not shown in chart). At the time, the Swiss franc experienced one of the largest appreciation phases in the post-Bretton Woods era while the short-term interest rate reached very low levels.

short-term interest rates do not. Moreover, Debortoli et al. (2018) find for the US that nonconventional monetary policy sufficed to offset the worst impact of the ELB.

Therefore, to estimate whether the ELB is a relevant constraint, we have to examine episodes with little or no nonconventional policy actions. During the episode starting in December 2002 policy-makers publicly made several references to foreign exchange interventions. However, they refrained from actually intervening (see Burkhard and Fischer, 2009). We therefore classify this period as an episode with binding ELB but no additional policy actions.

For the period starting during the global financial crisis Table 1 summarizes the most important decisions extracted from press releases at regular and exceptional monetary policy assessments. First, when the ELB became binding in late 2008, the SNB became quickly concerned with the strength of the Swiss franc. It therefore announced that it would intervene in the foreign exchange market to prevent a further appreciation against the euro in March 2009. Although the intervention level was not explicitly announced, markets believed that this implied a minimum exchange rate of CHF/EUR 1.50.[11] In addition, the SNB introduced a bond purchase programme during spring and summer 2009 with the aim of reducing risk premia on long-term corporate bonds (see Kettemann and Krogstrup, 2014). Therefore, during this episode the ELB was binding but there were several additional nonconventional policy actions.

Thereafter, the SNB abandoned this implicit exchange rate target. In September 2009 it still acted to prevent *any* appreciation against the euro, but on 10 December 2009 it announced to prevent only *any excessive* appreciation. This subtle change in tone came with a change in policy and the Swiss franc fell below CHF/EUR 1.50 on 18 December 2009. Although the SNB made regular references to the increasingly

[11] A Reuters journalist reported on 4 November 2009 that “The EUR/CHF pair has not been expected to go below the psychological 1.50 mark in the last eight polls.”, and quoted an analyst that “The SNB has responded with a range of unconventional policy measures, including FX intervention, and appears to be defending the area around EUR-CHF 1.5000” (see Mehta, 2009).

Table 1: SNB's policy actions from 2008 – 2015

Date	Scheduled meeting	3M-Libor range	Nonconventional policies and comments
5/2/2002	no	[0.75, 1.75%]	Lowered target range by 0.5pp because of continued concern over exchange rate against major currencies
7/26/2002	no	[0.25%, 1.25%]	Concern over a further real appreciation
3/6/2003	no	[0%, 0.75%]	Temporary narrowing of target range because of "technical factors"
6/17/2004	yes	[0%, 1%]	The interest target range again exhibits a spread of 100 basis points
9/19/2002	yes	[0.25%, 1.25%]	
Regular interest rate hikes up to a range of [2.25%,3.25%] until the onset of the Financial Crisis			
12/11/2008	yes	[0, 1%]	
3/11/2009	yes	[0, 0.75%]	Acts to prevent further CHF/EUR appreciation and buys Swiss franc bonds issued by private sector borrowers.
6/18/2009	yes	[0, 0.75%]	Takes firm action to prevent an appreciation against euro and continues to purchase Swiss franc bonds to reduce risk premia.
9/17/2009	yes	[0, 0.75%]	Acts decisively to prevent any appreciation against euro. If necessary purchases Swiss franc bonds.
12/10/2009	yes	[0, 0.75%]	Acts decisively to prevent any excessive appreciation against the euro. Its purchases of Swiss franc bonds are discontinued.
3/11/2010	yes	[0, 0.75%]	Acts decisively to prevent an excessive appreciation against euro.
6/17/2010	yes	[0, 0.75%]	
Between June 2010 and July 2011 the SNB does not take action to prevent an appreciation but comments, for example, that "the Swiss franc has appreciated". Moreover, concerns about the stability of the euro area are mentioned as of December 2010.			
8/3/2011	no	Close to zero	Expands sight deposits from CHF 30 billion to CHF 80 billion to weaken Swiss franc.
8/10/2011	no	Close to zero	Rapidly expands banks' sight deposits from CHF 80 billion to CHF 120 billion by conducting foreign exchange swap transactions.
8/17/2011	no	Close to zero	Expands sight deposits from CHF 120 billion to CHF 200 billion.
9/6/2011	no	Close to zero	No longer tolerates a CHF/EUR exchange rate below the minimum rate of 1.20. Prepared to buy foreign currency in unlimited quantities.
Between September 2011 and September 2014 the SNB reaffirms the minimum exchange rate as well as the target for the 3M-Libor at its regular monetary policy assessments.			
12/18/2014	no	[−0.75%, 0.25%]	Reaffirms minimum exchange rate but introduces −25bp interest on sight deposit balances.
1/15/2015	no	[−1.25%, −0.25%]	SNB discontinues minimum exchange rate and lowers interest rates on sight deposit balances to −75bp.

strong Swiss franc, little additional nonconventional policies were taken for one and a half years. Sight deposits of domestic banks increased until May 2010 reflecting an attempt to dampen the ongoing appreciation with foreign exchange interventions. No implicit or explicit exchange rate targets were announced, however. Moreover, sight deposits started to decline in June 2010 and the sentence about preventing an excessive appreciation vanished from the press release.[12] From September 2010 onwards, sight deposits remained largely stable, and the target range for the 3M-Libor remained unchanged. Therefore, the short period starting in January 2010 and ending in July 2011 represented an episode with a binding ELB, no commitment in terms of a nominal level target, and no permanent balance sheet expansions.

