MAGKS

Göttingen Kassel Aachen Siegen Marburg Gießen

Joint Discussion Paper
Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 35-2012

Matthias Neuenkirch and Peter Tillmann

Inflation Targeting, Credibility, and Non-Linear Taylor Rules

Coordination: Bernd Hayo • Philipps-University Marburg
Faculty of Business Administration and Economics • Universitätsstraße 24, D-35032 Marburg
Tel: +49-6421-2823091, Fax: +49-6421-2823088, e-mail: hayo@wiwi.uni-marburg.de

Inflation Targeting, Credibility, and Non-Linear Taylor Rules*

Matthias Neuenkirch†

RWTH Aachen University, Germany and Philipps-University Marburg, Germany

Peter Tillmann‡

Justus-Liebig-University Gießen, Germany

September 4, 2013

Abstract

In this paper we systematically evaluate how central banks respond to deviations from the inflation target. We present a stylized New Keynesian model in which agents' inflation expectations are sensitive to deviations from the inflation target. To (re-) establish credibility, monetary policy under discretion sets higher interest rates today if average inflation exceeded the target in the past. Moreover, the central bank responds non-linearly to past inflation gaps. This is reflected in an additional term in the central bank's instrument rule, which we refer to as the "credibility loss." Augmenting a standard Taylor (1993) rule with the latter term, we provide empirical evidence for the interest rate response for a sample of five inflation targeting (IT) economies. We find, first, that past deviations from IT feed back into the reaction function and that this influence is economically meaningful. Deterioration in credibility (ceteris paribus) forces central bankers to undertake larger interest rate steps. Second, we detect an asymmetric reaction to positive and negative credibility losses, with the latter dominating the former.

Keywords: Credibility, inflation expectations, monetary policy, Taylor rule.

JEL classification: C32, E31, E43, E52, E58.

*We thank Florian Neumeier, Britta Niehof, Matthias Uhl, participants of the DIW Macroeconometric Workshop in Berlin, the ifo Macro Seminar in Munich, the ZEW workshop on Recent Developments in Macroeconomics in Mannheim, and two anonymous referees for very helpful discussions and comments.

†Corresponding author. Email: matthias.neuenkirch@rwth-aachen.de

‡Email: peter.tillmann@wirtschaft.uni-giessen.de

1 Introduction

Over the past two decades, many central banks have adopted an inflation targeting (IT) framework. Although generally considered successful in stabilizing inflation, many IT economies have experienced periods, some of them prolonged, during which inflation deviated from the inflation target. In this paper we systematically evaluate how central banks responded to these deviations from the inflation target. Our analysis focuses on the following question: Do past deviations from target prompt central banks to set contemporaneous interest rates more aggressively?

In a first step, we present a stylized model in which agents' inflation expectations are sensitive to deviations from the inflation target. Credibility deteriorates if the central bank misses the announced target rate. To reestablish credibility, monetary policy is shown to respond to average past inflation being, say, above target by setting higher interest rates today. This is reflected in an additional term in the central bank's instrument rule, which we refer to as the "credibility loss." Hence, the central bank responds non-linearly to past inflation deviations, with the strength of the interest rate adjustment increasing in with extent of credibility loss. In a second step, we provide empirical evidence for the interest rate response to credibility loss for a sample of five IT economies.

This analysis contributes to two strands of the literature, the first of these being that addressing the nature of inflation deviations from target. In light of the recent inflation liftoff in the United Kingdom, Corder and Eckloff (2011) identify "sustained off-target inflation (SOTI) episodes" for a large set of IT countries. These authors are particularly interested in how SOTI episodes feed into inflation expectations. They show that short- and medium-term inflation expectations drift in the direction of inflation deviations. Svensson (2012) evaluates the costs of inflation deviations in terms of additional unemployment. If inflation expectations remain anchored and inflation exceeds the target, unemployment increases. He finds that average unemployment has been 0.8 percentage points higher due to positive inflation deviations. The persistence of inflation and long-term inflation expectations is addressed by Davis (2012). He modifies a standard New Keynesian model by introducing agents whose beliefs about the central bank's target rate lie between two extremes. Past inflation observations are used to update private beliefs about the target, which are interpreted as a measure of central bank credibility.

The second branch of the literature to which we contribute involves important non-linearities in interest rate setting that are neglected in the standard specification of estimated Taylor (1993) rules. The evidence provided by Dolado et al. (2004, 2005), Kim et al. (2005), Chevapatrakul et al. (2009), and Wolters (2012), among others, suggests that policy rates are adjusted in a non-linear way to inflation and output movements. The precise nature of non-linearity differs across studies and depends on the theoretical motivation. Furthermore, central banks often announce a target range around their inflation target, i.e., small deviations from the inflation target are tolerated, whereas large deviations are fought vigorously. Inflation deviations judged to be within a "comfort zone" require no action.[1] As a result, the interest rate response to inflation is non-linear.

The literature suggests three different motivations for non-linear interest rate setting. First, the Phillips curve tradeoff could be non-linear. Nobay and Peel (2000) and Dolado et al. (2005), among others, introduce convexity or concavity in a short-run Phillips curve that nests the linear tradeoff as a special case. This non-linearity is eventually reflected in non-linear policy steps. Second, asymmetric central bank preferences, i.e., deviations from the standard linear-quadratic framework, could be why the central bank adjusts interest rates non-linearly in response to inflation and output figures. Surico (2007a,b), Ruge-Murcia (2003), Nobay and Peel (2003), and Cukierman and Muscatelli (2008) introduce different preference asymmetries in models of optimal monetary policy. Third, non-linearity could arise from policymaker uncertainty about key economic data, the true model describing the economy, or over important parameters governing the monetary transmission mechanism (see Meyer et al. 2001; Swanson 2006; Tillmann 2011).

This paper offers an additional rationale for non-linear interest rate adjustment. If past deviations from the inflation target feed into current inflation expectations and if the absolute size of the deviation matters, we show that the resulting instrument rule includes not only the inflation rate, but also the credibility loss. Augmenting a standard forward-looking Taylor rule with the latter term, we provide empirical evidence for this modified interest rate rule in a sample of five IT economies. We find that past deviations from the inflation target feed back into the reaction function and that this influence is economically meaningful. Deterioration in credibility, ceteris paribus, forces central bankers to undertake larger interest rate steps.

The remainder of this paper is organized as follows. Section 2 presents an illustrative model that motivates our empirical specifications, which are described in Section 3. Section 4 introduces the credibility loss indicator and the estimation strategy. The results are discussed in Section 5. Conclusions are drawn in Section 6.

2 An illustrative model

In this section, we present a simple, illustrative model to motivate the inclusion of an additional term in a conventional instrument rule of monetary policy. The model appends an expectations formation mechanism proposed by Bomfim and Rudebusch (2000) to an otherwise standard New Keynesian model. The economic structure is described by the following New Keynesian Phillips curve (NKPC) and the IS curve, respectively:

$$\pi_t - \pi^* = \beta E_t (\pi_{t+1} - \pi^*) + \kappa y_t + e_t \quad (1)$$

$$y_t = E_t y_{t+1} - \frac{1}{\sigma} (i_t - E_t \pi_{t+1} - r) \quad (2)$$

[1] See Mishkin (2008) for a discussion.

π_t is the inflation rate, y_t is the output gap, i_t is the short-term nominal interest rate set by the central bank, and r is the natural real interest rate. An i.i.d. supply shock is denoted by e_t and E_t is the expectations operator. The coefficients β (the discount factor), κ (inversely reflecting the degree of nominal rigidities), and σ (the inverse of the elasticity of intertemporal substitution) are strictly positive.

The central bank minimizes squared fluctuations of inflation around a constant target π^* and squared fluctuations of the output gap weighted by a relative weight $\delta > 0$:

$$\mathcal{L} = (\pi_t - \pi^*)^2 + \delta y_t^2 \tag{3}$$

The central bank is assumed to be unable to commit to the fully optimal, i.e., inertial, policy plan. Instead, monetary policy operates under discretion and takes expectations of future inflation and future output as given. Minimizing Equation (3) with respect to output and inflation, subject to Equations (1) and (2), results in two first-order conditions that can be combined to the standard targeting rule:

$$y_t = -\frac{\kappa}{\delta}\left(\pi_t - \pi^*\right) \tag{4}$$

According to this rule, the central bank "leans against the wind" and depresses the real economy to counteract positive deviations from the inflation target. The strength of the economic contraction needed to fight an inflation deviation increases in the slope of the Phillips curve and decreases in the central bank's weight on output stabilization.

Agents' expectations are assumed to follow a simple rule of thumb suggested by Bomfim and Rudebusch (2000) and Tesfaselassie and Schaling (2010) that nests expectations formation under rational expectations as a special case. Future inflation expectations are determined as a weighted average of the constant inflation target and the average of past inflation rates:

$$E_t\pi_{t+1} = \lambda_t\pi^* + (1 - \lambda_t)\,\tilde{\pi}_{t-1} \tag{5}$$

$\tilde{\pi}_{t-1}$ is the average of past inflation rates $\frac{\pi_{t-1}+\ldots+\pi_{t-q}}{q}$ and λ_t is the relative weight attached to the inflation target. For $\lambda_t = 1$, the model collapses to the standard case of rational expectations, where expected inflation is equal to the inflation target due to the absence of serial correlation in the shock process, the lack of any backward-looking element in the model equations, and the discretionary nature of monetary policy. The higher λ_t, the higher the central bank's credibility. Credibility itself reflects past inflation performance and is modeled as a function of the absolute deviation of average past inflation from the inflation target with α being a positive constant:

$$\lambda_t = 1 - \alpha|\tilde{\pi}_{t-1} - \pi^*| \tag{6}$$

Using the absolute past deviations of inflation from target implies that expectations respond symmetrically to positive and negative deviations from target. This way of modeling expectations is inspired by a traditional squared loss function such as Equation (3).[2] Taking Equations (5) and (6) together, expected inflation evolves according to:

$$E_t\pi_{t+1} = \pi^* + \alpha\left(\tilde{\pi}_{t-1} - \pi^*\right)\left|\tilde{\pi}_{t-1} - \pi^*\right| \quad (7)$$

Expectations are a weighted sum of the rational expectations component π^* and a "non-rational" term. In the following, we refer to this term $((\tilde{\pi}_{t-1} - \pi^*)|\tilde{\pi}_{t-1} - \pi^*|)$ as the central bank's "credibility loss." While certainly ad hoc, this process of expectations formation is meant as an illustrative description of how past deviations from the inflation target affect the current level of credibility and, as a consequence, expectations of future inflation.[3]

Figure 1 plots the credibility loss as a function of $\tilde{\pi}_{t-1}$ for an inflation target of 2 percent. Credibility deteriorates non-linearly if past inflation deviated from target. Credibility suffers only mildly when inflation lies in the proximity of the inflation target, but is more seriously damaged by larger inflation deviations.

