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Roberto Billi

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Telephone international: +46 8 787 01 00
E-mail: info@riksbank.se

Price Level Targeting and Risk Management*

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Abstract

Many argue that, because the outlook for the economy is uncertain, monetary policy should apply a risk management approach by raising the policy interest rate gradually from its lower bound. Using a small New Keynesian model, I study the impact of outlook uncertainty on the economic performance of a central bank with a target for the price level or the level of nominal gross domestic product. I show that, in the presence of persistent supply and demand shocks, a price-level target is more effective at mitigating outlook uncertainty because it induces greater policy inertia and improves the tradeoffs faced by the central bank.

Keywords: nominal level targets, optimal policy, inertial Taylor rule

JEL: E31, E52, E58

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1 Introduction

Many argue that, because the outlook for the economy is inherently uncertain, central banks should apply a risk management approach to monetary policy, to determine the appropriate timing and pace of the liftoff of the policy interest rate from its zero lower bound (ZLB). For example, during a ZLB episode, if the economic recovery turns out to be stronger than anticipated, the central bank can raise earlier the policy rate or remove accommodation at a faster pace. However, if the central bank overstated the strength of the economic recovery and wants to add policy stimulus, the scope for lowering the policy rate is limited by its ZLB. The central bank, thus, faces an asymmetric risk in setting monetary policy, because of uncertainty about the evolution of the economy and the ZLB constraint.[1]

It, thus, would be prudent for a central bank to raise the policy interest rate gradually from the ZLB, to reduce the risk of chocking the recovery and thus being forced to revert back to easing policy. One issue, in fact, is that an unexpected policy reversal would tend to erode confidence in the central bank's ability to understand and stabilize the economy. It would also lead to question the usefulness of inflation targeting as a monetary policy framework. Whereas inflation targeting worked well for many central banks before the Great Recession, in light of its recent limitations there are debates over whether it should now be replaced.

This article sheds light on such pressing concerns for central banks. It shows that, when the ZLB threatens, uncertainty in the economic outlook hampers the effectiveness of monetary policy in stabilizing the economy, but the extent to which a central bank mitigates uncertainty depends crucially on its policy framework. In particular, the article compares the effects of an uncertain outlook for the economic performance of two monetary-policy frameworks, which are considered by some as preferable to inflation targeting, a target for the price level or the level of nominal gross domestic product (GDP). Such alternatives are conceptually appealing because the central bank then wants to make up for any past shortfalls from its nominal anchor, which ensures policy stimulus during ZLB episodes.

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[1] This article adopts the standard practice of referring to a zero lower bound for nominal interest rates, but the recent experience with negative nominal interest rates in Denmark, Japan, Sweden, Switzerland, and the eurozone suggests the effective lower bound is somewhat below zero. See Svensson (2010) for a discussion.

As studied recently by Billi (2016), the setting here is a small New Keynesian model with the central bank operating under optimal discretion and facing a ZLB on nominal interest rates. In the model, three types of shock buffet the economy. On the supply side of the economy, technology shocks push output gaps and prices in the same direction, whereas cost-push shocks instead cause an inflation-output tradeoff. On the demand side, adverse demand shocks and the ZLB constraint create a tradeoff between stabilizing current and future output, because it is desirable for the central bank in a ZLB episode to promise to induce an economic expansion after the ZLB episode. The stylized model offers a clear illustration of such tradeoffs in the evaluation of the policy frameworks. Before the evaluation, the model is calibrated to recent U.S. data, with the conduct of monetary policy described by a simple policy rule, namely a version of the Taylor rule with interest-rate smoothing, which features prominently in Federal reserve discussions. In the analysis the shocks are persistent, to generate propagation in the model as in the data. The policy frameworks are then ranked in terms of economic performance, based on the model's social welfare function.

Billi (2016) highlighted the following. First, if the economy is only subject to technology shocks, nominal-GDP-level targeting is clearly inferior because it fails to insulate the economy from technology shocks. In contrast, strict-price-level targeting and the simple policy rule fully insulate the economy from technology shocks. Second, if the economy is only subject to cost-push shocks, the outcome depends on the persistence of the shocks. With persistent cost-push shocks, strict-price-level targeting is superior.[2] Third, if the economy is only hit by demand shocks, nominal-GDP-level targeting is an inferior targeting framework, because it involves less policy inertia and, ironically, leads to larger falls in nominal GDP during ZLB episodes. The simple policy rule is even less effective and causes large fluctuations in output and prices. Fourth, accounting for all three types of shock, strict-price-level targeting is superior, because

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[2] More specifically, faced with only purely-temporary shocks to inflation (namely cost-push shocks, which are assumed to follow a white-noise stochastic process), nominal-GDP-level targeting and the simple policy rule may be preferable because they require the burden of shocks to be shared by prices and output. Strict-price-level targeting instead causes costly fluctuations in output. However, if shocks to inflation are persistent (cost-push shocks follow an autoregressive stochastic process), nominal-GDP-level targeting results in costly price fluctuations, and the two targeting frameworks are similarly effective in terms of social welfare, whereas the simple policy rule is less effective and causes even larger changes in prices.

it involves greater policy inertia and thus improves the tradeoffs faced by the central bank. Finally, such results are robust to a wide range of alternate calibrations.

This article introduces, into such a setting, a risk management approach to monetary policy. In the analysis, in addition to the aforementioned policy frameworks, also considered is the optimal commitment policy to be used as a benchmark for the evaluation.[3] The analysis considers two distinct economic environments, as regards the outlook for the economy. In one environment, agents rationally account for the existence of uncertainty about the future state of the economy (rational expectations). In the other environment, even though future shocks buffet the economy, the future state of the economy is assumed to be known in advance with absolute certainty (naive expectations). Thus, the distinctive feature of the two environments is, precisely, whether the central bank in setting monetary policy rationally accounts for uncertainty in the economic outlook. Outlook uncertainty is important for the economic performance of the policy frameworks because of the asymmetric risk imposed by the presence of the ZLB constraint.[4]

Comparing the model outcomes from such two distinct environments, the analysis produces two main results, related to the types of shock buffeting the economy. First, if the economy is only subject to supply shocks, that is technology and cost-push shocks only, economic performance is then the same in the two economic environments. The reason is that supply shocks do not lead to ZLB episodes in this analysis.[5] Still, strict-price-level targeting is a superior targeting framework, because it fully insulates the economy from technology shocks and transfers the burden of cost-push shocks onto output. In contrast, under nominal-GDP-level targeting, persistent cost-push shocks give rise to costly inflation fluctuations. However, inflation volatility is even larger under the simple policy rule.

As a second result, if the economy is also hit by demand shocks, uncertainty in the economic outlook then hampers the effectiveness of the central bank in stabilizing the economy

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[3] Billi (2016) did not consider the optimal commitment policy.

[4] Under rational expectations, the mere possibility of hitting the ZLB, even when not yet binding, shapes expectations in the economy. However, in the naive-expectations economy, the ZLB affects expectations only when actually binding.

