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Imperfect credibility and the zero lower bound

Martin Bodenstein [a], James Hebden [b], Ricardo Nunes [a,*]

[a] International Finance Division, Federal Reserve Board, Washington, DC 20551, USA
[b] MIT Sloan School of Management, USA

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A B S T R A C T

As the nominal interest rate cannot fall below zero, a central bank with imperfect credibility faces a significant challenge to stabilize the economy in a New Keynesian model during a large recession. We characterize the optimal monetary policy at the zero lower bound for the nominal interest rate if credibility is imperfect. Confronting monetary policy communication of the U.S. Federal Reserve and the Swedish Riksbank with such a framework, the credibility of both institutions is shown to have been low in the aftermath of the 2008 economic crisis.

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1. Introduction

When the nominal interest rate reaches zero, the central bank faces a severe time-inconsistency problem. Initially, a promise to keep the nominal interest rate low for an extended period will raise inflation expectations, lower current and future real interest rates, and thus stimulate current output. Once the economy has emerged from the recession, honoring the interest rate promise overstimulates the economy leading to elevated inflation and a positive output gap. Consequently, if a central bank's announced promises are perceived as not credible, no effective forward guidance is provided and the economy goes through a deeper recession than otherwise.[1]

We analyze the optimal monetary policy in a standard New Keynesian model when the central bank has imperfect credibility and the nominal interest rate is constrained to be non-negative. The central bank can promise a state-contingent policy plan; however, in the future it may obtain the opportunity to discard its earlier promises and re-optimize. By incorporating the idea that in practice central banks operate neither under full commitment nor under full discretion but have an intermediate degree of credibility, new insight arises into questions such as: how does the prospect of future re-optimizations affect current promises and policies? How are promises affected by the state of the economy? What are the economic consequences of re-optimizations? How does the intensity of the time-inconsistency problem change when interest rates are zero?

First, as private agents' expectations reflect the prospect of future re-optimizations, the lower is the credibility of the central bank the longer is the promise to keep the interest rate low.[2] Hence, contrary to the perception created in the literature, an announcement to keep the interest rate low for an extended period is not necessarily a sign of credibility. Second, re-optimizations do not prompt an immediate exit from the zero lower bound if the economy is still deep in recession. Even in this case, committing to future policy actions allows the central bank to better stabilize the economy. Third, as at the zero bound the central bank can only recur to forward guidance, inflation and output volatility are magnified when credibility is low. Fourth, the welfare gains of discarding previous promises are high when the zero bound

* Corresponding author. Tel.: +1 202 452 2337.
E-mail address: Ricardo.P.Nunes@frb.gov (R. Nunes).

[1] Following the seminal papers by Kydland and Prescott (1977) and Barro and Gordon (1983) the literature has taken two different approaches to tackle optimal policy problems—commitment and no commitment. Eggertsson (2006) provides a discussion of the time-inconsistency problem at the zero lower bound.

[2] These extended promises are not costless since they have to be delivered with positive probability. At the optimum the central bank balances the expected marginal benefits and costs.

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constraint is binding. While policy commitment is especially valuable in this case, unfortunately, the time-inconsistency problem also becomes exacerbated.

Although academics and policymakers alike deem credibility pivotal for the conduct of monetary policy as documented in Blinder (2000), the experiences of some central banks in the aftermath of the 2008 crisis have cast doubt on their credibility. Informally, this point is made in Walsh (2009) for the U.S. and in Svensson (2009, 2010) for Sweden. When formally mapping policy communication of the U.S. Federal Reserve and the Swedish Riksbank to our model, the credibility of both institutions falls between full commitment and full discretion.

In the case of the U.S., Federal Reserve officials stated repeatedly in 2009 that promising to allow inflation and the output gap to go above target has not been considered, i.e., the Federal Reserve does not intend to follow the optimal policy prescription of the New Keynesian model with full commitment. The model establishes a theoretical link between such statements and low central bank credibility.[3]

In April 2009, the Swedish Riksbank's announcement that the repo-rate would be near zero until the end of 2011 was incongruent with market expectations that policy rates would rise by the end 2010. This decoupling at the zero lower bound can be replicated in a model with low credibility of the monetary policymaker. Furthermore, the data on private sector forecasts support the hypothesis of low credibility.

In related work, Adam and Billi (2006, 2007) and Nakov (2008) analyze stochastic economies with the zero lower bound as an occasionally binding constraint. These authors consider only full commitment and full discretion. Schaumburg and Tambalotti (2007) examine imperfect credibility without the zero lower bound.[4] As the non-linearities associated with the zero lower bound prevent closed-form solutions, the imperfect credibility model is solved with global solution methods discussed in Debortoli and Nunes (2010).

Eggertsson and Woodford (2003) suggest implementing the optimal monetary policy at the zero lower bound through targeting an output-gap adjusted price index. While communicating policy through a price level instead of an interest rate path may be more transparent, the policymaker would still have to commit to a time-inconsistent price-level targeting rule. Thus, the concerns derived from our framework still apply.

By taking into account the zero lower bound constraint, Benhabib et al. (2001) show that active interest rate feedback rules can lead to liquidity traps and multiple equilibria. Schmitt-Grohé and Uribe (2007) analyze simple rules in linear stochastic economies and check ex post that the zero lower bound constraint is rarely violated. However, interest rate rules and multiple equilibria are not investigated in this paper.

To analyze more complex models, other authors have examined the implications of the zero lower bound in settings akin to perfect foresight, e.g., Eggertsson and Woodford (2003), Jung et al. (2005), Levin et al. (2010), and Bodenstein et al. (2009). However, the uncertainty about policy renouncements impacting agents' expectations and central bank policy in this paper cannot be captured in a perfect foresight setting. Thus, global methods that can handle occasionally binding constraints need to be employed.

The remainder of this paper is organized as follows. Section 2 presents the modeling framework. Section 3 reports results derived from the model. Sections 4 and 5 discuss the degree of central bank credibility in the U.S. and Sweden, respectively. Section 6 concludes.[5]

2. The model

The model consists of two building blocks: the private sector and the monetary authority. The behavior of the private sector is given by a standard New Keynesian model as described in Yun (1996) and Woodford (2003) among others. The central bank attempts to maximize the welfare of the representative household, but faces two limitations. First, the central bank's single instrument is the nominal interest rate on one-period, non-contingent debt which cannot fall below zero (zero lower bound).[6] Second, the central bank's commitment to earlier plans is revoked with a known and fixed probability (imperfect credibility).

2.1. Private sector

The optimization problems of households and firms imply the well-known linear aggregate demand and supply relationships

$$\pi_t = \kappa y_t + \beta E_t \pi_{t+1} + u_t, \tag{1}$$

[3] An earlier example of the imperfect credibility of central banks in industrialized economies is the Bank of Japan. In 1999/2000, the Bank of Japan never followed the prescription of the optimal policy under full commitment. After instituting a zero interest rate policy in February 1999, it raised interest rates in March 2000 although the economy was still weak and inflation was negative.

[4] The imperfect commitment setting with stochastic re-optimization was first proposed in Roberds (1987). Ball (1995) examines the role of imperfect credibility in disinflation episodes.

[5] The supplementary documentation provided online offers additional results and discussions.

[6] Goodfriend (2000) proposes three options to overcome the zero bound on interest rate policy: a carry tax on money, open market operations in long bonds, and monetary transfers. The choice to not include into the analysis these and other policies, such as fiscal stimulus (Christiano et al., 2011; Eggertsson, 2010) and credit easing policies (Gertler and Karadi, 2009; Del Negro et al., 2009), should not be interpreted as us passing judgement on the effectiveness of these policies. Furthermore, recent public debate in the U.S. indicates that political limits apply to employing these policies. The purpose of this paper is to shed light on the effectiveness of forward guidance through short term interest rates.

$$y_t = E_t y_{t+1} - \sigma(i_t - E_t \pi_{t+1}) + g_t, \tag{2}$$

$$u_t = \rho_u u_{t-1} + \varepsilon_{u,t}, \tag{3}$$

$$g_t = \rho_g g_{t-1} + \varepsilon_{g,t}, \tag{4}$$

here the innovations to the cost push shock u_t and the demand shock g_t are iid. π_t denotes the inflation rate, y_t is the output gap, and i_t is the nominal interest rate on one period non-contingent debt.[7] Expressing i_t in deviation from the steady state interest rate (with zero steady state inflation), the zero lower bound reads

$$i_t \geq -r^*, \tag{5}$$

where r^* is the steady state value of the nominal interest rate. For later use, the level of the nominal interest rate is defined as $\tilde{i}_t \equiv i_t + r^*$.