This episode came to an end when additional nonconventional measures were taken in August 2011. The strong appreciation of the Swiss franc and the dismal situation in Europe led to tumbling inflation in Switzerland and the SNB thus aimed to weaken the exchange rate to curb deflationary pressures. The 3M-Libor target was lowered as close as possible to 0% and commercial bank's sight deposits were expanded in three rounds from CHF 30 billion to CHF 200 billion. When the Swiss franc failed to weaken sufficiently the SNB implemented a change in its operational regime towards a nominal level target. In September 2011, it announced an explicit minimum exchange rate at CHF/EUR 1.20. We interpret this change in regime as a price-level target relative to the euro area. This regime remained in place until December 2014, when the SNB introduced negative interest rates on sight deposits, and, was abandoned in January 2015.[13]

To summarize, we can distinguish two episodes that are informative with respect to the adverse effects of the ELB and one episode about the impact of an explicit level

[12]With hindsight, the increase in sight deposits by CHF 42 billion was not only temporary but also modest compared to the CHF 170 billion expansion that followed in August 2011 and the CHF 391 billion expansion of sight deposits between August 2011 and May 2016.

[13]For studies analysing the credibility of the minimum exchange rate during this period see Hertrich and Zimmermann (2017), Jermann (2017), and Mirkov et al. (2016). For our empirical analysis, it matters only, however, that the minimum exchange rate was enforced and that the removal of the exchange rate was not anticipated.

target. First, the ELB was binding from December 2002 until April 2004 and again from January 2010 until July 2011. During both periods, the SNB refrained from nonconventional policy actions. Second, the introduction of the minimum exchange rate in September 2011 marks a shift in its operational regime towards a nominal level target, which was accompanied by negative interest on reserves in December 2014 and abandoned unexpectedly in January 2015.

3 Methodology

The meagre number of observations available to estimate the impact of the ELB and the minimum exchange rate regime require appropriate econometric methods. This section presents the model, the Bayesian estimation approach, the data, and the identification strategy.

3.1 Model and estimation

Assume that the data are generated by a vector autoregressive process:

$$y_t = B_{0,t} + B_{1,t} y_{t-1} + \ldots + B_{p,t} y_{t-p} + Q_t \varepsilon_t \quad (1)$$

$$\varepsilon_t \sim N(0, I_n) \ , \quad (2)$$

where y_t is a $n \times 1$ vector of endogenous variables and ε_t is an $n \times 1$ vector of exogenous shocks. $B_{0,t}, \ldots, B_{p,t}$ and Q_t are matrices containing the unknown time-varying parameters. The likelihood of the model is invariant to orthonormal transformations of Q_t, the contemporaneous impact of shocks on observed variables. We therefore parameterize the likelihood function in terms of $\Sigma_t = Q_t' Q_t$ and estimate this reduced form model. Only in a second step do we identify Q_t based on further restrictions derived from economic theory.

We assume that the reduced-form parameters change when the interest rate hit or left the ELB and when the minimum exchange rate was introduced. Thus, we rewrite the system for each sample as follows, extending Giannone et al. (2015) to the case of parameters that switch between different regimes. First, define the matrices $y = [y_{p+1}, \ldots, y_T]'$, $Y = vec(y)$, $x_t = [1, y'_{t-1}, \ldots, y'_{t-p}]'$, $x = [x_{p+1}, \ldots, x_T]'$, $X = I_{n_t} \otimes x$, and $e = vec([\varepsilon_{p+1}, \ldots, \varepsilon_T]')$. Then, split these matrices such that Y_0, X_0 and e_0 collect observations with $t-p, \ldots, t \in \{\text{ELB not binding}\}$, Y_1, X_1 and e_1 collect observations with $t-p, \ldots, t \in \{\text{ELB binding, no nonconventional actions}\}$ and Y_2, X_2 and e_2 collect observations with $t-p, \ldots, t \in \{\text{ELB binding, minimum exchange rate}\}$. Thus, we require that the observations as well their lags are in the respective regime.[14] Then, write the system as

$$Y_i = X_i \beta_i + e, \quad e_i \sim N(0, \Sigma_i \otimes I_{T_i - p}) \quad , \tag{3}$$

for $i \in \{0, 1, 2\}$, where $\beta_i = vec(B_i)$ with $B_i = [B_{0,i}, \ldots, B_{p,i}]'$ and Σ_i collect the parameters corresponding to the respective samples. Hence, the system can be written as a linear regression model and standard Bayesian methods for such models can be applied. The number of regressors is $k = np + 1$ and the number of observations are denoted by T_i in each sample.

We follow the bulk of the literature by selecting a natural conjugate prior distribution for the model parameters:

$$\Sigma_i \sim IW(\underline{\Psi}_i, \underline{d}_i), \quad \beta_i | \Sigma_i \sim N(\underline{\beta}_i, \Sigma_i \otimes \underline{\Omega}_i) \quad . \tag{4}$$

The posterior distribution can be shown to read (see e.g. Giannone et al., 2015,

[14]This implies that we lose observations with lags belonging to different regimes than the actual observations.

