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Nominal GDP Targeting and the Zero Lower Bound: Should We Abandon Inflation Targeting?*

Roberto M. Billi[†]

Sveriges Riksbank Working Paper Series No. 270

June 2013

Abstract

I compare nominal GDP level targeting to flexible inflation targeting in a small New Keynesian model subject to the zero lower bound on nominal policy rates. First, I study the performance of optimal discretionary policies. I find that, for a standard calibration, inflation targeting under discretion leaves the economy open to a deflationary trap. Nominal GDP level targeting under discretion, by contrast, provides a firm nominal anchor to the economy. Second, I study simple policy rules and the role of smoothing in the rules. With smoothing, a Taylor-type rule performs as well as a nominal GDP level rule. These results suggest that inflation targeting should not be ditched. Still, it can be improved significantly, by using policy rate smoothing to anchor inflation firmly.

Keywords: nominal GDP target, optimal policy, simple rules, zero lower bound

JEL: E31, E52, E58

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1 Introduction

With policy interest rates near zero and a weak economy, flexible inflation targeting, as practiced by major central banks, has come under intense public scrutiny and criticism. A conceptually appealing alternative, some argue, would be to adopt nominal GDP level targeting. In this case, the central bank would have to make up for any past deviations of nominal GDP from the target. In particular, when nominal GDP falls below target, the central bank has to compensate for the shortfall in economic activity by credibly promising further policy stimulus. Such forward policy guidance on the level of nominal GDP provides a way to stimulate the economy when policy is constrained by the zero lower bound (ZLB) on nominal interest rates. Thus, according to the relevant literature, nominal GDP level targeting is clearly a superior framework for monetary policy compared to inflation targeting.

In this article, however, I argue that flexible inflation targeting can be improved significantly. I compare inflation targeting to nominal GDP level targeting in a small New Keynesian model subject to the ZLB constraint. First, I study the performance of optimal discretionary policies. I find that, for a standard calibration of the model to U.S. data, inflation targeting under discretion leaves the economy open to a deflationary trap. Nominal GDP level targeting under discretion, by contrast, provides a firm nominal anchor to the economy. Second, I study simple policy rules and the role of smoothing in the rules. Such forward guidance on the policy interest rate provides stimulus to the economy. With smoothing, a Taylor-type rule performs as well as a nominal GDP level rule. These results suggest that inflation targeting should not be ditched. Still, it can be improved significantly, by using policy rate smoothing to anchor inflation firmly.

In the New Keynesian literature, the case for nominal GDP level targeting has recently been stressed by Woodford (2012). In fact, nominal GDP level targeting closely resembles the ideal policy in the small New Keynesian model, as studied in Woodford (2010). The desirability of a nominal level target when the ZLB becomes a binding constraint was stressed by Eggertsson and Woodford (2003) and Svensson (2003), well before the financial crisis and great recession. More

recently in the aftermath of the crisis, Billi (2011) and Coibion, Gorodnichenko, and Wieland (2012) study the optimal rate of inflation and the ZLB in the New Keynesian model. The literature, however, does not argue that policy rate smoothing is as effective as a nominal level target in providing a firm nominal anchor to the economy, as argued instead in this article.

Section 2 describes the model. Section 3 presents the policy evaluation. And Section 4 concludes. The Appendix contains technical details.

2 The model

I use a small New Keynesian model as described in Woodford (2010), but with a nominal GDP level target hardwired into the central bank’s objective function. I also introduce the target in a class of simple policy rules studied by Taylor and Williams (2010). In addition, I take into account that the nominal policy rate occasionally hits the ZLB. In such a setting, I explain how to account for the steady-state costs of inflation in the policy evaluation. After describing the salient features of an equilibrium that accounts for the ZLB and uncertainty about the evolution of the economy, I calibrate the model to U.S. data.

2.1 Private sector

The behavior of the private sector is summarized by two log-linearized, structural equations, namely an Euler equation and a Phillips curve, respectively describing the demand and supply side of the economy. The equations of this basic model are linearized around zero inflation.