[5] In the absence of the ZLB constraint, the model displays certainty equivalence and the outcome is independent of whether the future is uncertain.

during ZLB episodes. The deterioration in economic performance from outlook uncertainty is generally worst under nominal-GDP-level targeting, followed by the simple policy rule and then by strict-price-level targeting. The reason for such outcomes is that strict-price-level targeting induces greater policy inertia and, therefore, improves the tradeoffs faced by the central bank. At the same time, there is generally less scope for the simple policy rule to mitigate outlook uncertainty, because the simple policy rule leads to substantially less frequent encounters with the ZLB.[6]

In the New Keynesian literature, adverse demand shocks and the ZLB create a tradeoff between stabilizing current and future output, because it is desirable in a ZLB episode to promise to induce an economic expansion after the ZLB episode. As this article shows, uncertainty in the economic outlook worsens such a tradeoff, facing the central bank in the setting of monetary policy. As a consequence, monetary policy is not nearly as effective in stabilizing the economy as implied by the assumption that the outlook is know in advance with certainty. Because outlook uncertainty hampers the effectiveness of monetary policy, it is desirable for the central bank to raise the policy interest rate more gradually from the ZLB.

As the literature has shown, facing a ZLB constraint, monetary-policy frameworks that involve inertia, that is history-dependent policies, can lead to a better economic performance. Eggertsson and Woodford (2003), Jung, Teranishi and Watanabe (2005), Wolman (2005), and others, studied the ZLB and history-dependent policies but in the absence of outlook uncertainty.[7] The interaction between the ZLB and outlook uncertainty was studied by Orphanides and Wieland (2000), Adam and Billi (2006, 2007), Nakov (2008), Levin et al. (2010), Nakata (2013), Basu and Bundick (2014, 2015), Johannsen (2014), Plante, Richter and Throckmorton

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[6] However, if demand shock are more persistent than in the baseline calibration, there is more scope for the simple policy rule to mitigate outlook uncertainty and, therefore, the deterioration in economic performance from outlook uncertainty is then worst under the simple policy rule.

[7] Svensson (1999), Vestin (2006), and Giannoni (2014) argued for price-level targeting versus inflation targeting in the absence of the ZLB constraint. Related to this, the desirability of a price-level target when the ZLB is a constraint was stressed by Eggertsson and Woodford (2003), Svensson (2003), Wolman (2005), and Evans (2012), among others. A shortlist of recent proponents of nominal-GDP-level targeting includes Hatzius and Stehn (2011, 2013), Sumner (2011, 2014), Woodford (2012, 2013), Frankel (2013), and others. There is also an extensive literature on the notion of nominal income *growth* targeting, at first suggested by Meade (1978) and Tobin (1980) and then studied by Bean (1983), Taylor (1985), West (1986), McCallum (1988), Hall and Mankiw (1994), Jensen (2002), Walsh (2003), and others.

(2014), Evans et al. (2015), Seneca (2016), and others.[8] Relative to the existing literature, this article shows that the central bank mitigates outlook uncertainty more effectively under strict-price-level targeting than under nominal-GDP-level targeting. Thus, in a comparison between the two alternatives, a concern for risk management is a reason for central banks to prefer a target for the price level.

Section 2 describes the model and Section 3 introduces the monetary-policy frameworks. Section 4 describes the different environments, as regards the outlook for the economy. Section 5 presents the model outcomes and policy evaluation. Section 6 concludes. The Appendix contains technical details on the model solution.

2 The model

I use a small New Keynesian model as described in Woodford (2010), but I take into account that the nominal policy rate occasionally hits the ZLB. The behavior of the private sector is summarized by two structural equations, log-linearized around zero inflation, which describes the demand and supply sides of the economy.

On the demand side of the model economy, the Euler equation describes the representative household's expenditure decisions,

$$y_t = E_t y_{t+1} - \varphi \left(i_t - r - E_t \pi_{t+1} - v_t \right), \tag{1}$$

where E_t denotes the expectations operator conditional on information available at time t. y_t is output measured as the log-deviation from trend. π_t is the inflation rate, the log-change of prices from last period, $p_t - p_{t-1}$. Moreover, $i_t \geq 0$ is the short-term nominal interest rate constrained by a ZLB, whereas $r > 0$ is the steady-state real interest rate.[9] $\varphi > 0$ is the interest elasticity of real aggregate demand, capturing intertemporal substitution in household spending. The *demand shock*, v_t, represents other spending, such as government

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[8] Evans et al. (2015) also provide statistical evidence, based on Federal Reserve communications in recent decades, that risk-management considerations have been quite influential for actual monetary policy.

[9] Thus, $i_t - r - E_t \pi_{t+1}$ is the real interest rate in deviation from steady state.

spending, which has asymmetric effects on the economy due to the ZLB. A positive demand shock can be countered entirely by raising the nominal interest rate, whereas a large adverse shock that leads to hitting the ZLB causes an economic downturn.

On the supply side of the economy, the Phillips curve describes the optimal price-setting behavior of firms, under staggered price changes à la Calvo,

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + u_t, \tag{2}$$

where $\beta \in (0,1)$ is the discount factor of the representative household, determined as $1/(1+r)$. The slope parameter $\kappa > 0$ is a function of the structure of the economy.[10] $x_t \equiv y_t - y_t^n$ is the output gap in the economy. y_t^n is the natural rate of output, or potential output, the output deviation from the trend that would prevail in the absence of any price rigidities, which represents a *technology shock*. A positive technology shock implies slack in economic activity and downward pressure on prices, whereas a negative shock implies a strong economy and puts upward pressure on prices. Moreover, u_t is a cost-push shock, or a *mark-up shock* resulting from variation over time in the degree of monopolistic competition between firms, which creates an inflation-output tradeoff for monetary policy.

In the model economy, the three types of exogenous shocks (y_t^n, u_t, v_t) are assumed to follow AR(1) stochastic processes, with first-order autocorrelation parameters $\rho_j \in (-1,1)$ for $j = y^n, u, v$. Moreover, $\sigma_{\varepsilon j}\varepsilon_{jt}$ are the innovations that buffet the economy, which are independent across time and cross-sectionally, and normally distributed with mean zero and standard deviations $\sigma_{\varepsilon j} \geq 0$.

Finally, the policy frameworks to be considered are evaluated based on the model's social welfare function, a second-order approximation around zero inflation of the lifetime utility function of the representative household,

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[10] In this model $\kappa = (1-\alpha)(1-\alpha\beta)\alpha^{-1}\left(\varphi^{-1}+\omega\right)(1+\omega\theta)^{-1}$, where $\omega > 0$ denotes the elasticity of a firm's real marginal cost. $\theta > 1$ is the price elasticity of demand substitution with firms in monopolistic competition, and thus the seller's desired markup is $\theta/(\theta-1)$. Moreover, $\alpha \in (0,1)$ is the share of firms keeping prices fixed each period, so the implied duration between price changes is $1/(1-\alpha)$.

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_t^2 + \lambda \left(x_t - x^*\right)^2\right], \tag{3}$$

where $\lambda = \kappa/\theta$ is the weight assigned to stabilizing the output gap relative to inflation. x^* is the target level of the output gap, which stems from monopolistic competition and distortion in the steady state. Output subsidies are assumed to offset the monopolistic distortion so that the steady state is efficient, $x^* = 0$. As a result, in the analysis, there is no inflation bias but a stabilization bias due to discretionary policy.

3 The policy frameworks

The conduct of monetary policy is first described by a simple rule, to be used for the calibration of the model. It is then described by optimal discretion with a nominal-level target, namely a target for the price level or nominal-GDP level, hardwired into the central bank's objective function. Finally, monetary policy is represented by optimal commitment, used as a benchmark for the evaluation. Thus, in total, four different policy frameworks are considered in this analysis.

