

Monetary policy rules for Switzerland. New evidence from a central banker perspective¹

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Abstract

This paper uncovers the actual policy reaction function of the Swiss National Bank (SNB) using real-time model-based internal forecasts of inflation and the output gap since the onset of the new monetary policy concept in 2000. To study how market participants understand the SNB's behavior, we compare the actual Taylor rules to market-perceived policy rules using Consensus Economics survey-based measures of expectations. In light of the recent financial crisis and the subsequent massive Swiss franc appreciation, we analyze the nonlinearity of the policy rules using a novel semi-parametric approach. First, the results point out that the SNB reacts more strongly to its inflation forecasts three and four quarters ahead than to forecasts at shorter horizons. Second, the market participants have foreseen a higher inflation responsiveness of the central bank than found with the actual SNB policy rule. Third, the best fitting specification contains a reaction to the nominal effective Swiss franc appreciation. Finally, the semi-parametric regressions suggest that the central bank offsets movements in the output gap and the exchange rate to the extent that they become a concern for price stability and economic activity.

JEL Classification: E52, E58, C14

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1. Introduction

In December 1999, the Swiss National Bank (SNB) introduced a new monetary policy concept after having pursued monetary targeting for more than two decades. The new framework features the following core elements: overriding goal of price stability as a nominal anchor, an explicit definition of price stability, a medium-term conditional inflation forecast and a target range for the three-month Libor rate on the Swiss franc interbank market as a monetary policy instrument. While the new policy design resembles inflation targeting in many respects, it also differs from this concept as emphasized by Baltensperger, Hildebrand and Jordan (2007) and more recently in Jordan, Peytrignet and Rossi (2010). The authors point out that the new SNB strategy allies the virtues of a long-term nominal anchor with the necessity of preserving short run flexibility in actual policy making.

The main goal of this paper is to track as closely as possible the actual monetary policy decision-making process of the SNB in real-time since the introduction of the new policy concept. Pioneered by the seminal work of Orphanides (2001), it is well understood from the literature that estimations of the actual central bank policy reaction function should be based on real-time data. The real-time approach features the advantage of avoiding the problem of recurrent data revisions that could produce misleading policy recommendations. Our paper takes this insight into account.

The paper contributes to the literature in three main aspects. First, we use real-time SNB inflation forecasts and output gap estimations as relevant indicators of the information available to the SNB Governing Board ahead of each interest rate decision. Second, in addition to the model-based forecasts, we rely on survey data to investigate how market participants perceive the SNB to set its policy rate based on their expectations of macroeconomic fundamentals. For this purpose we use the latest available real-time Consensus Economics Forecasts (CEF) data on inflation and output growth before each quarterly interest rate decision. The comparison of the actual SNB Taylor rule with the CEF market-perceived rule will unveil to what extent different information sets affect the estimation of the policy reaction functions and could potentially lead to different monetary policy recommendations. We also estimate backward-looking policy rules to provide empirical insights on Taylor's (1993) original specification for Switzerland. Moreover, we account for a faster transmission channel in a small open economy through an exchange rate term that is included in some augmented forward and backward-looking specifications. Third, in order to study whether the SNB's responsiveness to macroeconomic fundamentals has changed during the recent financial crisis and in the period of massive Swiss franc appreciation, we perform rolling and recursive regressions and conduct relevant structural break tests. Finally, we complement the standard nonlinearity analysis of the Taylor rules with a novel semi-parametric technique. This new approach in the literature permits a more flexible modeling of the policy reaction function to the extent that it accounts for a

changing responsiveness of the central bank to macroeconomic variables. To our knowledge, this paper is the first to show whether the policy stance *ex ante* is consistent with Taylor's original idea using SNB model-based internal forecasts along with survey-based measures of expectations.

The empirical results point to the following main findings. First, in accordance with its framework, the SNB reacts more strongly to its inflation forecasts three and four quarters ahead than to the inflation projections at shorter horizons. In the forward-looking specifications with the output gap estimates, the market participants have perceived the Taylor principle to be satisfied already at the three quarters ahead horizon, while the principle is verified at the four quarters ahead horizon with the SNB data. A puzzling result is that the policy stance is destabilizing for inflation in the estimated backward-looking Taylor rules. Since inflation has been low for decades, a non-stabilizing coefficient rather points to a misspecification problem in the backward-looking rules. Second, the market participants have perceived a relatively higher reaction of the central bank to inflation than to the output gap estimates. Third, the rolling and recursive regressions do not point to considerable time variation in the inflation and output gap coefficients, whereas the stability tests indicate a possible structural break after the Lehman Brothers bankruptcy. The exchange rate estimates show that the central bank has implemented a stabilizing policy for the economy in the aftermath of the financial crisis. Finally, the semi-parametric regressions provide evidence for nonlinearity of the Taylor rules, particularly with the CEF measures of expectations. The regressions show a close to linear reaction of the central bank to the inflation forecasts whilst its responsiveness to the output gap estimates is nonlinear. The SNB's reaction to the exchange rate is nonlinear and suggests that the central bank has implemented a stabilizing policy for the economy since late 2009. Regarding the backward-looking Taylor rules, the empirical results point to a high degree of nonlinearity. Overall, the semi-parametric policy rules outperform the corresponding parametric specifications as they better fit the SNB's interest rate.

The remaining of the paper is organized as follows. Section 2 provides an overview of the related literature. Section 3 describes the data and the methodology used, while section 4 outlines the theoretical model. Section 5 contains the linear policy rules estimates and conducts the stability analysis of the Taylor rules. Section 6 introduces the semi-parametric modeling technique and displays the estimation results. Finally, the last section provides concluding comments on the main empirical findings and highlights avenues for future research.

2. Related literature

In the new monetary policy paradigm the interest rate is the central bank policy instrument. Taylor (1993), in his seminal contribution, has proposed a simple interest rate rule as an accurate description of the U.S. Federal Reserve (Fed) interest rate setting from 1987 to

1992. On the background of the New Keynesian framework, researchers have focused on the specification of forward-looking policy reaction functions and on rules that account for interest rate smoothing, as in Clarida, Galí and Gertler (1998, 1999 and 2000) for instance. The forward-looking modeling hinges on the long and variable lags in the monetary policy transmission process which require a preemptive approach to the interest rate setting. A comprehensive overview on the design of forward-looking Taylor rules is presented in Rudebusch and Svensson (1999), Batini and Haldane (1999), Batini, Harrison and Millard (2003) and Galí (2008) for instance. More recently, Coibion and Gorodnichenko (2011) have estimated forward-looking interest rate rules for the Fed to test the hypothesis of interest rate smoothing versus persistent shocks based on the Greenbook data set and on the Survey of Professional Forecasters (SPF). The researchers provide evidence for the former assumption to explain the persistence of the federal funds rate. In practice, we have to emphasize that central banks do not follow Taylor rules in a mechanical way but they are rather considered as useful indicators of the monetary policy stance.

Related research on monetary policy rules with real-time versus revised data includes Sauer and Sturm (2003). The latter have found evidence that the European Central Bank (ECB) has implemented an inflation stabilizing policy based on the forward-looking Taylor rules they have estimated, while its policy has been destabilizing according to the estimates from a backward-looking specification. Gerdesmeier and Roffia (2004) find that there are substantial differences in the estimated ECB policy rule coefficients depending on the data set used. In particular, the central bank implements an inflation stabilizing policy in real-time only based on a forward-looking specification of the Taylor rule. Along these lines, Gorter, Jacobs and de Haan (2008) provide a similar evidence for the ECB using Consensus Economics forecasts of inflation and real GDP growth in the estimation of an empirical reaction function. The absence of an inflation stabilizing policy found with the backward-looking rule highlights the importance of adopting a forward-looking perspective in the modeling of a central bank reaction function.

In addition, our paper evaluates potential non-linearities in the central bank policy rule. One strand of this literature has investigated the nonlinearity of the Taylor rule within regime-switching regression models based on the seminal paper of Mankiw, Miron and Weil (1987). In a similar vein, Gerlach and Lewis (2010) have estimated gradual regime switching Taylor rules for the ECB based on a Logistic Smooth Transition Regression (LSTR) methodology and have reported a change in the central bank's behavior at the tipping point of the recent financial crisis. Along this line of research, Owyang and Ramey (2004), Sims and Zha (2006), Assenmacher-Wesche (2006), Alcidi, Flamini and Fracasso (2005 and 2011) have found nonlinearities in the policy reaction function of other central banks and for different time periods. Within a Markov regime-switching approach, Perruchoud (2009) has estimated forward-looking Taylor rules for Switzerland with monthly data for the period 1975-2007. He has found that Swiss monetary policy has switched between a smooth and an active regime. The former takes place in normal periods and features large interest rate

smoothing, while the latter occurs in times that require the SNB to counteract large deviations of the exchange rate from its trend.

A recent strand of the literature investigates the nonlinearity of the Taylor rule following a semi-parametric approach. This methodology permits to estimate the policy rule within the empirical support of the variables and provides more flexibility than parametric-based approaches. Using splines in a Generalized Additive Model (GAM), Hayat and Mishra (2010) show evidence for a nonlinear policy rule for the Fed, as the central bank has reacted more strongly to inflation expectations in the range of 8% to 10%. Based on a kernel approach in the GAM framework, Conrad, Lamla and Yu (2010) have found nonlinearity in a Taylor rule for the ECB and the Fed and relate this result to asymmetric preferences of the central banks. Markov and de Porres (2011) report evidence for nonlinearity of the policy rule for several OECD central banks following the GAM methodology with splines. The researchers obtain a better forecasting performance of the semi-parametric Taylor rules compared to the parametric specifications particularly in the medium and longer term.

Moreover, our paper adds to the literature on monetary policy rules for Switzerland. Cuche (2000) has estimated forward-looking Taylor rules in a small open economy model. The author shows that including an exchange rate term in the policy rule is optimal and relevant for describing the behavior of the SNB. However, Cuche argues that the presence of the exchange rate term in the policy rule does not imply that the central bank has pursued an explicit exchange rate objective, but rather that it allows for achieving price stability together with the need to provide a cushion for economic activity. In a real-time versus ex-post data approach, Cuche-Curti, Hall and Zanetti (2008) point out that the impact of Swiss GDP revisions on monetary policy seems to be rather limited in their estimated policy rule. In a recent paper, Baurle and Menz (2008) estimate an open economy DSGE-VAR model for Switzerland and find that the optimal Taylor rule includes a small weight on the nominal exchange rate.

3. Data and methodology

3.1 Data

In order to track as closely as possible the actual monetary policy decision-making process of the SNB in real-time we rely on the most recent available internal forecasts of inflation and output gap estimates. The latter convey the available information set ahead of each quarterly monetary policy assessment. The inflation forecasts are generated from the SNB's ARIMA model, which is applied to the individual CPI items at the lowest possible level of disaggregation as pointed out in Huwiler and Kaufmann (2013). Besides, the SNB also relies on other non-structural, semi-structural and structural models to forecast inflation in the medium to long term. The ARIMA model is well suited to forecast inflation in the short term and as it is unconditional on the labor rate it can be more easily compared to the CEF inflation expectations. In a real-time forecasting exercise, Huwiler and Kaufmann (2013)

provide evidence that the ARIMA forecasts outperform other relevant benchmarks especially in the short term, for instance the published SNB inflation forecast, the quarterly Consensus Economics Forecasts and an AR(1) model. Based on their approach, for each quarter we use the ARIMA forecast produced at the end of the month preceding the regular monetary policy assessment. The forecasts refer to a horizon ranging from one quarter to four quarters ahead.

Moreover, we use real-time contemporaneous output gap estimates from the SNB Economic Analysis Unit. They are reported for the corresponding quarter of each monetary policy meeting. We employ the output gap estimates based on a Cobb-Douglas production function approach thus following Cuche-Curti, Hall and Zanetti (2008). The authors emphasize that this methodology displays the longest tradition and has received a special attention at the SNB. The output gap is obtained recursively with the most recent available data starting in 1985 Q1. The SNB's ARIMA inflation forecasts and output gap estimates are available since 2000 Q3, which spans almost the entire period since the onset of the new SNB monetary policy concept in 2000 Q1. The forecasts thus provide a unique framework that permits to closely follow the actual monetary policy decision-making process on a real-time basis.