Online Appendix):

$$\Sigma_i|y_i, X_i \sim IW(\bar{\Psi}_i, \bar{d}_i), \quad \beta_i|\Sigma_i, y_i, X_i \sim N(\bar{\beta}_i, \Sigma_i \otimes \bar{\Omega}_i) \quad , \tag{5}$$

with

$$\begin{aligned}
\bar{\beta}_i &= vec(\hat{B}_i) \\
\bar{\Omega}_i &= \Sigma_i \otimes (x_i'x_i + \underline{\Omega}_i^{-1})^{-1} \\
\bar{\Psi}_i &= \underline{\Psi}_i + \hat{\varepsilon}_i'\hat{\varepsilon}_i + (\hat{B}_i - \hat{\underline{\beta}}_i)'\underline{\Omega}_i^{-1}(\hat{B}_i - \hat{\underline{\beta}}_i) \\
\bar{d}_i &= T_i - p + \underline{d}_i
\end{aligned}$$

where $\hat{B}_i = (x_i'x_i + \underline{\Omega}_i^{-1})^{-1}(x_i'y_i + \underline{\Omega}_i^{-1}\underline{\beta}_i)$, $\hat{\varepsilon}_i = y_i - x_i\hat{B}_i$ and $\hat{\underline{\beta}}_i$ being a $k \times n$ matrix obtained from reshaping $\underline{\beta}_i$ suitably.

For the period in which the interest rate is not constrained by the ELB, we follow Uhlig (2005) and Weale and Wieladek (2016) and implement a weak prior with $\underline{\Psi}_0 = 0$ and $\underline{d}_0 = 0$.[15] For the ELB episodes, i.e., for $i \in \{1, 2\}$, the number of parameters is rather large compared to the number of observations. In this case, parameterizing the prior distribution, i.e., selecting $\underline{\beta}_i$, $\underline{\Omega}_i$, $\underline{\Psi}_i$ and $\underline{d}_i$, becomes critical. We approach this problem by implementing an a priori belief that the distribution of the parameters in the ELB episodes are similar to the one in the non-ELB episodes. To implement this idea, we parameterize the prior distribution for the ELB parameter using the posterior moments of the non-ELB parameters:

$$\underline{\beta}_i = \bar{\beta}_0, \quad \underline{\Omega}_i = \frac{\bar{\Omega}_0}{\lambda_i}, \quad \underline{\Psi}_i = \lambda_i \bar{\Psi}_0, \quad \underline{d}_i = \lambda_i \bar{d}_0, \tag{6}$$

[15] $\underline{\Omega}_0$ and $\underline{\beta}_0$ can be set to arbitrary values.

where λ_i is a parameter determining the tightness of the prior for the respective sample. Inspecting the prior distribution, if λ_i becomes larger, the prior distribution becomes tighter around the non-ELB bound sample estimates. We determine this prior weight by conducting a formal posterior analysis with respect to λ_i. Specifically, we add a Beta(2,2)-prior for λ_i and simulate from its posterior distribution by introducing a Random-Walk Metropolis-Hastings step into the otherwise standard posterior sampling procedure for the VAR coefficients (see e.g. Giannone et al., 2015, for an application of the same idea to a Bayesian VAR with different sets of dummy observations).[16] A detailed description of the sampling procedure is provided in the online Appendix.

3.2 Comparison with existing approaches

Using prior information for the short estimation sample is preferable to an SVAR estimated with a noninformative prior as this would either strongly limit the number of variables and lags that could be included in the model or would yield imprecise estimates.[17] Our approach also has advantages over Minnesota-type priors implementing a priori beliefs on the stochastic properties of the data. The bias introduced by such priors can be substantial if those a priori beliefs are inappropriate for the monetary regime in place. In contrast, our prior is conservative because its shrinkage works towards finding less pronounced changes between regimes, and thus, avoids parameter changes that are spuriously amplified by the prior specification.

Furthermore, our approach is more appropriate than a TVP-VAR for the present application although it shows some similarities to a such a model. In standard TVP-

[16]The weight of an observation from the non-ELB sample should not be larger than the weight of an ELB-sample observation. Therefore, we use a Beta distribution with support [0,1] instead of the Gamma distribution suggested by Giannone et al. (2015).

[17]Weale and Wieladek (2016) use two lags in their main specification having at their disposal five years of monthly data. They mention that extending the lag length would have required using a Minnesota-type prior. Our approach can be seen as a medium case that avoids a strong prior while still allowing for a longer lag length. This is especially relevant because our two regimes are of even shorter duration.

VAR analysis, parameters are allowed to vary in each period (see e.g. Baumeister and Benati, 2013, for an application including an ELB episode). Usually, it is assumed that the parameters in period t equal the parameters in $t-1$, distorted by an exogenous shock vector. To reduce the degrees of freedom, it is necessary to impose parametric assumptions on this shock vector. Our approach implements a similar idea. To see this, write β_1 (the parameters during the ELB period) as a function of β_0 (the parameters during normal times) and a shock vector ξ_1,

$$\beta_1 = \beta_0 + I(\tilde{i}_t \leq c)\xi_1 \quad ,$$

where $\tilde{i}_t$ is the SSR used to identify the ELB episodes and $I(\tilde{i}_t \leq c)$ is an indicator function if the policy instrument is constrained by a lower bound c. Further assume that $\xi_1 \sim N\left(0, (\frac{1}{\lambda_1} - 1)Var(\beta_0|y_0, X_0)\right)$. We then get

$$E(\beta_1|y_0, X_0) = E(\beta_0|X_0), \quad Var(\beta_1|y_0, X_0) = \frac{Var(\beta_0|X_0)}{\lambda_1} \tag{7}$$

which exactly corresponds to the prior distribution described above. This establishes that our approach is conceptually related to a TVP-VAR with occasional jumps. Inspecting the posterior distribution and equation (7), it becomes apparent that the scale of λ_1 simultaneously determines the weight of the prior distribution relative to the information contained in the actual data and the scale of the a priori variance of the shock to the parameter vector.