The Euler equation, which describes the representative household’s expenditure decisions, is given by

$$x_t = E_t x_{t+1} - \varphi (i_t - E_t \pi_{t+1} - r_t^n), \quad (1)$$

where E_t denotes the expectations operator conditional on information available at time t . x_t

denotes the measure of real economic activity or the real GDP gap, i.e., the deviation of real GDP from its flexible-price steady state. π_t is the inflation rate, i.e., the change in the log-price level ($\pi_t = p_t - p_{t-1}$). $i_t \geq 0$ denotes the short-term nominal interest rate (as well as the instrument of monetary policy, as discussed in the next subsection). And r_t^n is a natural rate of interest shock.¹ $\varphi > 0$ is the real-rate elasticity of the real GDP gap, i.e., the intertemporal elasticity of substitution of household expenditure.

The Phillips curve, which describes the optimal price-setting behavior of firms, under staggered price changes à la Calvo, is given by

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

where u_t is a mark-up shock, resulting from variation over time in the degree of monopolistic competition between firms. $\beta \in (0, 1)$ denotes the discount factor of the representative household.

The slope parameter,

$$\kappa = \frac{(1 - \alpha)(1 - \alpha\beta)}{\alpha} \frac{\varphi^{-1} + \omega}{1 + \omega\theta} > 0,$$

is a function of the structure of the economy, where $\omega > 0$ denotes the elasticity of a firm's real marginal cost with respect to its own output level. $\theta > 1$ is the price elasticity of demand substitution among differentiated goods produced by firms in monopolistic competition. Each period, a share $\alpha \in (0, 1)$ of randomly picked firms cannot adjust their prices, while the remaining $(1 - \alpha)$ firms get to choose prices optimally.

In addition, the exogenous shocks are assumed to follow AR(1) stochastic processes,

¹The shock r_t^n summarizes all shocks that under flexible prices generate variation in the real interest rate. It captures the combined effects of taste shocks, productivity shocks, and exogenous changes in government expenditures.

$$\begin{aligned}
r_t^n &= (1 - \rho_r) r_{ss} + \rho_r r_{t-1}^n + \sigma_{\varepsilon r} \varepsilon_{rt} \\
u_t &= \rho_u u_{t-1} + \sigma_{\varepsilon u} \varepsilon_{ut},
\end{aligned}$$

with first-order autocorrelation parameters $\rho_j \in (-1, 1)$ for $j = r, u$. The steady-state real interest rate r_{ss} is equal to $1/\beta - 1$, such that $r_{ss} \in (0, +\infty)$. And $\sigma_{\varepsilon j} \varepsilon_{jt}$ are the innovations that buffet the economy, which are independent across time and cross-sectionally, and normally distributed with mean zero and standard deviations $\sigma_{\varepsilon j} > 0$ for $j = r, u$.

2.2 Monetary policy

In this basic model, I consider a range of monetary policy frameworks, with nominal policy rates constrained by the ZLB. After describing a typical benchmark policy, I introduce a nominal GDP level target in optimal discretionary policies and in simple policy rules.

2.2.1 Ramsey plan

As a benchmark in the policy evaluation, I use the optimal Ramsey plan, i.e., the optimal commitment policy determined at time zero. The policymaker's objective function in this case is the social welfare function:

$$\min_{\{\pi_t, x_t, i_t \geq 0\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t [\pi_t^2 + \lambda x_t^2], \quad (3)$$

where λ denotes the weight assigned to stabilizing real GDP relative to inflation. This objective function, as explained by Woodford (2010), can be derived as a second-order approximation of the lifetime utility function of the representative household. The utility function is validly approximated around zero inflation. The approximation of the utility function allows to determine λ in terms of the structure of the model economy. Thus, λ is equal to κ/θ in this model.