To complete the process of expectations formation, we need to specify expectations of future output. Together with the formation of inflation expectations reflected in Equation (7), the monetary policy tradeoff under discretion, i.e., Equation (4), implies that expected output evolves according to:

$$E_t y_{t+1} = -\frac{\kappa}{\delta}\alpha\left(\tilde{\pi}_{t-1} - \pi^*\right)\left|\tilde{\pi}_{t-1} - \pi^*\right|. \quad (8)$$

Thus, while our model allows for deviations from rational expectations, expectations of inflation and output remain mutually consistent. Output expectations inherit dependence on the credibility loss from the process of inflation expectations.

To obtain the interest rate rule followed by the central bank, we insert both expectations into the IS curve and solve for the short-term interest rate, which is the central bank's policy instrument. The resulting interest rate rule is:

$$i_t = (\pi^* + r) + \frac{\sigma\kappa}{\delta}\left(\pi_t - \pi^*\right) + \alpha\left(1 - \frac{\sigma\kappa}{\delta}\right)\left[\left(\tilde{\pi}_{t-1} - \pi^*\right)\left|\tilde{\pi}_{t-1} - \pi^*\right|\right]. \quad (9)$$

Monetary policy adjusts interest rates as a response to current inflation deviations and credibility loss, i.e., average past inflation deviations. The latter determinant, which leads

[2] As an alternative, we experimented with the asymmetric specification $\lambda_t = 1 - \alpha\left(\tilde{\pi}_{t-1} - \pi^*\right)$, according to which credibility suffers from a positive inflation deviation but improves when inflation fell short of the target. Together with Equation (5) this would imply $E_t\pi_{t+1} = \pi^* + \alpha\left(\tilde{\pi}_{t-1} - \pi^*\right)^2$. Expectations would respond to squared inflation deviations from target. In this sense, asymmetry in the determination of credibility would be reflected in an implausible characterization of inflation expectations, i.e., the latter would increase when the target was undershot. According to a set of regressions, this specification is clearly rejected by the data. In the empirical part of the paper, however, we provide an extension of the model where the central bank reacts differently to positive and negative credibility losses.

[3] A preliminary test of Equation (7) for our sample countries confirms that one-year ahead Consensus Economics inflation expectations are positively affected by past credibility losses since the coefficients for α are positive and significant for a large variety of horizons q for $\tilde{\pi}_{t-1}$. An alternative would be to let the public solve a signal extraction problem to disentangle persistent and transitory shifts in the monetary policy rule or the inflation target, respectively. See Erceg and Levin (2003) for this approach. Alichi et al. (2009) use an endogenous credibility process similar to the one utilized here.

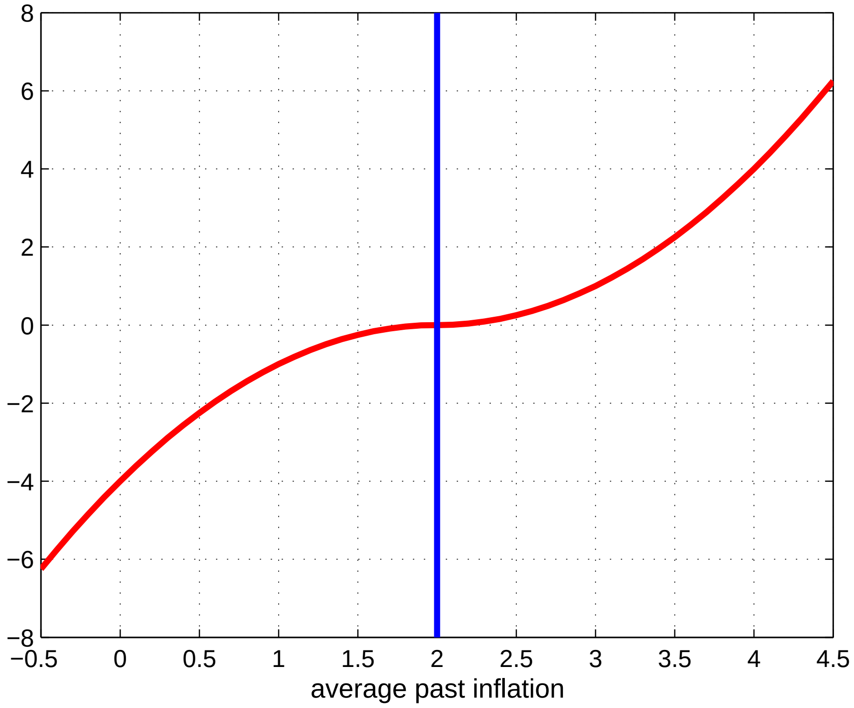

Figure 1: Credibility loss (y-axis) as a function of average past inflation (x-axis) for an inflation target of 2 percent

to a non-linear interest rate reaction, is absent in the conventional model. This instrument rule resembles the well-known backward-looking Taylor rule augmented by our credibility loss term. Note, however, that the equation is lacking the conventional interest rate response to the output gap, which is absorbed by the credibility loss term.

If $\delta > \sigma\kappa$, past inflation deviations feed positively into current interest rates. If average past inflation is, say, above target, the central bank sets a higher interest rate compared to a situation where average past inflation meets the target. Thus, in light of past deviations, the central bank tries to (re-)establish credibility by fighting inflation more aggressively. In addition, the response to past inflation deviations grows non-linearly in the absolute size of the deviation.[4] Furthermore, if the central bank attaches a larger weight to output fluctuations relative to inflation stabilization, i.e., if δ increases, the credibility loss term becomes more important. In this case inflation expectations are higher for a positive deviation from target and the real interest rate falls, which is expansionary for output.

The solution for inflation and output can be found by inserting the targeting rule and the expectations formation process back into the NKPC and using the method of undetermined

[4]For $\delta < \sigma\kappa$, the opposite is true and the conventional inflation argument in the interest rate rule becomes more important.

coefficients:

$$\pi_t = \pi^* + \alpha\beta \frac{\delta}{\delta+\kappa^2} \left(\tilde{\pi}_{t-1} - \pi^*\right) \left|\tilde{\pi}_{t-1} - \pi^*\right| + \frac{\delta}{\delta+\kappa^2} e_t \quad (10)$$

$$y_t = -\alpha\beta \frac{\kappa}{\delta+\kappa^2} \left(\tilde{\pi}_{t-1} - \pi^*\right) \left|\tilde{\pi}_{t-1} - \pi^*\right| - \frac{\kappa}{\delta+\kappa^2} e_t \quad (11)$$

For $\alpha = 0$, the solution collapses to the standard outcome under discretionary monetary policy, i.e., the solution for inflation and output are driven by the i.i.d. supply shock only. The higher the central bank's credibility, the less persistent inflation becomes. Put differently, the presence of imperfect credibility introduces persistence into the economy.

3 Empirical specifications

In this section, we use the interest rate rule derived from our simple model as a starting point before presenting "state-of-the-art" forward-looking Taylor rules augmented by the credibility loss term. Finally, we also consider (i) asymmetric reactions to positive and negative credibility losses, as well as (ii) differing reactions to credibility losses during the tenures of different central bank heads.

3.1 Theoretically-derived reaction function

First, we estimate the theoretically-derived model to establish the influence of credibility on interest rate setting:

$$i_t = \beta_0 r_t + \beta_1 \left(\pi_t - \pi^*\right) + \beta_2 \left[\left(\tilde{\pi}_{t-1} - \pi^*\right) \left|\tilde{\pi}_{t-1} - \pi^*\right|\right] + \epsilon_t. \quad \text{(M1)}$$

The central bank adjusts the interest rate in response to contemporaneous inflation deviations and the credibility loss term. The coefficient for the latter indicates whether past deviations from the inflation target are feeding back into today's interest rate setting. As mentioned before, the theory-consistent interest rate rule does not contain a response to output. As explained below in Section 4.2, we allow for time variation in the real interest rate.

3.2 Forward-looking reaction function with interest rate smoothing

These days, central banks usually adjust their target rates gradually in response to changes in inflation and output.[5] Such interest rate smoothing behavior itself could be a source of off-target inflation periods as a central bank adjusts toward the new target rate in small steps only, and thereby accepts missing the target for at least a certain period. Furthermore, central banks should act in a forward-looking manner to *expected* macroeconomic variables. To disentangle interest rate smoothing and losses in credibility, we add our

[5] See Coibion and Gorodnichenko (2012) for recent evidence on interest rate smoothing.

credibility loss term to a forward-looking Taylor rule (Clarida et al. 1998):

$$\begin{aligned} i_t = &\rho i_{t-1} + (1-\rho)\{\beta_0 r_t + \beta_1(E_t\pi_{t+12} - \pi^*) + \beta_2 E_t y_{t+12} \\ &+ \beta_3[(\tilde{\pi}_{t-1} - \pi^*)|\tilde{\pi}_{t-1} - \pi^*|]\} + \epsilon_t. \end{aligned} \tag{M2}$$

This specification incorporates a partial adjustment of the central bank interest rate to the *expected* 12-month ahead inflation gap and the *expected* 12-month ahead gross domestic product (GDP) growth, as well as to the credibility loss, with $0 \leq \rho < 1$ denoting the degree of interest rate smoothing.[6] A positive and significant coefficient for β_3 would indicate that credibility losses have an influence on interest rate setting that goes beyond a feedback effect into *one-year* ahead inflation expectations.