The discount factor is denoted by $\beta \in (0,1))$ and the slope of the Phillips curve is $\kappa = ((1-\upsilon)(1-\upsilon\beta)/\upsilon)((\sigma^{-1}+\omega)/(1+\omega\theta))$. υ is the probability with which a firm cannot adjust its price, σ is the intertemporal elasticity of substitution of the household, ω measures the elasticity of a firm's real marginal cost with respect to its own output level, and θ is the elasticity of substitution between the varieties produced by the monopolistic competitors.

2.2. Monetary policy

The monetary authority maximizes the present discounted value of its period objective function subject to the constraints (1)–(5). The period utility function U_t is of the quadratic form

$$U_t = -\pi_t^2 - \lambda y_t^2, \tag{6}$$

where $\lambda = \kappa/\theta$ as in Woodford (2003).

As in Roberds (1987), Schaumburg and Tambalotti (2007), and Debortoli and Nunes (2010), the policymaker has imperfect credibility. At the beginning of each period, a realization of the random variable X is drawn where $X = \{C,R\}$ with the probability distribution $p(C) = \eta$ and $p(R) = 1-\eta$ for $\eta \in [0,1]$. In the event $x = C$, the policymaker follows her previously announced policy path, whereas she reneges on her earlier promises if $x = R$. Thus, a policymaker's promises made in time t about the future path of the nominal interest rate will be implemented in period $t+s$ with probability η^s.

If $\eta = 1$, policy promises are always kept and the policymaker is referred to as fully committed or perfectly credible. If $\eta = 0$, the policymaker acts under full discretion. Adam and Billi (2006, 2007) and Nakov (2008) analyze the optimal monetary policy under the zero bound constraint in a fully stochastic environment for these two cases. The cases with $\eta \in (0,1)$ correspond to imperfect credibility and have not been previously analyzed.

Under imperfect credibility, the optimization problem of the policymaker is stated as

$$V(u_t,g_t) = \max_{\{y_t,\pi_t,i_t\}} E_t \sum_{t=0}^{\infty} (\beta\eta)^t \{-(\pi_t^2 + \lambda y_t^2) + \beta(1-\eta) E_t V^R(u_{t+1},g_{t+1})\}, \tag{7}$$

$$\text{s.t.} \quad \pi_t = \kappa y_t + \beta\eta E_t \pi_{t+1} + \beta(1-\eta) E_t \pi_{t+1}^R + u_t, \quad y_t = \eta E_t y_{t+1} + (1-\eta) E_t y_{t+1}^R - \sigma(i_t - \eta E_t \pi_{t+1} - (1-\eta) E_t \pi_{t+1}^R) + g_t,$$
$$i_t \geq -r^*, \quad u_t = \rho_u u_{t-1} + \varepsilon_{u,t}, \quad g_t = \rho_g g_{t-1} + \varepsilon_{g,t},$$

where variables evaluated under re-optimization carry the superscript R.

The objective function contains two parts. The first two terms refer to future paths in which current promises are kept. Due to the possibility of future re-optimizations, such histories are discounted at the rate $\beta\eta$. Second, at any point in time, current promises are discarded with probability $1-\eta$ and a new policy is formulated. The value obtained by the monetary authority in that case is summarized in the function V^R. The expectation terms in the constraints also reflect the uncertainty about future policy renouncements.

Assuming re-optimizations to occur stochastically rather than as endogenous decisions is a simplification analogous to the Calvo pricing model. This approach seems justified if some re-optimizations are uncorrelated with the state of the economy. Possible candidates for such events are changes in the dominating view within a central bank due to time-varying composition of its decision-making committee. Outside pressures by politicians and the financial industry of varying intensity are other candidates.[8] The timing of a re-optimization is not explained by this approach. However, it allows for examining how the anticipation of future policy re-optimizations interacts with commitments, and for

[7] In this economy households choose consumption, leisure, money and bond holdings subject to their budget constraints. Firms are monopolistic competitors and set nominal prices. The nominal price contracts are modeled as in Calvo (1983) and Yun (1996). This paper follows the literature in using the linear equations that are obtained from log-linearizing the non-linear equations around the model's deterministic steady state. Although such an approach removes possibly interesting non-linearities, it facilitates computations and the comparisons with earlier work on the zero bound constraint and/or optimal monetary policy. See also the discussion in Section 2.1 in Adam and Billi (2006).

[8] As emphasized by political economists, topics vaguely related to economics – such as foreign and defense policy or social values – have determined election outcomes, leading to a random composition of economic policy views among elected representatives. See Chapter 11 of Mueller (1989) for a discussion on the theory of probabilistic voting.

analyzing the effects of policy renouncements including their welfare effects. These issues cannot be addressed in either the full commitment or the full discretion frameworks presented in Adam and Billi (2006, 2007). While more complex credibility settings that could also explain the timing of re-optimizations are easily imagined, they come at greater computational burden.

2.3. Comments on the equilibrium concept

The Markov equilibrium approach is distinct from a reputation mechanism or trigger strategies, as for instance in Chari and Kehoe (1990). While our approach can be used to examine the effects of credibility on policies in more complex models, a reputation framework would be required to capture the effects of policies on building and losing credibility. In standard models of reputation, however, re-optimizations cannot be analyzed because the off-equilibrium path threats by the private sector effectively deter re-optimizations by the central bank. However, if the type of the central bank is private information, re-optimizations can occur in a reputation model. Re-optimizations are then usually triggered by a large shock or the approaching end of a term limit. Such exogenous events can be considered to be partially captured by the re-optimization shock.[9]

A reputation mechanism would require that atomistic private agents could learn, gauge, and coordinate on the punishment to apply to the central bank.[10] All told, a reputation model enhanced with random coordination failures among private agents may share similarities with the approach taken in this paper despite the obvious differences in assumptions. In such a model, the central bank would promise a certain policy for the next period, but if coordination on the punishment mechanism broke down, the central bank would re-optimize.

2.4. Equilibrium and solution

Recasting problem (7) into the recursive formulation of Marcet and Marimon (2009) and rearranging terms, the problem can be written as

$$V(s_t) = \min_{\{\gamma_t^1,\gamma_t^2\}} \max_{\{y_t,\pi_t,i_t\}} h(y_t,\pi_t,i_t,\gamma_t^1,\gamma_t^2,s_t) + \beta[\eta E_t V(s_{t+1}) + (1-\eta)E_t V^R(s_{t+1}^R)] \tag{8}$$

$$\begin{aligned}
&\text{s.t.} \quad i_t \geq -r^*,\\
&u_t = \rho_u u_{t-1} + \varepsilon_{u,t}, \quad g_t = \rho_g g_{t-1} + \varepsilon_{g,t},\\
&\mu_{t+1}^1 = \gamma_t^1, \quad \mu_0^1 = 0, \quad \mu_{t+1}^2 = \gamma_t^2, \quad \mu_0^2 = 0,
\end{aligned}$$

where $s_t = (u_t,g_t,\mu_t^1,\mu_t^2)$ and $s_t^R = (u_t,g_t)$ summarize the state of the dynamic system in case policy plans are continued or re-optimized, respectively. Lagrange multipliers associated with the behavioral constraints are denoted by (γ_t^1,γ_t^2) and

$$h(y_t,\pi_t,i_t,\gamma_t^1,\gamma_t^2,s_t) \equiv -\pi_t^2 - \lambda y_t^2 + \gamma_t^1 h_t^{PC} + \gamma_t^2 h_t^{IS} - I_\eta \mu_t^1 \pi_t + I_\eta \frac{1}{\beta} \mu_t^2 (y_t + \sigma \pi_t), \tag{9}$$

$$h_t^{IS} \equiv -y_t + (1-\eta)E_t y_{t+1}^R - \sigma(i_t - (1-\eta)E_t \pi_{t+1}^R) + g_t,$$

$$h_t^{PC} \equiv \pi_t - \kappa y_t - \beta(1-\eta)E_t \pi_{t+1}^R - u_t,$$

where I_η is an indicator function satisfying $I_\eta = 0$ for $\eta = 0$ and $I_\eta = 1$ otherwise.