The *simple policy rule* employed is a version of the Taylor rule subject to the ZLB constraint, along the lines of Taylor and Williams (2010):

$$i_t = \max\left\{0, \phi_i i_{t-1}^u + (1-\phi_i)\left[r + \phi_\pi \pi_t + \phi_x \left(y_t - y_t^n\right)\right]\right\}, \tag{4}$$

where ϕ_π and ϕ_x are positive response coefficients on inflation and the output gap, respectively. The rule incorporates smoothing in the behavior of the interest rate, through a positive value of the coefficient ϕ_i. Moreover, i_{t-1}^u denotes an unconstrained or notional interest rate, the preferred setting of the policy rate in the previous period that would occur absent the ZLB constraint. Such an approach implies that the central bank compensates to some extent for the lost monetary stimulus due to the existence of the ZLB, even though the central bank does not commit to making up for past shortfalls from a nominal-level target.

Under optimal discretion, the central bank has an objective function rather than a simple rule and re-optimizes its policy decision in each period.[11] In such a setting, two monetary policy frameworks are considered. First, with *strict-price-level targeting* the objective function is assumed to take the form:

$$\min_{i_t \geq 0} E_t \sum_{j=0}^{\infty} \beta^j p_{t+j}^2,$$

where p_t is the log of the price level, which is equal to $p_{t-1} + \pi_t$. In this framework, the policymaker seeks to stabilize prices without concern for output stability and, therefore, transfers the entire burden of shocks onto output. The framework involves inertia in the behavior of policy, because the current policy decision depends on the past price level.

Second, with *nominal-GDP-level targeting*, the objective function now takes the form:

$$\min_{i_t \geq 0} E_t \sum_{j=0}^{\infty} \beta^j n_{t+j}^2,$$

where n_t is nominal GDP measured as the log-deviation from trend, which is equal to $p_t + y_t$. In this framework, the policymaker seeks to stabilize both prices and output, as opposed to focusing entirely on price stability, which now requires the burden of shocks to be shared by prices and output. As a consequence, however, the current policy decision involves relatively less dependence on the past price level, and the policymaker acts less in accordance with a precommitment to price stability, relative to strict-price-level targeting.

Finally, as a benchmark for the policy evaluation, I use the optimal plan, the *optimal commitment policy.* In such a framework, rather than re-optimizing a policy decision in each period as under optimal discretion, the policymaker is assumed able and willing to fully commit to its policy announcements, to maximize the welfare of the representative household. The central bank's objective function, in this ideal framework, is then the social welfare function, equation (3), described in the previous section.[12]

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[11] In this analysis, as in Woodford (2010), the outcome under optimal discretion corresponds to a Markov perfect equilibrium of the noncooperative game among successive policymakers, which implies that the central bank rationally accounts for how the current state of the economy affects future decisions.

[12] The planner chooses $\{\pi_t, x_t, i_t \geq 0\}_{t=0}^{\infty}$ to achieve $\min E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_t^2 + \lambda x_t^2\right]$.

4 Outlook uncertainty

Regarding the outlook for the economy, for each policy framework introduced above, two distinct environments are considered. In one environment the outlook is assumed to be known with absolute certainty, but in the other the outlook is known to be inherently uncertain.

In both economic environments, at equilibrium, the policymaker chooses a policy based on a response function $\mathbf{y}(\mathbf{s}_t)$ and a state vector $\mathbf{s}_t$. The corresponding expectations function is then given by

$$\mathbf{E}_t\mathbf{y}(\mathbf{s}_{t+1}) = \int \mathbf{y}(\mathbf{s}_{t+1}) f(\varepsilon_{t+1}) d(\varepsilon_{t+1}),$$

where $f(\cdot)$ is a probability density function of the future innovations that buffet the economy, with a standard deviation of $\sigma_\varepsilon \geq \mathbf{0}$. In such a setting, an equilibrium is then given by a response function and expectations function, $\mathbf{y}(\mathbf{s}_t)$ and $\mathbf{E}_t\mathbf{y}(\mathbf{s}_{t+1})$, which satisfy the equilibrium conditions of the model, derived in Appendix A.1.

Naive expectations. In the first environment, the future state of the economy is assumed to be known in advance with absolute certainty ($\sigma_\varepsilon = \mathbf{0}$). In such a setting, agents expect no further shocks to the economy, regardless of the existence of future shocks and the ZLB. As a consequence, the ZLB constraint affects expectations and the setting of policy only when the constraint binds in the economy, as shown by Eggertsson and Woodford (2003), Jung, Teranishi and Watanabe (2005), Adam and Billi (2006, 2007), Nakov (2008), and others. By ignoring the existence of uncertainty about the evolution of the economy, the model can be solved with a standard numerical method, as done in Orphanides and Wieland (2000), Reifschneider and Williams (2000), Williams (2009), Coibion, Gorodnichenko, and Wieland (2012), and Guerrieri and Iacoviello (2015), among others.[13]

Rational expectations. The second environment, however, takes into account the existence of uncertainty about the future state of the economy ($\sigma_\varepsilon > \mathbf{0}$). When the ZLB threatens, the mere possibility of hitting the ZLB causes expectations of a future economic downturn

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[13] Setting $\sigma_\varepsilon = \mathbf{0}$, then $\mathbf{E}_t\mathbf{y}(\mathbf{s}_{t+1})$ simplifies to $\mathbf{y}(\mathbf{s}_{t+1})$. Thus, as noted by Reifschneider and Williams (2000), expectations for future values of policy are fully consistent with the model's predictions for future economic conditions, subject to the assumption that all future shocks to the economy are zero.

and therefore prompts for adding policy stimulus today. But if the existence of uncertainty is ignored, as in the first environment, the effects of the ZLB are smaller because naive agents expect higher future inflation, which boosts economic activity and inflation during ZLB episodes. Thus, uncertainty in the outlook for the economy is important for economic performance because of the asymmetric risk imposed by the presence of the ZLB constraint. It is an asymmetric risk because the economic downturn from an unanticipated shock is larger than the effect of a shock of opposite sign. Such effects of uncertainty and the ZLB constraint were shown by Adam and Billi (2006, 2007), and Nakov (2008), among others. To solve the model accounting for outlook uncertainty, I use the same numerical procedure as in Billi (2011, 2016).[14]

5 The effects of outlook uncertainty

After calibrating the model, I study the impact of outlook uncertainty on the economic performance of the two targeting frameworks, relative to the optimal commitment policy. I also consider the performance of the inertial Taylor rule used for the model calibration. By comparing the model outcomes under the different frameworks, I show that outlook uncertainty hampers the ability of the central bank to stabilize the economy during ZLB episodes. I also show that the extent to which the central bank mitigates outlook uncertainty depends crucially on its policy framework.

5.1 Baseline calibration

The model economy is calibrated to U.S. data for recent decades, as in Billi (2016), with the conduct of monetary policy described by the inertial Taylor rule (4) that features prominently in Federal Reserve discussions. The values of the rule coefficients are taken from English, Lopez-Salido and Tetlow (2015), with ϕ_π set to 1.5, ϕ_x set to 1/4 (quarterly rates) and ϕ_i set to 0.85. The rule thus accounts for smoothing in the setting of the policy interest rate.