We replace current realizations of macroeconomic variables with expected future variables. With this specification, we deliberately depart from our theoretical model in which the central bank responds only to current inflation and a backward-looking term reflecting credibility. We do so to account for the fact that most central banks' policy decisions are of a forward-looking nature, which, however, cannot easily be incorporated in our theoretical model. Since the model presented in Section 2 is intended to be illustrative only, we consider this an acceptable modification toward empirical realism.

3.3 Asymmetry and different regimes

In the following, we present two modifications of M2. First, we explore the robustness of our findings with respect to a possible asymmetric adjustment to positive and negative credibility losses. Our illustrative model treats positive and negative past deviations from the inflation target equally, but it might be the case that empirically we observe an asymmetric adjustment of the central bank interest rate to positive and negative credibility losses. Therefore, we estimate the following model:

$$\begin{aligned} i_t = &\rho i_{t-1} + (1-\rho)\{\beta_0 r_t + \beta_1(E_t\pi_{t+12} - \pi^*) + \beta_2 E_t y_{t+12} \\ &+ d_t^{pos}\beta_3^{pos}[(\tilde{\pi}_{t-1} - \pi^*)|\tilde{\pi}_{t-1} - \pi^*|] + d_t^{neg}\beta_3^{neg}[(\tilde{\pi}_{t-1} - \pi^*)|\tilde{\pi}_{t-1} - \pi^*|]\} + \epsilon_t. \end{aligned} \tag{M3}$$

d_t^{pos} is a dummy variable that takes the value 1 if the credibility loss term is positive and 0 otherwise, whereas d_t^{neg} takes the value 1 if the credibility loss term is negative and 0 otherwise. Thus, the coefficient β_3^{pos} indicates the weight of positive credibility losses in the central bank's reaction function, whereas β_3^{neg} measures the influence of negative credibility losses.[7] All other variables are defined as in model M2.

Second, we allow for differing reactions to the credibility loss term across the tenures of

[6]We choose not to add an exchange rate variable. Research on estimated as well as optimal Taylor rules (see, e.g., Clarida 2001; Collins and Siklos 2004) suggests that adding this variable does not substantively change inferences based on the standard Taylor rule specification.

[7]Note that we have only two observations for Sweden, where we actually find positive credibility losses (see also Table A.1 in the Appendix). Therefore, results for positive credibility losses must be interpreted very cautiously in the case of Sweden. In all other countries, however, we have at least 30 observations per category.

different central bank governors. Focusing on the central bank's head is straightforward in Canada and New Zealand since the governors of these central banks are solely responsible for monetary policy. In the case of the three other central banks, a monetary policy committee decides on the appropriate monetary policy. However, empirically, the central bank's head is found to have a huge influence on committee decisions. Although it is doubtful that the governor always has complete discretion in setting the interest rate, he is almost never outvoted in monetary policy decisions (Claussen et al. 2012). This implies that the governor should have at least some agenda-setting power when it comes to a vote in the monetary policy committee. As a consequence, we focus on the central bank's head in all five countries to identify changes in the monetary policy "regime" and estimate the following model:[8]

$$\begin{aligned} i_t =& \rho i_{t-1} + (1-\rho)\{\beta_0 r_t + \beta_1(E_t\pi_{t+12} - \pi^*) + \beta_2 E_t y_{t+12} \\ &+ d_t^k \beta_3^k [(\tilde{\pi}_{t-1} - \pi^*)|\tilde{\pi}_{t-1} - \pi^*|]\} + \epsilon_t. \end{aligned} \tag{M4}$$

d_t^k indicates a set of $k = 2$ dummy variables ($k = 3$ in the case of Canada and Sweden) which take the value 1 when the respective regime $k = 1, 2$ ($k = 1, 2, 3$) is in place and 0 otherwise. Thus, the coefficient β_3^k indicates the weight of credibility losses in the reaction function during the k^{th} regime.[9] All other variables are defined as in model M2.

4 Data and estimation strategy

4.1 Credibility loss indicator

Our sample includes five IT economies: Australia (AUS), Canada (CAN), New Zealand (NZ), Sweden (SWE), and the United Kingdom (UK).[10] The sample period starts with the introduction of inflation targets in AUS (April 1993), SWE (January 1993), and the UK (October 1992). The Bank of Canada and the Reserve Bank of New Zealand formally introduced inflation targeting in February 1991 and January 1990, respectively. However, these two central banks implemented their current inflation target after a disinflationary period. Consequently, we start in January 1995 (CAN) and January 1993 (NZ), respectively, times at which both central banks had adopted their current level of target inflation (2 percent).[11] Our sample period ends in December 2008 as some of the central banks examined in this paper have engaged in unconventional monetary policy since then. Table

[8] Note that considering all changes in the composition of monetary policy committees would lead to too many regimes for a sensible identification of regime effects on the credibility loss coefficient.

[9] Note that we have only 13 and 11 observations for Gordon Thiessen's and Mark Carney's tenures as Governor of the Bank of Canada (see also Table A.1 in the Appendix). Therefore, results for these two governors should be interpreted very cautiously. In all other cases, however, we have at least 30 observations per governor.

[10] Note that the IT episodes in other economies (e.g., Norway and some emerging market economies) are too short for this type of analysis as it requires a 60-month initialization period before the actual estimation period.

[11] Note that the Bank of England also changed its inflation target. Before January 2004, the midpoint of its inflation band was 2.5 percent defined in terms of the retail price index.

1 provides a summary of the sample countries and their inflation target characteristics.

Table 1: Sample countries and inflation targets

Country	**IT since**	**Disinflation**	**Target**	**Sample start**
Australia (AUS)	1993/04		2.5%	1993/04
Canada (CAN)	1991/02	until 1994/12	2%	1995/01
New Zealand (NZ)	1990/01	until 1992/12	2%	1993/01
Sweden (SWE)	1993/01		2%	1993/01
United Kingdom (UK)	1992/10		2%	1992/10

Source: Roger (2009) and central bank websites.

We compute the term $[(\tilde{\pi}_{t-1} - \pi^*) \, |\tilde{\pi}_{t-1} - \pi^*|]$ as an indicator of credibility losses in the central bank's reaction function. In case of inflation range targeting, we use the midpoint of the target range as the inflation target π^*.[12] One interesting feature of this indicator is its non-linear structure (see also Figure 1). Small deviations from the target become negligible, whereas larger deviations (particularly those larger than 1 percentage point) result in a higher "penalty" in the central bank's reaction function. This can be interpreted as an accelerating effect, insofar as the credibility loss term plays a noticeable role only when it takes larger values.

As this indicator relies on an average of past inflation rates, we need to choose (i) an appropriate inflation measure and (ii) the appropriate lag length. For the inflation measure, we choose the growth rates of the seasonally adjusted consumer price index over the previous year's period.[13] The second decision involves an assumption about how long the memory of households and agents is when it comes to deviations from the central bank's inflation target. As mentioned above, interest rate smoothing is one reason for the off-target inflation periods observed in many IT economies. However, this temporary effect due to interest rate smoothing should vanish when considering a full tightening and easing cycle, i.e., positive and negative deviations from target should average out. By using a credibility loss indicator with a memory of 60 months, we should be able to disentangle actual credibility losses from temporary "credibility losses" resulting from the central bank's interest rate smoothing behavior.[14]

[12] Some of the central banks are required to keep inflation within a band, rather than meeting a single inflation target value. However, the focus on the midpoint of inflation bands should not be a concern as our indicator (i) is constructed over a longer horizon and, therefore, not prone to temporary fluctuations and (ii) nets out positive and negative deviations from the midpoint. Moreover, even in countries with an inflation band, inflation should be close to the target midpoint in the medium run.

[13] As an alternative, we could employ month-over-month growth rates of this variable. However, a reaction to such a variable would not represent the central bank behavior very well since central banks usually do not react to every temporary inflation shock, which potentially disappears after one month. In contrast, the year-over-year measure provides a more robust characterization of actual changes in the level of inflation and is therefore more suitable in our analysis.

[14] As part of our robustness tests, we varied the lag length of the credibility loss indicator and estimated model M2 for all horizons from 1 to 60 months. See also the end of Section 5.2 and Figure A.1 in the Appendix.

Figures 2-6 provide some insight into how the credibility loss indicator is generated. The left panels plot the actual inflation rate and the target value of inflation. The middle panels show the inflation gap, i.e., actual inflation minus the IT and the resulting 60-month credibility loss indicator. The right panels display the latter indicator (left scale) and the central bank interest rate (right scale).

First, Figures 2-6 nicely show how positive and negative deviations of the inflation rate from its target average out over time, i.e., only prolonged periods of overshooting or undershooting the target result in actual credibility losses. Second, in Sweden, we mostly observe that the inflation target is undershot, i.e., the credibility loss indicator is mostly negative, which is, among other things, the motivation for Svensson's (2012) paper cited in the introduction. Third, we observe a positive bivariate correlation between the central bank interest rate and the credibility losses in all countries, with the exception of Canada. For instance, the correlation coefficient is 0.68 in the United Kingdom and 0.52 in New Zealand.

4.2 Other data

Data are collected at a monthly frequency from the OECD (inflation and long-term interest rates) and IMF (central bank interest rates) statistical databases as well as from Consensus Economics (inflation and GDP growth forecasts). We employ the central bank interest rates as the left-hand side variable. The growth rate of the seasonally adjusted consumer price index over the previous year's period serves as the explanatory variable in model M1, whereas in models M2-M4 we use the 12-month ahead expected inflation rate and the corresponding expected GDP growth rate.[15] The choice of the latter is motivated by the fact that most central banks focus on expected GDP growth rather than on the expected GDP gap in their communications (Gerlach 2007), probably due to the difficulty of measuring the latter in real time. Accordingly, we follow the literature (see, e.g., Gorter et al. 2008; Sturm and de Haan 2011) and use expected GDP growth rather than the expected GDP gap.[16] Finally, in light of Clarida's (2012) persuasive evidence, we model the real interest rate as a time-varying variable based on 10-year real government bond returns.[17]

[15] Note that both variables are directly available as growth rates to the previous year's period from Consensus Economics.