It follows from Marcet and Marimon (2009) and Debortoli and Nunes (2010) that the optimal policy and the value functions are time invariant if the state space is enlarged to contain the lagged Lagrange multipliers (μ_t^1,μ_t^2). The multipliers summarize previous state-contingent promises, with the case of non-binding promises corresponding to the multipliers being zero. Since the multipliers are not physical state variables, only commitment impedes the monetary authority from ignoring previous promises, reflecting the time-inconsistent nature of the problem. In fact, resetting the Lagrange multipliers to zero is optimal, and occurs in equilibrium whenever the monetary authority is allowed to do so.

The equilibrium with imperfect commitment satisfies the following conditions: first, given $\{y_t^R,\pi_t^R\}_{t=0}^\infty$ and the value V^R, the path $\{y_t,\pi_t,i_t\}_{t=0}^\infty$ solves problem (7). Second, the value function V^R is such that $V^R(u_t,g_t) = V(u_t,g_t,\mu_t^1=0,\mu_t^2=0)$ and V is defined by Eq. (8). Third, denoting the optimal policy functions as $(y_t,\pi_t) = \psi(u_t,g_t,\mu_t^1,\mu_t^2)$, the pair (y_t^R,π_t^R) satisfies the condition $(y_t^R,\pi_t^R) = \psi(u_t,g_t,0,0)$.

The first part of the definition requires optimality given the constraints. The second part defines the value of re-optimization V^R to be the continuation value without binding promises, i.e., the lagged Lagrange multipliers are at zero.[11]

[9] Backus and Driffill (1985a,b), Barro (1986), Cukierman and Liviatan (1991), and more recently in King et al. (2008) and Lu (2011) have modeled endogenous commitment by assuming policymakers of different types.

[10] While agents may be able to learn a rational expectations equilibrium (see Marcet and Sargent, 1989), in reputation models the punishment cannot be learnt through experience as it constitutes an off-equilibrium phenomenon. Also, the punishments in such models are often not renegotiation-proof.

[11] The two value functions would not coincide if policy objectives are not consensual. This case is analyzed in Debortoli and Nunes (2006) who consider two political parties with different utility functions. In such a situation, the continuation value function depends on which party gains power.

The third part requires the policy functions that private agents expect to be implemented under re-optimization (y_t^R, π_t^R) to be consistent with the optimal policy functions implemented when there are no promises to be honored.

The solution of Eq. (8) is not standard, as both the value function V^R and the policy functions under re-optimization are unknown. In addition, the solution requires maximizing with respect to the controls and minimizing with respect to the Lagrange multipliers. The numerical algorithm described in Appendix B uses a direct approximation of the value function.

The two model features that dictate the use of global methods are the presence of the occasionally binding zero bound constraint and the possibility of policy renouncements. Most of the literature on monetary policy at the zero bound assumes perfect foresight to simplify the treatment of the binding constraint. However, this assumption of perfect foresight inhibits studying the link between monetary policy and household expectations about future policy renouncements. By construction, households do not anticipate policy changes in such a setting.

3. Results

The model is parameterized as in Adam and Billi (2006, 2007) and Woodford (2003) to facilitate comparisons. Table 1 summarizes these choices. Absent empirical guidance for the re-optimization probability η, or equivalently the expected duration of promise $\alpha = 1/(1-\eta)$, the analysis assumes several values for η. However, Sections 4 and 5 present evidence that η lies in the neighborhood of 0.5, i.e., $\alpha = 2$, for the U.S. and Sweden. Appendix D reports on sensitivity analysis with respect to alternative values of σ and experiments with a hybrid Phillips curve.

Papers such as Reifschneider and Williams (2000), Schmitt-Grohé and Uribe (2007), and Billi (2011) have indicated that the nominal interest rate reaches zero with low probability for long-run inflation targets observed in reality. However, once the economy is at the zero bound, as has been the case in several industrialized countries in the aftermath of the 2008 crisis, additional shocks have amplified effects on economic activity.

Our work is not designed to shed light on the causes of the 2008 crises, which are subject to ongoing debate, but to analyze a particular dimension of the policy response to the Great Recession that has followed. To this end, the demand shock g captures key features of this episode: a negative output gap, inflation well below trend, and near-zero policy interest rates. In this regard, the modeling strategy resembles Christiano et al. (2011) and Levin et al. (2010).

3.1. Credibility at the zero lower bound

Monetary policy faces a time-inconsistency dilemma when the nominal interest rate reaches zero in response to a large contractionary demand shock. A promise to keep the interest rate low for an extended period, such that inflation and the output gap are expected to rise above their target values in the future, reduces the contemporaneous real interest rate and buffers the impact of the shock. Since the announced overshooting of the output gap and inflation in future periods would create welfare losses, the central bank will find it optimal to raise the path of the interest rate as the shock unwinds. This temptation is most pronounced once the economy enters the phase of elevated inflation and positive output gaps.

The ability of a central bank to stabilize the economy may thus be greatly diminished when credibility is imperfect. To characterize the promises and re-optimizations under the optimal policy with imperfect credibility, the analysis starts with the impulse response functions after a large and persistent contraction in aggregate demand in period 1 that pushes the nominal interest rate to zero. More specifically, across experiments it is set $g_1 = -10$, $u_1 = 0$, and $(\varepsilon_{u,t}, \varepsilon_{g,t}) = 0\ \forall t \geq 2$. However, specific histories of x_t differ across experiments. The lagged Lagrange multipliers are initialized at zero, i.e., $\mu_1^1 = \mu_1^2 = 0$. Later in this section, all possible shock histories are considered.

3.1.1. Promises

For different levels of credibility ($\alpha = 2$, $\alpha = 4$, and full commitment), the left column of Fig. 1 informs about the optimal promises of the central bank in period 1, i.e., the evolution of the nominal interest rate, the output gap, and inflation for the specific history of no policy re-optimizations ($x_t = C\ \forall t \geq 1$). The lower the credibility of the monetary authority is, the more extreme its promises are. The policymaker with $\alpha = 2$ promises to keep the interest rate at zero over the entire horizon plotted, whereas the policymaker with $\alpha = 4$ promises to keep the interest rate at zero for six periods.

Given the central bank's imperfect credibility, private agents correctly incorporate the possibility of future re-optimizations when forming expectations. In its attempt to influence private sector expectations, the less credible central bank thus extends its promise to keep the interest rate low.

However, these promises may turn out to be very costly to the central bank, if it is not presented with the opportunity to re-optimize its policy. In this case, the low interest rate fuels a sizable and persistent boom with increased inflation, as seen in particular for $\alpha = 2$. Hence, at the optimum, the policymaker equates the expected marginal benefits from a promise to keep the interest rate low with the costs of having to deliver on such a promise (the cost of not re-optimizing). With low credibility, promises become more extreme because such promises are unlikely to be fulfilled and private sector expectations are harder to influence.

The literature persistently points out that, relative to a policymaker acting under full discretion, a fully committed policymaker announces to keep the interest rate at zero for an extended period of time (for example, Eggertsson and Woodford, 2003; Adam and Billi, 2006; Walsh, 2009). In a purely forward looking model, such inference is correct only for

Table 1
Parameterization.

Parameter	Value	Economic meaning
β	0.9913	Discount factor
υ	0.66	Probability of no price change
σ	6.25	Interest rate sensitivity consumption
ω	0.47	Elasticity of firms' marginal cost
θ	7.66	Price elasticity of demand
κ	0.024	Slope of Phillips curve
λ	0.003	Weight on output in utility function
ρ_u	0	Persistence cost push shock
σ_u	0.154	Standard deviation cost push shock
ρ_g	0.8	Persistence demand shock
σ_g	1.524	Standard deviation demand shock
η	[0,1]	Credibility level, or $1/(1-\eta)\equiv\alpha\in[1,+\infty]$

Note: This table summarizes the parameterization of the model at quarterly frequency.