2.2.2 Optimal discretionary policies

Under optimal discretion, the policymaker does not commit to the Ramsey plan and instead re-optimizes in each period, as described in Woodford (2010). I focus on two monetary policy frameworks in such a setting. First, with **inflation targeting** under discretion, the policymaker's objective function takes the form:

$$\min_{(\pi_t, x_t, i_t \geq 0)} E_0 \sum_{t=0}^{\infty} \beta^t [(\pi_t - \pi^*)^2 + \lambda^d (x_t - x^*)^2], \quad (4)$$

where λ^d denotes the weight assigned to stabilizing real GDP relative to inflation. If the weight is zero, the central bank is labeled a *strict* inflation targeter. But if the weight is positive, the central bank is then a *flexible* inflation targeter. $\pi^* \geq 0$ denotes the inflation target pursued by the central bank, as part of its legislative mandate to achieve price stability. And x^* is the resulting real GDP gap target.²

Raising π^* limits the incidence of hitting the ZLB. If π^* is below a critical value, a bad shock can unanchor inflation from its target and push the economy into a deflationary spiral. The representative household then suffers an infinite welfare loss, because inflation and real GDP are unbounded. However, as I argued in Billi (2011), raising π^* above the critical value ensures that the economy reverts to a stable equilibrium rather than to an unstable path. But in that paper I did not consider the anchoring effect of a nominal GDP level target.

As a second framework for monetary policy under discretion, I consider **nominal GDP level targeting**. The policymaker's objective function becomes:

$$\min_{(y_t, i_t \geq 0)} E_0 \sum_{t=0}^{\infty} \beta^t (y_t - \bar{y}_t)^2, \quad (5)$$

where y_t denotes the nominal GDP gap, which is equal to $p_t + x_t$. \bar{y}_t denotes the corresponding target, which is assumed to increase at a deterministic rate $\bar{p}_t + x^*$. And \bar{p}_t is the corresponding

²Phillips curve (2) implies $x^* = (1 - \beta) \kappa^{-1} \pi^*$.

price level target which increases at rate π^* , such that $\bar{p}_t = \bar{p}_{t-1} + \pi^*$. Raising π^* serves as prevention against a deflationary spiral. But the scope for prevention is limited, because of the anchoring effect of the nominal GDP level target.

2.2.3 Simple policy rules

In addition to the optimal policies, I focus on two simple policy rules along the lines of Taylor and Williams (2010). The first is a version of the **Taylor rule** subject to the ZLB constraint:

$$i_t = \max \left[0, \phi_\pi (\pi_t - \pi^*) + \phi_x (x_t - x^*) + (1 - \phi_i) i^* + \phi_i i_{t-1}^u \right]. \quad (6)$$

The second is a **nominal GDP level rule** with ZLB constraint:

$$i_t = \max \left[0, \phi_y (y_t - \bar{y}_t) + (1 - \phi_i) i^* + \phi_i i_{t-1}^u \right]. \quad (7)$$

In the rules, i^* denotes the equilibrium nominal policy rate, which is equal to $r_{ss} + \pi^*$. The rules incorporate forward policy guidance, or smoothing in the behavior of the interest rate, through a positive value of the coefficient ϕ_i . But as argued, for example, by Taylor and Williams (2010) and Giannoni (2012), values of ϕ_i above 1 would imply unusual behavior by the central bank. i_{t-1}^u denotes the preferred setting of the policy rate in the previous period that would occur absent the ZLB. Thus, the policy rate is kept below its equilibrium value following an episode when the ZLB is a binding constraint on policy. This approach implies that the rules compensate for the lost monetary stimulus due to the existence of the ZLB.

2.3 Measuring welfare

Next, I need a criterion to evaluate the monetary policy frameworks. As argued in Woodford (2009), objective function (3) is the right criterion because it includes the costs of steady-state

inflation. To clarify, the welfare loss associated with inflation in period t includes two parts:

$$E_0 [\pi_t^2] = \pi^{*2} + E_0 [(\pi_t - \pi^*)^2].$$

On the right side, the first term is the welfare loss due to steady-state inflation, and the second term is the loss due to inflation variability. Both parts are relevant for a correct policy evaluation in this model in the presence of the ZLB. Neglecting, in particular, the first term would imply that welfare is strictly increasing in π^* , because raising π^* limits the incidence of hitting the ZLB. This is the case, for example, in Coibion, Gorodnichenko, and Wieland (2012) when they linearize the model around zero inflation.³

2.4 Equilibrium

In 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 takes the form:

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

where $f(\cdot)$ is a probability density function of the future innovations that buffet the economy. Because there is uncertainty about the future state of the economy, the ZLB is an occasionally-binding constraint among the endogenous variables in the model.