The assumption that the parameters change only in specific periods may not be innocuous in the view of a DSGE model. Reduced-form parameters change with the expected duration of the ELB period (see Kulish et al., 2014). Thus, we must assume in our empirical analysis that the variation in these expectations are, from an empirical point of view, negligible within the respective samples. This is certainly appropriate for the minimum exchange rate regime because its introduction and sudden removal were unexpected.[18]

Against this backdrop, the advantages of our approach prevail. In a TVP-VAR, no a priori information is exploited regarding the timing of parameter changes. The fact that we determine a priori time periods with potential regime changes based on narrative evidence reduces the degrees of freedom considerably. This allows us to parameterize the distribution of the parameter innovations less tightly than necessary in standard TVP-VAR analysis. Thus, parameters are allowed to change less frequently but to a larger extent.[19] Furthermore, our approach is much lighter computationally. Typical applications with Bayesian TVP-VARs include only a few variables and restrict the dynamics to a small number of lags to make the estimation tractable.[20]

3.3 Data and identification

The whole sample range covers the period from January 1994 to November 2014.[21] All models comprise an estimate of monthly Swiss GDP, subindices for imported and domestic consumer prices, as well as a nominal effective exchange rate. The nominal effective exchange rate is defined against 24 of the most important trading partners of Switzerland. However, we invert the exchange rate such that it is defined as the price of basket of foreign currencies in Swiss francs; i.e., a decrease is an appreciation of the Swiss franc. We use a monthly GDP interpolation because a

[18]An inspection of interest rate futures data also supports this assumption. We only observe a substantial change in the implied 3M-Libor forward rates in the second half of 2011 (when the SNB introduced the minimum exchange rate against the euro) and in January 2015 (when interest rates moved into distinctly negative territory and the minimum exchange rate was abandoned).

[19]Nevertheless, we estimated a TVP-VAR (the results are provided in the online Appendix). These confirm that the responses are more persistent around the ELB samples. However, the model does not capture the more sudden change in parameters and policy that we attempt to measure using our model.

[20]Baumeister and Benati (2013) limit the number of lags to two in their VAR with four variables referring to computational feasibility.

[21]The start date of this sample is guided by Stulz (2007) who finds a significant downward shift in the mean of Swiss CPI inflation in mid-1993. Therefore, all data are from a low-inflation period. The sample ends before the SNB announced to introduce negative interest rates at −25 basis points on sight deposits in December 2014.

monthly industrial production series is lacking.[22] All variables are transformed by taking logarithms of the levels. Following Baumeister and Benati (2013), we include the difference between the 10-year government bond yield and the 3M-Libor (term spread) instead of a short-term interest rate.[23] This allows us to include a variable with meaningful variation even though the SNB's operational target was constrained by the ELB.[24]

We employ alternatively recursive and sign restriction schemes to identify impulse responses to risk shocks. Baumeister and Hamilton (2015) emphasize that supposedly agnostic sign restrictions may impose implausible prior assumptions on key structural parameters of interest. We therefore explore various identification strategies with and without sign restrictions.

We identify risk shocks, that is, shocks that increase uncertainty in Switzerland's main trading partners and potentially lead to an appreciation of the Swiss franc.[25] The reason is that the Swiss franc is generally regarded as a safe haven currency that appreciates in times of crisis (see e.g. Ranaldo and Söderlind, 2010).[26] Despite the fact that the ELB is a one-sided constraint, our VAR is linear such that a positive shock has exactly the opposite effect of a negative shock. This is in line with Swanson and Williams (2014a) who find (theoretically as well as empirically)

[22] We follow Stulz (2007) to calculate a monthly measure of real GDP. The interpolation uses the Chow-Lin procedure assuming a linear relationship between the unobservable series of interest and some higher-frequency indicator variables (Chow and Lin, 1971). The monthly indicator variables to perform the interpolation stem from the expenditure side of GDP. These include goods exports (proxy for total exports), retail sales (proxy for consumption), imports of investment goods (proxy for total imports and business investment). We are grateful to Jonas Stulz for providing his code for performing the interpolation.

[23] Using other interest rate spreads leads to similar results.

[24] An extension to explicitly incorporate the censoring of the short-term interest rate by the ELB could be modelled along the lines of Nakajima (2011) and Bäurle et al. (2016).

[25] Theoretically, the dynamics of the economy at the ELB change for various shocks when the interest rate is constrained. The theoretical literature often focuses on preference shocks (see e.g. Cook and Devereux, 2013) while the empirical literature mostly identifies conventional and nonconventional monetary policy shocks (see e.g. Baumeister and Benati, 2013, Wu and Xia, 2016, Weale and Wieladek, 2016), as well as technology shocks (see Garìn et al., 2018).

[26] Moreover, the Swiss franc appreciation during the global financial crisis is often regarded as a consequence of financial market participants' perceptions of higher global risk (see Danthine, 2011).

that for a sufficiently strongly binding ELB constraint medium- and long-term bond yields respond symmetrically to shocks. Iwata and Wu (2006), Nakajima (2011), and Bäurle et al. (2016) instead take the non-negativity constraint explicitly into account.