[16] A widely followed practice in the literature is to employ the Hodrick-Prescott (1997) filter to create a GDP gap measure. However, this assumes perfect knowledge of all future expected GDP growth observations since it estimates trend GDP growth based on a two-sided filter.

[17] We subtract the current inflation rate from the long-term interest rate to generate a proxy for the real interest rate. We focus on the 10-year government bond since it is available for all countries in the OECD database. Alternatively, one could use government bonds with other maturities. However, bonds with a longer maturity are not available for all sample countries and bonds with a shorter maturity are more sensitive to the central bank interest rate and thus not a good proxy for the steady-state real interest rate.

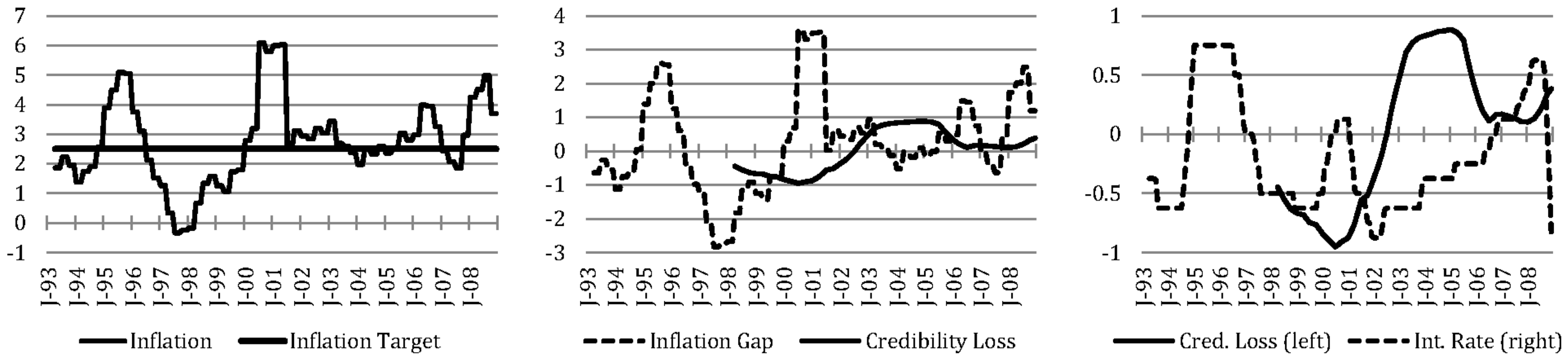

Figure 2: Actual inflation, inflation target, inflation gap, credibility loss, and interest rate for Australia

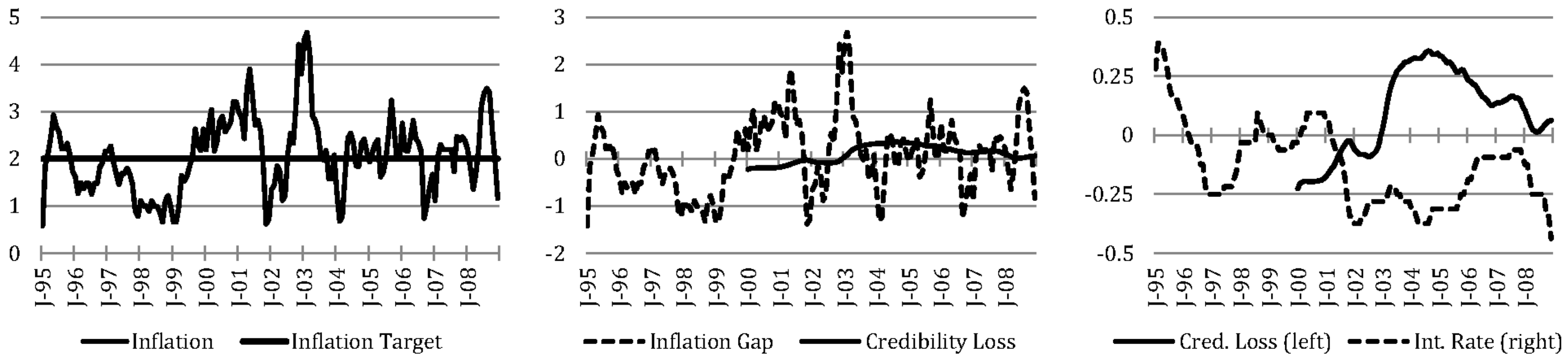

Figure 3: Actual inflation, inflation target, inflation gap, credibility loss, and interest rate for Canada

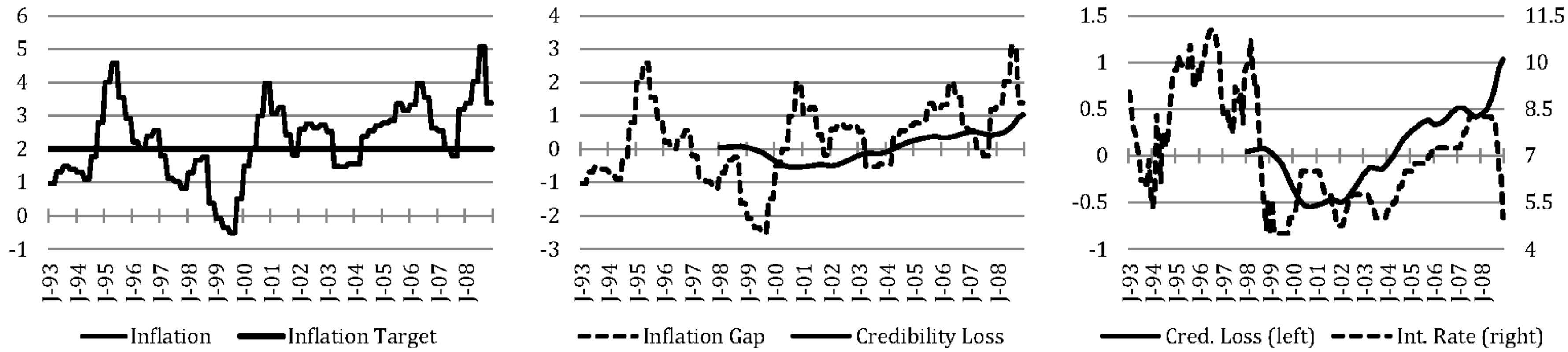

Figure 4: Actual inflation, inflation target, inflation gap, credibility loss, and interest rate for New Zealand

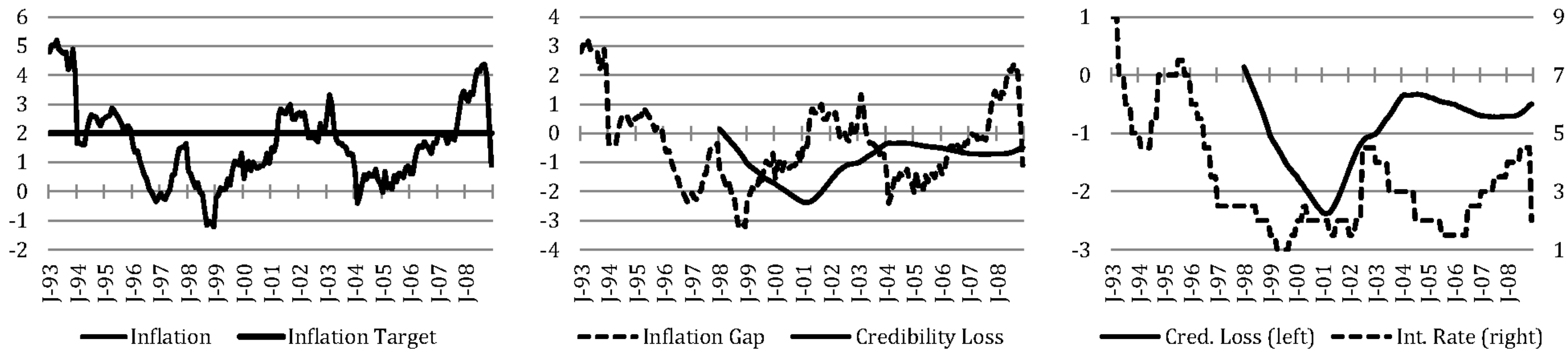

Figure 5: Actual inflation, inflation target, inflation gap, credibility loss, and interest rate for Sweden

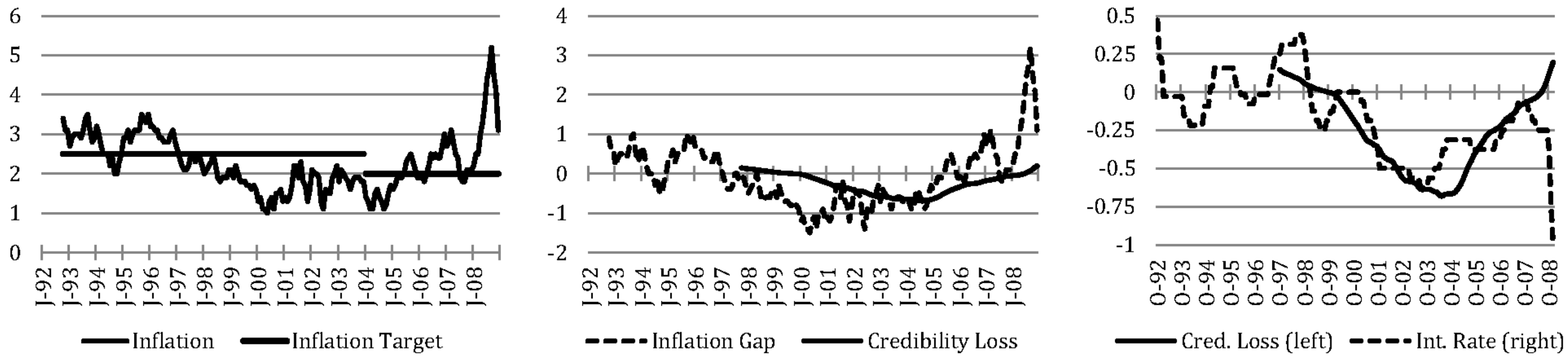

Figure 6: Actual inflation, inflation target, inflation gap, credibility loss, and interest rate for the United Kingdom

4.3 Estimation strategy

Table A.2 in the Appendix shows unit root tests for all variables employed in models M1-M4. Augmented Dickey-Fuller (1979) tests reject the null hypothesis of a unit root in all but two cases (central bank interest rate in Canada and real interest rate in New Zealand). Since the overwhelming majority of series is I(0), we estimate models M1-M4 in levels.