In such a setting, I provide the following equilibrium definition:

Definition 1 (SREE) *A stochastic, rational-expectations equilibrium is given by a response function and corresponding expectations function, $\mathbf{y}(\mathbf{s}_t)$ and $\mathbf{E}_t \mathbf{y}_{t+1}(\mathbf{s}_t)$, respectively, which satisfy the equilibrium conditions, derived in Appendix A.1.*

Ignoring the existence of uncertainty about the evolution of the economy, the model could

³In fact, in their figure 2A, the dash line is strictly increasing.

be solved with standard linear-quadratic methods.⁴ By contrast, I must use a global numerical procedure to find an equilibrium that accounts for the ZLB and a stochastic process like the one studied here. See Billi (2011) for a description of my numerical procedure. When the ZLB threatens, the mere possibility of hitting the ZLB causes expectations of a future decline in GDP below potential and inflation below its target, as we showed in Adam and Billi (2006, 2007). But in those papers we did not study nominal GDP targeting or smoothing in simple policy rules.

2.5 Calibration

Before turning to the policy evaluation, I calibrate the model to U.S. data with the parameter values shown in table 1. Specifically, I use the parameter values in Giannoni (2012) but assume a more persistent real-rate shock as in previous research on the ZLB. Overall, therefore, the calibration is very similar to the one I used in Billi (2011) if price indexation is set to zero.

[Table 1 about here]

3 Policy evaluation

Employing the small New Keynesian model with a standard calibration to U.S. data, I evaluate the optimal policies and simple policy rules. In the evaluation, I take into account that the nominal policy rate occasionally hits the ZLB. After illustrating the anchoring effect of a nominal GDP level target, I show that policy rate smoothing also anchors inflation firmly.

3.1 Optimal policies

The starting point for the evaluation is the performance of the optimal policies. I show that under optimal discretion the economy can fall into a deflationary trap, in which the representative

⁴For example, Coibion, Gorodnichenko, and Wieland (2012) use a standard procedure that solves models in which agents are assumed to have perfect foresight about the evolution of the economy.

household suffers an infinite welfare loss. There are ways, however, to reduce the risk of inflation becoming unanchored.

One way is to raise the inflation target above a critical value. To illustrate, figure 1 shows the welfare loss, measured as the permanent consumption loss relative to the Ramsey plan, as a function of the inflation target.⁵ In the top panel, the critical value of the inflation target is between 1.6 percent annual (strict inflation targeting) and 1.8 percent annual (flexible inflation targeting). The flexible inflation targeter is assumed to assign an optimal weight to stabilizing real GDP relative to inflation.⁶ At the critical value of the inflation target, the welfare loss relative to the Ramsey plan is minimized or, conversely, welfare is maximized for the representative household in the economy. The intuition for why the critical value is slightly lower with strict inflation targeting is straightforward. If inflation targeting is strict, inflation is less variable and therefore more tightly anchored to the target. As a result, the economy is less prone to a deflationary spiral. On the other hand, by focusing entirely on stabilizing inflation, real GDP is more variable than would otherwise be the case. With strict inflation targeting, the welfare loss at the critical value amounts to 0.85 percent of permanent consumption, but declines to 0.79 percent of permanent consumption in the case of flexible inflation targeting. Thus, on balance, flexible inflation targeting is preferable in terms of welfare to strict inflation targeting.