For the models identified recursively we add, alternatively, three measures of uncertainty. Following, Baker et al. (2016) we identify the structural shock by assuming that innovations to these measures are exogenous for the Swiss economy. In other words, they are ordered first in our recursive identification scheme. In the first specification, we use the US and EU uncertainty measures by Baker et al. (2016) and compute an average weighted by Swiss export shares to those economic areas to approximate policy uncertainty. In the second specification, we approximate stock market uncertainty by an export-weighted average of the implied volatility of the S&P 500 (US VIX) and German DAX. The US VIX is often regarded as a measure of "global risk appetite" (see Brunnermeier et al., 2009, and references therein). However, we use weights reflecting the share of Swiss exports to the corresponding regions to derive measures that are more relevant for the Swiss economy. In the third specification, we use the monthly average of the global real economic uncertainty measure by Scotti (2016).[27]

In addition to the recursive scheme, we use the sign restriction approach by Uhlig (2005) to identify a risk premium shock. The VAR identified with sign restrictions does not include the uncertainty measures but adds an import price index at the docks so that the total number of variables remains unchanged. The identifying assumptions are that, in the short run, the exchange rate appreciates and the term spread increases, while import prices at the docks and output decline. Table 2 shows that these restrictions are in line with the impulse responses of the small-open economy DSGE model by Justiniano and Preston (2010), estimated by Bäurle

[27] A further possibility would be the macroeconomic uncertainty measure by Jurado et al. (2015). We experimented with their measure but decided to focus on global uncertainty measures, including European countries because they are likely more relevant for the Swiss economy than for the US.

and Menz (2008) for Switzerland.[28] We also see that only the response to the risk premium shock shows a negative reaction of the exchange rate and a simultaneous increase in the term spread. This feature enables us to disentangle the risk premium shock from other shocks. Including the term spread is particularly useful because it increases even with a binding ELB. The reason is that the short-rate is expected to increase at some point in the future, which raises the long-rate relative to the short-rate because of the expectations hypothesis.[29]

Table 2: Signs of initial impulse responses

	Exchange rate	Term spread	Import prices	Output
Technology	−	−	−	+
Cost push	−	−	+	−
Preference	−	−	−	+
Monetary policy	−	−	−	−
Risk premium	−	+	−	−

Note: The table gives the signs of initial impulse responses according to the small open-economy DSGE model presented by Bäurle and Menz (2008) which is based on Justiniano and Preston (2010). The signs of the shocks are chosen so that the domestic currency appreciates. The impulse responses and the corresponding model are shown in the online Appendix.

3.4 Convergence of the sampler

We estimate all models with 5 lags and a constant. For the recursive scheme, the impulse responses are based on 15,000 draws from the posterior distribution of the reduced form VAR coefficients, where 3,000 additional draws at the beginning of the chain are discarded to alleviate the effect of the initial λ. For the VAR identified with sign restrictions we obtain 10 draws from the space of possible impulse vectors for each of the 15,000 draws from the posterior distribution of the reduced form parameters. The inference is based on draws that satisfy our sign restrictions, typically more than 12,000. The restrictions are imposed for the six initial months.

[28]We also checked that the sign restrictions continue to hold under an exchange rate rule that approximates the exchange rate interventions. See the online Appendix for impulse responses under various policy regimes and with binding ELB for a large risk premium shock.

[29]This is also in line with the theoretical result by Swanson and Williams (2014a) that the impact of news on yields with binding ELB is more attenuated at the short end of the yield curve than at the long end.

We assessed mixing properties of the MCMC algorithm for λ formally using the inverse of a spectral density-based efficiency factor (see Geweke, 1992).[30] The estimated efficiency factor is far below 20, a value which is considered a reasonable threshold (see e.g. Primiceri, 2005, Carriero et al., 2014, Baumeister and Hamilton, 2015). Furthermore, we test whether the parameter mean based on the first 10th of the draws is significantly different from the second half of the draws. The numerical standard error of the respective means is estimated using a spectral density estimate as suggested by Geweke (1992). We cannot reject the null hypothesis of equal means, suggesting that convergence is fine. We also investigated convergence visually by looking at the means of an expanding number of draws, finding no evidence of changes after less than half of the draws.