To overcome potential endogeneity biases and deal with potential non-spherical errors, we use GMM as estimation method.[18] An important consideration is the selection of valid instruments.[19] Hayo and Hofmann (2006) point out that it is easy to find instruments that fulfill the orthogonality conditions between regressors and error term in the context of Taylor rules. However, the use of weak instruments, i.e., instruments that do not contribute much to explaining the instrumented variable, can lead to substantial biases in estimators and test statistics (see, e.g., Hahn and Hausman 2003; Stock et al. 2002).

Following Hayo and Hofmann (2006), we address the instrument selection problem by applying an automatic model selection algorithm called Autometrics (Doornik 2009). Autometrics starts from a general model and removes redundant instruments. In the course of doing so, it searches all possible paths of the testing-down process and reports the most parsimonious model that does not violate a reduction test. Thus, the strongest instruments will be selected from a given choice of variables and their lags. This does not remove all arbitrariness as the researcher still needs to choose the potential instrumental variables and their maximum lag length. Nevertheless, it appears to be superior to the ad hoc methods typically employed in empirical research.

We consider a general set of potential instruments for every country and the variables (i) inflation gap in model M1 and (ii) the expected inflation gap and (iii) expected GDP growth in models M2-M4. This set contains six lags of the central bank interest rate and the inflation gap (the actual inflation rate as defined above minus the IT) as well as growth rates to the previous year's period of the following variables: seasonally adjusted industrial production, a broad monetary aggregate, the real effective exchange rate, and the world oil price.[20] The final set of instruments is found in Table A.3 in the Appendix. The respective last rows provide a test of weak instruments as proposed by Stock and Yogo (2003) and rule out the case of weak instruments. Our instrument selection procedure and the final instrument sets are further confirmed by the J-statistics, which are insignificant across all specifications and countries (see Tables 2-3 as well as Tables A.4-A.8 in the Appendix).

[18] GMM estimations do not require specific assumptions about the distribution or the variance-covariance matrix of the error term.

[19] Another important choice when it comes to GMM estimations is the weighting matrix. Following past practice, we use a heteroskedasticity and auto-correlation consistent weighting matrix as proposed by Newey and West (1987).

[20] Sources: Central bank interest rate: IMF. Inflation gap, industrial production, and broad monetary aggregate: OECD. Real effective exchange rate: World Bank. Oil price: Federal Reserve Bank of St. Louis database.

Finally, estimation of the models obviously requires a 60-month initialization period. Consequently, all estimations actually commence five years after the month in which the current IT was officially adopted (see Table 1).

5 Results

5.1 Theoretically-derived reaction function

In this section, we show the empirical results for the theoretically-derived reaction function employing the contemporaneous inflation gap and the credibility loss indicator. Table 2 sets out the results for specification M1. Based on our theoretical considerations in Section 2, we expect significant and positive reactions to the inflation gap and the credibility indicator.

Table 2: Theoretically-derived reaction function (M1)

	AUS		**CAN**		**NZ**		**SWE**		**UK**	
$\hat{\beta}_0$ (Real Int. Rate)	1.682	***	1.210	***	1.481	***	1.829	***	1.769	***
$\hat{\beta}_1$ (Infl. Gap)	1.931	***	1.879	***	1.868	***	2.590	***	1.872	***
$\hat{\beta}_2$ (Cred. Loss)	0.589	***	0.221		2.298	***	1.425	***	0.729	*
Observations	129		108		132		132		135	
R-Squared	0.297		0.245		0.496		0.422		0.647	
S.E. of Regression	0.789		1.230		0.962		1.270		0.764	
J-Statistic	9.49		14.89		11.83		3.65		14.01	

Notes: Estimation of model M1. The dependent variable is the central bank interest rate. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

The so-called Taylor principle is met for all five countries as a 1 percentage point increase in the inflation gap is associated with a raise of the nominal interest rate by more than 1 percentage point. More interestingly, the credibility loss indicator is (highly) significant in all countries except Canada. This implies that central banks adjust their target rate in a non-linear fashion. Positive deviations from the inflation target over the past five years require a target rate raise in addition to the reaction to current inflation.

The theoretically-derived reaction function does very well at explaining the evolution of central bank target rates. For instance, the R^2 ranges from 24.5 percent in Canada up to 64.7 percent in the United Kingdom.

5.2 Forward-looking reaction function with interest rate smoothing

Generally, central banks adjust their target rates gradually in response to changes in macroeconomic conditions and also react to changes in output. Furthermore, it is expected macroeconomic variables that—given the outside lag of monetary policy—the central bank should consider in its reaction function. To accommodate these empirical findings, we estimate a standard forward-looking Taylor rule with interest rate smoothing and add the credibility loss term. Again, we emphasize that this modification is clearly a departure from the theoretically-derived reaction function presented in Section 2. However, in our view, it is an acceptable modification toward empirical realism.

Table 3 provides the results for specification M2. The upper part of the table presents the short-run coefficients, i.e., adjustment of the central bank interest rate to the real interest rate $(1-\rho)\beta_1$, the expected inflation gap $(1-\rho)\beta_1$, expected GDP growth $(1-\rho)\beta_2$, and the credibility loss indicator $(1-\rho)\beta_3$, respectively, which (on average) takes place in every month. The long-run coefficients are the estimated values for β_0, β_1, β_2, and β_3 as denoted in model M2 and provide useful information about steady-state adjustment to the explanatory variables.

Table 3: Forward-looking specification with interest rate smoothing (M2)

	AUS		**CAN**		**NZ**		**SWE**		**UK**	
$\hat{\rho}$ (IR Smoothing)	0.953	***	0.949	***	0.899	***	0.865	***	0.889	***
$(1-\hat{\rho})\hat{\beta_0}$ (Real Int. Rate)	0.042	***	0.036	**	-0.007		0.070	***	0.078	***
$(1-\hat{\rho})\hat{\beta_1}$ (Exp. Infl. Gap)	0.085	***	0.096		0.209	***	0.333	***	0.235	***
$(1-\hat{\rho})\hat{\beta_2}$ (Exp. GDP)	0.037	**	0.288	***	0.220	***	0.125	***	0.152	***
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.031	**	0.285	***	0.243	***	0.117	***	0.308	***
Long-Run Coefficients										
$\hat{\beta_0}$ (Real Int. Rate)	0.889	***	0.719	**	-0.071		0.515	***	0.709	***
$\hat{\beta_1}$ (Exp. Infl. Gap)	1.806	***	1.894		2.062	***	2.469	***	2.121	***
$\hat{\beta_2}$ (Exp. GDP)	0.782	**	5.693	***	2.174	***	0.927	***	1.371	***
$\hat{\beta_3}$ (Cred. Loss)	0.659	**	5.639	***	2.397	***	0.870	***	2.783	***
Observations	129		108		132		132		135	
R-Squared	0.954		0.977		0.939		0.891		0.978	
S.E. of Regression	0.165		0.176		0.337		0.333		0.162	
J-Statistic	10.88		9.31		11.30		15.06		16.68	

Notes: Estimation of model M2. The dependent variable is the central bank interest rate. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

The results indicate a high degree of interest rate smoothing, which implies that central banks adjust only very gradually to changes in expected macroeconomic conditions. This behavior is typical in central banking since the precise effects of monetary policy are uncertain. By adjusting interest rates gradually, the central bank can obtain new information, allowing it to evaluate the previous step and make a decision as to whether (or not) to continue with the current interest rate cycle (Brainard 1967). This interest rate smoothing behavior is especially prevalent in Australia and Canada, where only 4.7 and 5.1 percent, respectively, of interest rate changes are attributed to changes in the other explanatory variables. In contrast, the inertia parameter for Sweden is lower (0.865), which can be explained by the lower frequency of policy meetings per year (six) compared to the other countries (AUS: eleven, CAN: eight, NZ: eight, the UK: twelve).

The credibility loss term is significant and positive in all five countries. Hence, this term conveys information beyond that provided by expected inflation gap and expected GDP growth. The coefficients for expected GDP growth are significant in all five cases as well, indicating that the sample central banks also put some effort into stabilizing output. However, the coefficients for the expected inflation gap are significant only in four countries (AUS, NZ, SWE, and UK). Since past credibility losses obviously affect future expectations of the inflation gap (and GDP growth), the absence of a significant reaction to the expected inflation gap in Canada might be due to collinearity between these two variables. Considering the coefficients' size, past credibility losses (and expected GDP growth) are seemingly more important drivers of contemporaneous monetary policy than is the expected inflation gap. Finally, the theoretical finding that a relatively large weight on output stabilization is associated with a more important credibility loss term is nicely observed in the case of Canada where both coefficients are much larger than they are for the other countries.