In addition to the SNB model-based forecasts we also consider survey-based measures of expectations in the empirical analysis. For this purpose, we use the quarterly Consensus Economics Forecasts (CEF) of inflation and real GDP growth. The CEF reports contain the market participants' expectations for the current quarter and from one to four quarters ahead. However, as the CEF forecasters report output growth expectations in the survey, we compute the output gap estimates using a standard two-sided H-P filter. First, we obtain the real GDP forecasts by combining the GDP growth forecasts with the level of the seasonally adjusted real GDP since 2000 Q2, following the approach of Heppke-Falk and Hufner (2004), Poplawski-Ribeiro and Rülke (2011) for instance. Second, we apply an H-P filter to the GDP forecasts to determine the level of forecasted potential GDP and we then compute the output gap forecasts.³ Adam and Cobham (2004) provide an extensive discussion on the difference between real-time, nearly real-time and quasi real-time data based on the seminal paper of Orphanides and van Norden (2002). The authors highlight that the nearly real-time output gaps are obtained by applying a filtering procedure to the full sample of real-time data, while the quasi real-time output gaps are generated using a rolling filter on the observations available at the time of the estimation from the revised data. As the quarterly CEF survey for Switzerland starts in 1998 Q2, the sample period is too short to perform rolling or recursive real-time estimations of potential output and we rely

³ The expected output gap is defined as the real GDP forecast minus potential GDP forecast expressed in percentage points of the potential real GDP forecast. A smoothing parameter of 3000 is applied to the quarterly data as this yields the most consistent estimates for Swiss data compared to the standard smoothing parameter of 1600. Moreover, a comparison of the SNB output gap estimates computed with the production function approach with the CEF H-P filtered output gap estimates shows that they are very similar.

on the estimates of potential output obtained from the full real-time sample. Therefore, in the empirical analysis with the CEF data we use nearly real-time estimates of the output gap.

In the backward-looking specifications we include the latest vintage of total CPI inflation and the actual output gap based on the production function approach. Moreover, we also estimate the policy rule with two SNB measures of core inflation: a trimmed mean and median inflation. The first variable excludes from total CPI inflation 15% of the goods with the highest and lowest annual rate of change. The second one excludes approximately 50% of price changes on each side of the distribution. In some Taylor rule specifications we also include the most recent observed annual rate of change of the nominal or real effective exchange rate to account for a shorter transmission channel in the policy reaction function.⁴ All data are collected at the quarterly frequency and span most of the period of new monetary policy design from 2000 Q3 to 2012 Q2. Finally, as a policy rate we use the SNB's official three-month Libor target rate on the Swiss franc.⁵ Even though the SNB uses a target range for the Libor, it bases its published conditional inflation forecast on a specific Libor level. The Libor level used in the inflation forecast is what we call "target rate".⁶

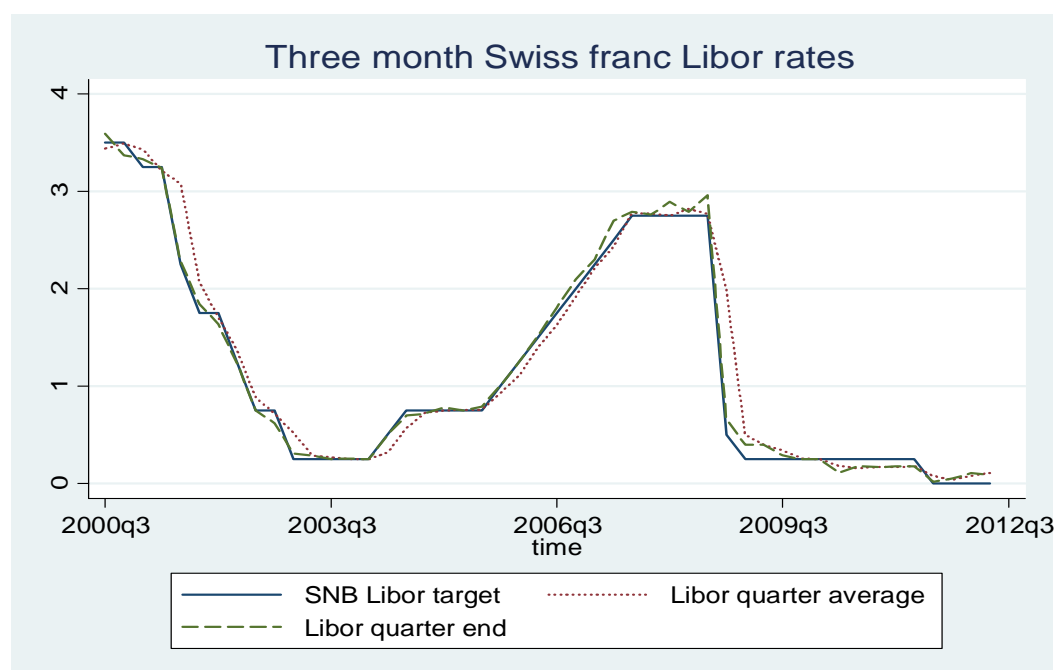
Figure 1 shows that the SNB Libor target and actual market rates are very closely linked. Hence, our empirical results will not be affected by the choice of either the target or market Libor rate. In addition, there is almost no difference between the quarterly average and the end-of-quarter libor market rates. From an econometric perspective, the end-of-quarter rates should be preferred to rule out endogeneity issues.

The summary statistics of the variables are reported in table 1. The data point out that on average the market participants have perceived a slightly higher inflation at every horizon compared to the SNB forecasts. However, the three and four quarters ahead inflation expectations are in the range of 0% to 1.8% which is fully in line with the SNB price stability definition. Similarly, the four quarters ahead SNB inflation forecasts are between 0.2% and 1.4% which is consistent with price stability as well. In addition, the CEF inflation expectations exhibit a lower variability than the SNB projections for most horizons except four quarters ahead. The average output gap is negative with the SNB and actual data, while the mean CEF estimate is close to zero. The nominal and real effective Swiss franc appreciation point to a slight upward trend and have reached a maximum level of 22.79% and 19.82% respectively in 2011 Q3.

⁴ The nominal and real effective exchange rates are provided by the SNB. We include the annual rate of change of the variables in the regressions which corresponds to either a nominal or real Swiss franc appreciation.

⁵ We obtain similar estimation results using the end-of-period Libor market rate as a dependent variable.

⁶ An alternative approach would be to model the probability of a policy rate change. This analysis is left for future research.

Figure 1: SNB Target and market Libor rates**Table 1.: Summary statistics**

| SNB data (%) | Mean | Std. dev. | Min | Max |
|--|-------|-----------|-------|-------|
| Inflation one quarter ahead | 0.74 | 0.79 | -0.90 | 3.00 |
| Inflation two quarters ahead | 0.74 | 0.70 | -1.10 | 2.60 |
| Inflation three quarters ahead | 0.72 | 0.54 | -0.60 | 2.10 |
| Inflation four quarters ahead | 0.71 | 0.28 | 0.20 | 1.40 |
| Output gap estimate | -0.76 | 1.44 | -3.25 | 1.83 |
| Output gap change estimate | -0.02 | 0.51 | -1.66 | 1.15 |
| CEF data (%) | | | | |
| Inflation one quarter ahead | 0.84 | 0.74 | -1.10 | 2.50 |
| Inflation two quarters ahead | 0.87 | 0.59 | -0.60 | 2.00 |
| Inflation three quarters ahead | 0.94 | 0.42 | 0.00 | 1.80 |
| Inflation four quarters ahead | 1.01 | 0.30 | 0.40 | 1.50 |
| Output gap estimate | -0.01 | 2.26 | -5.84 | 4.00 |
| Output gap change estimate | 0.00 | 1.26 | -4.19 | 1.69 |
| Actual data (%) | | | | |
| Libor target rate | 1.18 | 1.11 | 0.00 | 3.50 |
| Libor market rate | 1.20 | 1.13 | 0.02 | 3.59 |
| Total CPI inflation | 0.76 | 0.86 | -1.01 | 2.92 |
| Core trimmed inflation | 0.94 | 0.46 | -0.12 | 2.03 |
| Core median inflation | 1.08 | 0.43 | 0.23 | 2.24 |
| Output gap | -0.25 | 1.47 | -2.56 | 2.82 |
| Output gap change | -0.05 | 0.61 | -2.73 | 0.60 |
| Nominal effective Swiss franc appreciation | 3.33 | 5.18 | -4.23 | 22.79 |
| Real effective Swiss franc appreciation | 1.99 | 4.81 | -5.27 | 19.82 |

3.2 Methodology

Regarding the methodology, we estimate the Taylor rules with the Ordinary Least Squares (OLS) method.⁷ In this perspective, Gorter, Jacobs and de Haan (2008) point out that this approach is justified by the use of forecasts and expectations variables based on real-time data. We have also tested the series for stationarity using the standard Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. The ADF and PP tests show that in most of the series we reject the unit root hypothesis and the KPSS statistics do not report evidence against stationarity for all series used in the regressions. This result is in line with the economic intuition for stationarity as there has been a stable monetary policy regime in place during the last decade in Switzerland.

In order to study the stability of the Taylor rule coefficients we perform rolling and recursive window regressions and conduct conventional tests for structural breaks. In the rolling estimation we use a window size of 30 observations, while in the recursive approach the estimation range is progressively extended as more observations become available over time. In both approaches, the first regression refers to the period before the financial meltdown, from 2000 Q3 to 2007 Q4.

At a more general level, based on Hastie and Tibshirani (1986 and 1990) we investigate the nonlinearity of the Taylor rule specifications with a semi-parametric modeling approach. The latter is a well suited method to detect nonlinearities in the policy rule within the support of the explanatory variables. This framework is a special case of a family of semi-parametric models known as Generalized Additive Models (GAMs). As pointed out in Wood (2006), a GAM is a generalized linear model in which the linear predictor is a sum of smooth functions of the explanatory variables. In that regard, the approach requires a method to represent the functions and to estimate their degree of smoothness. Hence, the GAMs are represented through penalized regression splines which are estimated with penalized regression methods in two steps. First, the degree of smoothness is computed with a Generalized Cross Validation (GCV) algorithm. The latter balances the need to fit the data with the requirement to avoid model overfitting. Based on Kim and Gu (2004) we apply an additional penalty term in the GCV procedure to further rule out overfitting. In a second step, the smooth functions are then estimated with Penalized Iterative Reweighted Least Squares (PIRLS) as outlined in Wood (2006). More formally, we solve the following penalized least squares optimization problem: $\underset{\beta}{\text{Min}} \|y - X\beta\|^2 + \lambda\beta' S\beta$, where λ controls the smoothness of the splines and S is a matrix of constant terms.

⁷ For the backward-looking Taylor rules we also perform GMM regressions where we instrument the explanatory variables with their lagged values. The J-statistics for overidentifying restrictions do not show evidence against the validity of the instruments used in the estimations. Moreover, the difference-in-Sargan tests we have implemented do not point to the presence of endogeneity problems and the regressions can be safely performed with OLS.

In the empirical analysis, we set up univariate and bivariate models in which the policy rate is set as a smooth function of macroeconomic fundamentals. In the former, the explanatory variables enter additively the reaction function, while in the bivariate policy rules the dependent variable is a single function of all covariates. The univariate and bivariate GAMs are estimated in the R software using the *mgcv* package developed by Wood. A convenient hallmark of the GAM is that it does not require to provide assumptions on the specific functional form of the Taylor rule which offers considerable flexibility. The GAM methodology is preferred to kernel based estimators because the former relies on orthogonal bases and is distributional-free compared to the Nadaraya-Watson type of estimators.⁸

4. Theoretical framework

In a major contribution, Woodford (2003) advocates the view of central banking as a management of private sector expectations. From this standpoint, the monetary authority aims at anchoring agents' expectations with its targets to achieve better stabilization outcomes. As argued by Holmsen et al. (2008), some variants of the forward-looking reaction functions are used by Norges Bank and other inflation targeting central banks to communicate their monetary policy intentions. Regarding Swiss monetary policy, Jordan, Peytrignet and Rossi (2010) highlight that the SNB is not an inflation targeting central bank as it has opted for a more flexible policy design. In addition, as a natural benchmark comparison we consider the standard policy rule proposed by Taylor (1993) along with some augmented and modified versions that contain backward-looking variables. Consider the following interest rate rule:

$$i_t^T = r^* + \pi^* + \beta_\pi E_t \{ \pi_{t+k} - \pi^* | \Omega_t \} + \beta_y E_t \{ y_{t+q} - y_{t+q}^* | \Omega_t \} + \beta_z z_t + \varepsilon_t \quad (1)$$

where i_t^T refers to the three-month Libor target rate on the Swiss franc, r^* and π^* denote the equilibrium real interest rate and the central bank's inflation objective respectively.⁹ $\pi_{t+k} - \pi^*$ and $x_t \equiv (y_{t+q} - y_{t+q}^*)$ correspond to the inflation and output gaps forecasts k and q quarters ahead correspondingly and z_t refers to other economic fundamentals like the exchange rate for instance. Finally, E_t is the expectations operator and Ω_t denotes the available information set of either the central bank or the market participants, and the one based on actual data. ε_t stands for an i.i.d error term.