[Figure 1 about here]

Though raising the inflation target helps to avoid the deflationary trap, another way is to adopt nominal GDP level targeting. In this case, as the bottom panel of figure 1 shows, even if the inflation target is zero, inflation remains firmly anchored and therefore the economy does not fall into the deflationary trap. However, an inflation target slightly above zero minimizes the

⁵I first obtain the value of objective function (3) by averaging across 10,000 stochastic simulations each 1,000 periods long after a burn-in period. I then convert this value into a permanent consumption loss, as explained in Appendix A.2.

⁶I find that in the case of optimal discretion, welfare is maximized with a weight λ^d of 0.001. I, thus, use this optimal weight in the analysis. Of course, this weight is smaller than the corresponding λ of 0.003 in the Ramsey plan, because lack of commitment causes a stabilization bias. To reduce the stabilization bias, the central bank has to focus more on stabilizing inflation compared to the Ramsey plan.

welfare loss relative to the Ramsey plan. As the bottom panel shows, with nominal GDP level targeting, the optimal inflation target that minimizes the welfare loss is 0.1 percent annual. With nominal GDP level targeting, the welfare loss at the optimal inflation target amounts to about 0.08 percent of permanent consumption, which represents a substantial decline in the welfare loss compared to the inflation targeting cases depicted in the top panel. In fact, the scale of the welfare loss is one order of magnitude smaller in the bottom panel than in the top panel. Thus, nominal GDP level targeting is clearly preferable in terms of welfare to inflation targeting. Furthermore, in contrast to inflation targeting, nominal GDP level targeting provides a firm nominal anchor to the economy.

During a ZLB episode, in particular, nominal GDP level targeting allows inflation to temporarily rise above its target. This bout of inflation implies a speedier economic recovery than would otherwise be the case. The reason is that the surge in prices encourages firms to expand production. The ability to jump start the economic recovery and push inflation above target are salient features of the Ramsey plan. However, the inflation targeter under discretion lacks the resolve to push inflation above target. To illustrate, figure 2 shows the expected evolution of the model economy after a -2 standard deviation real-rate shock.⁷ Shown are the expected paths under the optimal discretionary policies, with optimal inflation targets that minimize the welfare loss relative to the Ramsey plan. Also shown is the expected path in the case of the Ramsey plan. With the Ramsey plan, the nominal policy rate is gradually raised back to its equilibrium level during the economic recovery (top panel). This prolonged monetary stimulus causes real GDP to rise above potential (middle panel) and inflation to rise above its target (bottom panel). Also in the case of nominal GDP level targeting, prolonged monetary stimulus pushes inflation above target, albeit to a lesser extent than in the Ramsey plan. But with flexible inflation targeting, inflation does not rise above its target during the economic recovery.

⁷I obtain the expected paths by averaging across 10,000 stochastic simulations. In comparing the policy rate paths in the top panel of figure 2, one has to keep in mind that the equilibrium levels are not the same. In the case of inflation targeting, the equilibrium level of the nominal policy rate is clearly higher. The reason is that the optimal inflation target is noticeably higher with inflation targeting than with nominal GDP level targeting, as shown in figure 1.

[Figure 2 about here]

Nominal GDP level targeting is, therefore, more effective at stabilizing the economy than inflation targeting. Table 2 shows the performance of the discretionary policies, with optimal inflation targets that minimize the welfare loss relative to the Ramsey plan. The table reports the expected frequency and duration of ZLB episodes. It also reports the welfare loss relative to the Ramsey plan. With the Ramsey plan, the nominal policy rate is expected to hit the ZLB about 13 percent of the time. But the incidence of hitting the ZLB edges down to 12 percent with nominal GDP level targeting and to 10 percent with flexible inflation targeting.⁸ The lower incidence of hitting the ZLB is associated with higher inflation targets and, of course, higher costs of steady-state inflation. With flexible inflation targeting, the welfare loss due to steady-state inflation is 0.2 percent of permanent consumption. In addition, the welfare loss due to inflation variability is 0.49 percent of permanent consumption. And the welfare loss due to real GDP variability is 0.1 percent of permanent consumption. In sum, with flexible inflation targeting, the total welfare loss relative to the Ramsey plan is 0.79 percent of permanent consumption. By contrast, with nominal GDP level targeting, the total welfare loss amounts to only 0.08 percent of permanent consumption. Thus, in the case of optimal discretion, nominal GDP level targeting performs clearly better than inflation targeting.