The values of the structural parameters of the model are also standard in the related

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[14] See Appendix A.2 for a description of the algorithm used to solve the model in both environments. The second environment is obtained by setting $\sigma_\varepsilon = \mathbf{0}$.

literature. Specifically, β is set to 0.99, to imply a steady-state interest rate of 4% annual. φ is set to 6.25.[15] The implied parameters κ and λ are then equal to 0.024 and 0.003 (quarterly), respectively. Finally, regarding the calibration of the shocks, $\rho_{y^n,u,v}$ are set to 0.8 to generate persistent effects on the economy. At the same time, $\sigma_{y^n,v}$ are set to 0.8% (quarterly) to try to replicate respectively the volatility of output and nominal interest rates in the data, whereas σ_u is set to 0.05% (quarterly) to match the inflation volatility in the data.[16]

Overall, as Billi (2016) showed, with the simple policy rule and baseline calibration, the model does a fairly good job in replicating the relevant features of recent U.S. data.[17] Moreover, accounting for persistent supply and demand shocks buffeting the economy, the ranking of the simple policy rule and two targeting frameworks was shown, in Billi (2016), to be robust to a wide range of alternate calibrations of the model.

5.2 Liftoff from the ZLB

Adverse demand shocks lead to ZLB episodes in this analysis. Using the calibrated model, Figure 1 shows the expected liftoff of the nominal interest rate from the ZLB after an adverse demand shock.[18] In each of the four panels of the figure, only one of the policy frameworks is considered. For example, the bottom-right panel shows the expected liftoff under the optimal commitment policy, both with naive expectations (dashed green line) and rational expectations (solid blue line), as regards the outlook for the economy, as well as the difference between the two economic environments (dash-dotted red line). In both environments, given the size of the shock, the weakness of the economy prompts the central bank to cut the nominal interest rate

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[15] α is set to 0.66, so the duration between price changes $1/(1-\alpha)$ is 3 quarters. θ is set to 7.66, so the markup over marginal costs $\theta/(\theta-1)$ is 15%. Moreover, ω is set to 0.47.

[16] The sample period used to calibrate the shocks is the same as in Billi (2016), 1984Q1-2014Q4, which ensures the results are directly comparable. Moreover, extending the sample to the latest available data does not affect the good fit of the model to the data.

[17] Still, output and inflation are somewhat less persistent in the model results than in the data, because this basic model, for the sake of simplicity, does not allow for structural propagation mechanisms that give rise to output and inflation inertia. As a consequence, the stylized model may understate the frequency and duration of ZLB episodes. Under the simple policy rule and baseline calibration, the model predicts that the policy rate hits the ZLB less than 3 percent of the time, and the expected duration of a ZLB episode is about three quarters (Table 2). In actuality, the federal funds rate has been near the ZLB from the end of 2008 to the end of 2015. See Section 2.4 of Billi (2016) for further details of the model calibration and fit to the data.

[18] Shown are expected paths after a -3.5 standard deviation demand shock, using the baseline calibration described in Section 5.1. The expected paths are obtained by averaging across 10,000 stochastic simulations.

all the way to the ZLB. However, as the panel shows, under the optimal commitment policy, outlook uncertainty results in a slower pace of policy normalization, as the nominal interest rate rises more gradually.

[Figure 1 about here]

Similarly, as the other panels in Figure 1 show, outlook uncertainty leads to a slower pace of policy normalization also under the other policy frameworks considered in the analysis, that is strict-price-level targeting, nominal-GDP-level targeting, as well as the simple policy rule.[19] In each of the policy frameworks, the reason for the slowdown of the pace of policy normalization is that, as noted earlier, the expectation of further adverse shocks hitting the economy prompts the central bank to provide additional policy stimulus to the economy.

To illustrate the economic performance of the policy frameworks, Figures 2 and 3 show the expected paths of the price level and nominal GDP level, respectively, during a ZLB episode.[20] As the bottom-right panels show, under the optimal commitment policy, prices and nominal GDP rise permanently, both with naive and rational expectations about the outlook for the economy.[21] The reason for the permanent increase in the price level is that, under the optimal commitment policy, the central bank's objective function is the social welfare function, which does not imply the price level as a policy goal. At the same time, prices and nominal GDP rise by more under rational expectations, because of the greater policy stimulus provided to the economy after the liftoff of the nominal interest rate from the ZLB (Figure 1).

[Figures 2 and 3 about here]

Regarding the economic performance of the simple policy rule and targeting frameworks, as the other panels in Figures 2 and 3 show, prices and nominal GDP fall after the liftoff from the ZLB, both with naive and rational expectations. In both environments, ironically,

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[19] Under the simple policy rule and naive expectations, in the top-left panel of Figure 1, the expected path of the nominal interest rate does not quite reach the ZLB for a three-standard-deviation shock (not shown). For this reason, the policy response to a somewhat larger shock is shown.

[20] Shown are expected paths after a -3 standard deviation demand shock, using the baseline calibration.

[21] Under the optimal commitment, during the first part of the ZLB episode, nominal GDP falls despite an increase in the price level (Figures 2 and 3). The reason is that, at the same time, real GDP falls (not shown).

nominal-GDP-level targeting results in a larger fall in nominal GDP, compared to strict-price-level targeting. The reason is that, as noted earlier, strict-price-level targeting implies a greater dependence of current policy decisions on the past price level, and thus a surge in economic activity and prices after the ZLB episode.[22] At the same time, in each of the policy frameworks, the downturn in the economy is deeper under rational expectations, because the expectation of further adverse shocks hitting the economy hampers the effectiveness of the central bank in stabilizing the economy during ZLB episodes. In sum, for each of the policy frameworks, outlook uncertainty and the ZLB constraint prompt the central bank to provide additional policy stimulus to the economy.

5.3 Effectiveness of monetary policy

The ability of the central bank to stabilize the economy depends on its policy framework. I rank the policy frameworks, considering supply and demand shocks. To start, Table 1 summarizes the performance of each policy framework in the presence of only supply shocks, namely technology shocks and mark-up shocks only, by setting σ_v to zero in the baseline calibration. The table reports the expected frequency and duration of ZLB episodes, as well as the welfare loss due to business cycles.[23] In the table, the top panel shows the results with naive expectations, the middle panel shows the outcome with rational expectations, and the bottom panel shows the difference between the two environments because of outlook uncertainty.

[Table 1 about here]

As the table shows, in each of the policy frameworks, there is no difference in economic performance between the two environments in the presence of supply shocks only. The reason is that, even though supply shocks generally result in a welfare loss due to fluctuations in

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[22] Under strict-price-level targeting, the real interest rate falls deeper below its equilibrium value (not shown), which implies a greater degree of monetary policy stimulus to the economy.

[23] To calculate the welfare loss, first the value of the objective function (3) is obtained by averaging across 10,000 stochastic simulations each 1,000 periods long after a burn-in period. This value is then converted into a permanent consumption loss, as explained in Appendix A.3.

inflation and output, supply shocks do not lead to ZLB episodes in this analysis.[24] Still, performance is different under the two targeting frameworks, with strict-price-level targeting resulting in a smaller total welfare loss from the supply shocks relative to nominal-GDP-level targeting. This difference in performance occurs because, as noted earlier, nominal-GDP-level targeting fails to insulate the economy from technology shocks and results in fluctuations in inflation and output. In addition, under nominal-GDP-level targeting, persistent mark-up shocks give rise to costly inflation fluctuations. However, inflation volatility is even larger under the simple policy rule. Thus, both targeting frameworks lead to a better economic performance regarding total welfare relative to the simple policy rule, even if the economy is hit by supply shocks only.