⁸ The splines rely on basis functions while the kernel estimators use a local constant approximation of the distribution.

⁹ We set $\pi^* = 1\%$ which corresponds to past average inflation. Choosing another numerical value would only affect the constant term in the regressions.

We can further assume that the central bank implements gradual policy rate adjustments to avoid disruptive effects in financial markets originating from large swings in interest rates. In this case the following partial adjustment mechanism takes place:

$$i_t = \rho i_{t-1} + (1 - \rho) i_t^T \quad (2)$$

where i_t is the observed policy rate, i_t^T corresponds to the policy rate target and ρ is the interest rate smoothing parameter. At each quarterly policy meeting the Governing Board implements $(1 - \rho)$ of the desired target interest rate. Combining equations (1) and (2) yields the following Taylor rule specification:

$$i_t = \rho i_{t-1} + (1 - \rho) \left(r^* + \pi^* + \beta_\pi E_t \{ \pi_{t+k} - \pi^* | \Omega_t \} + \beta_y E_t \{ y_{t+q} - y_{t+q}^* | \Omega_t \} + \beta_z z_t \right) + \varepsilon_t \quad (3)$$

As previously highlighted, in the empirical analysis we consider different forecast horizons for inflation ranging from one to four quarters ahead ($k = 1, 2, 3, 4$), while we consider only the contemporaneous output gap estimates mainly due to data availability ($q = 0$) and also to account for a shorter transmission lag in the economy. This approach is also in line with Cuche-Curti, Hall and Zanetti (2008) who use the one year ahead inflation rate and the contemporaneous output gap in the estimation of their policy rule. In the backward-looking Taylor rules we use the actual annual CPI inflation and the output gap obtained with the production function approach. We additionally present the regression results with the SNB core inflation variables to study the central bank reaction to these narrower inflation measures.

Based on equations (1) and (3), we analyze 48 forward-looking specifications and 6 backward-looking Taylor rules that are estimated with the SNB, CEF and actual data. In the next section, we report the empirical results from the linear parametric estimations and discuss the stability of the coefficients.

5. Parametric Taylor rules

5.1. Linear model estimations

In this subsection we report the estimation results of the best fitting forward and backward-looking Taylor rules. The specifications are presented in the appendix where I stands for inflation, O for output gap, E and Q for nominal and real effective appreciation correspondingly, S for interest rate smoothing, B and F for backward and forward-looking policy rules respectively. First, in the spirit of a strict inflation targeting approach, IF_j contain only the inflation forecasts as explanatory variables ranging from one to four quarters ahead. The goal of these specifications is to study how the policy rate responds to inflation along the forecast horizon. Second, in rules IOF_j we additionally include a reaction to the contemporaneous output gap estimate to determine to what extent the SNB takes

due account of the economic outlook in setting the Libor target rate. Furthermore, we account for a faster transmission channel in a small open economy through either the nominal or real effective appreciation of the Swiss franc in rules IOEF_j and IOQF_j and in specifications IEF_j and IQF_j respectively without the output gap estimate. In line with the literature, we set up a partial adjustment mechanism in rules IOSF_j, IOESF_j, IOQSF_j, ISF_j, IESF_j and IQSF_j to model the central bank practice of interest rate smoothing. This approach should permit to understand how quickly the policy rate is adjusted to the desired target level. Finally, with the aim to shed new light on Taylor's original policy rule formulation we provide evidence on some backward-looking reaction functions in the appendix. In the latter, IOB corresponds to the standard Taylor rule while IOEB and IOQB refer to the augmented models with either a nominal or real effective appreciation of the Swiss franc. IOSB, IOESB and IOQSB relate to the corresponding backward-looking Taylor rules with interest rate smoothing.

5.1.1 Taylor rules with focus only on inflation forecast

We first start the empirical analysis by presenting the estimation results of the forward-looking Taylor rules that account only for a central bank responsiveness to the inflation forecasts. The goal of this specification is to provide evidence on strict inflation targeting type of rules in the spirit of Rudebusch and Svensson (1999) and Svensson (2003). The regression results are displayed in table 2.

At first glance, table 2 points out that the coefficient estimates of the policy rules are broadly similar based on the SNB and CEF data. Both with the SNB and CEF projections, there is an increasing responsiveness of the central bank to the inflation forecasts along the horizon considered in the regressions. This result is perfectly in line with the previous literature, in particular with the recent paper of Hamilton, Pruitt and Borger (2009). The latter have found an increasing policy reaction of the U.S. Federal Reserve to macroeconomic variables along the forecast horizon and have interpreted this result as evidence for a gradual adjustment of the policy rate to macroeconomic fundamentals.

Looking further ahead, an interesting discrepancy emerges between the SNB and CEF data regarding the inflation forecast horizon that gives rise to an inflation stabilizing policy. Based on the SNB forecasts, the Taylor principle is satisfied with the three and four quarters ahead inflation projections, while the CEF data indicate that market participants have perceived the central bank to implement an inflation stabilizing policy already at the two quarters ahead horizon. Overall, there is a stronger reaction to the inflation forecasts based on the CEF data except at the four quarters ahead horizon.

From an information criterion perspective, the AIC and BIC statistics suggest that the best model is the one with the four and three quarters ahead inflation forecasts respectively with the SNB and CEF data. The RMSE statistics corroborate the evidence from the information criteria for the best fitting model.

Table 2: Taylor rules with inflation forecasts

| SNB data | <i>k</i>=1 | <i>k</i>=2 | <i>k</i>=3 | <i>k</i>=4 |
|---|-----------------------|-----------------------|-----------------------|-----------------------|
| β_π | 0.8315*** (0.1291) | 0.8970*** (0.1604) | 1.0882*** (0.1855) | 2.5397*** (0.3307) |
| $r^* + \pi^*$ | 1.3902*** (0.2452) | 1.4126*** (0.2532) | 1.4831*** (0.2556) | 1.9125*** (0.2459) |
| Adj. R^2 | 0.3324 | 0.3005 | 0.2639 | 0.4042 |
| AIC | 129.0773 | 131.3136 | 133.7626 | 123.6114 |
| BIC | 132.8197 | 135.056 | 137.505 | 127.3538 |
| RMSE | 0.8904309 | 0.9114168 | 0.9349663 | 0.8411489 |
| CEF data | | | | |
| β_π | 0.9796*** (0.1953) | 1.3143*** (0.2453) | 1.9849*** (0.3447) | 2.3907*** (0.5770) |
| $r^* + \pi^*$ | 1.3363*** (0.2240) | 1.3441*** (0.2154) | 1.2887*** (0.1879) | 1.1472*** (0.2041) |
| Adj. R^2 | 0.4161 | 0.4671 | 0.5642 | 0.4026 |
| AIC | 122.6441 | 118.2554 | 108.6038 | 123.7414 |
| BIC | 126.3865 | 121.9978 | 112.3462 | 127.4838 |
| RMSE | 0.8327157 | 0.7955052 | 0.7194161 | 0.8422889 |
| Obs. | 48 | 48 | 48 | 48 |
| Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level. | | | | |

5.1.2 Taylor rules with inflation forecast and output gap estimate

The empirical evidence shows that, once we account for the output gap estimate, the Taylor principle is verified one quarter later compared to the previous results for both data sets. Based on the SNB forecasts, the central bank implements an inflation stabilizing policy at the four quarters ahead horizon, while the professional forecasters have foreseen the Taylor principle to be verified already at the three quarters ahead horizon. The regressions results with the output gap estimate as an additional explanatory variable are reported in table 3.

Second, consistently with the earlier evidence, there is an increasing reaction of the SNB to inflation along the forecast horizon used in the regressions with the SNB and CEF data up to the fourth and third quarter correspondingly.

In addition, the effect of the output gap estimate seems robust to the inflation forecast horizon in both databases. As the estimated coefficients are positive and significant the

SNB has implemented a stabilizing policy for the economic outlook. Interestingly, based on the SNB forecasts, at the four quarters ahead inflation horizon the estimated coefficients are very close to Taylor's original findings. Besides, table 3 points out that the SNB has reacted more strongly to the output gap estimates compared to the market participants' perceptions at all inflation forecast horizons. For instance, based on the four quarters ahead inflation forecasts, in the event of a 1 percentage point increase in the output gap estimate the policy rate increases by 0.43 and 0.24 percentage points respectively with the SNB and CEF data. The estimated equilibrium nominal interest rate is increasing along the inflation horizon to reach nearly 2% with the SNB data.

Table 3: Taylor rules with inflation forecasts and output gap estimates

| SNB data | <i>k=1, q=0</i> | <i>k=2, q=0</i> | <i>k=3, q=0</i> | <i>k=4, q=0</i> |
|---|-----------------------|-----------------------|-----------------------|-----------------------|
| β_{π} | 0.5012*** (0.1287) | 0.5599*** (0.1179) | 0.7006*** (0.1397) | 1.6277*** (0.3279) |
| β_y | 0.4557*** (0.0688) | 0.4706*** (0.0663) | 0.4857*** (0.0648) | 0.4315*** (0.0490) |
| $r^* + \pi^*$ | 1.6520*** (0.2062) | 1.6818*** (0.2011) | 1.7434*** (0.1931) | 1.9765*** (0.1909) |
| Adj. R^2 | 0.6218 | 0.6239 | 0.6211 | 0.6589 |
| AIC | 102.7491 | 102.4812 | 102.8271 | 97.78964 |
| BIC | 108.3627 | 108.0948 | 108.4407 | 103.4032 |
| RMSE | 0.662897 | 0.6610498 | 0.6634361 | 0.6295208 |
| CEF data | | | | |
| β_{π} | 0.5285** (0.2256) | 0.8152*** (0.2194) | 1.3849*** (0.3388) | 1.2507** (0.5697) |
| β_y | 0.2362*** (0.0826) | 0.2229*** (0.0682) | 0.1955*** (0.0574) | 0.2414*** (0.0688) |
| $r^* + \pi^*$ | 1.2642*** (0.1700) | 1.2818*** (0.1694) | 1.2560*** (0.1617) | 1.1627*** (0.1781) |
| Adj. R^2 | 0.5487 | 0.5974 | 0.6646 | 0.5419 |
| AIC | 111.2301 | 105.7477 | 96.97598 | 111.9405 |
| BIC | 116.8437 | 111.3613 | 102.5896 | 117.5541 |
| RMSE | 0.7241248 | 0.6839299 | 0.6242077 | 0.7295029 |
| Obs. | 48 | 48 | 48 | 48 |
| Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level. | | | | |

We have also performed the regressions with the change in the output gap estimates in the spirit of a speed-limit policy as outlined in Walsh (2003). However, as most of the coefficients are not significant and some have a wrong sign the results are not presented in the paper. Including in the regressions the change of the output gap in addition to the output gap level yields insignificant coefficient estimates.

In line with the earlier evidence, the AIC, BIC and RMSE statistics indicate that the specification with the four and three quarters ahead inflation should be preferred with the SNB and CEF forecasts correspondingly. The information criteria clearly point out that the specifications with the output gap should be preferred to the rules that exhibit only the inflation forecasts as explanatory variables.

To sum up, the evidence shows that in the short run, one to two quarters ahead, the SNB stabilizes primarily business cycle fluctuations as it can hardly affect inflation within a short time span. Conversely, at a longer horizon, three or four quarters ahead, the monetary authority focuses on stabilizing inflation in line with its price stability mandate.

5.1.3 Taylor rules adding an exchange rate term

At first sight, we find a significant and negative effect of the nominal effective appreciation of the Swiss franc on the policy rate with both the SNB and CEF data. This reaction implies a stabilizing policy as the central bank alleviates the exchange rate pressures on the economy by cutting the Libor target rate in the event of a Swiss franc appreciation. Second, the impact is robust to the inflation forecast horizon used in the regressions. Third, the results previously obtained with the inflation forecasts and the output gap estimates remain qualitatively unaltered from including the exchange rate in the reaction function.¹⁰ Table 4 displays the coefficient estimates of the forward-looking Taylor rules augmented with a nominal effective Swiss franc appreciation.¹¹

Based on the SNB forecasts, the central bank implements an inflation stabilizing policy at the four quarters ahead horizon, while the market participants have perceived the Taylor principle to be fulfilled already at the three quarters ahead horizon. Besides, the SNB's reaction to the output gap estimates is in line with the earlier evidence with both the SNB and CEF data. The empirical results are similar with the CEF data, notwithstanding a smaller output gap coefficient estimate and a slightly higher central bank reaction to the exchange rate. Thus, following a 1 percentage point nominal effective appreciation the monetary authority decreases the Libor target rate by 0.05 and 0.08 percentage points respectively based on the SNB and CEF data. From a model selection perspective, the AIC, BIC and the

¹⁰ It is also worth mentioning that the correlations between the explanatory variables are quite low which suggests that there are no collinearity problems in the regressions.