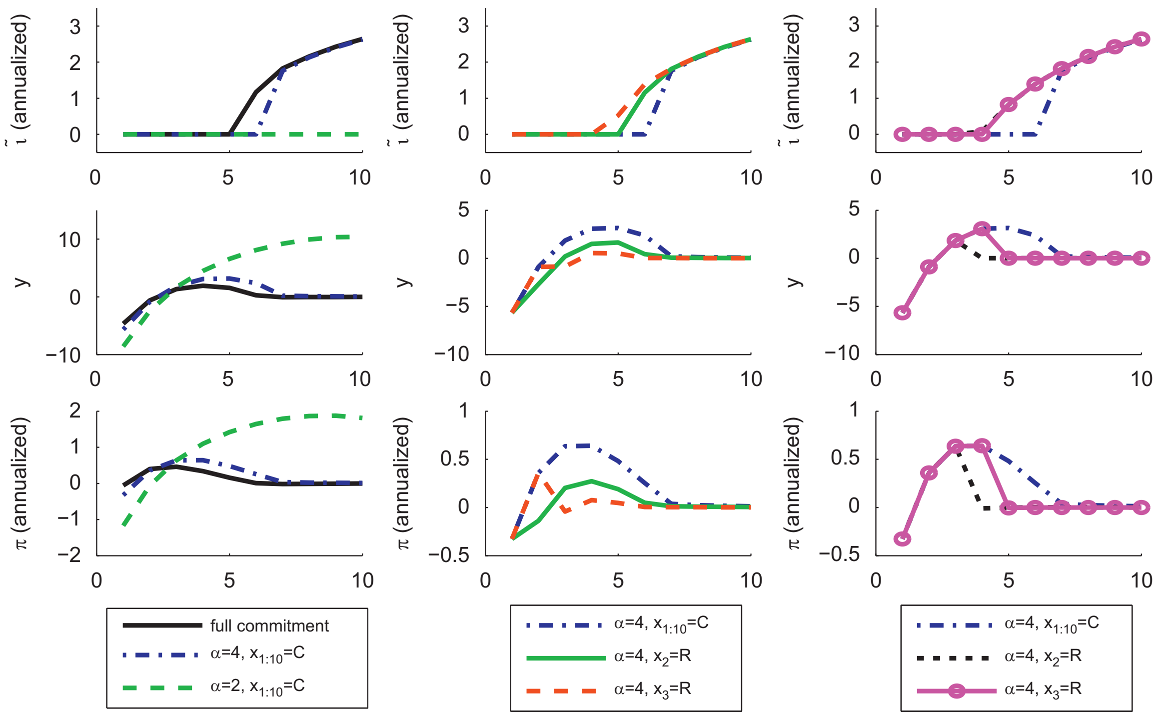

Fig. 1. Imperfect credibility and the zero lower bound. Notes: the figure plots the transition dynamics in response to a negative and large demand shock causing the interest rate to reach its zero lower bound. The shocks are initialized at $u_1=0$, $g_1=-10$, and $(\varepsilon_{u,t},\varepsilon_{g,t})=0\ \forall t\geq 2$.

these two extreme cases.[12] As shown in the left column of Fig. 1, the (conditional) announcement that the interest rate is planned to be at zero for a long period should not be necessarily understood as a signal of high credibility. If, contrary to the model assumptions, credibility was endogenously affected by more extreme promises, a less credible central bank might or might not promise a lower path of the interest rate depending on the costs of promising a lower interest rate path versus the effects identified here.

3.1.2. Renouncements

Even a re-optimizing policymaker with low credibility chooses to leave the contemporaneous interest rate at zero while the economy is still in deep recession. The middle column of Fig. 1 confirms this claim for $\alpha=4$ when a policy renouncement occurs in period 2 ($x_2=R$ and $x_t=C\ \forall t\neq 2$) or period 3 ($x_3=R$ and $x_t=C\ \forall t\neq 3$). One could therefore infer that policy commitments are not relevant in times of a deep recession: the interest rate will be at zero irrespective of

[12] If inflation is not purely forward looking due to price indexation, the observed interest rate may be lower under full discretion than under full commitment for a given-sized demand shock. As shown in Appendix D, state-contingent promises of the full commitment planner may stabilize the economy so well relative to full discretion that a fully committed policymaker can leave the zero lower bound regime sooner.

policy renouncements. However, such inference is misguided. If policy is reformulated in the midst of the recession, the incentive to keep the interest rate low at later dates is reduced as the shock unwinds. Although the contemporaneous interest rate remains unchanged, inflation and the output gap react immediately.[13] Commitment matters well before the central bank faces the temptation to start raising the contemporaneous interest rate.

While the economy is on its recovery path, the interest rate may still be zero due to earlier commitments. As depicted in the right column of Fig. 1, the central bank raises the interest rate immediately if a re-optimization occurs in this phase. For re-optimizations in period 4 ($x_4 = R$, $x_t = C\ \forall t \neq 4$) or 5 ($x_5 = R$, $x_t = C\ \forall t \neq 5$), such action puts an end to the policy of elevated inflation and positive output gap previously promised and brings both variables closer to target.

Similarly, as shown in Appendix B, once the economy has exited from the zero bound, it is immaterial whether new commitments are made after a policy renouncement. Having exited from the zero lower bound, commitments are hardly of value with respect to the demand shocks.

3.2. *Distribution of responses*

To highlight the characteristics of the model, the impulse response functions shown so far have been based on specific histories for x_t, $\varepsilon_{g,t}$, and $\varepsilon_{u,t}$. The next two experiments analyze more generally the distribution of impulse responses at the zero bound.

3.2.1. *First experiment*

We first restrict attention to histories with $g_1 = -10$ and $\varepsilon_{g,t} = 0\ \forall t \geq 2$, and $u_1 = 0$ and $\varepsilon_{u,t} = 0\ \forall t \geq 2$, but allow for all possible histories of x_t. Fig. 2 shows the mean impulse response under imperfect credibility with $\alpha = 4$ (left column) and $\alpha = 2$ (right column) surrounded by the impulse response functions lying between the 1st and 99th percentiles, the shaded areas. The figure also displays the impulse responses when the policymaker has full commitment or acts under full discretion, respectively. With still conditioning on a specific history for the demand and cost-push shocks, there is no uncertainty about the impulse responses under full commitment and full discretion, the two cases presented by Adam and Billi (2006, 2007).

For the mean response under imperfect credibility, the path of the interest rate is higher at least in the near term than under full commitment or full discretion. The results remain largely unaffected when replacing the mean by the median of the impulse responses. Nevertheless, the output gap and inflation temporarily rise above their target values for the mean response under limited credibility as is the case under full commitment. However, this mean response is surrounded by considerable uncertainty. The shaded area spanned by the 1st and 99th percentile responses covers the special cases depicted in Fig. 1.

As in the full discretion case, the impulse response functions for histories with many re-optimization events do not imply a post-recession boom with inflation. However, for imperfect credibility, in such a scenario the economy does not perform as poorly as the economy under full discretion. Thus, being somewhat committed but re-optimizing in many periods by chance is different from being known to have no commitment at all. Consequently, even central banks with low credibility should attempt to use forward guidance to the best of their ability rather than abandon this tool completely.

3.2.2. *Second experiment*

In considering all possible histories for x_t, $\varepsilon_{g,t}$, and $\varepsilon_{u,t}$ for $t > 1$, we distinguish two cases. In the first case, the economy experiences a large negative demand shock that pushes the nominal interest rate to zero, $g_1 = -10$, $u_1 = 0$, whereas for the second case the economy is initially at $g_1 = 0$, $u_1 = 0$.

Fig. 3 plots the interquantile range between the 99th percentile response and the 1st percentile response when policymakers act under full discretion, imperfect credibility ($\alpha = 4$), and full commitment. The dashed lines depict the interquantile ranges when the economy is initially at the zero bound ($g_1 = -10$) and the solid lines depict the case when the economy is initialized at $g_1 = 0$. Appendix B details the dynamics of inflation, output gap, and the interest rate.

The economy experiences higher uncertainty about the future paths of the output gap and the inflation rate as measured by the interquantile range when the economy is initially at the zero lower bound. Monetary policy can no longer counteract shocks as effectively as it can when the interest rate is positive. The resulting increase in the economy's sensitivity to shocks translates into (temporarily) increased uncertainty about the output gap and the inflation rate. As the nominal interest rate is the predominant shock absorber when the interest rate is positive, the uncertainty about the future path of the nominal interest rate is lower when the economy is initially at the zero bound. For periods further in the future, the interquantile ranges for the two cases ($g_1 = -10$ and $g_1 = 0$) converge as it is less likely for the zero bound to remain binding for the case with $g_1 = -10$ once the initial demand shock has sufficiently receded.

At the zero lower bound, the interquantile ranges for inflation and the output gap are substantially higher in an economy with imperfect credibility compared to an economy with full commitment. Doubts about the commitment of the central bank impinge upon its ability to use interest rate announcements for forward guidance. Under full discretion the increase in uncertainty is therefore most pronounced.

[13] Also, as the economy is still deeper in recession in period 2, the promised path for the interest rate is lower for the case of $x_2 = R$ than for $x_3 = R$.