I now introduce also demand shocks in the policy evaluation. Table 2 summarizes the performance of each policy framework in the presence of both supply and demand shocks, using the baseline calibration. As the table shows, adding the demand shocks into the analysis does not change the ranking of the policy frameworks. However, because demand shocks lead to ZLB episodes, economic performance is now different in the two environments because of outlook uncertainty. In each of the policy frameworks, outlook uncertainty leads to an increase in both the frequency and duration of ZLB episodes, because outlook uncertainty hampers the effectiveness of the central bank in stabilizing the economy during ZLB episodes.

[Table 2 about here]

As the table also shows, because demand shocks lead to ZLB episodes, outlook uncertainty has adverse effects on economic performance. In each of the policy frameworks, the expectation of further shocks to the economy now causes an increase in the volatility of both inflation and output. However, the deterioration in economic performance from outlook uncertainty is different under the two targeting frameworks, with strict-price-level targeting resulting in a smaller welfare loss from outlook uncertainty, relative to nominal-GDP-level targeting. The reason is that, both with naive and rational expectations, strict-price-level targeting implies

---

[24] As a robustness check, the standard deviations of the technology shock and mark-up shock were each raised by 50% relative to the baseline calibration, but the larger supply shocks still did not lead to ZLB episodes in the simulations (not shown). Absent the ZLB constraint the model displays certainty equivalence.

greater policy inertia and, therefore, improves the tradeoffs faced by the central bank. At the same time, nominal-GDP-level targeting results in a smaller welfare loss from outlook uncertainty, relative to the simple policy rule. Both with naive and rational expectations, there is less scope for the simple policy rule to mitigate outlook uncertainty, because the simple rule leads to substantially less frequent encounters with the ZLB.[25]

To increase the impact of outlook uncertainty on the economic performance of the policy frameworks, I raise the likelihood of hitting the ZLB. To do so, I first increase the volatility of the demand shock, relative to the baseline. Table 3 summarizes the performance of each policy framework in the presence of both supply and demand shocks, but demand shocks are assumed to be substantially larger than in the baseline.[26] The table shows that, even in the presence of much larger demand shocks, the ranking of the policy frameworks is still the same as in the baseline. Moreover, the deterioration in economic performance from outlook uncertainty is still worst under nominal-GDP-level targeting, followed by the simple policy rule and then by strict-price-level targeting.

[Table 3 about here]

I also increase the persistence of the demand shock relative to the baseline, with Table 4 summarizing the results.[27] As the table shows, increasing the persistence of the demand shock does not change the ranking of the policy frameworks, relative to the baseline. However, the deterioration in economic performance from outlook uncertainty is now worst under the simple policy rule, followed by the targeting frameworks. The different ranking occurs because, under this calibration, there is now somewhat more scope for the simple policy rule to mitigate outlook uncertainty. In fact, the simple policy rule leads to more frequent encounters with the ZLB under this calibration, compared to the other tables.

---

[25] With rational expectations and persistent shocks, as Billi (2016) showed, the ranking of the simple policy rule and two targeting frameworks is robust to a wide range of alternate calibrations. For this reason, the article does not report results of other calibrations besides changes to the demand shock.

[26] The standard deviation of the demand shock was raised by 50% relative to the baseline.

[27] The autocorrelation of the demand shock was raised from 0.8 to 0.85. At the same time, because the numerical procedure then failed to converge under the simple policy rule, the response coefficient on inflation in the rule was raised a little, from 1.5 to 2.5, to ensure greater policy stimulus and obtain a numerical solution. In the model the nominal interest rate is the only available policy instrument, so the model does not account for other policies used in actuality to stabilize output such as balance-sheet policies and fiscal spending.

[Table 4 about here]

Finally, as a comparison of the results in Tables 2 to 4 shows, in the presence of larger or more persistent demand shocks than in the baseline, there is a greater difference in economic performance between the two environments in each of the policy frameworks, because of more frequent and protracted ZLB episodes. Overall, because the central bank faces a ZLB constraint, the deterioration in economic performance from outlook uncertainty is worse under nominal-GDP-level targeting than under strict-price-level targeting.

6 Concluding remarks

This article sheds light on recent proposals to apply a risk management approach to monetary policy during ZLB episodes. Namely, it would be prudent for a central bank to raise the policy interest rate gradually from the ZLB, because the outlook for the economy is inherently uncertainty. The article compares the impact of outlook uncertainty on the economic performance of two alternatives to inflation targeting, a target for the price level or the level of nominal GDP. The setting is a standard model, calibrated to recent U.S. data, which offers a clear illustration of the tradeoffs faced by the central bank. As the analysis clarifies, in the presence of persistent supply and demand shocks, a concern for risk management is a reason to prefer a price-level target. Still, as the analysis is conducted in a stylized model, further study is needed to extend the results to a broader class of models.

A Appendix

A.1 Equilibrium conditions

I first derive the equilibrium conditions and then summarize them in a table.

The targeting frameworks. To solve the model, recall the definition of the price level,

$$p_t \equiv p_{t-1} + \pi_t. \tag{5}$$

Using this identity, the problem can be written as

$$
\begin{aligned}
V(\mathbf{s}_t) = {} & \max\left[-(p_t + I y_t)^2 + \beta E_t V(\mathbf{s}_{t+1})\right] \\
& \text{subject to (1), (2), (5) and } i_t \geq 0 \\
& \text{and } \mathbf{E}_t \mathbf{y}(\mathbf{s}_{t+1}) \text{ given,}
\end{aligned}
$$

where I represents an indicator function, which is equal to 1 for nominal-GDP-level targeting and equal to 0 for strict-price-level targeting. Write the period Lagrangian

$$
\begin{aligned}
L_t = {} & -(p_t + I y_t)^2 + \beta E_t V(\mathbf{s}_{t+1}) \\
& + m_{1t}\left[\pi_t - \beta E_t \pi_{t+1} - \kappa(y_t - y_t^n) - u_t\right] \\
& + m_{2t}\left[-y_t + E_t y_{t+1} - \varphi(i_t - r - E_t \pi_{t+1} - v_t)\right] \\
& + m_{3t}\left[-p_t + p_{t-1} + \pi_t\right] \\
& \text{and } \mathbf{E}_t \mathbf{y}(\mathbf{s}_{t+1}) \text{ given.}
\end{aligned}
$$