¹¹ We do not present the estimation results with the real effective appreciation of the Swiss franc as they are qualitatively very similar.

RMSE statistics show that the best specification features four and three quarters ahead inflation forecasts with the SNB and CEF data respectively.

Table 4: Taylor rules augmented with a nominal effective appreciation

| SNB data | <i>k=1, q=0</i> | <i>k=2, q=0</i> | <i>k=3, q=0</i> | <i>k=4, q=0</i> |
|---|------------------------|------------------------|------------------------|------------------------|
| β_π | 0.4189*** (0.0952) | 0.4471*** (0.0895) | 0.5430*** (0.1326) | 1.4142*** (0.2971) |
| β_y | 0.4607*** (0.0562) | 0.4776*** (0.0592) | 0.4920*** (0.0608) | 0.4366*** (0.0482) |
| β_e | -0.0522*** (0.0181) | -0.0485** (0.0188) | -0.0470** (0.0195) | -0.0502*** (0.0164) |
| $r^* + \pi^*$ | 1.8085*** (0.2180) | 1.8191*** (0.2156) | 1.8603*** (0.2097) | 2.0858*** (0.1993) |
| Adj. R^2 | 0.6728 | 0.6648 | 0.6576 | 0.7066 |
| AIC | 96.71204 | 97.87471 | 98.88814 | 91.47909 |
| BIC | 104.1968 | 105.3595 | 106.3729 | 98.96389 |
| RMSE | 0.6096594 | 0.617088 | 0.6236368 | 0.5773165 |
| CEF data | | | | |
| β_π | 0.4107** (0.1754) | 0.6640*** (0.2010) | 1.2041*** (0.3514) | 1.4129*** (0.4727) |
| β_y | 0.2602*** (0.0655) | 0.2453*** (0.0620) | 0.2148*** (0.0573) | 0.2275*** (0.0686) |
| β_e | -0.0661*** (0.0207) | -0.0614*** (0.0217) | -0.0586*** (0.0209) | -0.0810*** (0.0222) |
| $r^* + \pi^*$ | 1.4654*** (0.1792) | 1.4671*** (0.1692) | 1.4409*** (0.1411) | 1.4304*** (0.1555) |
| Adj. R^2 | 0.6355 | 0.6708 | 0.7329 | 0.6821 |
| AIC | 101.8906 | 96.99865 | 86.97078 | 95.32946 |
| BIC | 109.3754 | 104.4835 | 94.45558 | 102.8143 |
| RMSE | 0.6434496 | 0.6114823 | 0.5508316 | 0.6009421 |
| Obs. | 48 | 48 | 48 | 48 |
| Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level. | | | | |

In general, table 4 suggests that the SNB has reacted relatively less strongly to the inflation forecasts than to the output gap estimates based on the internal data compared to the market participants' perceptions.¹² Moreover, the empirical fit of the policy rules is further enhanced by including an exchange rate term in the regressions as evidenced by the reported relevant statistics.

5.1.4 Summary of results for Taylor rules with partial adjustment

Overall, the results for estimations of Taylor rules with a partial adjustment point to a substantial degree of interest rate smoothing which is slightly more pronounced with the CEF data than with the SNB forecasts. In general, the policy rate is adjusted to the desired target level within a period ranging from three to five quarters. To conserve space, we report the details in tables A.1. and A.2. in the appendix. The main results can be summarized as follows.

As previously found, table A.1. shows that there is an increasing reaction of the central bank to inflation along the forecast horizon up to four and three quarters ahead respectively with the SNB and CEF data. However, compared to the results of table 3 the SNB implements an inflation stabilizing policy already at the two and three quarters ahead horizons correspondingly based on the CEF and SNB estimates, which is one quarter in-advance than previously found. With the CEF database, all output gap and some inflation forecast coefficient estimates are not statistically significant which might cast doubts on the empirical validity of the Taylor rule specification with interest rate smoothing. Indeed, in two seminal papers Rudebusch (2002 and 2006) argues that the estimation of interest rate rules with policy inertia at the quarterly frequency is prone to substantial caveats. He shows that the resulting high predictive ability of the estimated policy rules with interest rate smoothing is inconsistent with the evidence from the term structure of interest rates. Besides, relying on a new database of models, Taylor and Wieland (2009) show that rules that contain policy inertia in addition to the growth rate of output are not robust. The large autoregressive coefficient of the interest rate, which is often found empirically, may point to a possible model misspecification and is likely to capture persistent shocks rather than to correspond with the central bank practice of smoothing the policy rate. Table A.1. reports that the SNB's reaction to the output gap estimate is slightly dampened once we account for interest rate smoothing in the estimated policy rules with the SNB and CEF data. In line with the earlier evidence, the market participants have perceived a relatively stronger central bank reaction to the inflation forecasts than to the output gap estimates. From a model selection perspective, the AIC, BIC and RMSE statistics suggest that the specification with the three quarters ahead inflation forecasts should be preferred with both databases.

¹² The evidence for a relatively stronger central bank reaction to the output gap estimates than to the inflation forecasts obtained with the SNB data might be related to an important informational content of the output gap estimates about future inflation in addition to the ARIMA forecasts.

Table A.2. points to a more strongly negative and significant effect of the nominal effective Swiss franc appreciation on the policy rate than previously obtained in the Taylor rules without smoothing. The policy inertia and inflation coefficients are slightly reduced while the output gap estimates are robust to including the exchange rate in the regressions. Moreover, with both the SNB and CEF data the Taylor principle is verified already at the three quarters ahead inflation forecast horizon. In addition, most of the output gap and some inflation forecast estimates are not significant with the CEF data as previously reported. Broadly, accounting for a partial adjustment mechanism in the augmented forward-looking Taylor rules entails a twice as strong central bank reaction to the nominal appreciation of the domestic currency than found without interest rate smoothing. Finally, the AIC, BIC and RMSE criteria point to the model with three quarters ahead inflation forecasts as the best specification, consistently with the results from table A.1.

Furthermore, we have also estimated the Taylor rules augmented with the forecasts of the nominal and real appreciation of the Swiss franc ranging from one to four quarters ahead. As a data generating process, we have assumed a random walk for the level of the nominal and real effective exchange rate. However, the empirical evidence is not satisfactory as it points to a weak and positive relation between the nominal or real effective appreciation and the Libor target rate in all policy rules, and thus the results are not reported. Besides, the other forward-looking specifications from the appendix perform worse in describing the central bank reaction function and the estimation results are available on demand.

Finally, we discuss the estimation results of the backward-looking Taylor rules with three different measures of inflation: total CPI, core trimmed and core median inflation respectively.

5.1.5 Summary of results for backward-looking Taylor rules

At first sight, the empirical evidence is quite surprising as it raises concerns about the relevance of actual CPI inflation in the backward-looking policy rule. Indeed, the estimated inflation coefficients are mostly not significant and the Taylor principle is not satisfied in neither specification. The results also provide a weak evidence on the monetary authority responsiveness to the core inflation measures. In light of the findings, the central bank behavior seems to substantially differ with the forward or backward-looking data used in the estimation of the Taylor rules which is consistent with the results in the literature. Again, to conserve space, the detailed results are reported in tables A.3. to A.6. in the appendix.

In addition, we report a strong and robust effect of the output gap on the policy rate whose magnitude is similar to the output gap coefficient estimates obtained with the forward-looking Taylor rules. The estimation results are also qualitatively unaltered from including the nominal effective Swiss franc appreciation in the regressions as shown in table A.4. The effect of the nominal effective appreciation is of a similar size than obtained in the

forward-looking specifications.¹³ The Taylor rules with partial adjustment do not yield satisfactory results as in most cases the inflation coefficient is not significant and is further negative in some specifications. The exchange rate estimates point to a robust negative and stronger response to the Swiss franc nominal effective appreciation.

In a nutshell, the empirical evidence suggests that we should rely on a forward-looking specification of the SNB policy reaction function rather than on a backward-looking Taylor rule. Additionally reacting to the nominal effective Swiss franc appreciation permits to track more closely the Libor target rate set by the SNB Governing Board and suggests a stabilizing effect on the business cycle. In view of the model selection statistics, the best fitting model without interest rate smoothing involves the four quarters ahead inflation forecasts based on the SNB data. With interest smoothing the best policy rules contain the three quarters ahead inflation forecasts. As regards the CEF data, the best fitting models are obtained with the inflation forecasts three quarters ahead regardless of the presence of a partial adjustment mechanism. In terms of the RMSE criterion the best specification without interest rate smoothing is IOEF_j with an inflation horizon of four and three quarters ahead respectively for the SNB and CEF data.

5.2. Stability of the Taylor rules and structural break tests

In this subsection we first perform rolling and recursive window regressions of the baseline forward and backward-looking policy rules presented in the paper. The aim is to investigate the stability of the Taylor rules parameters over time particularly during the recent financial crisis. In the rolling approach we apply a fixed window of 30 observations in the estimations, while in the recursive regressions the window size is progressively extended by one quarter over time. In both procedures the first estimation spans the period before the financial turmoil from 2000 Q3 to 2007 Q4.¹⁴ In a second step, we perform structural break tests.

5.2.1 Stability of Taylor rules

In general, the rolling and recursive regressions do not show evidence for important time variation in the Taylor rules parameters based on the SNB, CEF and actual data. In particular, there is no evidence that the SNB's responsiveness to economic fundamentals has fundamentally changed neither at the peak of the financial crisis nor since the

¹³ The regressions with the real effective appreciation of the Swiss franc are not reported as they yield very similar results. In addition, the regressions with the change in the output gap are not presented neither as the coefficient estimates are mostly not significant.

¹⁴ We have chosen a window size of 30 observations in order to obtain statistically reliable results. To save some space the estimated coefficients are not presented in the paper but are available from the authors on demand.

introduction of the Swiss franc floor against the euro. Besides, the coefficient estimates from the rolling and recursive regressions are qualitatively similar.¹⁵

The forward-looking policy rules with only the inflation forecast gap as explanatory variable feature quite stable coefficients over time. Including a reaction to the output gap estimate in the reaction function leads to a higher variation in the coefficients even though it does not suggest the presence of a break. The Taylor rules that account for an exchange rate responsiveness point out that the estimated coefficient has gradually decreased and has turned negative since late 2009, thus implying a stabilizing central bank policy on the economy. The rules with policy inertia show that there has been a temporary and gradual decrease in interest rate smoothing at the peak of the financial downturn, while thereafter the estimated coefficient has returned to its pre-crisis level. Finally, the augmented forward-looking Taylor rules with policy inertia and exchange rate responsiveness indicate that, although there is some time variation in the interest rate smoothing, inflation forecast gap and output gap coefficients, the exchange rate estimate has remained broadly stable. Importantly, the magnitude of the exchange rate reaction is in line with the evidence from the linear estimations.

A comparison of the empirical results obtained with the SNB and CEF data reveals that they are qualitatively similar for many specifications. However, the findings suggest that the market participants have perceived an increasing inflation reaction of the central bank relative to the economic outlook over time compared to the estimates obtained with the SNB data. This result might point out that as inflationary pressures have dampened in the midst of the crisis, the central bank has put a relatively higher emphasis on business cycle considerations and on securing the stability of the financial system.

The backward-looking policy rules do not exhibit a high variation in the coefficients, although they point to some gradual change in the inflation and output gaps responsiveness. Consistently with the previous results, the exchange rate coefficient turns negative from 2010 on thus implying a stabilizing central bank policy for the economy. The specification with policy inertia shows that the interest rate smoothing has temporarily decreased at the tipping point of the crisis as previously found. Finally, there is no evidence that the Taylor principle has been fulfilled based on actual data which is in line with the findings from the linear regressions.

5.2.2 Tests of structural breaks

Most of the test statistics seem to support the presence of a structural break in the policy rules occurring at the peak of the financial crisis in 2008 Q3. However, we have to highlight that the relevant tests are performed with a relatively small number of observations, which

¹⁵ To conserve space, the graphs of the rolling and recursive windows are not reported but are available on demand.

might undermine the accuracy of the test statistics. Additionally, Kahn (2012) brings to the fore that it is still an open question whether monetary policy reaction functions have undergone a fundamental structural change during the financial crisis. In view of the previous arguments the results from the tests should be interpreted with particular caution.