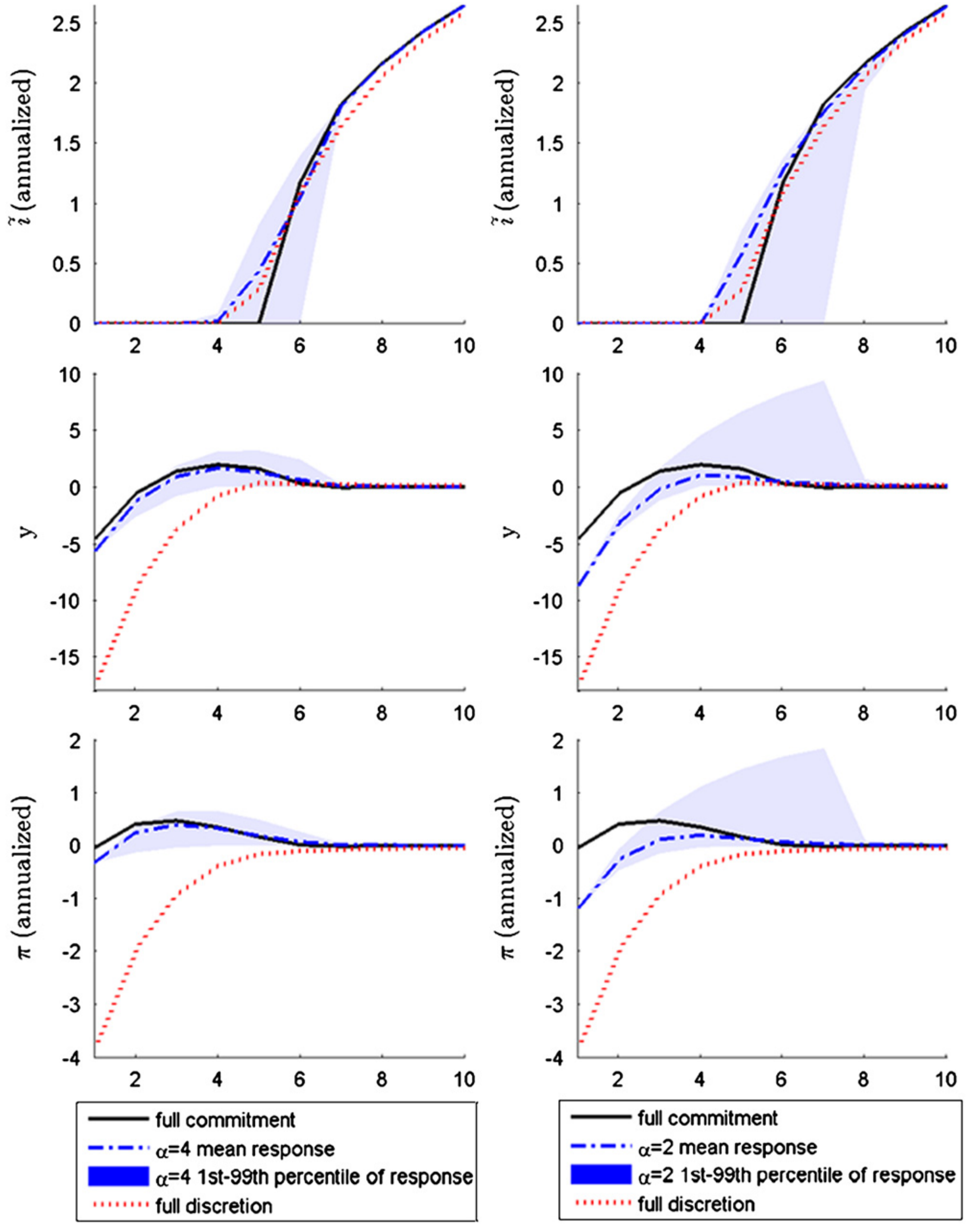

Fig. 2. Distribution of impulse response functions—re-optimization uncertainty only. Notes: the figure plots the transition dynamics in response to a negative and large demand shock causing the interest rate to reach its zero lower bound. The shocks are initialized at $u_1 = 0$, $g_1 = -10$, and $(\varepsilon_{u,t}, \varepsilon_{g,t}) = 0\ \forall t \geq 2$. The mean and selected percentiles are computed from simulated histories of the commitment shock (i.e. $x_t \in \{C,R\}$). For the full commitment and full discretion cases, there is no uncertainty with regard to x_t shocks, and therefore any percentile coincides with the mean.

Away from the zero bound, by contrast, the interquantile ranges differ little across credibility levels. In the 2008/2009 recession, markets have experienced increased volatility and uncertainty in the inflation and output outlook.[14] Our findings suggest that this rise in uncertainty is in part due to low credibility and the zero lower bound constraint.

[14] While volatility and uncertainty did go up during the Great Recession, it is harder to determine whether experienced volatility increased after interest rates were reduced to zero. The zero lower bound sample is short, and volatility may increase before due to large shocks and the anticipation of the zero lower bound constraint. The variance in GDP inflation and output growth in the U.S. were respectively 0.79 and 0.35 in the period 2006:Q1-2008:Q3; these values increased to 0.92 and 0.52 in the period 2009:Q1-2011:Q3.

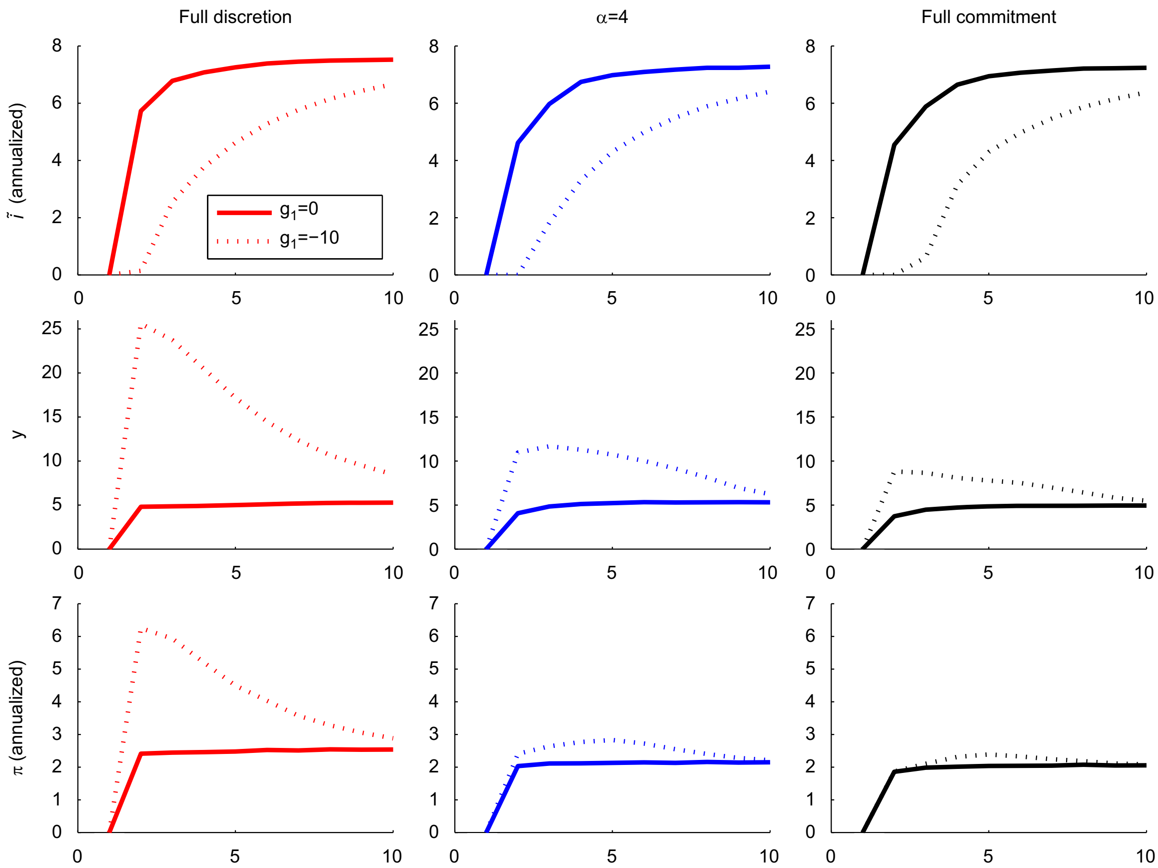

Fig. 3. Forecast uncertainty—interquantile range. Notes: the figure plots the difference between the 99th and 1st percentiles in several scenarios. In all simulations, the shocks $(\varepsilon_{u,t}, \varepsilon_{g,t}, x_t)$ are drawn from their respective distributions. For the cases reported with the solid lines, the simulations are initialized at $u_1 = 0$, $g_1 = 0$. For the cases reported with the dashed lines, the simulations are initialized at $u_1 = 0$, $g_1 = -10$, which causes the interest rate to reach its zero lower bound.