The Kuhn-Tucker conditions are

$$
\partial L_t / \partial \pi_t = m_{1t} + m_{3t} = 0 \tag{6}
$$

$$
\partial L_t / \partial y_t = -2I(p_t + I y_t) - \kappa m_{1t} - m_{2t} = 0 \tag{7}
$$

$$
\partial L_t / \partial i_t \cdot i_t = -\varphi m_{2t} \cdot i_t = 0, \quad m_{2t} \geq 0, \quad i_t \geq 0 \tag{8}
$$

$$
\begin{aligned}
\partial L_t / \partial p_t = {} & -2(p_t + I y_t) + \beta \partial E_t V(\mathbf{s}_{t+1}) / \partial p_t \\
& - (\beta m_{1t} - \varphi m_{2t}) \cdot \partial E_t \pi(\mathbf{s}_{t+1}) / \partial p_t + m_{2t} \cdot \partial E_t y(\mathbf{s}_{t+1}) / \partial p_t - m_{3t},
\end{aligned} \tag{9}
$$

whereas the Envelope condition is

$$\partial V\left(\mathbf{s}_t\right)/\partial p_{t-1}=m_{3t},$$

which implies that

$$\beta\partial E_t V\left(\mathbf{s}_{t+1}\right)/\partial p_t=\beta E_t m_{3t+1}.$$

Optimal commitment policy. The problem can be written as

$$V\left(\mathbf{s}_t\right)=\max\left[-\pi_t^2-\lambda\left(y_t-y_t^n\right)^2+\beta E_t V\left(\mathbf{s}_{t+1}\right)\right]$$
$$\text{subject to (1), (2) and } i_t\geq 0.$$

Write the period Lagrangian

$$\begin{aligned}L_t=&-\pi_t^2-\lambda\left(y_t-y_t^n\right)^2+\beta E_t V\left(\mathbf{s}_{t+1}\right)\\&+m_{1t}\left[\pi_t-\kappa\left(y_t-y_t^n\right)-u_t\right]-m_{1t-1}\pi_t\\&+m_{2t}\left[-y_t-\varphi\left(i_t-r_{ss}-\pi^*-v_t\right)\right]+m_{2t-1}\beta^{-1}\left(y_t+\varphi\pi_t\right).\end{aligned}$$

The Kuhn-Tucker conditions are

$$\partial L_t/\partial\pi_t=-2\pi_t+m_{1t}-m_{1t-1}+\beta^{-1}\varphi m_{2t-1}=0 \tag{10}$$

$$\partial L_t/\partial y_t=-2\lambda\left(y_t-y_t^n\right)-\kappa m_{1t}-m_{2t}+\beta^{-1}m_{2t-1}=0 \tag{11}$$

$$\partial L_t/\partial i_t\cdot i_t=-\varphi m_{2t}\cdot i_t=0,\quad m_{2t}\geq 0,\quad i_t\geq 0. \tag{12}$$

The equilibrium conditions of the model are summarized as follows:

Policy framework	Equilibrium conditions	State vector $\mathbf{s}_t$
Simple policy rule	(1), (2) and (4)	$\left(y_t^n, u_t, v_t, i_{t-1}^u\right)$
Targeting frameworks	(1), (2) and (5)-(9)	$(y_t^n, u_t, v_t, p_{t-1})$
Optimal commitment	(1), (2) and (10)-(12)	$(y_t^n, u_t, v_t, m_{1t-1}, m_{2t-1})$

A.2 Numerical procedure

I find a numerical solution, as in Billi (2011, 2016), as a fixed point in the equilibrium conditions. To do this, the state vector is discretized into a grid of interpolation nodes, with a support of ±4 standard deviations for each state variable, which is large enough to avoid erroneous extrapolation. If the state is not on this grid, the response function is evaluated with multilinear interpolation. The approximation residuals are evaluated at a finer grid, to ensure the accuracy of the results. The expectations function is evaluated with Gaussian-Hermite quadrature, and the derivatives are evaluated with a standard two-sided approximation. The initial guess is the linearized solution that ignores the ZLB constraint.

A.3 Permanent consumption loss

I obtain the permanent consumption loss as in Billi (2011, 2016). The expected lifetime utility of the representative household is validly approximated by

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t = \frac{U_c \overline{C}}{2} \frac{\alpha\theta\left(1+\omega\theta\right)}{\left(1-\alpha\right)\left(1-\alpha\beta\right)} L, \tag{13}$$

where $\overline{C}$ is steady-state consumption; $U_c > 0$ is steady-state marginal utility of consumption; and $L \geq 0$ is the value of objective function (3).

At the same time, a steady-state consumption loss of $\mu \geq 0$ causes a utility loss of

$$E_0 \sum_{t=0}^{\infty} \beta^t U_c \overline{C} \mu = \frac{1}{1-\beta} U_c \overline{C} \mu. \tag{14}$$

Equating the right sides of (13) and (14) gives

$$\mu = \frac{1-\beta}{2} \frac{\alpha\theta\left(1+\omega\theta\right)}{\left(1-\alpha\right)\left(1-\alpha\beta\right)} L.$$