Based on Hansen (2001), we have performed several tests for a break in the Taylor rules coefficients following the recent advances in the design of time series tests for structural change. First, relying on the approach of Chow (1960) we have implemented tests for a break occurring either at the onset of the crisis in 2007 Q3 or at the peak of the downturn in 2008 Q3. For the former, the F statistics do not show evidence for a break in the coefficients of the Taylor rules. However, for the latter the Chow statistics suggest that there has been a change in the parameters after the Lehman Brothers collapse in most policy rules. Second, we have applied Andrews (1993) tests of structural change with an unknown break date with a trimming of 25%. The results corroborate the evidence for a break in the coefficients occurring in 2008 Q3. Finally, we have performed the Bai and Perron (1998 and 2003) sequential procedure to estimate the number of breaks and test for multiple structural changes based on the $\text{Sup } F_{T(l+1|l)}$ statistic. Given the relatively small number of observations and the applied high trimming the tests allow for a maximum of two breaks. The results tend to confirm the previous evidence for a break in 2008 Q3 and point to a change in some Taylor rules between 2003 Q2 and 2005 Q2 depending on the data and specifications. The latter period refers to the previous cycle of policy accommodation. Nevertheless, when we allow for possible serial correlation and heteroskedasticity in the error structure, the confidence intervals of the break dates are in some cases implausibly large and for some specifications the algorithm does not converge well.

In the rolling and recursive window procedures we assume that the model remains linear over specific periods whereas the policy rule parameters can change over time. In addition, in a more general setting, we allow for a nonlinear model in which the reaction of the central bank to economic fundamentals might change along with the level of the explanatory variables. Hence, the semi-parametric approach further complements the stability analysis of the Taylor rules by investigating the relationship between the policy rate and the covariates.

6. Semi-parametric Taylor rules

In this section we present the regression results of the Taylor rules estimated with a semi-parametric approach. In order to investigate the nonlinearity of the policy rules within the support of the explanatory variables we estimate two types of specifications: univariate and bivariate Taylor rules. In the former, the policy rate is a sum of additive smooth functions of the explanatory variables whereas in the latter the dependent variable is a single spline of all covariates. From a statistical perspective, the univariate rules exhibit a faster rate of convergence whereas the bivariate rules are exposed to a possible curse of dimensionality

problem.¹⁶ Nonetheless, the bivariate regression is more general as it allows for a possible interaction between the explanatory variables and provides a convenient visual approach to describe the policy reaction function. With the semi-parametric technique, the nonlinearity is defined as a changing central bank responsiveness to economic fundamentals along the level of the explanatory variables and is reflected in the shape of the estimated splines.

We first estimate a univariate rule that contains the inflation forecast gap as a single covariate. In a next step, the second univariate model additionally includes a smooth function of the output gap estimate in the policy rule. Finally, the third univariate specification contains a reaction to the nominal effective Swiss franc appreciation in addition to the inflation forecast gap and the output gap estimate. The bivariate Taylor rule is a single function of the inflation forecast gap and the output gap estimate. We also provide estimation results of the backward-looking Taylor rules with total CPI and the two SNB core inflation measures.¹⁷ The forward-looking policy rules can be written in the following more general form accordingly:

$$\text{Univariate 1 FTR: } i_t = c + s(E_t \{\pi_{t+k} - \pi^*\}) + \varepsilon_t \quad (4)$$

$$\text{Univariate 2 FTR: } i_t = c + s_1(E_t \{\pi_{t+k} - \pi^*\}) + s_2(E_t \{y_{t+q} - y_{t+q}^*\}) + \varepsilon_t \quad (5)$$

$$\text{Univariate 3 FTR: } i_t = c + s_1(E_t \{\pi_{t+k} - \pi^*\}) + s_2(E_t \{y_{t+q} - y_{t+q}^*\}) + s_3(\Delta e_{nom,t}) + \varepsilon_t \quad (6)$$

$$\text{Bivariate FTR: } i_t = c + s(E_t \{\pi_{t+k} - \pi^*\}, E_t \{y_{t+q} - y_{t+q}^*\}) + \varepsilon_t \quad (7)$$

where $k = 1, \dots, 4$, $q = 0$ and $s(\cdot)$ denotes a spline which is a smooth function of covariates.

The backward-looking specifications are as follows:

$$\text{Univariate 1 BTR: } i_t = c + s_1(\pi_t - \pi^*) + s_2(y_t - y_t^*) + \varepsilon_t \quad (8)$$

$$\text{Univariate 2 BTR: } i_t = c + s_1(\pi_t - \pi^*) + s_2(y_t - y_t^*) + s_3(\Delta e_{nom,t}) + \varepsilon_t \quad (9)$$

$$\text{Bivariate BTR: } i_t = c + s(\pi_t - \pi^*, y_t - y_t^*) + \varepsilon_t \quad (10)$$

Tables 5 to 8 report the estimated degrees of freedom of the splines along with some relevant statistics for the forward-looking specifications estimated with the SNB and CEF

¹⁶ The latter corresponds to a slower rate of asymptotic convergence of the spline along with the dimension considered. The bivariate specification has a rate of convergence of $n^{-2/3}$ compared to the rate of $n^{-4/5}$ and n^{-1} in the univariate and parametric rules respectively.

¹⁷ The estimations of the other Taylor rules specifications are not presented as they do not display the best model fit and the results are available from the authors on demand.

data.¹⁸ Table 9 shows the regression results for the semi-parametric backward-looking Taylor rules. We have checked that the estimation results remain qualitatively unaltered from using the end-of-quarter Libor market rate as a dependent variable.

Table 5: Univariate forward-looking Taylor rules with inflation forecasts

| Univariate 1 FTR | SNB data | CEF data |
|--------------------------------|---------------------|---------------------|
| $s(E_t \{\pi_{t+1} - \pi^*\})$ | 1.000***/(1.08e-05) | 1.792***/(9.29e-07) |
| Adj. R^2 | 0.332 | 0.456 |
| Dev.exp. | 0.347 | 0.477 |
| AIC | 131.0773 | 122.0013 |
| RMSE | 0.8904309 | 0.7968421 |
| $s(E_t \{\pi_{t+2} - \pi^*\})$ | 1.248***/(0.000133) | 1.837***/(9.7e-08) |
| Adj. R^2 | 0.309 | 0.511 |
| Dev.exp. | 0.327 | 0.530 |
| AIC | 132.98 | 116.9302 |
| RMSE | 0.9035819 | 0.7551364 |
| $s(E_t \{\pi_{t+3} - \pi^*\})$ | 1.380***/(0.000603) | 1.642***/(1.31e-09) |
| Adj. R^2 | 0.279 | 0.585 |
| Dev.exp. | 0.300 | 0.600 |
| AIC | 135.1477 | 108.8167 |
| RMSE | 0.9216768 | 0.6967655 |
| $s(E_t \{\pi_{t+4} - \pi^*\})$ | 1.000***/(7.21e-07) | 6.117***/(1.22e-05) |
| Adj. R^2 | 0.404 | 0.519 |
| Dev.exp. | 0.417 | 0.581 |
| AIC | 125.6114 | 119.9309 |
| RMSE | 0.8411489 | 0.7126497 |
| Obs. | 48 | 48 |

Note: The table reports the estimated degrees of freedom of the splines and relevant statistics. The degrees of freedom refer to the number of parameters required to estimate the smooth term. P-values are denoted in parenthesis. "Dev.exp." refers to the explained model deviance. Superscripts *** indicate significance at the 1% level, ** at the 5% level, * at the 10% level.

¹⁸ The reported degrees of freedom correspond to the number of parameters needed to estimate the splines. As evidence for nonlinearity we refer to the large number of estimated degrees of freedom of the smooth terms: larger than one in the univariate specifications and more than two estimated degrees of freedom in the bivariate models.

Table 6: Univariate forward-looking Taylor rules with inflation forecasts and output gap estimates

| Univariate 2 FTR | SNB data | CEF data |
|---------------------------------|---------------------|---------------------|
| $s_1(E_t\{\pi_{t+1} - \pi^*\})$ | 1.000***/(0.00357) | 1.000***/(0.00907) |
| $s_2(E_t\{y_t - y_t^*\})$ | 1.958***/(1.11e-06) | 7.743***/(2.83e-07) |
| Adj. R^2 | 0.642 | 0.783 |
| Dev.exp. | 0.664 | 0.823 |
| AIC | 103.0144 | 83.83469 |
| RMSE | 0.6381685 | 0.4632576 |
| $s_1(E_t\{\pi_{t+2} - \pi^*\})$ | 1.000***/(0.00486) | 1.000***/(0.00432) |
| $s_2(E_t\{y_t - y_t^*\})$ | 2.788***/(4.57e-07) | 7.620***/(1.18e-06) |
| Adj. R^2 | 0.660 | 0.786 |
| Dev.exp. | 0.687 | 0.825 |
| AIC | 101.3186 | 82.97617 |
| RMSE | 0.6162409 | 0.4603081 |
| $s_1(E_t\{\pi_{t+3} - \pi^*\})$ | 1.000***/(0.00271) | 1.000***/(2.1e-05) |
| $s_2(E_t\{y_t - y_t^*\})$ | 3.212***/(9.8e-08) | 2.319***/(0.000261) |
| Adj. R^2 | 0.677 | 0.712 |
| Dev.exp. | 0.706 | 0.732 |
| AIC | 99.1608 | 92.93962 |
| RMSE | 0.5972393 | 0.5702744 |
| $s_1(E_t\{\pi_{t+4} - \pi^*\})$ | 1.000***/(0.000465) | 1.000***/(3.44e-05) |
| $s_2(E_t\{y_t - y_t^*\})$ | 2.963***/(2.65e-06) | 7.833***/(1.22e-08) |
| Adj. R^2 | 0.694 | 0.805 |
| Dev.exp. | 0.720 | 0.841 |
| AIC | 96.32947 | 78.78875 |
| RMSE | 0.5829011 | 0.4387142 |
| Obs. | 48 | 48 |

Note: The table reports the estimated degrees of freedom of the splines and relevant statistics. The degrees of freedom refer to the number of parameters required to estimate the smooth term. P-values are denoted in parenthesis. "Dev.exp." refers to the explained model deviance. Superscripts *** indicate significance at the 1% level, ** at the 5% level, * at the 10% level.

The evidence from table 5 reveals that all estimated smooth terms are statistically significant in the univariate specifications. Based on the SNB data, we find a close to linear relation between the Libor target rate and the inflation forecasts, even though the degree

of nonlinearity rises along with the one to three quarters ahead horizon. With the CEF data there is a stronger evidence for nonlinearity, which tends to increase along the forecast horizon and is particularly high with the four quarters ahead inflation forecasts.¹⁹ The latter exhibits six estimated degrees of freedom of the inflation forecast gap smooth term. Overall, there is a higher degree of nonlinearity in the policy rules with the CEF measures of expectations at all horizons in comparison with the SNB forecasts. Regarding the AIC and RMSE criteria, the best specification contains four and three quarters ahead inflation forecasts with the SNB and CEF data respectively. This finding is in line with the results reported from the parametric regressions. Importantly, as there is evidence for nonlinearity in the estimated policy rules particularly with the CEF data, we obtain a better model fit with the semi-parametric approach than with the parametric Taylor rules.

Table 6 displays the regression results of the univariate Taylor rules where the policy rate is an additive function of the inflation forecast gap and output gap estimate. All estimated smooth functions are significant and the semi-parametric rules feature a higher explanatory power compared to their parametric counterparts.

At first sight, the table suggests that the roots of nonlinearity lie in the output gap estimate smooth term. Indeed, the inflation forecast gap function is linear in all specifications, while the output gap estimate spline is highly nonlinear. The nonlinearity of the output gap could be explained by a more cautious reaction of the SNB to the output gap which is a variable measured with more noise than inflation. In general, the RMSE is smaller compared to the one of the corresponding bivariate Taylor rules from table 8 for most specifications which points to a better model fit achieved with the univariate approach. The policy rules with the four quarters ahead inflation forecasts feature the best fit with the Libor target rate and are preferred from an information criterion approach.

Table 7 shows the estimation results of the univariate policy rules augmented with a nominal effective Swiss franc appreciation. The estimated functions of the explanatory variables are all significant and the explanatory power of the models is higher compared to the parametric regressions.

Figures 2 and 3 display the shape of the estimated smooth functions for the best fitting rules with the SNB and CEF data.²⁰ First, we see that there is a linear reaction to the inflation forecast gap in most policy rules as previously found.

¹⁹ Empirically, it is difficult to ascertain the source of nonlinearity as it may originate from either asymmetric central bank preferences, time-inconsistent policy decisions or/and a nonlinear structure of the economy.

²⁰ Shaded areas display a 95% confidence interval and dots refer to partial residuals. The tight confidence interval obtained for the linear smooth term corresponds to an identification constraint which is imposed on the splines in the case of a linear relation between the dependent variable and the covariates.