4 Results

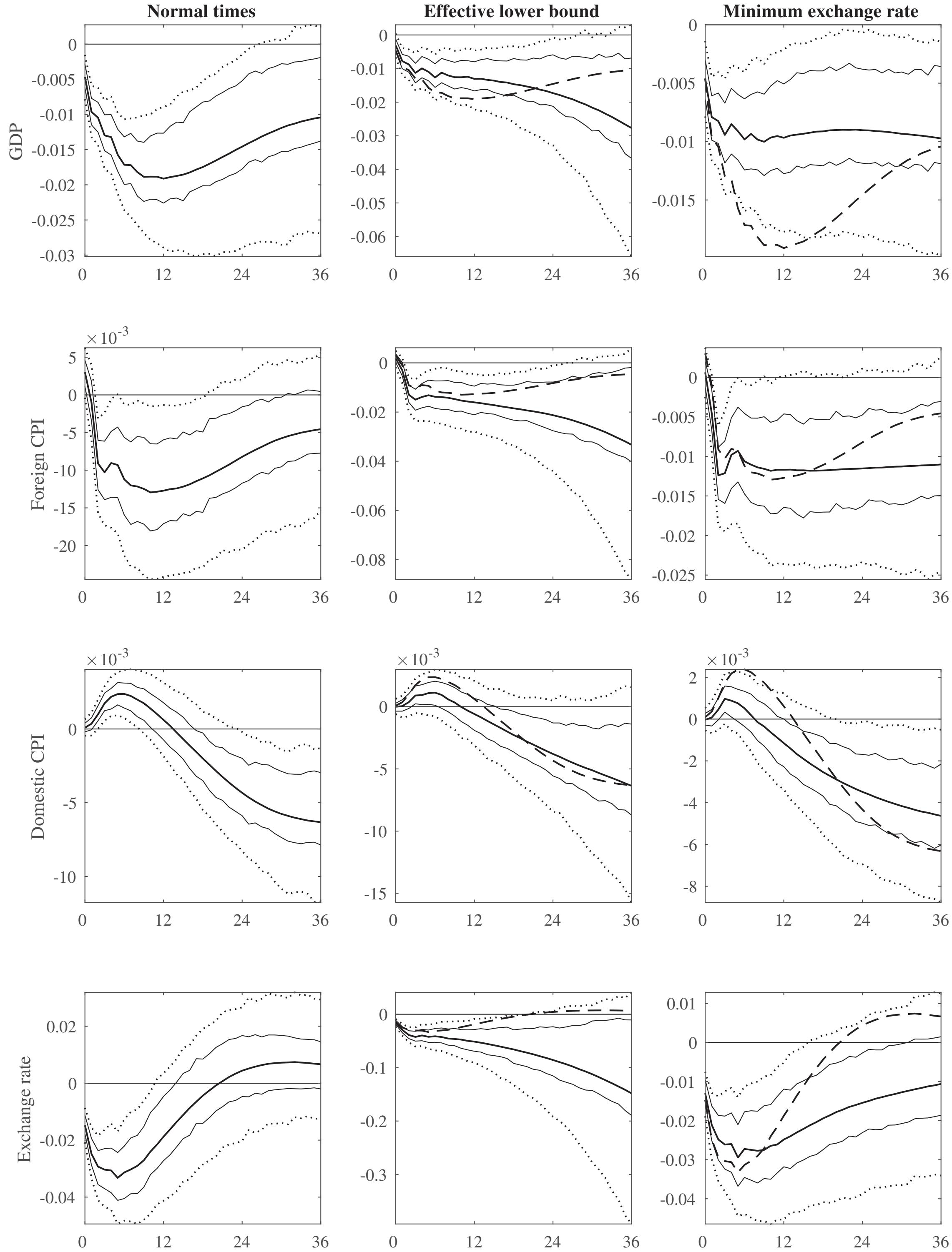
As a reference for our further results, we derive the impulse responses during normal times, that is, away from the ELB. The first column of Figure 2 shows that, after a policy uncertainty shock, output as well as the CPI for imported products fall quickly. However, the responses of the macroeconomic variables reach a trough at approximately 12 months and then tend to their initial level. The CPI for domestic goods initially increases and shows a delayed and permanent decline. Finally, the exchange rate shows a temporary response and returns relatively quickly to its initial level.

The second column of Figure 2 shows the impulse responses for the sample with a binding ELB but without nonconventional policies. For comparability, the dashed line gives the posterior median during normal times.[31] The timing and magnitude of

[30]Conditional on λ, the remaining parameters are independent across draws. Therefore, convergence is not an issue as long as the chain for λ has converged to its stationary distribution.

[31]The prior for the small samples with binding ELB and the minimum exchange rate uses the parameters of the sample during normal times and we determine the weight given to this prior using a formal posterior analysis. The posterior median of λ, the prior weight, is lower for the sample

Figure 2: Policy uncertainty shock



Note: Monthly posterior median impulse responses to a policy uncertainty shock in terms of one unit of the log-uncertainty measure. 80%- and 50%-HPDI (highest posterior density intervals) are given as solid and dotted lines. Shock identified as an orthogonal innovation to a weighted average of the policy uncertainty indices for the US and EU by Baker et al. (2016). The responses are normalized by the initial median response of the uncertainty index. All responses are measured in percent.

the responses in the first few months are similar as during normal times. Differences emerge, however, at longer horizons. The responses of all variables except domestic consumer prices are more persistent. None of the posterior median responses return to the initial level after a temporary risk shock. The impact is most severe for the exchange rate, imported consumer prices, and GDP. Meanwhile, the impulse response for the domestic CPI is similar as during normal times. This is consistent with the idea that the impact of the ELB is almost immediately reflected in fast-moving, forward-looking variables.

The empirical results differ from the predictions of the basic New Keynesian model in one important aspect. Theoretically, the ELB should amplify the impact of the risk shock on the exchange rate and output immediately.[32] In our empirical estimates, however, the impulse responses are similar initially and differ only after some months. In other words, the impact is more persistent rather than immediately larger. While this finding does not line up with the basic New Keynesian model, it is confirmed by Caggiano et al. (2017) who show that the impact of uncertainty shocks on real activity is more pronounced when the monetary policy response is constrained by the ELB. As in our case, the difference does not occur immediately but with some delay and therefore their impulse responses are more persistent.

The third column of Figure 2 shows that, under the minimum exchange rate regime, the impulse responses resemble more closely those during normal times but are still somewhat more persistent. Relative to a binding ELB, the responses of the exchange rate and foreign CPI are less persistent. One explanation of this result may be that, by coincidence, policy uncertainty has become less prevalent. This is unlikely to be the main explanation because the period from September 2011 to May 2014 included severe uncertainty regarding the future of the euro zone related to the dismal Greek

with binding ELB than for the sample with the minimum exchange rate (details are provided in the online Appendix). This suggests that the data during normal times are less informative for the ELB sample and indicates that the impulse responses may change.

[32] See also the impulse responses based on the DSGE model in the online Appendix.

debt situation, as well as the 2013 United States debt-ceiling crisis.

Qualitatively, the results are similar if the shock is identified using the VIX as a measure of stock market uncertainty and using sign restrictions (for brevity, the figures are provided in the online Appendix). During normal times, real activity, the prices of imported consumer goods and the exchange rate respond immediately but the responses tend to be temporary. Domestic consumer prices respond with a delay and the response is permanent. With binding ELB, all responses tend to be more persistent. However, during the period with an explicit exchange rate target, the responses resemble those during normal times.