3.3. Time inconsistency and welfare

While policy commitment is especially valuable at the zero bound, unfortunately, the time-inconsistency problem also becomes exacerbated.[15] Fig. 4 shows the difference between the value of staying committed in period T, $V_{T,x_T=C}$, and the value of re-optimizing in period T, $V_{T,x_T=R}$, both for an economy that has experienced a large negative demand shock ($g_1 = -10$) and an economy that is initialized at $g_1 = 0$. Note that as a result of the time-inconsistency problem, for a fixed credibility level the central bank achieves higher utility in a given period when a re-optimization occurs.[16] The welfare gain from reneging on an earlier promise is significantly higher at every point in time when the economy is in a severe recession compared to the case of $g_1 = 0$.[17] This analysis also suggests that periods of zero interest rates may play an important role in empirically identifying parameters that govern policy credibility.

On a separate note, the analysis presented in Fig. 4 may be regarded as a candidate explanation for the intense political pressure on the Federal Reserve since the beginning of the 2008/2009 recession. While public criticism of the Federal Reserve concentrated originally on regulatory issues, monetary policy itself has become the critics' focus over the course of 2010 and 2011. Financial market commentators have repeatedly urged the Federal Reserve to raise interest rates for fear of

[15] Because the welfare difference between full discretion and full commitment is higher in a model with the zero lower bound, in a model of sustainable plans the threat of the discretionary equilibrium may sustain solutions closer to the commitment equilibrium. However, in a model with private information on central bank types and atomistic private agents similar to King et al. (2008), this effect is not necessarily present.

[16] This illustration of the time-inconsistency problem should not be confused with a comparison of welfare under full discretion against welfare under full commitment.

[17] For the case of $g_1 = -10$, the temptation to renege is the highest in period 3. Revisiting Fig. 1 reveals that re-optimizing in period 3 avoids the costly overshooting of inflation and the output gap. The economy is stabilized more effectively if the opportunity to re-optimize occurs in this period rather than any other.

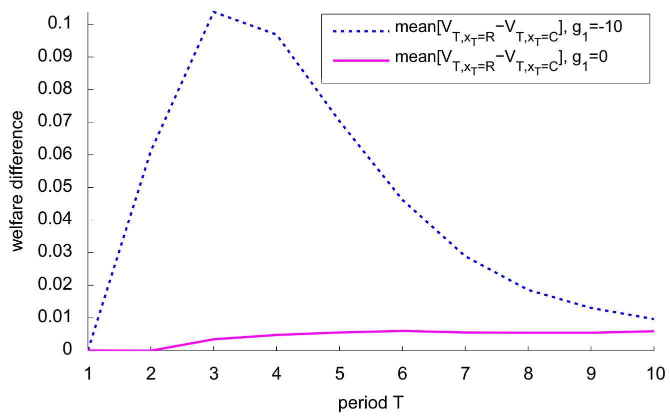

Fig. 4. Pressure to re-optimize. Notes: the figure plots the mean period T expectation of the gain in discounted welfare due to a re-optimization in period T, in simulations of imperfect credibility with $\alpha=4$. In all simulations, the shocks $(\varepsilon_{u,t},\varepsilon_{g,t},x_t)$ are drawn from their respective distributions. For the cases represented by the dotted line and the solid line, simulations are initialized at $u_1=0$, $g_1=-10$ and $u_1=0$, $g_1=0$, respectively. The innovations and re-optimization shocks $(\varepsilon_{u,t},\varepsilon_{g,t},x_t)$ are set to be the same across scenarios. While the last two terms in Eq. (9) make the problem recursive, they are not welfare relevant and consequently they are omitted from the welfare calculations. Thus, the welfare measure is equivalent to computing the discounted sum of the period utility function in Eq. (6).

future inflation, and members of the U.S. Congress have openly debated proposals to replace the Fed's dual mandate by an inflation target in order to force the Fed onto a tighter policy path.[18] The public discourse has not gone unnoticed among policymakers. Chairman Ben Bernanke himself stated in a Time Magazine article honoring him as "Person of the Year 2009": "It is true that the Federal Reserve faces a lot of political pressure and is unpopular in many circles."

4. Inference on policy credibility in the U.S.

Analyzing publicly accessible central bank communication, the model can inform on the level of credibility for the U.S. Federal Reserve. Section 5 will perform a similar analysis for the Swedish Riksbank. For both cases, α lies in the neighborhood of 2.

4.1. Formal evaluation of qualitative statements

Throughout 2009, both the vice chairman Kohn and chairman Bernanke stated repeatedly their intention to follow an interest rate policy that would prevent inflation and the output gap from rising above their long-run target values, contrary to the optimal policy under full commitment (see Kohn, 2009a; Bernanke, 2009, and the discussion in Walsh, 2009). Most explicitly on October 9, 2009 Kohn states: "To be sure, we have not followed the theoretical prescription of promising to keep rates low enough for long enough to create a period of above-normal inflation." (Kohn, 2009b).[19]

Examining these qualitative implications for the paths of the output gap and the inflation rate shows that for the model to deliver results consistent with Kohn (2009b) the level of credibility α cannot exceed 2. Specifically, the algorithm employed follows the parameterization in Table 1 and seeks the values of α and g_1, the demand shock in the initial period, that minimize the quadratic distance function $d(\alpha,g_1)$ with

$$d(\alpha,g_1)\equiv\omega_1^y(y_1(\alpha,g_1)-y_{2009:Q3})^2+\omega_1^\pi(4\pi_1(\alpha,g_1)-\pi_{2009:Q3})^2+\sum_{j=2}^{T}d_j(\alpha,g_1),$$

$$d_j(\alpha,g_1)\equiv\omega_j^y\max(\overline{y}_j(\alpha,g_1),0)^2+\omega_j^\pi\max(4\overline{\pi}_j(\alpha,g_1),0)^2. \tag{10}$$

The first two terms capture the distance of the model output gap and annualized inflation from their counterparts in the data at the time of Kohn's speech. The two summation terms implement the qualitative statement of Kohn (2009b) quantitatively. For given α and g_1, the value of the criterion function increases whenever the expected path of the output gap or inflation exceed their long-run target values. In the baseline specification of the distance function, it is set $T=20$, $\omega_i^\pi=1$, and $\omega_i^y=1$ for each i. The initial values for the output gap and annualized inflation in the data are $y_{2009:Q3}=-8\%$ and $\pi_{2009:Q3}=-1.3\%$.[20]

[18] For the discussion of inflation scares see Krugman (2009). For documentation on the resurrected debate on inflation targeting see Felsenthal (2011).

[19] For additional discussion of this quote, see also King (2010).

[20] The value $y_{2009:Q3}=-8\%$ is consistent with the CBO or a linearly quadratic detrended output gap measure. The value $\pi_{2009:Q3}=-1.3\%$ is calculated in deviation to an implicit inflation target of 2%. The model is simulated 10 000 times for 20 periods by drawing the shocks $(\varepsilon_{u,t},\varepsilon_{g,t},x_t)$ from their respective distributions to calculate the mean transition paths for the output gap and inflation. In an alternative specification, the weights are fixed at $\omega_i^\pi=1$ and $\omega_i^y=16\lambda$, where λ is the weight on the output gap in the central bank's period welfare function, but the main results are not changed.