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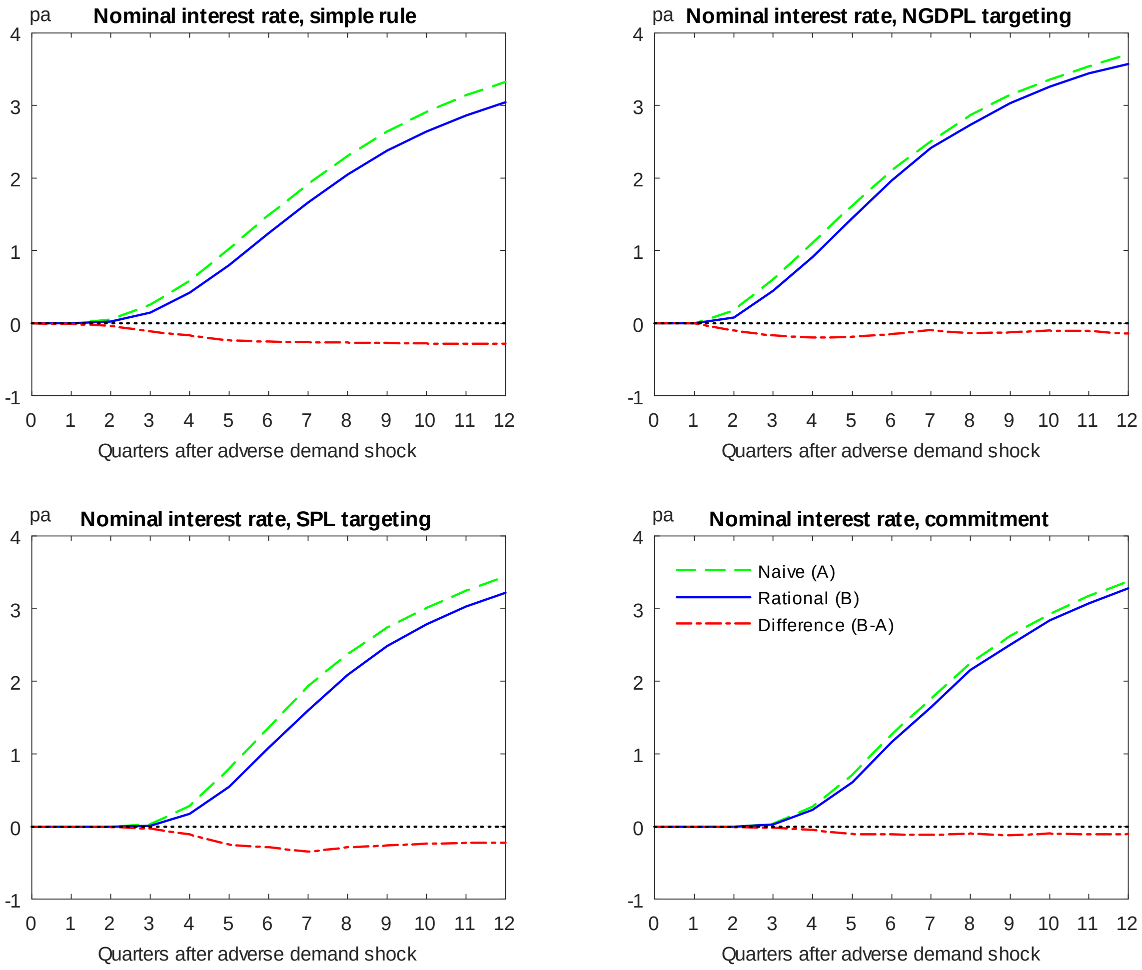
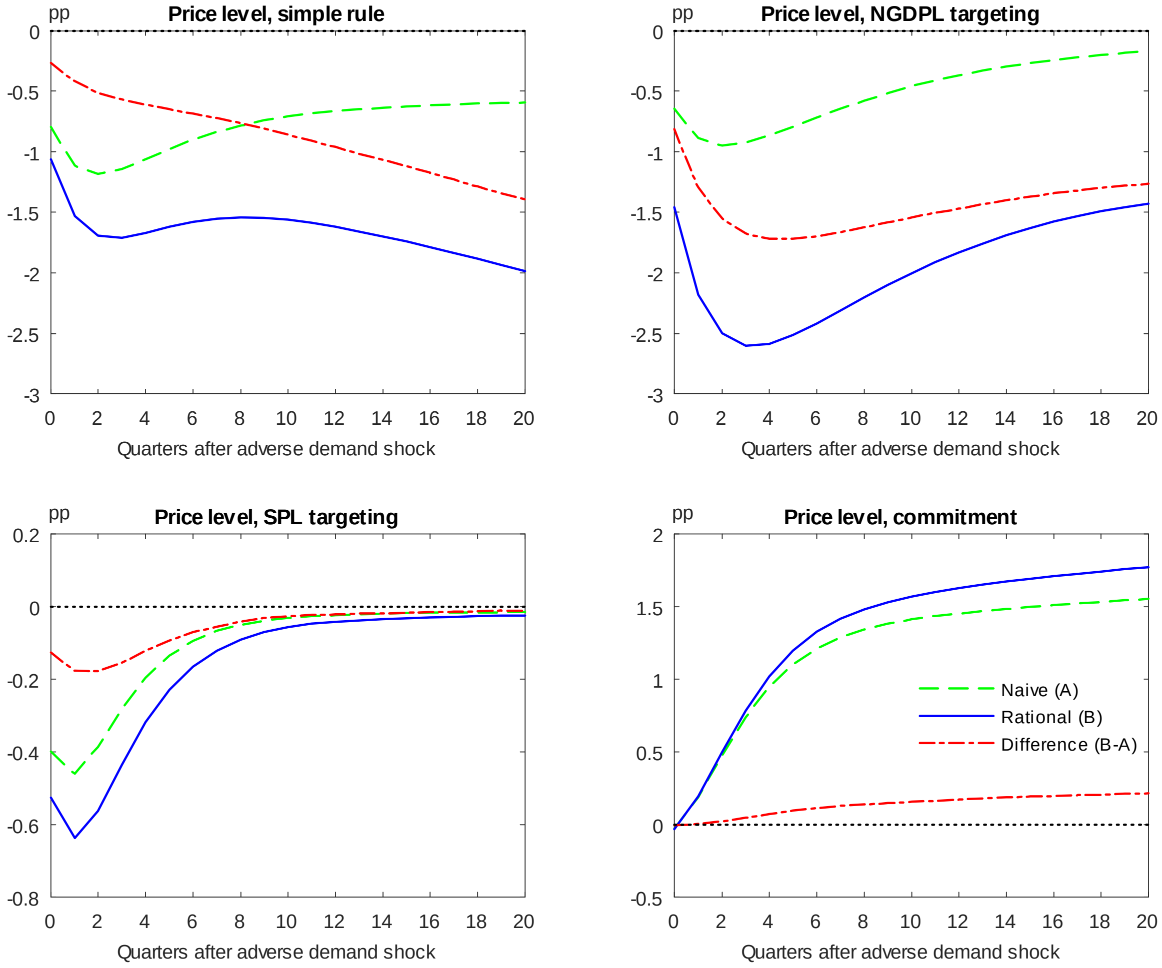
Figure 1: Slower pace of policy normalization because of outlook uncertainty



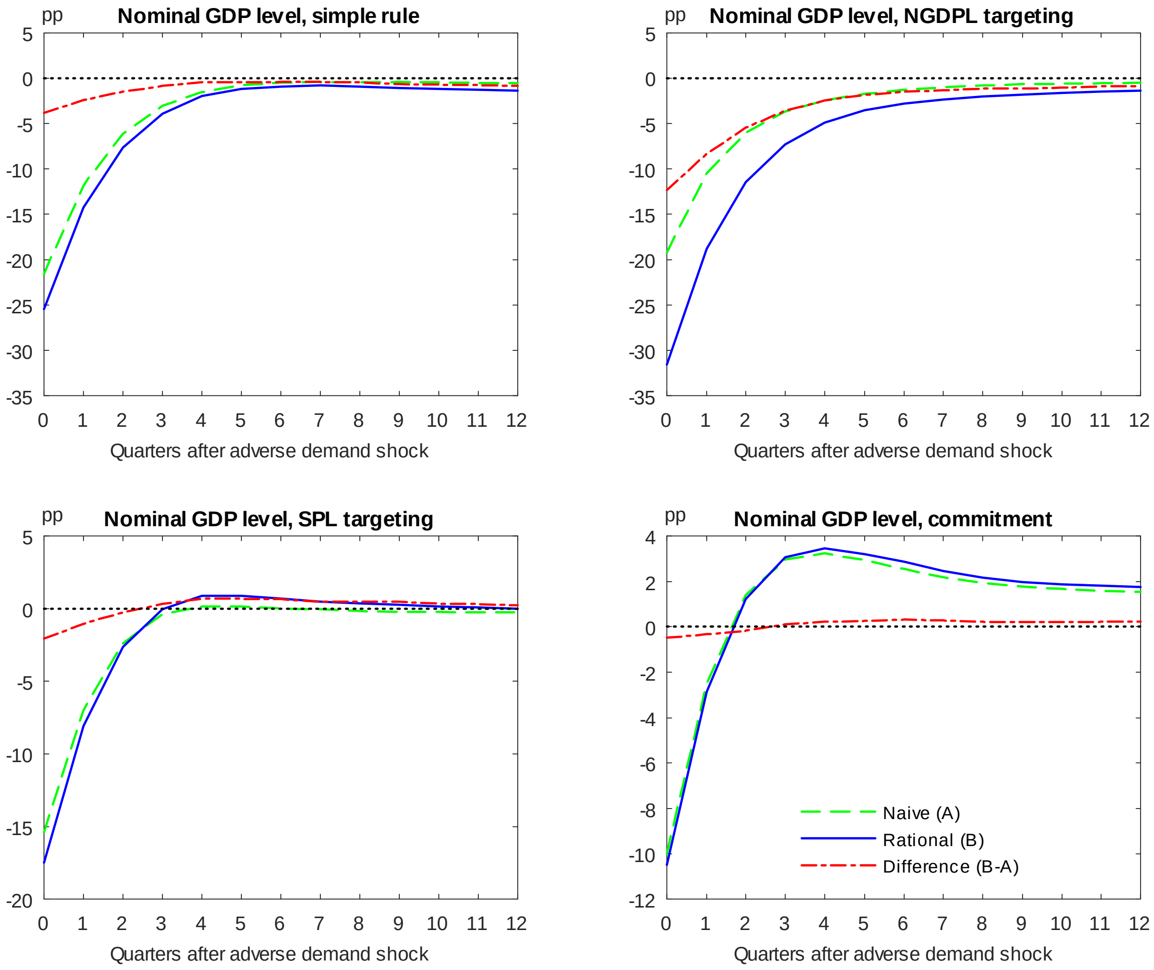
Notes: Shown are expected paths after a -3.5 standard deviation v_t shock, using the baseline calibration of Section 5.1. Values are expressed as percent annual (pa).