In general, deviations from the inflation target in the past feed back into today's interest rate setting even when allowing for interest rate smoothing and estimating a forward-looking Taylor rule that also includes expected GDP growth. Put differently, our credibility loss indicator is meaningful even in a state-of-the-art Taylor rule. This implies that deterioration in credibility forces central bankers to undertake larger interest rate steps (ceteris paribus). The influence of past credibility losses on today's reaction function is meaningful. In terms of size, we find an economically relevant impact. The long-run coefficients indicate a reaction from 66 basis points (bps) in Australia to 564 bps in Canada.[21]

Figure A.1 in the Appendix shows the short-run coefficients for the credibility loss term (and the corresponding 90 percent error bands) with different horizons ranging from 1 to 60 months as a robustness test.[22] The figure clearly supports the choice of a longer horizon as, for instance, in Canada, the coefficient is only significant and positive for horizons of 44 months or longer. The findings of negative coefficients for short horizons are also in line with the idea of interest rate smoothing being one source of off-target inflation periods. The central bank adjusts toward the new target rate in small steps only, thereby accepting missing the target for a certain period. This leads to negative coefficients for the credibility loss terms with a relatively short time horizon. Over a full tightening and easing cycle, however, the central bank makes sure that the credibility losses do not become permanent and reacts significantly positively to past deviations from the target.

[21] The coefficients for the credibility loss term found for model M2 are different from those for model M1 in Table 2 (particularly for Canada and the United Kingdom) since we incorporate expected macroeconomic conditions rather than focusing on contemporaneous inflation as well as interest rate smoothing. However, the long-run coefficients for Australia and New Zealand are statistically equal to the coefficients in Table 2.

[22] We did not choose longer horizons for the credibility loss since a longer horizon automatically implies a loss of observations in the empirical estimations.

5.3 Asymmetry and different regimes

In this section, we present results for specifications M3 and M4. In M3, we consider a possible asymmetric adjustment to positive and negative credibility losses, whereas M4 allows for varying reactions to the credibility loss term across the tenures of different central bank governors. To provide a better comparison with previous results, Table 4 includes the coefficients for the forward-looking specification with interest rate smoothing (M2), which serves as basis for the M3 and M4 modifications. To conserve space, we report only the short-run coefficients.[23] Furthermore, we present only the coefficient for the different credibility loss variables. The complete results can be found in the Appendix (Tables A.4-A.8).

First, the results for M3 clearly show that the overall reaction to the credibility loss term in Table 3 (model M2) is not due to a symmetric reaction to positive and negative credibility losses. It is either positive credibility losses (CAN) or negative credibility losses (AUS, NZ, SWE, UK)[24] that are driving the coefficients for the overall loss term. This implies that undershooting the target has a larger influence on the central bank interest rate than does overshooting. The negative credibility losses can also be interpreted as "gains" in credibility since the central bank has kept inflation below target for a prolonged period. As a result of this situation, the central bank is allowed to (ceteris paribus) keep its interest rate at a level that is lower than the expected macroeconomic conditions would permit.

Second, all significant coefficients for the different regimes indicate a theory-consistent positive reaction to past credibility losses (results for M4). However, there are some differences across countries. The coefficients for different regimes in NZ, SWE, and the UK are relatively homogeneous and statistically identical; however, AUS and CAN reveal a different pattern. During Glenn Stevens's and Mark Carney's tenures as governors of their respective central banks, the reaction to past credibility losses is negative but not significant.[25] Consequently, the overall coefficients in AUS and CAN are driven by the tenures of Ian Macfarlane and David Dodge.

[23] The long-run coefficient can be easily obtained by dividing the respective coefficient by $(1 - \hat{\rho})$.

[24] As indicated in footnote 7 and Table A.1 in the Appendix, the coefficient for negative credibility losses in Sweden is based only on two observations. Thus, the "wrong" negative sign is not relevant for our conclusions.

[25] Note that both governors were mostly dealing with credibility losses inherited from their predecessors since both took office at the end of the sample period (Stevens: September 2006, Carney: February 2008). It would be interesting to differentiate between inherited credibility losses and those self-induced. However, the average tenure of a governor is too short to precisely disentangle between the two using a 60-month indicator.

Table 4: Further results for an asymmetric adjustment and for different "regimes" (M2-M4)

Australia	**M2**		**M3**		**M4**	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.031	**	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-0.014		—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.087	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (MacFarlane))	—		—		0.037	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Stevens))	—		—		-0.405	

Canada	**M2**		**M3**		**M4**	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.285	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		0.477	***	—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		-0.054		—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Thiessen))	—		—		0.157	
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Dodge))	—		—		0.353	***
$(1-\hat{\rho})\hat{\beta_3^3}$ (Cred. Loss (Carney))	—		—		-1.840	

New Zealand	**M2**		**M3**		**M4**	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.243	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-0.588		—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.453	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Brash))	—		—		0.195	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Bollard))	—		—		0.444	**

Sweden	**M2**		**M3**		**M4**	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.117	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-3.600	***	—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.142	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Backstrom))	—		—		0.152	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Heikensten))	—		—		0.060	
$(1-\hat{\rho})\hat{\beta_3^3}$ (Cred. Loss (Ingves))	—		—		0.157	

United Kingdom	**M2**		**M3**		**M4**	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.308	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		0.031		—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.330	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (George))	—		—		0.329	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (King))	—		—		0.276	***

Notes: Estimation of models M2-M4. The dependent variable is the central bank interest rate. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3. Full results are set out in Tables A.4-A.8 in the Appendix.

6 Concluding remarks

In this paper, we systematically evaluate how central banks respond to deviations from the inflation target. We present a stylized New Keynesian model in which agents' inflation expectations are sensitive to deviations from the target. To (re-)establish credibility, monetary policy under discretion is shown to set higher interest rates today when average inflation exceeded the target in the past. Moreover, monetary policy responds non-linearly to past inflation gaps. This is reflected in an additional term in the central bank's optimal instrument rule, which we refer to as "credibility loss."

Augmenting a standard forward-looking Taylor (1993) rule including interest rate smoothing with the latter term, we provide empirical evidence for the interest rate response for a sample of five IT economies. We find, first, that past deviations from the inflation target feed back into the reaction function and that this influence is economically meaningful. Deterioration in credibility, ceteris paribus, forces central bankers to undertake larger interest rate steps. Second, we detect an asymmetric reaction to positive and negative credibility losses across the five sample countries. It is mostly negative credibility losses (AUS, NZ, SWE, UK) that drive the reaction to the overall loss term. Such negative credibility losses can also be interpreted as "gains" in credibility since the central bank has kept inflation below target for a prolonged period. As a result of this achievement, the central bank is allowed to (ceteris paribus) keep its interest rate at a level that is lower than the expected macroeconomic conditions would allow. Finally, reaction to past credibility losses is relatively homogeneous across the tenures of different central bank governors in NZ, SWE, and the UK. In AUS and CAN, however, the overall reaction to past credibility losses is mostly driven by the tenures of Ian Macfarlane and David Dodge.

Our results have important policy implications. Blinder (2000) emphasizes that to maintain central bank credibility, it is important that agents actually believe in the inflation target. Thus, announcement of a specific numerical inflation target must be followed by actually meeting the target to maintain the bank's credibility. If a central bank fails to meet its target for a prolonged period of time, it will lose credibility and need to take steps to regain it. In case of inflation being above target, the central bank has to react not only to the current inflation gap; an additional increase in the target rate is required to restore credibility. In contrast, negative credibility losses—which can also be interpreted as credibility gains—allow the central bank to keep its interest rate at a level lower than the expected macroeconomic conditions would permit.

Loss of credibility is of particular relevance in the context of current discussions about exit strategies from historically low, crisis-induced monetary policy rates. In particular, the Bank of England could face problems with its interest rate setting in the near future as inflation rates have been above the target for quite some time (4 percent and more during 2011), even during a period of low GDP growth rates, i.e., the ongoing economic and financial crisis. These figures imply that the Bank of England has to raise interest rates by more than the expected inflation gap to reestablish the credibility of its inflation target. If inflation remains above target, keeping monetary policy at historically low rates for some additional time could worsen the central bank's credibility problem. At the same time, however, the public might understand that the prolonged period of off-target inflation in the United Kingdom reflects systematic policy responses to a particularly bad global situation. As a consequence, the public would not punish the Bank of England with a loss of credibility. This would amount to a regime shift in the determination of credibility and could be analyzed once sufficient observations for the current state are available. Finally, there is some good news for central banks that have undershot their IT over the last 60 months: they will be allowed (ceteris paribus) to postpone or slow down the necessary tightening of interest rates for some time due to their "gains" in credibility in the past.

We show that sustained off-target inflation episodes are associated with deterioration in credibility as measured by our indicator and, therefore, are feeding back into the central bank's reaction function. However, our sample countries are mature economies and do not face severe deflation or inflation problems. Central banks in emerging market IT countries arguably have lower credibility in the first place. Investigating these countries and thereby explicitly addressing their disinflation periods could be an interesting task for future research.

References

[1] Alichi, A., H. Chen, K. Clinton, C. Freedman, M. Johnson, O. Kamenik, T. Kisinbay, and D. Laxton (2009): "Inflation targeting under imperfect credibility," *IMF Working Paper* No. 09/94.

[2] Blinder, A. (2000): "Central bank credibility: Why do we care? How do we build it?" *American Economic Review* 90, 1421-1431.

[3] Bomfim, A. N. and G. D. Rudebusch (2000): "Opportunistic and deliberate disinflation under imperfect credibility," *Journal of Money, Credit and Banking* 32, 707-721.

[4] Brainard, W. (1967): "Uncertainty and the effectiveness of policy," *American Economic Review* 57, 411-425.

[5] Chevapatrakul, T., T.-H. Kim, and P. Mizen (2009): "The Taylor principle and monetary policy approaching a zero lower bound on nominal rates: Quantile regression results for the United States and Japan," *Journal of Money, Credit and Banking* 41, 1705-1723.

[6] Clarida, R. (2001): "The empirics of monetary policy rules in open economies," *International Journal of Finance and Economics* 6, 215-223.