Using the measure of global real activity uncertainty by Scotti (2016) shows that these results are not a mere artefact of the short sample at the ELB (see the online Appendix). During normal times, this shock has little impact on the exchange rate and inflation. Therefore, we expect from theory that the responses should not differ much when the ELB is binding because the real interest rate will not increase much. With binding ELB, estimation uncertainty increases but the median impulse response is similar to the response during normal times. In addition, the responses during the minimum exchange rate regime are similar as well. Thus, we find muted reactions of output and prices in all regimes. A thorough investigation why this uncertainty measure does not lead to an appreciation of the Swiss franc is beyond the scope our empirical study. However, we may conjecture that uncertainty about real activity is not triggering safe haven inflows in the same way as policy uncertainty or stock market volatility does.

Scholl and Uhlig (2008) emphasize that the median response can be misleading, because it does not come from any particular point in the parameter space (see also Fry and Pagan, 2007). Moreover, the highest posterior density intervals (HPDI) for impulse responses with binding ELB are considerably wider than those in normal times and under the minimum exchange rate regime, which hampers a direct comparison. Therefore, to test whether the responses are indeed more persistent, Table 3 shows the posterior probability of a negative impulse response at 24 months and whether the trough of the response is reached at 24 months or later. The former has the advantage that it measures what a central bank eventually cares about, namely, whether the economy stabilizes after a certain period of time given the policy regime in place. The second measure is more closely related to the shape of the response. In the online Appendix, we provide estimates based on simulated data from a DSGE model. They suggest that the second measure of persistence is conservative because it tends to signal less persistence when the number of observations small.

We first focus on the policy uncertainty shock in Panel (A) and then discuss the differences relative to the other specifications. During normal times, observing a negative long run response is quite likely for GDP and prices. The posterior probabilities are 0.89 or higher. For the exchange rate, however, the measures suggest that the negative response is likely temporary. The posterior probability of a negative response only amounts to 0.37. With a binding ELB, the posterior probability of a negative response increases for the imported CPI as well as for the exchange rate. The largest impact is on the exchange rate with a probability rising to 0.94. Thus, there is a high chance that the exchange rate is still appreciated after two years. Under the minimum exchange rate regime, the probability of a persistent response declines somewhat for the exchange rate.

This general pattern is confirmed by our second measure of persistence, namely, the posterior probability that we observe a trough of the response at 24 months or later. Overall, the results are more pronounced. During normal times, this probability is low for all variables except domestic consumer prices. Thus, it is rather unlikely that the three variables are still declining after two years. With a binding ELB, however, the probability increases to 0.74 for GDP, 0.71 for the imported CPI and

Table 3: Posterior probabilities

(A) Policy uncertainty shock

	GDP	Imported CPI	Domestic CPI	Exchange rate
Probability of negative response at 24 months				
Normal times	0.98	0.89	0.93	0.39
Effective lower bound	0.97	0.96	0.90	0.93
Minimum exchange rate	0.96	0.92	0.93	0.87
Probability of trough at or later than 24 months				
Normal times	0.19	0.14	0.94	0.03
Effective lower bound	0.72	0.70	0.86	0.80
Minimum exchange rate	0.34	0.30	0.84	0.11

(B) Stock market uncertainty shock

	GDP	Imported CPI	Domestic CPI	Exchange rate
Probability of negative response at 24 months				
Normal times	0.92	0.81	0.99	0.26
Effective lower bound	0.95	0.95	0.97	0.89
Minimum exchange rate	0.94	0.93	0.99	0.71
Probability of trough at or later than 24 months				
Normal times	0.26	0.13	0.83	0.06
Effective lower bound	0.76	0.72	0.89	0.83
Minimum exchange rate	0.49	0.38	0.83	0.21

(C) Risk premium shock (sign restrictions)

	GDP	Imported CPI	Domestic CPI	Exchange rate
Probability of negative response at 24 months				
Normal times	0.73	0.62	0.90	0.29
Effective lower bound	0.84	0.85	0.90	0.79
Minimum exchange rate	0.83	0.74	0.94	0.48
Probability of trough at or later than 24 months				
Normal times	0.06	0.04	0.58	0.03
Effective lower bound	0.47	0.50	0.74	0.69
Minimum exchange rate	0.08	0.11	0.67	0.06

(D) Real activity uncertainty shock

	GDP	Imported CPI	Domestic CPI	Exchange rate
Probability of negative response at 24 months				
Normal times	0.48	0.43	0.71	0.36
Effective lower bound	0.56	0.48	0.73	0.45
Minimum exchange rate	0.44	0.37	0.65	0.33
Probability of trough at or later than 24 months				
Normal times	0.04	0.03	0.22	0.19
Effective lower bound	0.28	0.25	0.40	0.39
Minimum exchange rate	0.03	0.04	0.19	0.14

Note: The table gives two measures for the persistence of the responses: the posterior probability of a negative response after 12 months and the posterior probability that the minimum of the response occurs at or later than 12 months.

0.81 for the exchange rate. Two years after the initial shock we therefore find a more than three-quarter probability that the exchange rate is still appreciating. Under the minimum exchange rate regime, the probability that the three macroeconomic variables are still falling is again closer to the values derived during normal times. For the domestic CPI, we find that the probability of a permanent reduction is high irrespective of the regime in place.

The posterior probabilities for the stock market uncertainty shock and the shock identified using sign restrictions are similar (Panels B and C). Focusing on the posterior probability of reaching a trough at 24 months or later, we observe a substantial increase in persistence of the exchange rate and imported CPI responses at the ELB, and the responses become less persistent during the minimum exchange rate episode. For the real activity uncertainty shock the pattern is less pronounced (Panel D). We conclude that the ELB can lead to more persistent responses of output and inflation for shocks that imply an immediate appreciation of the currency.