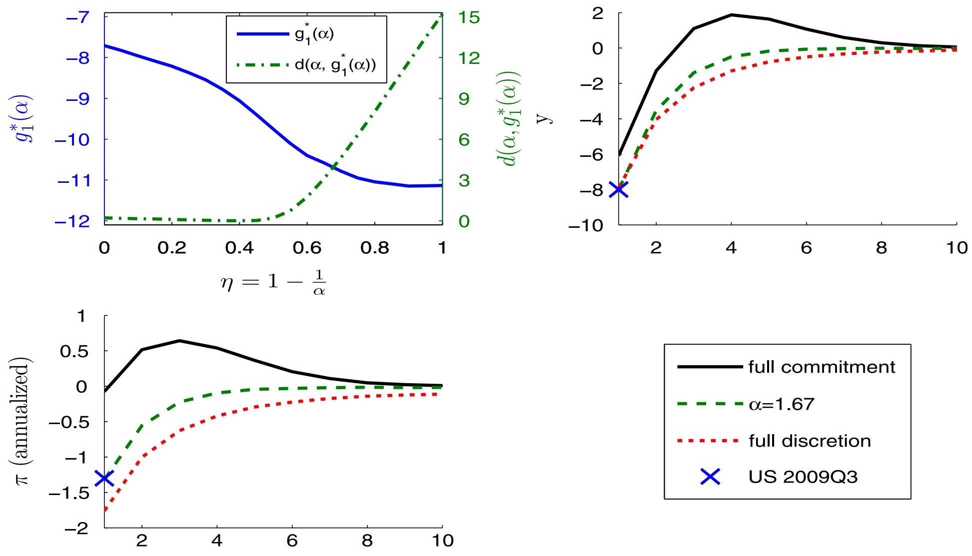

Fig. 5. Credibility of U.S. monetary policy. Notes: the first panel plots the distance function for difference values of the re-optimization probability $\eta = 1-(1/\alpha) \in [0,1]$, evaluated at the optimized value of $g_1^*(\alpha)$, which is also depicted. The remaining plots show the responses of the output gap and inflation at different values of credibility. The shocks are initialized at $u_1 = 0, g_1^*(\alpha)$, and $(\varepsilon_{u,t}, \varepsilon_{g,t}) = 0\ \forall t \geq 2$. The remaining parameters follow the values in Table 1. All histories regarding the commitment shock are considered (i.e. $x_t \in \{C,R\}$) for the computation of the means. For the full commitment and full discretion cases, there is no uncertainty with regard to x_t shocks.

Fig. 5 shows the value of the objective function for the re-optimization probability $\eta = 1-(1/\alpha) \in [0,1]$ (dashed line, right scale), evaluated at its optimized value of the demand shock $g_1^*(\alpha)$ (solid line, left scale). The distance function $d(\alpha, g_1^*(\alpha))$ is close to zero for values of η below 0.5, and reaches its minimum at $\eta = 0.4$ or $\alpha = 1.67$. The descriptive statements of Federal Reserve officials over the course of 2009 thus reflect a credibility level α below 2. As more information about the Federal Reserve's internal views during 2009 is released over time, it may become feasible to draw sharper conclusions about the Federal Reserve's credibility.

The remaining two panels in Fig. 5 contrast the mean paths of inflation and the output gap for $\alpha = 1.67$ with the paths derived under full commitment and full discretion. The model under full commitment cannot avoid the expected overshooting of policy targets or match the large recession and subdued inflation in earlier periods. Under full discretion and $\alpha = 1.67$, lack of strong forward guidance implies a sharper reduction in economic activity, although the demand shock reduces in size to $g_1^*(\alpha = 0) = -8$ and $g_1^*(\alpha = 1.67) = -9$, respectively. The objective function reaches its minimum at $\alpha = 1.67$ rather than $\alpha = 0$, as the improved fit in initial conditions compensates for the slightly worse performance with respect to the overshooting of policy targets in later periods. As reported in Appendix D, a model with modest price indexation implies a similar degree of central bank credibility.

4.2. Discussion

In explaining their approach, policymakers have tried to shift attention away from credibility concerns by emphasizing fears of losing control over inflation expectations.[21] However, such fears may still reflect a low degree of credibility. Although long-run inflation expectations are well-anchored for any degree of credibility, inflation can be hard to control in the medium-run if credibility is low. Another explanation attempt originates from central banks' preference for models with backward-looking expectations or learning dynamics. However, insofar as a model features some forward-looking dynamics, the key mechanism of lowering current real interest rates through promising higher future inflation is still at work. Furthermore, as shown in Appendix D, the presence of backward-looking behavior may aggravate a recession thus creating room for forward guidance to ameliorate the effects of a given negative shock.[22]

5. Inference on policy credibility in Sweden

To assess monetary policy credibility in Sweden, differences between market expectations and the Riksbank's announced interest rate paths can be employed. Since February 2007, the Riksbank has published its intended (mean) path for the

[21] Kohn (2009b) elaborates on such arguments and mentions "the risk of altering inflation expectations beyond the horizon that is desirable".
[22] Finally, the private sector choosing to dismiss announcements and engaging in backward-looking behavior may also be a consequence of low central bank credibility. Evans and Ramey (1992), Brock and Hommes (1997) and the literature that followed model private agents as choosing among different predictors based on their performance and availability. If the central bank disseminates and produces credible forecasts, then a larger fraction of private agents is likely to form rational expectations (see the discussions in Tobin, 1972; Sargent et al., 1973).

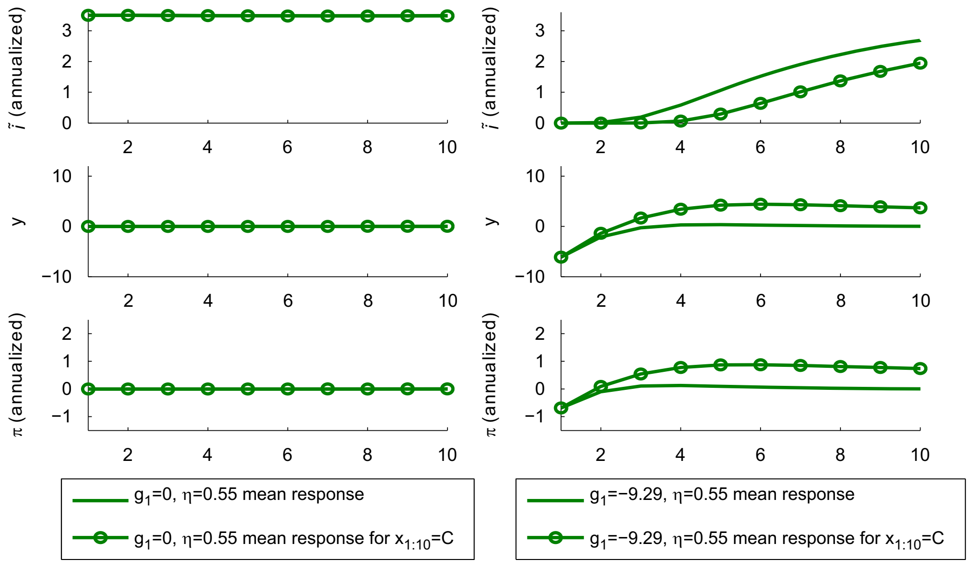

Fig. 6. Forecasts and policy renouncements. Notes: the figure plots the mean transition dynamics in response to a negative and large demand shock causing the interest rate to reach its zero lower bound. The simulations are initialized at $u_1=0$, $g_1=-10$. For the case of the solid line, the shocks $(\varepsilon_{u,t},\varepsilon_{g,t},x_t)$ are drawn from their respective distributions. For the case of the dot-dashed line, the shocks $(\varepsilon_{u,t},\varepsilon_{g,t})$ are similarly drawn from their respective distributions, but with $x_t=C\ \forall t\geq 1$.

repo-rate, the short-term interest rate used by the Riksbank to achieve its policy goals. To judge the effectiveness of its announcements, the Riksbank also publishes the market expectation for the interest rate path derived from forward rates.[23]

5.1. Market expectations and announced policy

Before turning to the Swedish experience in detail, it is worthwhile pointing out that the announced interest rate path of a central bank with imperfect credibility can differ significantly from market expectations at the zero lower bound, but does not differ otherwise.

Both in the model and in reality, commitments to future actions can only influence expectations and ultimately market outcomes if these commitments are clearly announced to the public as highlighted in the discussion of Fig. 1. To facilitate real-life communication central banks may be reluctant to incorporate their own expected re-optimizations in their published real-time forecast. In Fig. 6, the first path (solid line) – depicting the mean over all possible histories of the cost-push, demand, and re-optimization shocks – can be interpreted as reflecting market expectations. The central bank's announced forecast is represented by the second path (solid-dotted line) which depicts the mean over all possible histories of the cost-push and demand shock under the assumption that the central bank honors by chance its state-contingent commitments in each period, i.e., $x_t=C\ \forall t\geq 1$.[24]

Away from the zero bound, the mean paths announced by the central bank and those expected by the private sector, shown in the left panels of Fig. 6, basically coincide for two reasons. First, the interest rate can freely adjust to offset demand shocks. Second, negative and positive cost-push shocks affect the economy symmetrically and cancel each other on average, whether or not the paths reflect possible re-optimizations. When the economy is at the zero lower bound (right panel of Fig. 6), demand shocks cannot be fully stabilized and the zero lower bound inequality induces asymmetric effects. The announced mean interest rate forecast of the central bank lies strictly below the mean interest rate forecast of the private sector, as the latter takes into account the possibility of future re-optimizations. Consistent with tighter expected monetary policy, the market also expects a smaller rise in the output gap and a smaller rise in inflation in the future. These predictions of the model, both away from and at the zero lower bound, fit well with recent experience of the Swedish Riksbank.