[Table 2 about here]

3.2 Simple policy rules

As the next step in the evaluation, I study the performance of the simple policy rules. I show that the deflationary trap is a problem not only under discretionary policies but also under simple policy rules. But a solution to the trap is to incorporate policy rate smoothing in the rules.

⁸At the same time, the expected duration of a ZLB episode under the two policy frameworks is roughly the same, or 2 consecutive quarters.

To study the role of smoothing in the rules, I search numerically for the optimal rule coefficients and inflation targets that minimize the welfare loss relative to the Ramsey plan. Figure 3 shows the welfare loss, measured as the permanent consumption loss relative to the Ramsey plan, as a function of the rule coefficients. In each panel a single rule coefficient is changed, while the other rule coefficients and the inflation target are at their optimal values that minimize the welfare loss.⁹ Thus, each panel illustrates the marginal effect of a single rule coefficient on the welfare of the representative household in this model economy.

[Figure 3 about here]

As the top-left panel shows, the smoothing coefficient in the Taylor rule provides the greatest marginal effect on welfare. In fact, in the case of the Taylor rule, the welfare loss falls from 0.17 to about 0.02 percent of permanent consumption when the smoothing coefficient is raised from 0.7 to 1. But the smoothing coefficient has a smaller effect on welfare in the nominal GDP level rule, as the welfare loss only falls from about 0.03 to 0.01 of permanent consumption. Thus, the role of smoothing is greater in the Taylor rule than in the nominal GDP rule. As the top-right panel shows, the coefficient on the inflation gap in the Taylor rule bares almost no visible effect on welfare, even though the coefficient ranges widely between 0.1 to 1. This occurs because there is a tension between stabilizing inflation and real economic activity. And the bottom panels show that, the coefficients on nominal and real GDP gaps in the rules have a moderate effect on welfare, as the welfare loss falls by roughly 0.06 percent of permanent consumption. This last result highlights a role for policy to react to a measure of economic activity, because the GDP gap is an indicator of future inflationary pressures in the economy.

In this model, the optimal rule coefficients are in practice equal to 1. As the various panels in figure 3 show, raising each of the rule coefficients towards 1 leads to a decline in the welfare loss

⁹This figure highlights the computational challenge in the analysis. Obtaining the results in the figure requires searching for the optimal inflation target for each combination of the rule coefficients in each of the rules. In the case of the Taylor rule, for example, there are three rule coefficients and therefore the search is over a four-dimensional parameter space. For each parameter combination, the model has to be solved and then stochastic simulations allow to obtain the welfare loss. But a single step in the search process can take hours on a workstation. To address this computational challenge, I thus resort to high performance computing.

or, in other terms, a welfare improvement for the representative household in the economy. But the higher the rule coefficients, the smaller the welfare improvement. This occurs because with a strong policy response, the welfare loss as a function of the rule coefficients becomes practically flat. As a result, raising the rule coefficients above 1 (not shown in the figure) would not lead to a noticeable, further improvement in welfare for the representative household in the economy.

Next, I illustrate the anchoring effect of policy rate smoothing. To do so, figure 4 shows the welfare loss, measured as the permanent consumption loss relative to the Ramsey plan, as a function of the inflation target. If the rule is labeled as optimal coefficients, the rule coefficients are set to 1. But if the rule is labeled as suboptimal smoothing, the smoothing coefficient is lowered to 0.7, while the other rule coefficients and the inflation target are at their optimal values that minimize the welfare loss relative to the Ramsey plan. As the top panel shows, the critical value of the inflation target is 1.3 percent annual in the case of the Taylor rule with suboptimal smoothing. At the critical value of the inflation target, the welfare loss is minimized and therefore welfare is maximized for the representative household in the economy. As the bottom panel shows, by contrast, the Taylor rule with optimal coefficients is associated with well-anchored inflation in the economy. Because of optimal smoothing in the Taylor rule, the optimal inflation target that minimizes the welfare loss is now zero. In addition, the nominal GDP level rule, either with optimal coefficients or with suboptimal smoothing, is also associated with well-anchored inflation. These results, thus, suggest a role for smoothing in the Taylor rule to provides a firm nominal anchor to the economy.