To test the robustness of the results we estimated several alternative specifications (the results are given in the online Appendix). For brevity, we focus the discussion on the second measure of persistence, the policy uncertainty measure, and an alternative set of sign restrictions. We examine a different horizon (36 months), fewer lags ($p = 3$), estimate the model in first differences, and identify a general deflationary shock using sign restrictions. Once the ELB is binding, any deflationary shock requiring a monetary policy response should imply a more persistent response of the exchange rate. We thus alleviate the sign restrictions requiring that the import price index declines and that the term spread increases, while leaving all other variables unrestricted. Qualitatively the results are similar but slightly less pronounced when using first differences or a deflationary shock.

We also examine other priors that put more weight on persistent parameter regions when estimating the model in normal times (this also influences our prior for the

ELB regimes). Instead of the noninformative prior, we use a Minnesota-type prior following Del Negro and Schorfheide (2011).[33] As we would expect, the responses during normal times become more persistent compared to the noninformative prior. Clearly, the difference between the various regimes will therefore be smaller if we impose a strong prior that the impulse responses are persistent during normal times as well.[34] Nevertheless, for the exchange rate, the differences between the regimes are still relevant. Moreover, the responses become less persistent under the minimum exchange rate regime for the exchange rate and the imported CPI. We also forced the prior weight to a very low value ($\lambda = 0.2$) in order to reduce the importance of the prior. The results are qualitatively similar but somewhat less pronounced in the minimum exchange rate sample.

As a final robustness check, we examined whether the higher persistence is an artefact of estimating the model on a small sample. We defined two placebo samples – from December 1994 to April 1996 and December 1999 to August 2001 – during which the ELB was not binding but with the same number of observations as in the actual ELB sample. We then use the entire non-ELB to determine the prior and re-estimate the model on the placebo ELB sample. We find that the persistence is lower on the placebo sample than on the entire sample with non-binding ELB. This suggests that we tend to underestimate the persistence when reducing the number of observations. Therefore, our main result, that the persistence increases during the short period with binding ELB, is not an artefact of estimation uncertainty due to the small number of observations.

This outcome is confirmed by estimated impulse responses using simulated data from the DSGE model discussed in the online Appendix. The advantage is that we observe the exogenously given risk premium and therefore identification of the risk

[33] Using the notation by Del Negro and Schorfheide (2011) we set $\lambda_2 = 4, \lambda_3 = 1, \lambda_5 = 1$ and the hyperparameter controlling the overall tightness of the prior to $\lambda_1 = 0.1$.

[34] Because we estimate the model on a sample for which Benati (2008) documented very little inflation persistence, the noninformative prior remains our preferred specification.

premium shock is straightforward. We estimate the impulse responses on a large sample (180 observations) and small sample (36 observations) with data simulated without the ELB restriction. There is little persistence in the responses for GDP, the CPI for imported products, and the exchange rate. Meanwhile, the domestic CPI shows a persistent response. Reducing the sample size to 36 observations tends to lower our measure of persistence for most variables which implies that the higher persistence at the ELB is not a mere artefact of the small number of observations.[35]

5 Concluding remarks

New Keynesian DSGE models make strong predictions about the dynamics of output, prices, and the exchange rate once effective lower bound on nominal interest rates is binding: we expect a severe recession, deflation, and a strong appreciation of the currency. However, modest policy interventions, if they are credible, can almost fully offset those adverse consequences.

To empirically assess those predictions we find episodes with a binding ELB and no nonconventional policy actions. During these episodes, the impulse responses for output, prices, and the exchange rate become more persistent. During periods with a minimum exchange rate, however, the impulse responses resemble those during normal times.

Our findings have two implications that are of interest for policy-makers. First, we show that the ELB has been a constraint and its impact was more serious in a regime without nonconventional policy actions. Second, it emphasizes that a nominal level target, which most central banks have hesitated to introduce despite facing the ELB,

[35] This finding is consistent with the general result that the persistence in autoregressive models tends to be underestimated in small samples (see e.g. Andrews, 1993). The idea that VARs estimated on a small number of observations tend to underestimate persistence in macroeconomic variables is also consistent with the fact that Minnesota-type priors, which impose persistence, tend to improve forecasting performance of VARs, at least on samples including the Great Inflation.

has some of the beneficial effects we expect from theory.

The empirical analysis does not assess the costs, credibility, and welfare implications of a temporary exchange rate floor. It is well known that stabilizing the exchange rate reduces welfare away from the ELB (see Galí and Monacelli, 2005) but that it may prove beneficial once the ELB is binding (see Svensson, 2001, Fujiwara et al., 2013, Cook and Devereux, 2016).[36] Therefore, switching temporarily to an exchange rate target at the ELB, an idea along the lines of McCallum (2006), may be more appropriate than introducing an exchange rate peg in all periods. Moreover, Bernanke (2017) suggests switching to a temporary price-level target at the ELB. He addresses concerns that targeting the price level can have adverse effects during normal times, for example if supply shocks hit the economy, and therefore proposes a temporary regime change at the ELB. Other nominal level targets alleviate these concerns by providing more flexibility when facing supply shocks and therefore there may be no need to switch targets between episodes with binding and non-binding ELB. Eggertsson and Woodford (2003) show that the optimal price level target varies with the output gap, which shares some commonalities with a nominal GDP level target.

Although we do not address whether the policies implemented by the SNB were optimal from a welfare perspective, the findings suggest that a temporary switch to a level target at the ELB can help in stabilizing the economy.

[36] Moreover, exchange rate interventions may have relevant spill-over effects on other economies as suggested by Coenen and Wieland (2004).

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