[7] Clarida, R. (2012): "What has—and has not—been learned about monetary policy in a low-inflation environment? A review of the 2000s," *Journal of Money, Credit and Banking* 44 (Supplement), 123-140

[8] Clarida, R., J. Gali, and M. Gertler (1998): "Monetary policy rules in practice: Some international evidence," *European Economic Review* 42, 1033-1067.

[9] Claussen, C. A., E. Matsen, O. Roisland, and R. Torvik (2012): "Overconfidence, monetary policy committees and chairman dominance," *Journal of Economic Behavior and Organization* 81, 699-711.

[10] Coibion, O. and Y. Gorodnichenko (2012): "Why are target interest rate changes so persistent?" *American Economic Journal: Macroeconomics* 4, 126-162.

[11] Collins, S. and P. Siklos (2004): "Optimal monetary policies and inflation targets: Are Australia, Canada and New Zealand different from the US?" *Open Economies Review* 15, 347-362.

[12] Corder, M. and D. Eckloff (2011): "International evidence on inflation expectations during sustained off-target (SOTI) episodes," *Bank of England Quarterly Bulletin* 2011 Q2.

[13] Cukierman, A. and A. Muscatelli (2008): "Nonlinear Taylor rules and asymmetric preferences in central banking: Evidence from the United Kingdom and the United States," *B.E. Journal of Macroeconomics (Contributions)* 8, Article 7.

[14] Davis, J. S. (2012): "Central bank credibility and the persistence of inflation and inflation expectations," *Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute Working Paper* No. 117.

[15] Dickey, D. A. and W. A. Fuller (1979): "Distribution of the estimators for autoregressive time series with a unit root," *Journal of the American Statistical Association* 74, 427-431.

[16] Dolado, J., R. Maria-Dolores, and M. Naveira (2005): "Are monetary policy reactions functions asymmetric? The role of non-linearity in the Phillips curve," *European Economic Review* 49, 485-503.

[17] Dolado, J., R. M.-D. Pedrero, and F. J. Ruge-Murcia (2004): "Non-linear monetary policy rules: Some new evidence for the U.S.," *Studies in Nonlinear Dynamics and Econometrics* 8, Issue 3, Article 2.

[18] Doornik, J. A. (2009): "Autometrics," in: J. L. Castle and N. Shephard: "*The methodology and practice of econometrics*," Oxford University Press.

[19] Erceg, C. J. and A. T. Levin (2003): "Imperfect credibility and inflation persistence," *Journal of Monetary Economics* 50, 915-944.

[20] Gerlach, S. (2007): "Interest rate setting by the ECB, 1999-2006: Words and deeds," *International Journal of Central Banking* 3, 1-45.

[21] Gorter, J., J. Jacobs, and J. de Haan (2008): "Taylor rules for the ECB using expectations data," *Scandinavian Journal of Economics* 110, 473-488.

[22] Hahn, J. and J. Hausman (2003): "Weak instruments: Diagnosis and cures in empirical econometrics," *American Economic Review* 93, 118-125.

[23] Hayo, B. and B. Hofmann (2006): "Comparing monetary policy reaction functions: ECB versus Bundesbank," *Empirical Economics* 31, 645-662.

[24] Hodrick, R. and E. Prescott (1997): "Postwar U.S. business cycles: An empirical investigation," *Journal of Money, Credit and Banking* 29, 1-16.

[25] Kim, D. H., D. R. Osborne, and M. Sensier (2005): "Non-linearity in the Fed's monetary policy rule," *Journal of Applied Econometrics* 20, 621-639.

[26] Meyer, L. H., E. T. Swanson, and V. W. Wieland (2001): "NAIRU uncertainty and non-linear policy rules," *American Economic Review* 91, 226-231.

[27] Mishkin, F. S. (2008): "*Comfort zones, shmumfort zones*," Sandridge Lecture at the Virginia Association of Economists, Lexington, VA, March 27, 2008.

[28] Newey, W. K. and K. D. West (1987). "A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix," *Econometrica* 55, 703-708.

[29] Nobay, A. R. and D. A. Peel (2000): "Optimal monetary policy with a nonlinear Phillips curve," *Economics Letters* 67, 159-164.

[30] Nobay, A. R. and D. A. Peel (2003): "Optimal discretionary monetary policy in a model with asymmetric central bank preferences," *Economic Journal* 113, 657-665.

[31] Roger, S. (2009): "Inflation targeting at 20: Achievements and challenges," *IMF Working Paper* 09/236.

[32] Ruge-Murcia, F. J. (2003): "Inflation targeting under asymmetric preferences," *Journal of Money, Credit and Banking* 25, 763-785.

[33] Stock J. H., J. H. Wright, and M. Yogo (2002): "A survey of weak instruments and weak identification in generalized method of moments," *Journal of Business and Economic Statistics* 20, 518-529.

[34] Stock J.H. and M. Yogo (2003): "Testing for weak instruments in linear IV regression," *mimeo*, Harvard University.

[35] Sturm, J.-E. and J. de Haan (2011), "Does central bank communication really lead to better forecasts of policy decisions? New evidence based on a Taylor rule model for the ECB," *Review of World Economics* 147, 41-58.

[36] Surico, P. (2007a): "The Fed's monetary policy rule and U.S. inflation: The case of asymmetric preferences," *Journal of Economic Dynamics and Control* 31, 305-324.

[37] Surico, P. (2007b): "The monetary policy of the European Central Bank," *Scandinavian Journal of Economics* 109, 115-135.

[38] Svensson, L. E. O. (2012): "The possible unemployment cost of average inflation below a credible target," *mimeo*, Sveriges Riksbank.

[39] Swanson, E. T. (2006): "Optimal non-linear policy: signal extraction with a non-normal prior," *Journal of Economic Dynamics and Control* 30, 185-203.

[40] Taylor, J. (1993): "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy* 39, 195-214.

[41] Tesfaselassie, M.F. and E. Schaling (2010): "Managing disinflation under uncertainty," *Journal of Economic Dynamics and Control* 34, 2568-2577.

[42] Tillmann, P. (2011): "Parameter uncertainty and nonlinear monetary policy rules," *Macroeconomic Dynamics* 15, 184-200.

[43] Wolters, M. H. (2012): "Estimating monetary policy reaction functions using quantile regressions," *Journal of Macroeconomics* 34, 342-361.

Appendix

Table A.1: Number of observations per category and country

Australia			
Positive Cred. Loss	77	MacFarlane	101
Negative Cred. Loss	52	Stevens	28

Canada			
Positive Cred. Loss	72	Thiessen	13
Negative Cred. Loss	36	Dodge	84
		Carney	11

New Zealand			
Positive Cred. Loss	71	Brash	56
Negative Cred. Loss	61	Bollard	76

Sweden			
Positive Cred. Loss	2	Backstrom	60
Negative Cred. Loss	130	Heikensten	36
		Ingves	36

United Kingdom			
Positive Cred. Loss	30	George	69
Negative Cred. Loss	105	King	66

Notes: The left part of the table shows the number of observations for positive and negative values of the credibility loss indicator; the right part displays the number of observations during the tenure of the respective central bank's head.

Table A.2: Unit root tests

	AUS		**CAN**		**NZ**		**SWE**		**UK**	
CB Int. Rate	-3.36	**	-1.54		-4.54	***	-2.72	*	-1.96	**
Real Int. Rate	-2.72	*	-3.80	**	-1.48		-3.19	*	-1.74	*
Infl. Gap	-2.47	**	-3.93	***	-1.80	*	-1.92	*	-3.15	*
Exp. Infl. Gap	-1.98	**	-3.57	***	-3.92	**	-3.36	*	-2.07	**
Exp. GDP	-2.56	**	-4.00	***	-2.98	***	-2.28	**	-2.64	***
Cred. Loss	-3.11	**	-3.33	*	-4.25	***	-2.89	***	-2.60	*

Notes: The table shows results of Augmented Dickey-Fuller (1979) tests. The test includes a constant if this term is significant. Lag length is selected based on the Schwarz criterion. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. CB = Central Bank.

Table A.3: Instrument sets for GMM estimations

	AUS	**CAN**	**NZ**	**SWE**	**UK**
Model M1					
CB Int. Rate	L3, L6	L2	L1, L4	L5	
Infl. Gap	L1, L3	L1, L2	L1, L3	L1	L1
Ind. Prod.		L6			
Broad Money		L3, L5		L5	L2, L3
Real Eff. Exch. Rate	L2, L3	L5, L6	L1, L4		L4, L6
Oil Price	L1, L3	L1, L2, L3, L4, L5	L1, L3		L1
F-Test (Infl. Gap)	145.2***	22.6***	202.1***	380.4***	286.5***

Models M2-M4					
CB Int. Rate	L1, L2, L3, L4	L1, L4	L1, L4, L6	L1, L4, L5, L6	L1, L3, L4
Infl. Gap	L1, L5	L1, L2, L3	L1, L3, L4, L6	L1, L3	L1, L2, L6
Ind. Prod.	L1, L6	L1, L2	L1, L5, L6	L1, L2, L3, L4, L5, L6	L1, L4, L5, L6
Broad Money	L1, L2	L5	L1, L6	L1	L2
Real Eff. Exch. Rate	L1, L3	L6	L1, L2, L5, L6	L2, L6	L1, L4, L6
Oil Price	L1, L3, L4	L3, L5, L6	L1, L6	L1, L2, L6	L2, L5, L6
F-Test (Exp. Infl. Gap)	71.0***	38.9***	120.0***	171.3***	55.9***
F-Test (Exp. GDP)	37.5***	72.9***	69.5***	102.8***	101.3***

Notes: The table shows instrument sets for estimation of model M1 and models M2-M4. The "F-Test" rows provide a test of weak instruments as proposed by Stock and Yogo (2003). CB = Central Bank, L = Lag.