[Figure 4 about here]

Optimal smoothing in the rules makes inflation temporarily rise above target during a ZLB episode. This surge in inflation promotes a more rapid economic recovery than can be achieved with suboptimal smoothing in the rules. To illustrate, figure 5 shows the expected evolution of the model economy after a -2 standard deviation real-rate shock. Shown are the expected paths under the simple policy rules, with optimal inflation targets that minimize the welfare

loss relative to the Ramsey plan. With optimal coefficients in the rules, real GDP rises above potential and inflation rises above target during the economic recovery (solid lines in the various panels). However, the surge in inflation is modest, as the inflation gap only rises to about 0.3 percent annual in the case of the Taylor rule and to about 0.2 percent annual in the case of the nominal GDP rule. But with suboptimal smoothing the shape of the economic recovery is quite different (dash-dot lines in the various panels). In particular, because of the limited amount of monetary stimulus, inflation does not rise noticeably above target during the economic recovery.

[Figure 5 about here]

With optimal smoothing, therefore, the Taylor rule is as effective as the nominal GDP rule in stabilizing the economy. Table 3 shows the performance of the simple policy rules, with optimal inflation targets that minimize the welfare loss relative to the Ramsey plan. The table reports in the top panel the performance of the rules with optimal coefficients and in the bottom panel the performance of the rules with suboptimal smoothing. Comparing the two panels, optimal smoothing in the rules is associated with a lower inflation target and therefore a higher incidence of hitting the ZLB. It is also associated with a lower welfare loss. As the top panel shows, with optimal smoothing, the total welfare loss in the case of the Taylor rule is only 0.02 percent of permanent consumption, which is only 0.01 percent higher than in the case of the nominal GDP rule. The results suggest that with optimal smoothing, therefore, the Taylor rule in practice performs as well as the nominal GDP rule.

[Table 3 about here]

4 Conclusion

In this article, I shed light on recent proposals directed at major central banks to abandon inflation targeting and instead adopt nominal GDP level targeting. To do so, I evaluate optimal policies and simple policy rules in a small New Keynesian model subject to the ZLB constraint.

According to the New Keynesian literature, nominal GDP level targeting is clearly a superior framework for monetary policy compared to inflation targeting. But, in this article, I show that inflation targeting can be improved significantly, by using policy rate smoothing to anchor inflation firmly. A Taylor rule with smoothing performs as well as a nominal GDP rule. Thus, the analysis suggests that inflation targeting should not be ditched. Central banks can use forward guidance on the policy interest rate directly, as opposed to forward guidance on the level of nominal GDP.

A Appendix

A.1 Equilibrium conditions

I first derive the Kuhn-Tucker conditions that close the model in the case of optimal policies. With simple policy rules instead, the rule itself closes the model. Next, I summarize the equilibrium conditions in a table.

Ramsey plan. The Lagrangian of problem (1)-(3) is

$$\begin{aligned} \max_{\{\pi_t, x_t, i_t \geq 0\}_{t=0}^{\infty}} \min_{\{m_{1t}, m_{2t}\}_{t=0}^{\infty}} \mathcal{L} \equiv E_0 \sum_{t=0}^{\infty} \beta^t \{ & -\pi_t^2 - \lambda x_t^2 \\ & + m_{1t} [\pi_t - \kappa x_t - u_t] - m_{1t-1} \pi_t \\ & + m_{2t} [-x_t - \varphi (i_t - r_t^n)] + m_{2t-1} \beta^{-1} (x_t + \varphi \pi_t) \} . \end{aligned}$$