Table 7: Univariate forward-looking Taylor rules augmented with a nominal effective appreciation

| Univariate 3 FTR | SNB data | CEF data |
|---------------------------------|----------------------------------|----------------------------------|
| $s_1(E_t\{\pi_{t+1} - \pi^*\})$ | 1.000 ^{***} /(0.00269) | 1.000 ^{***} /(0.000319) |
| $s_2(E_t\{y_t - y_t^*\})$ | 1.000 ^{***} /(5.45e-08) | 6.863 ^{***} /(1.17e-07) |
| $s_3(\Delta e_{nom,t})$ | 1.000 ^{***} /(0.00695) | 1.000 ^{***} /(3.42e-06) |
| Adj. R^2 | 0.673 | 0.811 |
| Dev.exp. | 0.694 | 0.846 |
| AIC | 98.71204 | 77.31332 |
| RMSE | 0.6096594 | 0.4317504 |
| $s_1(E_t\{\pi_{t+2} - \pi^*\})$ | 1.000 ^{***} /(0.0048) | 1.000 ^{***} /(0.00712) |
| $s_2(E_t\{y_t - y_t^*\})$ | 1.000 ^{***} /(1.96e-08) | 6.425 ^{***} /(5.35e-07) |
| $s_3(\Delta e_{nom,t})$ | 1.000 ^{**} /(0.0144) | 2.879 ^{***} /(0.00928) |
| Adj. R^2 | 0.665 | 0.817 |
| Dev.exp. | 0.686 | 0.857 |
| AIC | 99.87483 | 76.70425 |
| RMSE | 0.617086 | 0.4163399 |
| $s_1(E_t\{\pi_{t+3} - \pi^*\})$ | 1.000 ^{***} /(0.00914) | 1.000 ^{***} /(0.000151) |
| $s_2(E_t\{y_t - y_t^*\})$ | 1.000 ^{***} /(3.77e-09) | 5.383 ^{***} /(2.04e-06) |
| $s_3(\Delta e_{nom,t})$ | 2.688 [*] /(0.05787) | 3.364 ^{***} /(0.003217) |
| Adj. R^2 | 0.681 | 0.837 |
| Dev.exp. | 0.713 | 0.871 |
| AIC | 99.01822 | 70.76039 |
| RMSE | 0.590475 | 0.3959071 |
| $s_1(E_t\{\pi_{t+4} - \pi^*\})$ | 1.000 ^{***} /(0.000144) | 1.593 ^{***} /(9.05e-05) |
| $s_2(E_t\{y_t - y_t^*\})$ | 1.000 ^{***} /(2.32e-08) | 2.413 ^{***} /(3.35e-07) |
| $s_3(\Delta e_{nom,t})$ | 3.012 ^{**} /(0.013603) | 3.476 ^{***} /(1.70e-05) |
| Adj. R^2 | 0.738 | 0.817 |
| Dev.exp. | 0.766 | 0.846 |
| AIC | 89.73297 | 74.54792 |
| RMSE | 0.5324261 | 0.4317302 |
| Obs. | 48 | 48 |

Note: The table reports the estimated degrees of freedom of the splines and relevant statistics. The degrees of freedom refer to the number of parameters required to estimate the smooth term. P-values are denoted in parenthesis. "Dev.exp." refers to the explained model deviance. Superscripts ^{***} indicate significance at the 1% level, ^{**} at the 5% level, ^{*} at the 10% level.

Figure 2: Univariate forward-looking Taylor rule with the exchange rate, SNB data

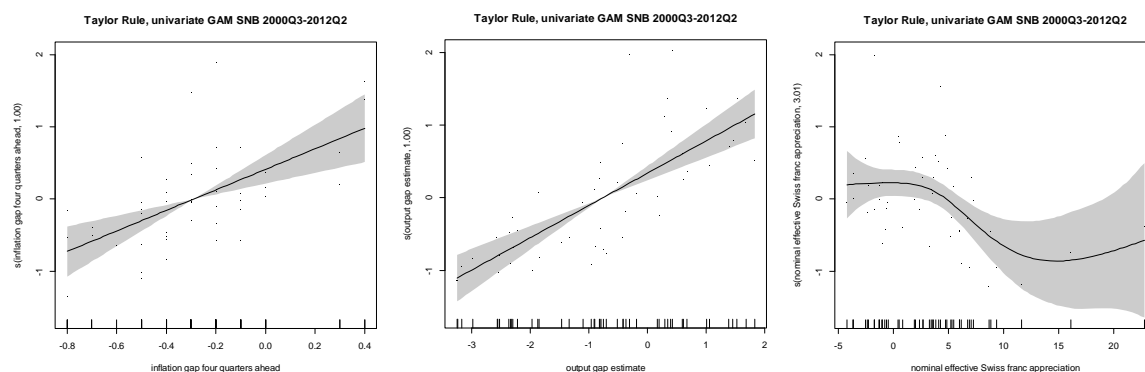


Figure 3: Univariate forward-looking Taylor rule with the exchange rate, CEF data

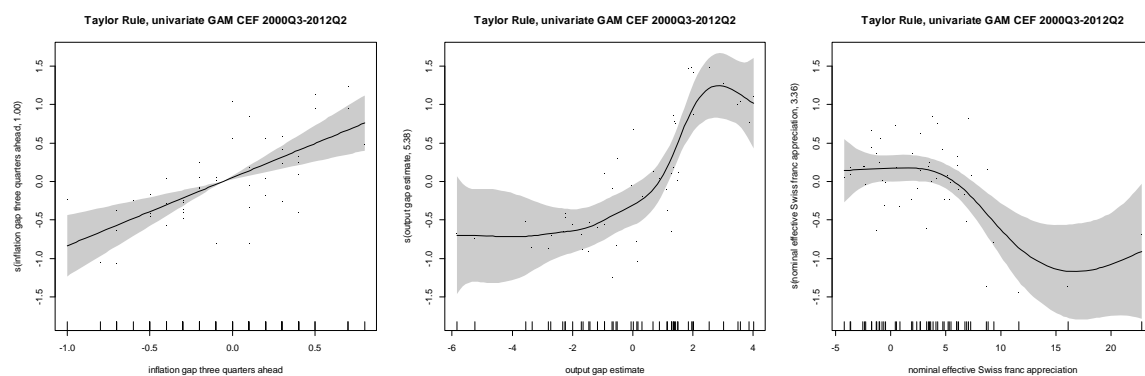
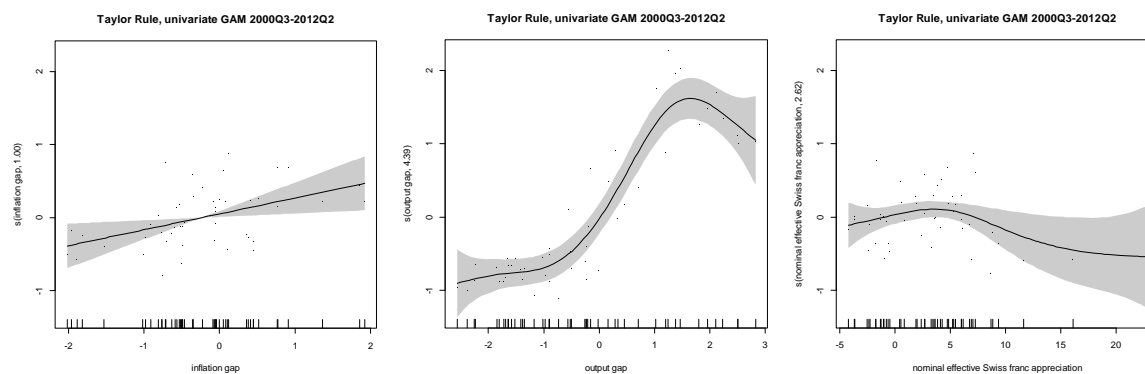


Figure 4: Univariate backward-looking Taylor rule with the exchange rate, Actual data



Second, there is a linear reaction to the output gap estimates with the SNB data, while the estimated smooth terms are nonlinear with the CEF expectations. In particular, the market participants perceive the SNB to strongly react to positive output gap estimates while its response is almost flat to negative ones. This result indicates that the professional forecasters foresee the SNB to counteract more strongly future inflationary pressures stemming from above potential economic activity.

As pointed out in Genberg and Gerlach (2010), this evidence can be rationalized on the grounds of the SNB's hierarchical mandate and the price stability definition which is

formulated in terms of an inflation zone than as a specific numerical value. In a theoretical framework, Orphanides and Wieland (2000) show that if a central bank targets an inflation zone than a specific value, the optimal reaction function is nonlinear. The link to the Orphanides and Wieland paper is justified on the following grounds. First, the SNB does not target a specific inflation value. Its price stability definition is formulated in terms of an inflation range from 0 to 2%. Second, we find evidence for nonlinearity in the estimated reaction functions. Hence, the observed nonlinearity of the estimated actual and market-perceived policy rules can be related to the hierarchical SNB's mandate which defines a specific priority on price stability. Moreover, the SNB's reaction to the exchange rate reflects price stability concerns to the extent that a strong Swiss franc appreciation can lead to deflationary developments. Similarly, a strongly positive output gap signals future inflationary concerns which might entail a more aggressive policy response outside the zone of price stability. As long as expected inflation is in the 0-2% range, there are no risks to price stability and the SNB can focus on stabilizing economic activity. However, outside this range, the policy gears mainly towards offsetting inflationary or deflationary pressures. Therefore, the perceived nonlinearity of the output gap function shows that market participants have well understood the nonlinear nature of the SNB's monetary policy design.

The perceived higher nonlinearity of the output gap function could be related to SNB's communication through the conditional inflation forecast. At the regular quarterly monetary policy assessments, the central bank communicates an inflation forecast for the current quarter and the following eleven quarters which are conditioned on the current policy rate. It can be argued that the difference between the published inflation forecast and the current inflation rate may be considered as a slope measure of the expected risks to price stability.²¹ Hence, it is possible that market participants foresee future inflationary pressures stemming from above potential output and expect the SNB to react more strongly to maintain inflation in the zone of price stability which is also reflected in the slope measure. As a sensitivity analysis, we have checked for this issue by including in the semi-parametric regressions the slope computed with the four, eight and eleven quarters ahead inflation forecasts. We find that the baseline results remain qualitatively unaltered. Moreover, for shorter inflation horizons we obtain a positive and significant effect of the slope on the policy rate, while the effect becomes negative and in some specifications insignificant at longer forecast horizons. Therefore, it seems that market participants focus on shorter inflation horizons to evaluate the risks to price stability, while an increasing inflation slope at longer horizons suggests that the current policy stance can be more expansionary. This result is consistent with the evidence reported in Genberg and Gerlach (2010).

²¹ We are grateful to Marcel Savioz for pointing out this issue. More formally,

$$slope_t = E_t \{ \pi_{t+p} | i_t \} - \pi_t, p = 0, \dots, 11$$

Third, there is a significant reaction to the exchange rate whose degree of nonlinearity increases along the inflation forecast horizon. Figure 2 shows that the exchange rate smooth term is nearly flat for small variations in the Swiss franc external value. Conversely, the estimated function points to a strongly negative relation between the Libor target rate and the sharp nominal appreciation of the domestic currency. This finding suggests that the Swiss National Bank does not seem to respond to small variations in the exchange rate but strongly reacts to a sizeable appreciation of the Swiss franc. According to our estimates, the SNB swiftly cuts the policy rate above a threshold level of approximately 5%.²² This result points to an increased concern about a strong appreciation that might engineer deflationary pressures and trigger an economic downturn. Therefore, the SNB's reaction to the exchange rate is fully consistent with its price stability mandate. Figure 3 corroborates this result for the CEF data. The AIC and RMSE criteria point to the Taylor rules with four and three quarters ahead inflation forecasts as the best specification for the SNB and CEF data respectively. As previously found, the semi-parametric modeling technique yields a better fit of the policy rules than the parametric approach to the extent that it tracks more closely the central bank reaction to the level of economic fundamentals. Moreover, accounting for a central bank responsiveness to the nominal Swiss franc appreciation substantially improves the fit of the Taylor rules and is also rationalized from an economic standpoint.

The estimated bivariate policy rules provide strong evidence for nonlinearity in particular with the CEF data as displayed in table 8. In most specifications the degree of nonlinearity increases along the forecast horizon used in the regressions. There is also evidence for a higher degree of nonlinearity with the CEF than with the SNB data as previously reported. The estimated functions are all significant and the bivariate Taylor rules feature a higher explanatory power compared to the parametric reaction functions particularly with the CEF data. Based on the AIC and RMSE criteria the best specification contains the four quarters ahead inflation forecasts, which is one additional quarter ahead for the CEF data than obtained with the parametric rules. In general, there is a better model fit with the semi-parametric bivariate regressions than with the parametric Taylor rules.