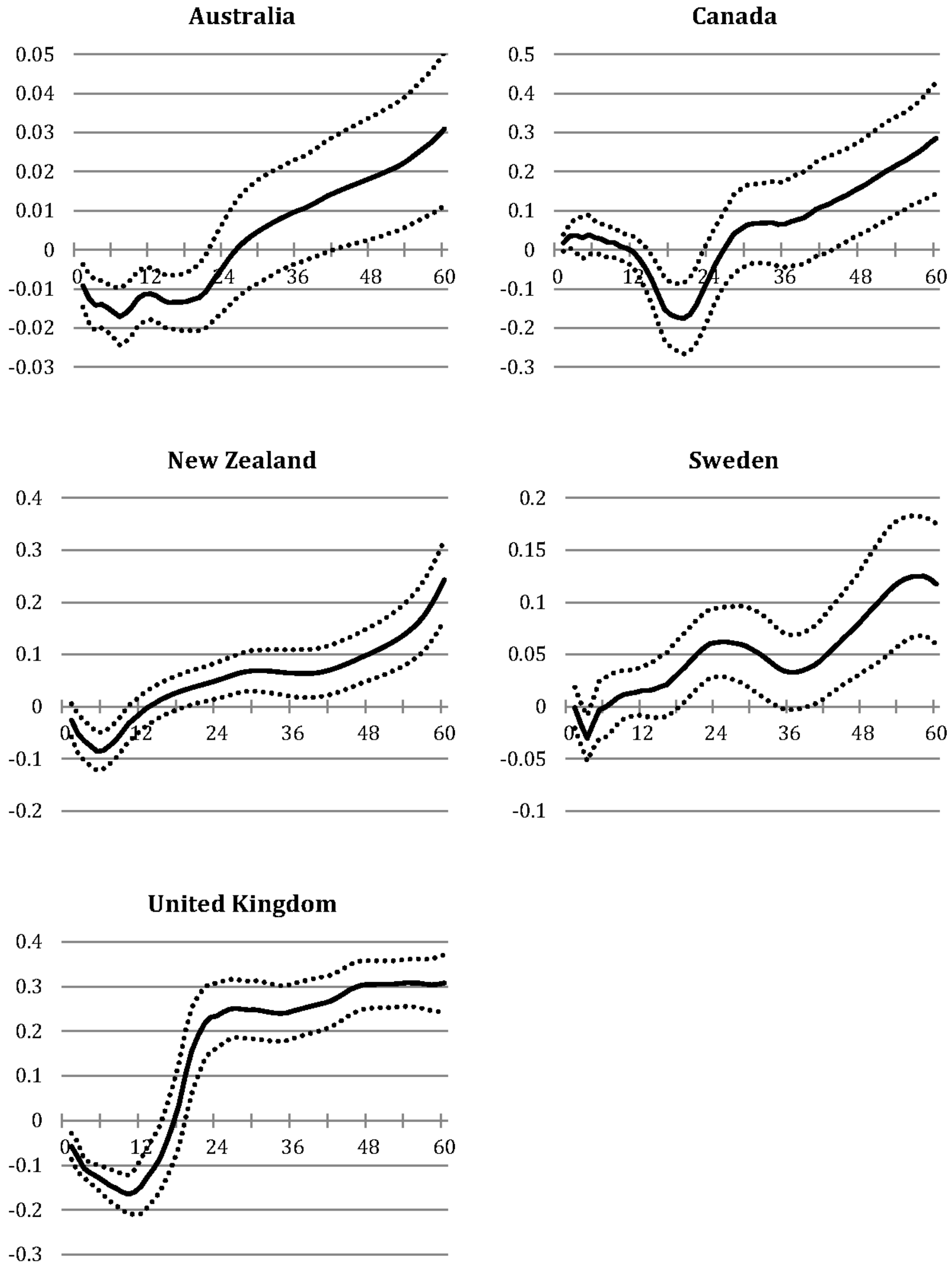

Figure A.1: Results for different horizons for the credibility loss indicator using model M2

Notes: The figure shows the short-run coefficients for the credibility loss term (and the corresponding 90 percent error bands) in model M2 with different horizons ranging from 1 to 60 months.

Table A.4: Further results for Australia

	M2		M3		M4	
$\hat{\rho}$ (IR Smoothing)	0.953	***	0.956	***	0.966	***
$(1-\hat{\rho})\hat{\beta_0}$ (Real Int. Rate)	0.042	***	0.043	***	0.048	***
$(1-\hat{\rho})\hat{\beta_1}$ (Exp. Infl. Gap)	0.085	***	0.091	***	0.100	***
$(1-\hat{\rho})\hat{\beta_2}$ (Exp. GDP)	0.037	**	0.039	**	0.010	
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.031	**	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-0.014		—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.087	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (MacFarlane))	—		—		0.037	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Stevens))	—		—		-0.405	
R-Squared	0.954		0.955		0.958	
S.E. of Regression	0.165		0.164		0.159	
J-Statistic	10.88		11.07		11.51	

Notes: Estimation of Equations M2, M3, and M4. The dependent variable is the central bank interest rate. Number of observations: 129. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

Table A.5: Further results for Canada

	M2		M3		M4	
$\hat{\rho}$ (IR Smoothing)	0.949	***	0.950	***	0.954	***
$(1-\hat{\rho})\hat{\beta_0}$ (Real Int. Rate)	0.036	**	0.015		0.025	
$(1-\hat{\rho})\hat{\beta_1}$ (Exp. Infl. Gap)	0.096		0.098		0.095	
$(1-\hat{\rho})\hat{\beta_2}$ (Exp. GDP)	0.288	***	0.293	***	0.269	***
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.285	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		0.477	***	—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		-0.054		—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Thiessen))	—		—		0.157	
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Dodge))	—		—		0.353	***
$(1-\hat{\rho})\hat{\beta_3^3}$ (Cred. Loss (Carney))	—		—		-1.840	
R-Squared	0.977		0.976		0.977	
S.E. of Regression	0.176		0.180		0.176	
J-Statistic	9.31		8.42		9.43	

Notes: Estimation of Equations M2, M3, and M4. The dependent variable is the central bank interest rate. Number of observations: 108. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

Table A.6: Further results for New Zealand

	M2		M3		M4	
$\hat{\rho}$ (IR Smoothing)	0.899	***	0.944	***	0.898	***
$(1-\hat{\rho})\hat{\beta_0}$ (Real Int. Rate)	-0.007		0.054		-0.024	
$(1-\hat{\rho})\hat{\beta_1}$ (Exp. Infl. Gap)	0.209	***	0.392	*	0.124	
$(1-\hat{\rho})\hat{\beta_2}$ (Exp. GDP)	0.220	***	0.058		0.247	***
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.243	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-0.588		—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.453	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Brash))	—		—		0.195	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Bollard))	—		—		0.444	**
R-Squared	0.939		0.940		0.938	
S.E. of Regression	0.337		0.336		0.340	
J-Statistic	11.30		10.16		11.41	

Notes: Estimation of Equations M2, M3, and M4. The dependent variable is the central bank interest rate. Number of observations: 132. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

Table A.7: Further results for Sweden

	M2		M3		M4	
$\hat{\rho}$ (IR Smoothing)	0.865	***	0.856	***	0.840	***
$(1-\hat{\rho})\hat{\beta_0}$ (Real Int. Rate)	0.070	***	0.089	***	0.086	***
$(1-\hat{\rho})\hat{\beta_1}$ (Exp. Infl. Gap)	0.333	***	0.377	***	0.413	***
$(1-\hat{\rho})\hat{\beta_2}$ (Exp. GDP)	0.125	***	0.128	***	0.146	***
$(1-\hat{\rho})\hat{\beta_3}$ (Cred. Loss)	0.117	***	—		—	
$(1-\hat{\rho})\hat{\beta_3}^{pos}$ (Positive Cred. Loss)	—		-3.600	***	—	
$(1-\hat{\rho})\hat{\beta_3}^{neg}$ (Negative Cred. Loss)	—		0.142	***	—	
$(1-\hat{\rho})\hat{\beta_3^1}$ (Cred. Loss (Backstrom))	—		—		0.152	***
$(1-\hat{\rho})\hat{\beta_3^2}$ (Cred. Loss (Heikensten))	—		—		0.060	
$(1-\hat{\rho})\hat{\beta_3^3}$ (Cred. Loss (Ingves))	—		—		0.157	
R-Squared	0.891		0.895		0.894	
S.E. of Regression	0.333		0.329		0.331	
J-Statistic	15.06		14.94		15.77	

Notes: Estimation of Equations M2, M3, and M4. The dependent variable is the central bank interest rate. Number of observations: 132. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.

Table A.8: Further results for the United Kingdom

	M2		M3		M4	
$\hat{\rho}$ (IR Smoothing)	0.889	***	0.893	***	0.891	***
$(1-\hat{\rho})\hat{\beta}_0$ (Real Int. Rate)	0.078	***	0.094	***	0.076	***
$(1-\hat{\rho})\hat{\beta}_1$ (Exp. Infl. Gap)	0.235	***	0.266	***	0.218	***
$(1-\hat{\rho})\hat{\beta}_2$ (Exp. GDP)	0.152	***	0.127	***	0.152	***
$(1-\hat{\rho})\hat{\beta}_3$ (Cred. Loss)	0.308	***	—		—	
$(1-\hat{\rho})\hat{\beta}_3^{pos}$ (Positive Cred. Loss)	—		0.031		—	
$(1-\hat{\rho})\hat{\beta}_3^{neg}$ (Negative Cred. Loss)	—		0.330	***	—	
$(1-\hat{\rho})\hat{\beta}_3^1$ (Cred. Loss (George))	—		—		0.329	***
$(1-\hat{\rho})\hat{\beta}_3^2$ (Cred. Loss (King))	—		—		0.276	***
R-Squared	0.978		0.978		0.978	
S.E. of Regression	0.162		0.163		0.162	
J-Statistic	16.68		16.01		16.75	

Notes: Estimation of Equations M2, M3, and M4. The dependent variable is the central bank interest rate. Number of observations: 135. A significance level of 1%, 5%, and 10% is indicated by ***, **, and *, respectively. The set of GMM instruments can be found in Table A.3.