5.2. Quantitative analysis for Sweden

As shown in the left panels of Fig. 7, the Riksbank reduced the repo-rate by 100 basis points to 1% on February 11, 2009. As was the case on earlier dates, the new repo-rate path and corresponding market expectations remained well aligned.

[23] The market expectations of the repo-rate are calculated as the forward rate from the prices of interest derivatives and forward rate agreements with different maturities corrected for premia for maturity, liquidity, and credit risk. Sveriges Riksbank (2009) and Svensson (2009, 2010) provide more details on the data and draw connections to credibility and forecast targeting at different times.

[24] Importantly, this analysis does not assume that the degree of commitment perceived by the central bank α_{cb} lies above the value perceived by the private sector α_{ps}. The interested reader is referred to Appendix D.5 for the case $\alpha_{ps}<\alpha_{cb}$.

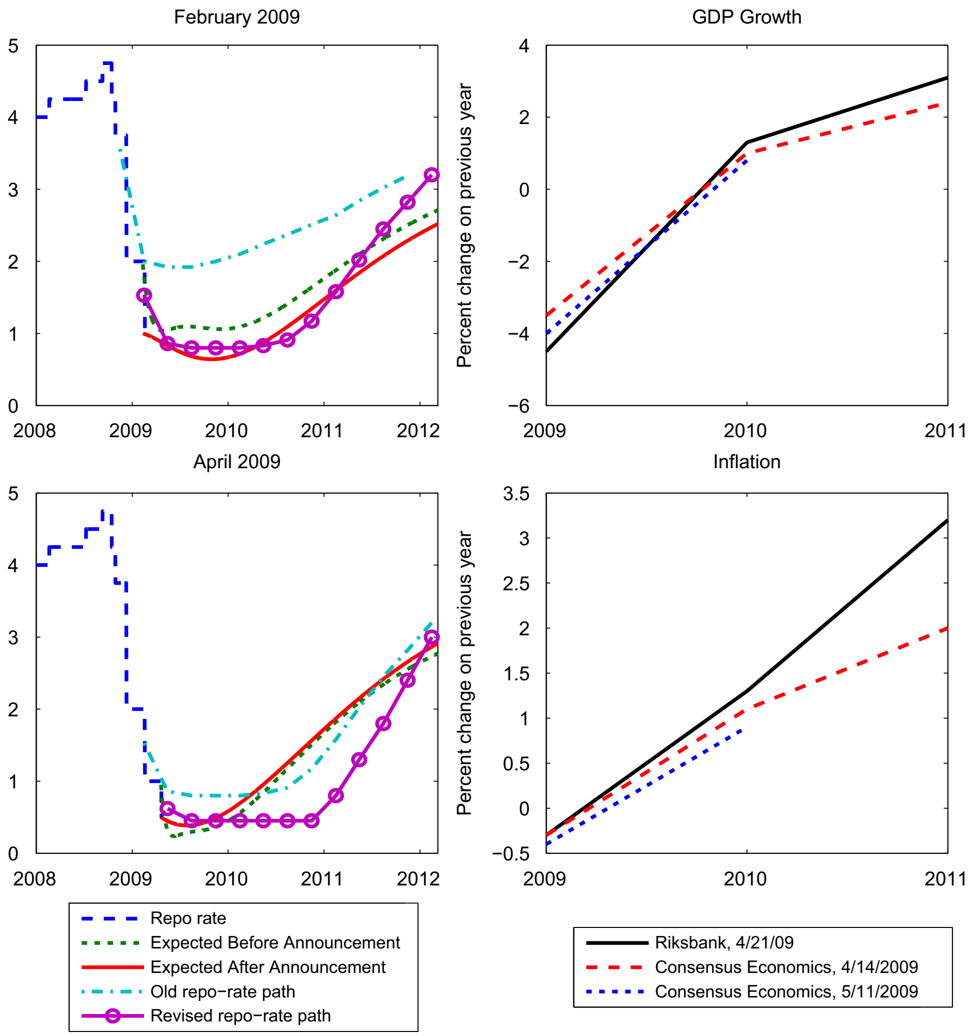

Fig. 7. Low credibility and market expectations. Notes: the left column plots the Riksbank's forecast of the repo-rate path as announced in February and April 2009 in the upper and lower panels, respectively, along with the old forecast, the historical path, and the market expectation of the path both preceding and following each announcement. The right column plots Riksbank's forecasts for inflation and GDP growth announced on April 21, 2009. Also shown are means of long-term and nearer-term forecasts surveyed on April/14/2009 and May/11/2009, respectively (sources: Statistics Sweden and the Riksbank, Consensus Economics).

At the April 21 meeting, the repo-rate was reduced further and approached the effective lower bound.[25] This time, the repo-rate path and market expectations decoupled with the latter suggesting considerably faster tightening. These patterns are also present at later dates in 2009 (not displayed); market expectations are not aligned with the repo-rate path only in periods of very low interest rates. Being able to replicate such behavior, the model lends support to the Riksbank's own assessment that it experienced a credibility problem in 2009. The Riksbank concedes this possibility in its annual monetary policy report, Sveriges Riksbank (2009).

The credibility argument goes unchallenged if confronted with the April 2009 private sector and central bank forecasts for Swedish GDP growth and inflation. In line with the theoretical predictions, the right panels of Fig. 7 show that the inflation and GDP growth outlook reported by Consensus Economics (both on April 14 and May 11) were below the Riksbank's corresponding forecasts (dated April 21).[26] In light of these findings, attempts to explain the misalignment of the interest rate paths by forecast divergence with respect to GDP growth and inflation seem unconvincing. Absent strong

[25] For reasons not considered in the model, central banks are often reluctant to set interest rates exactly at zero and operate with a positive lower bound. Although the repo-rate was lowered to 25 basis points later in 2009, the Riksbank argued in April 2009 that 50 basis point would be the lowest operational level for the repo-rate.

[26] The timing of private sector forecasts relative to the central bank's is of minor importance, as market expectations for the repo-rate before and after April 21 remained seemingly unchanged with private forecasters being slightly more pessimistic in May 2009.

credibility problems, a lower private sector forecast of inflation and output relative to the central bank's forecast is inconsistent with the private sector expecting faster monetary tightening.

Having established that imperfect credibility is a promising explanation for the Swedish experience in April 2009, a procedure similar to the one for the U.S. can inform about the Riksbank's level of credibility by searching for values of α and the demand shock that minimize a quadratic distance function. Aside from the distance of the output gap and inflation between the model generated values and the data in April 2009, the objective function also takes into account the spread between the announced interest rate path and the path expected by the private sector. The unique minimum of the new distance function occurs at $\alpha = 2.22$. Appendix D.5 provides details and additional results.

6. Conclusion

When the nominal interest rate reaches zero, central bank credibility and the public's perception thereof are crucial for the conduct of monetary policy, as the lack of credibility cannot be compensated for by additional movements in the contemporaneous interest rate. In reality, central banks have some credibility, but they typically do not operate under full commitment. Central banks announce and describe future policies to influence current economic decisions, but markets realize that not all state-contingent promises will necessarily be honored. To address these issues, we analyzed the optimal monetary policy at the zero bound in a setting that allows for imperfect credibility.

Extension of the theoretical framework are easily imagined. Considering more complex models and imperfect credibility settings is desirable. For instance, central banks have also used unconventional measures to affect the economy and interest rate spreads at the zero lower bound. While incorporating such features is certainly interesting, it is necessary to first understand the effects of imperfect credibility on conventional monetary policy. Furthermore, as unconventional monetary policy and fiscal policy face limits with regard to their credibility and fiscal sustainability as discussed in Goodfriend (2011), forward guidance through an announced path of the interest rate remains a tool that central banks may want to employ at the zero lower bound.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jmoneco.2012.01.002.

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