Figure 5 portrays the estimated bivariate Taylor rules for different inflation forecast horizons. On each graph we display the shape of the predicted policy rate (z-axis) as a function of the inflation forecast gap (x-axis) and the output gap estimate (y-axis). The figure shows that the Libor target rate is an increasing function of the inflation forecast gap and output gap estimates in most specifications. In all regressions, there is a linear responsiveness of the central bank to the inflation forecast gaps, while there seems to be a nonlinear reaction to the output gap estimate along the inflation forecast horizon particularly with the CEF data. For instance, with the four quarters ahead inflation forecasts

²² Note that the exchange rate function is estimated with considerable uncertainty for a Swiss franc appreciation above 10%.

the market participants perceive the SNB to strongly react to output gap estimates above zero, while they foresee a nearly flat responsiveness to negative and close to zero output gaps. As previously emphasized, in most cases the shape of estimated surface points to increasing nonlinearity of the policy rule along the inflation forecast horizon. Moreover, the evidence does not seem to suggest the presence of an interaction term between the explanatory variables in the policy rules.

Table 8: Bivariate forward-looking Taylor rules with inflation forecasts and output gap estimates

| Bivariate FTR | SNB data | CEF data |
|---|----------------------------------|----------------------------------|
| $s(E_t\{\pi_{t+1} - \pi^*\}, E_t\{y_t - y_t^*\})$ | 2.886 ^{***} /(5.86e-10) | 5.173 ^{***} /(7.69e-09) |
| Adj. R^2 | 0.638 | 0.665 |
| Dev.exp. | 0.660 | 0.702 |
| AIC | 103.469 | 101.7386 |
| RMSE | 0.6421599 | 0.6013394 |
| $s(E_t\{\pi_{t+2} - \pi^*\}, E_t\{y_t - y_t^*\})$ | 3.006 ^{***} /(5.86e-10) | 6.013 ^{***} /(1.61e-09) |
| Adj. R^2 | 0.642 | 0.706 |
| Dev.exp. | 0.665 | 0.744 |
| AIC | 102.9771 | 96.18632 |
| RMSE | 0.6372828 | 0.5577008 |
| $s(E_t\{\pi_{t+3} - \pi^*\}, E_t\{y_t - y_t^*\})$ | 3.573 ^{***} /(8.7e-10) | 5.686 ^{***} /(3.13e-11) |
| Adj. R^2 | 0.657 | 0.750 |
| Dev.exp. | 0.683 | 0.780 |
| AIC | 101.5583 | 88.21181 |
| RMSE | 0.620553 | 0.516751 |
| $s(E_t\{\pi_{t+4} - \pi^*\}, E_t\{y_t - y_t^*\})$ | 3.651 ^{***} /(8.67e-11) | 8.929 ^{***} /(3.82e-10) |
| Adj. R^2 | 0.692 | 0.772 |
| Dev.exp. | 0.716 | 0.816 |
| AIC | 96.34783 | 86.21075 |
| RMSE | 0.5868129 | 0.4730321 |
| Obs. | 48 | 48 |

Note: The table reports the estimated degrees of freedom of the splines and relevant statistics. The degrees of freedom refer to the number of parameters required to estimate the smooth term. P-values are denoted in parenthesis. "Dev.exp." refers to the explained model deviance. Superscripts ^{***} indicate significance at the 1% level, ^{**} at the 5% level, ^{*} at the 10% level.

Figure 5: Bivariate forward-looking Taylor rules, SNB and CEF data

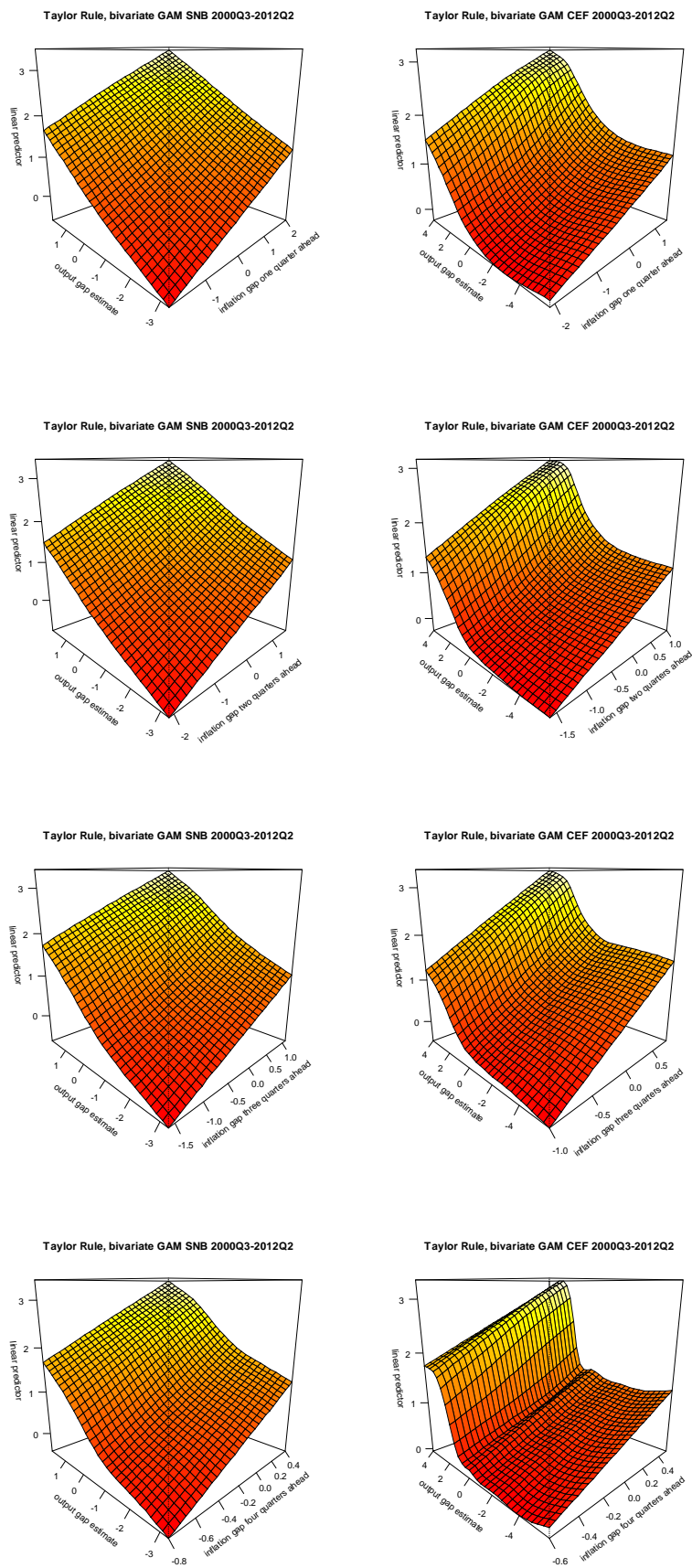


Table 9: Univariate and bivariate backward-looking Taylor rules

| Univariate 1 BTR | Total CPI | Core trimmed | Core median |
|---------------------------------|------------------------|------------------------|------------------------|
| $s_1(\pi_t - \pi^*)$ | 1.000*** (0.00451) | 1.000*** (0.000426) | 1.000** (0.0414) |
| $s_2(y_t - y_t^*)$ | 4.468*** (2.47e-14) | 4.496*** (7.72e-15) | 4.354*** (2.02e-14) |
| Adj. R^2 | 0.871 | 0.882 | 0.858 |
| Dev.exp. | 0.886 | 0.896 | 0.874 |
| AIC | 56.18088 | 51.89721 | 60.76308 |
| RMSE | 0.3718316 | 0.3553984 | 0.3909394 |
| Univariate 2 BTR | | | |
| $s_1(\pi_t - \pi^*)$ | 1.000** (0.0151) | 1.000*** (2.82e-11) | 1.000*** (0.00528) |
| $s_2(y_t - y_t^*)$ | 4.395*** (5.61e-14) | 4.071*** (1.27e-13) | 4.210*** (1.2e-11) |
| $s_3(\Delta e_{nom,t})$ | 2.624 (0.1306) | 1.000*** (1.49e-06) | 1.000** (0.01988) |
| Adj. R^2 | 0.885 | 0.888 | 0.868 |
| Dev.exp. | 0.904 | 0.902 | 0.885 |
| AIC | 52.93154 | 49.92389 | 58.04949 |
| RMSE | 0.3408596 | 0.3440233 | 0.3733283 |
| Bivariate BTR | | | |
| $s(\pi_t - \pi^*; y_t - y_t^*)$ | 7.657*** (1.41e-14) | 8.111*** (2.24e-16) | 7.507*** (4.68e-15) |
| Adj. R^2 | 0.857 | 0.888 | 0.862 |
| Dev.exp. | 0.880 | 0.908 | 0.884 |
| AIC | 62.99982 | 51.41768 | 60.94428 |
| RMSE | 0.3814106 | 0.3348833 | 0.3744991 |
| Obs. | 48 | 48 | 48 |

Note: The table reports the estimated degrees of freedom of the splines and relevant statistics. The degrees of freedom refer to the number of parameters required to estimate the smooth term. P-values are denoted in parenthesis. "Dev.exp." refers to the explained model deviance. Superscripts *** indicate significance at the 1% level, ** at the 5% level, * at the 10% level.

Finally, the semi-parametric backward-looking Taylor rules point to the presence of nonlinearities in particular with respect to the output gap and the exchange rate. The regression results are presented in table 9 and the estimated splines are displayed in figure 4. Most of the estimated smooth terms are significant and the RMSE point to a much closer fit of the policy rate with the semi-parametric Taylor rules than with the parametric reaction functions. The univariate specification without the exchange rate term indicates that the central bank reaction to inflation is linear while its responsiveness to the output gap is strongly nonlinear. This result thus corroborates the previous evidence obtained with the SNB and CEF forecasts. The specification with the exchange rate term confirms the earlier findings about the linearity of the inflation gap smooth term obtained with both the SNB and CEF data. The estimated output gap function suggests that the SNB reacts more strongly to positive output gaps to alleviate future inflationary pressures which is consistent with the previous results. In addition, the regressions corroborate the stronger reaction of the central bank to a substantial nominal effective Swiss franc appreciation with the total CPI measure. Nevertheless, this evidence is relatively mixed with the core inflation measures as the exchange rate terms are linear. The bivariate specifications show strong evidence for nonlinearity of the policy rule with the total CPI and the core inflation measures. In general, the univariate policy rules augmented with the exchange rate variable display a higher explanatory power and better in-sample fit than the parametric reaction functions and are preferred in light of the information criterion statistic.

To sum up, the evidence for nonlinearity with the semi-parametric regressions can be rationalized from the SNB's hierarchical mandate. The central bank reacts more strongly to large variations in macroeconomic fundamentals to contain future inflationary pressures while it takes into account the developments of the economy. Along these lines, the SNB firmly responds to inflation while it reacts more aggressively to the output gap and the nominal Swiss franc appreciation to the extent that these variables become a concern for price stability and economic activity.

6. Conclusion

This paper provides new insights on understanding the SNB's policy reaction function based on internal macroeconomic forecasts and on the CEF measures of expectations. The empirical results point to the following main findings.

First, in line with the recent literature, there is a strong evidence for increasing central bank reaction to inflation along with the forecast horizon. Second, the market participants seem to have well understood the SNB's price stability commitment as they have perceived even a stronger central bank reaction to inflation than found with the SNB internal forecasts. Third, the best specification contains a reaction term to the Swiss franc appreciation along with the output gap estimate and the inflation forecasts four and three quarters ahead with the SNB and CEF data respectively. Finally, the semi-parametric

regression results provide some empirical support for the nonlinear modeling of the policy rules. Notwithstanding a close to linear reaction to inflation there is clearly a nonlinear response to the output gap and the exchange rate.

The semi-parametric estimations suggest that the SNB has counteracted a strong Swiss franc appreciation possibly to prevent the emergence of an adverse feedback-loop from the exchange rate movements to prices and real economic activity. This policy responsiveness shows a strong evidence for the SNB's price stability commitment and accounts for a high level of inflation credibility in the monetary institution. Nevertheless, the market participants seem to have perceived a higher degree of nonlinearity in the policy rules than found with the SNB internal data. This evidence may reflect a more cautious approach to modeling the perceived Taylor rule on the part of the professional forecasters. They might face some degree of uncertainty regarding the SNB's relative preferences for the key explanatory variables in the policy reaction function. Therefore, in terms of policy recommendation, a better clarification of the weights attached to the stabilization of the economic outlook and to the exchange rate developments relative to the inflation objective would improve the private sector understanding of the SNB's monetary policy rule.