Figure 2: Outlook uncertainty and price stability during a ZLB episode



Notes: Shown are expected paths after a -3 standard deviation v_t shock, using the baseline calibration of Section 5.1. Values are in percentage points (pp).

Figure 3: Outlook uncertainty and economic stability during a ZLB episode



Notes: Shown are expected paths after a -3 standard deviation v_t shock, using the baseline calibration of Section 5.1. Values are in percentage points (pp).

Table 1: Outlook uncertainty and economic performance, with supply shocks only[a]

	ZLB episodes		Welfare loss[b]		
	Freq.[c]	Duration[d]	π	x	Tot.
	Naive (A)				
Simple policy rule	0.0	0.0	10.4	0.4	10.8
Nominal-GDP-level targeting	0.0	0.0	5.7	1.0	6.7
Strict-price-level targeting	0.0	0.0	0.0	5.3	5.3
Optimal commitment	0.0	0.0	0.9	1.9	2.8
	Rational (B)				
Simple policy rule	0.0	0.0	10.4	0.4	10.8
Nominal-GDP-level targeting	0.0	0.0	5.7	1.0	6.7
Strict-price-level targeting	0.0	0.0	0.0	5.3	5.3
Optimal commitment	0.0	0.0	0.9	1.9	2.8
	Difference (B-A)				
Simple policy rule	0.0	0.0	0.0	0.0	0.0
Nominal-GDP-level targeting	0.0	0.0	0.0	0.0	0.0
Strict-price-level targeting	0.0	0.0	0.0	0.0	0.0
Optimal commitment	0.0	0.0	0.0	0.0	0.0

a. Baseline calibration of Section 5.1 but with $\sigma_v = 0$.

b. Permanent consumption loss (basis points).

c. Expected percent of time at the ZLB.

d. Expected number of consecutive quarters at the ZLB.

Table 2: Outlook uncertainty and economic performance, with supply and demand shocks[a]

	ZLB episodes		Welfare loss[b]		
	Freq.[c]	Duration[d]	π	x	Tot.
	Naive (A)				
Simple policy rule	1.4	2.8	21.3	25.9	47.2
Nominal-GDP-level targeting	6.0	1.8	6.8	4.4	11.2
Strict-price-level targeting	8.6	2.9	0.5	7.6	8.1
Optimal commitment	9.7	3.1	1.7	3.1	4.8
	Rational (B)				
Simple policy rule	2.5	3.1	24.9	28.6	53.5
Nominal-GDP-level targeting	11.1	2.1	11.9	10.8	22.7
Strict-price-level targeting	15.4	3.1	1.0	9.2	10.2
Optimal commitment	12.7	3.2	2.0	3.5	5.5
	Difference (B-A)				
Simple policy rule	1.1	0.3	3.6	2.7	6.3
Nominal-GDP-level targeting	5.1	0.3	5.1	6.4	11.5
Strict-price-level targeting	6.8	0.2	0.5	1.6	2.1
Optimal commitment	3.0	0.1	0.3	0.4	0.7

a. Baseline calibration of Section 5.1.

b. Permanent consumption loss (basis points).

c. Expected percent of time at the ZLB.

d. Expected number of consecutive quarters at the ZLB.

Table 3: Outlook uncertainty and economic performance, with larger demand shocks[a]

	ZLB episodes		Welfare loss[b]		
	Freq.[c]	Duration[d]	π	x	Tot.
	Naive (A)				
Simple policy rule	2.2	3.0	23.9	32.1	56.0
Nominal-GDP-level targeting	7.1	1.9	7.5	6.8	14.3
Strict-price-level targeting	10.8	3.2	0.9	9.3	10.2
Optimal commitment	12.8	3.2	2.4	4.0	6.4
	Rational (B)				
Simple policy rule	5.3	3.6	35.0	39.2	74.2
Nominal-GDP-level targeting	14.3	2.3	16.5	17.7	34.2
Strict-price-level targeting	20.1	3.5	1.9	12.2	14.1
Optimal commitment	15.7	3.6	2.8	4.5	7.3
	Difference (B-A)				
Simple policy rule	3.1	0.6	11.1	7.1	18.2
Nominal-GDP-level targeting	7.2	0.4	9.0	10.9	19.9
Strict-price-level targeting	9.3	0.3	1.0	2.9	3.9
Optimal commitment	2.9	0.4	0.4	0.5	0.9

a. Baseline calibration of Section 5.1 but with $\sigma_v = 0.88$.

b. Permanent consumption loss (basis points).

c. Expected percent of time at the ZLB.

d. Expected number of consecutive quarters at the ZLB.

Table 4: Outlook uncertainty and economic performance, with more persistence in the demand shocks[a]

	ZLB episodes		Welfare loss[b]		
	Freq.[c]	Duration[d]	π	x	Tot.
	Naive (A)				
Simple policy rule	3.6	3.7	20.6	24.5	45.1
Nominal-GDP-level targeting	5.8	2.0	7.5	5.9	13.4
Strict-price-level targeting	9.1	3.7	0.9	8.6	9.5
Optimal commitment	10.0	3.9	2.2	3.3	5.5
	Rational (B)				
Simple policy rule	8.3	4.7	36.4	36.8	73.2
Nominal-GDP-level targeting	12.2	2.4	17.0	15.2	32.2
Strict-price-level targeting	17.4	3.9	2.0	11.1	13.1
Optimal commitment	12.7	3.9	2.6	3.7	6.3
	Difference (B-A)				
Simple policy rule	4.7	1.0	15.8	12.3	28.1
Nominal-GDP-level targeting	6.4	0.4	9.5	9.3	18.8
Strict-price-level targeting	8.3	0.2	1.1	2.5	3.6
Optimal commitment	2.7	0.0	0.4	0.5	0.8

a. Baseline calibration of Section 5.1 but with $\rho_v = 0.85$ and $\phi_\pi = 2.5$.

b. Permanent consumption loss (basis points).

c. Expected percent of time at the ZLB.

d. Expected number of consecutive quarters at the ZLB.

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Sveriges Riksbank
Visiting address: Brunkebergs torg 11
Mail address: se-103 37 Stockholm

Website: www.riksbank.se
Telephone: +46 8 787 00 00, Fax: +46 8 21 05 31
E-mail: registratorn@riksbank.se