Future research should focus on assessing the forecasting performance of the semi-parametric Taylor rules out of the sample used for the estimations. In addition, on the grounds of a normative approach, we should study the optimality of monetary policy rules within a specifically designed theoretical framework.

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Appendix

Taylor rules specifications

$$\mathbf{IF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IOF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \beta_y E_t \{y_t - y_t^*\} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IOEF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \beta_y E_t \{y_t - y_t^*\} + \beta_e \Delta e_{nom,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IOQF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \beta_y E_t \{y_t - y_t^*\} + \beta_e \Delta e_{real,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IOSF}_j: i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + (1 - \rho)\beta_y E_t \{y_t - y_t^*\} + \varepsilon_t, j=1, \dots, 4.$$

IOESF_j:

$$i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + (1 - \rho)\beta_y E_t \{y_t - y_t^*\} + (1 - \rho)\beta_e \Delta e_{nom,t} + \varepsilon_t, j=1, \dots, 4.$$

IOQSF_j:

$$i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + (1 - \rho)\beta_y E_t \{y_t - y_t^*\} + (1 - \rho)\beta_e \Delta e_{real,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IEF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \beta_e \Delta e_{nom,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IQF}_j: i_t = r^* + \pi^* + \beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \beta_e \Delta e_{real,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{ISF}_j: i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IESF}_j: i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + (1 - \rho)\beta_e \Delta e_{nom,t} + \varepsilon_t, j=1, \dots, 4.$$

$$\mathbf{IQSF}_j: i_t = (1 - \rho)(r^* + \pi^*) + \rho i_{t-1} + (1 - \rho)\beta_\pi E_t \{\pi_{t+j} - \pi^*\} + (1 - \rho)\beta_e \Delta e_{real,t} + \varepsilon_t, j=1, \dots, 4.$$

IOB: $i_t = r^* + \pi^* + \beta_\pi (\pi_t - \pi^*) + \beta_y (y_t - y_t^*) + \varepsilon_t$

IOEB: $i_t = r^* + \pi^* + \beta_\pi (\pi_t - \pi^*) + \beta_y (y_t - y_t^*) + \beta_e \Delta e_{nom,t} + \varepsilon_t$

IOQB: $i_t = r^* + \pi^* + \beta_\pi (\pi_t - \pi^*) + \beta_y (y_t - y_t^*) + \beta_e \Delta e_{real,t} + \varepsilon_t$

IOSB: $i_t = (1-\rho)(r^* + \pi^*) + \rho i_{t-1} + (1-\rho)\beta_\pi (\pi_t - \pi^*) + (1-\rho)\beta_y (y_t - y_t^*) + \varepsilon_t$

IOESB:

$$i_t = (1-\rho)(r^* + \pi^*) + \rho i_{t-1} + (1-\rho)\beta_\pi (\pi_t - \pi^*) + (1-\rho)\beta_y (y_t - y_t^*) + (1-\rho)\beta_e \Delta e_{nom,t} + \varepsilon_t$$

IOQSB:

$$i_t = (1-\rho)(r^* + \pi^*) + \rho i_{t-1} + (1-\rho)\beta_\pi (\pi_t - \pi^*) + (1-\rho)\beta_y (y_t - y_t^*) + (1-\rho)\beta_e \Delta e_{real,t} + \varepsilon_t$$

Table A.1.: Forward-looking Taylor rules with partial adjustment

| SNB data | <i>k=1, q=0</i> | <i>k=2, q=0</i> | <i>k=3, q=0</i> | <i>k=4, q=0</i> |
|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|
| ρ | 0.7192*** (0.1155) | 0.7088*** (0.1196) | 0.7116*** (0.1060) | 0.6840*** (0.1293) |
| β_π | 0.5927*** (0.1942) | 0.8630*** (0.2338) | 1.3516*** (0.3121) | 1.9229*** (0.5481) |
| β_y | 0.4206** (0.1637) | 0.4047** (0.1522) | 0.3973*** (0.1367) | 0.3929*** (0.1283) |
| $r^* + \pi^*$ | 1.4172*** (0.2479) | 1.4894*** (0.2226) | 1.6352*** (0.2015) | 1.8295*** (0.2055) |
| Adj. R^2 | 0.8818 | 0.8929 | 0.9060 | 0.8881 |
| AIC | 43.24917 | 38.61833 | 32.50665 | 40.67517 |
| BIC | 50.64976 | 46.01892 | 39.90724 | 48.07576 |
| RMSE | 0.3520622 | 0.3351384 | 0.3140417 | 0.3425525 |
| CEF data | | | | |
| ρ | 0.8024*** (0.0959) | 0.7626*** (0.1152) | 0.7178*** (0.1239) | 0.7964*** (0.1140) |
| β_π | 0.4310 (0.3351) | 1.1917** (0.4528) | 2.2636*** (0.5931) | 1.7560 (1.4052) |
| β_y | 0.2161 (0.1611) | 0.1354 (0.1494) | 0.0801 (0.1133) | 0.1635 (0.1947) |
| $r^* + \pi^*$ | 0.9170*** (0.2608) | 1.0689*** (0.2236) | 1.1067*** (0.2192) | 0.8424** (0.3247) |
| Adj. R^2 | 0.8668 | 0.8795 | 0.9026 | 0.8708 |
| AIC | 48.88603 | 44.18017 | 34.15295 | 47.45841 |
| BIC | 56.28662 | 51.58076 | 41.55354 | 54.859 |
| RMSE | 0.37382 | 0.3555665 | 0.3195902 | 0.3681855 |
| Obs. | 47 | 47 | 47 | 47 |

Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level.

Table A.2.: Forward-looking Taylor rules with partial adjustment and nominal effective appreciation

| SNB data | <i>k=1, q=0</i> | <i>k=2, q=0</i> | <i>k=3, q=0</i> | <i>k=4, q=0</i> |
|-----------------|------------------------|------------------------|------------------------|------------------------|
| ρ | 0.6878*** (0.1165) | 0.6850*** (0.1194) | 0.6896*** (0.1041) | 0.6540*** (0.1208) |
| β_π | 0.4145*** (0.1305) | 0.6108*** (0.2174) | 1.0006*** (0.3278) | 1.4867*** (0.4734) |
| β_y | 0.4364*** (0.0835) | 0.4263*** (0.0938) | 0.4182*** (0.0866) | 0.4080*** (0.0716) |
| β_e | -0.1063*** (0.0345) | -0.0954*** (0.0351) | -0.0859** (0.0343) | -0.0946*** (0.0298) |
| $r^* + \pi^*$ | 1.7745*** (0.2014) | 1.7859*** (0.1960) | 1.8647*** (0.1778) | 2.0598*** (0.1750) |
| Adj. R^2 | 0.9054 | 0.9112 | 0.9196 | 0.9113 |
| AIC | 33.68803 | 30.70143 | 26.03476 | 30.68198 |
| BIC | 42.93877 | 39.95216 | 35.2855 | 39.93271 |
| RMSE | 0.3113187 | 0.3015828 | 0.2869762 | 0.3015204 |
| CEF data | | | | |
| ρ | 0.7455*** (0.0882) | 0.7112*** (0.1027) | 0.6646*** (0.1015) | 0.7048*** (0.0983) |
| β_π | 0.2051 (0.2158) | 0.8122* (0.4389) | 1.7674*** (0.5674) | 1.8979** (0.8523) |
| β_y | 0.2766*** (0.1019) | 0.2017 (0.1303) | 0.1401 (0.0997) | 0.1695 (0.1308) |
| β_e | -0.1469*** (0.0469) | -0.1226*** (0.0430) | -0.1038*** (0.0328) | -0.1465*** (0.0355) |
| $r^* + \pi^*$ | 1.4685*** (0.1993) | 1.4951*** (0.1877) | 1.4729*** (0.1542) | 1.4594*** (0.1682) |
| Adj. R^2 | 0.8964 | 0.9058 | 0.9288 | 0.9100 |
| AIC | 37.94672 | 33.46479 | 20.33121 | 31.3356 |
| BIC | 47.19746 | 42.71553 | 29.58195 | 40.58634 |
| RMSE | 0.3257474 | 0.3105802 | 0.2700814 | 0.3036244 |
| Obs. | 47 | 47 | 47 | 47 |

Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level.

Table A.3.: Backward-looking Taylor rules

| | <i>Total CPI</i> | <i>Core trimmed</i> | <i>Core median</i> |
|---|-----------------------|-----------------------|-----------------------|
| β_π | 0.2225 (0.1363) | 0.6467* (0.3245) | 0.1487 (0.2937) |
| β_y | 0.5797*** (0.0738) | 0.5574*** (0.0734) | 0.6252*** (0.0741) |
| $r^* + \pi^*$ | 1.3768*** (0.1569) | 1.3563*** (0.1421) | 1.3241*** (0.1541) |
| Adj. R^2 | 0.7438 | 0.7812 | 0.7240 |
| AIC | 84.05713 | 76.47871 | 87.61816 |
| BIC | 89.67073 | 82.09231 | 93.23176 |
| RMSE | 0.5456141 | 0.5041984 | 0.5662332 |
| Obs. | 48 | 48 | 48 |
| Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level. | | | |

Table A.4.: Backward-looking Taylor rules with nominal effective appreciation

| | <i>Total CPI</i> | <i>Core trimmed</i> | <i>Core median</i> |
|---|-----------------------|------------------------|------------------------|
| β_π | 0.1958* (0.1117) | 0.6995** (0.2805) | 0.4720 (0.3215) |
| β_y | 0.5616*** (0.0718) | 0.5179*** (0.0621) | 0.5337*** (0.0661) |
| β_e | -0.0388** (0.0168) | -0.0467*** (0.0119) | -0.0553*** (0.0161) |
| $r^* + \pi^*$ | 1.4951*** (0.1489) | 1.5049*** (0.1329) | 1.4596*** (0.1431) |
| Adj. R^2 | 0.7711 | 0.8244 | 0.7743 |
| AIC | 79.56123 | 66.83559 | 78.891 |
| BIC | 87.04604 | 74.3204 | 86.3758 |
| RMSE | 0.5099161 | 0.4466108 | 0.5063685 |
| Obs. | 48 | 48 | 48 |
| Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level. | | | |

Table A.5.: Backward-looking Taylor rules with partial adjustment

| | <i>Total CPI</i> | <i>Core trimmed</i> | <i>Core median</i> |
|---------------|-----------------------|-----------------------|-----------------------|
| ρ | 0.6305*** (0.1368) | 0.6786*** (0.1311) | 0.6970*** (0.1221) |
| β_{π} | 0.0961 (0.1818) | -0.2549 (0.4492) | -0.9006** (0.4166) |
| β_y | 0.6482*** (0.1133) | 0.7283*** (0.1389) | 0.8494*** (0.1543) |
| $r^* + \pi^*$ | 1.2092*** (0.1615) | 1.1641*** (0.1764) | 1.2705*** (0.1436) |
| Adj. R^2 | 0.9027 | 0.9026 | 0.9099 |
| AIC | 34.13592 | 34.15409 | 30.50763 |
| BIC | 41.53651 | 41.55468 | 37.90822 |
| RMSE | 0.3195323 | 0.3195941 | 0.3074338 |
| Obs. | 47 | 47 | 47 |

Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level.

Table A.6.: Backward-looking Taylor rules with partial adjustment and nominal effective appreciation

| | <i>Total CPI</i> | <i>Core trimmed</i> | <i>Core median</i> |
|---------------|------------------------|------------------------|------------------------|
| ρ | 0.6190*** (0.1272) | 0.6152*** (0.1271) | 0.6398*** (0.1146) |
| β_{π} | 0.0455 (0.1329) | 0.0586 (0.2789) | -0.1899 (0.3316) |
| β_y | 0.6120*** (0.0795) | 0.6168*** (0.0878) | 0.6637*** (0.1003) |
| β_e | -0.0805*** (0.0195) | -0.0808*** (0.0209) | -0.0798*** (0.0225) |
| $r^* + \pi^*$ | 1.4692*** (0.1275) | 1.4659*** (0.1229) | 1.4743*** (0.1222) |
| Adj. R^2 | 0.9234 | 0.9233 | 0.9237 |
| AIC | 23.76609 | 23.82629 | 23.61028 |
| BIC | 33.01683 | 33.07702 | 32.86102 |
| RMSE | 0.280133 | 0.2803125 | 0.2796691 |
| Obs. | 47 | 47 | 47 |

Note: OLS estimates, HAC corrected standard errors with 3 lags are reported in parenthesis, *** indicates significance at the 1% level, ** at the 5% level, * at the 10% level.