The Kuhn-Tucker conditions of this problem are

$$\partial \mathcal{L} / \partial \pi_t = -2\pi_t + m_{1t} - m_{1t-1} + \beta^{-1} \varphi m_{2t-1} = 0 \quad (8)$$

$$\partial \mathcal{L} / \partial x_t = -2\lambda x_t - \kappa m_{1t} - m_{2t} + \beta^{-1} m_{2t-1} = 0 \quad (9)$$

$$\partial \mathcal{L} / \partial i_t \cdot i_t = -\varphi m_{2t} \cdot i_t = 0, \quad m_{2t} \geq 0, \quad i_t \geq 0. \quad (10)$$

Inflation targeting under discretion. The Lagrangian of problem (1), (2) and (4) is

$$\begin{aligned} \max_{(\pi_t, x_t, i_t \geq 0)} \min_{(m_{1t}, m_{2t})} \mathcal{L} \equiv & E_t \sum_{j=0}^{\infty} \beta^j \left\{ -(\pi_{t+j} - \pi^*)^2 - \lambda^d (x_{t+j} - x^*)^2 \right. \\ & + m_{1t+j} [\pi_{t+j} - \beta E_{t+j} \pi_{t+j+1} - \kappa x_{t+j} - u_{t+j}] \\ & \left. + m_{2t+j} [-x_{t+j} + E_{t+j} x_{t+j+1} - \varphi (i_{t+j} - E_{t+j} \pi_{t+j+1} - r_{t+j}^n)] \right\} \\ & \text{and } \{\mathbf{y}(\mathbf{s}_{t+j})\} \text{ given for } j \geq 1. \end{aligned}$$

The Kuhn-Tucker conditions are

$$\partial \mathcal{L} / \partial \pi_t = -2(\pi_t - \pi^*) + m_{1t} = 0 \quad (11)$$

$$\partial \mathcal{L} / \partial x_t = -2\lambda^d (x_t - x^*) - \kappa m_{1t} - m_{2t} = 0 \quad (12)$$

$$\partial \mathcal{L} / \partial i_t \cdot i_t = -\varphi m_{2t} \cdot i_t = 0, \quad m_{2t} \geq 0, \quad i_t \geq 0. \quad (13)$$

Nominal GDP targeting under discretion. To solve for a stationary equilibrium, I use the price level in deviation from its trend

$$\hat{p}_t \equiv p_t - \bar{p}_t = \hat{p}_{t-1} + \pi_t - \pi^*. \quad (14)$$

Using this identity, the Lagrangian of problem (1), (2), (5) and (14) can be written as

$$\begin{aligned}
\max_{(\pi_t, x_t, i_t \geq 0, \hat{p}_t)} \min_{(m_{1t}, m_{2t}, m_{3t})} \mathcal{L} \equiv & E_t \sum_{j=0}^{\infty} \beta^j \{ -(\hat{p}_{t+j} + x_{t+j} - x^*)^2 \\
& + m_{1t+j} [\pi_{t+j} - \beta E_{t+j} \pi_{t+j+1} - \kappa x_{t+j} - u_{t+j}] \\
& + m_{2t+j} [-x_{t+j} + E_{t+j} x_{t+j+1} - \varphi (i_{t+j} - E_{t+j} \pi_{t+j+1} - r_{t+j}^n)] \\
& + m_{3t+j} [-\hat{p}_{t+j} + \hat{p}_{t+j-1} + \pi_{t+j} - \pi^*] \} \\
& \text{and } \{\mathbf{y}(\mathbf{s}_{t+j})\} \text{ given for } j \geq 1.
\end{aligned}$$

The Kuhn-Tucker conditions are

$$\partial \mathcal{L} / \partial \pi_t = -2(\hat{p}_t + x_t - x^*) + m_{1t} + m_{3t} = 0 \quad (15)$$

$$\partial \mathcal{L} / \partial x_t = -2(\hat{p}_t + x_t - x^*) - \kappa m_{1t} - m_{2t} = 0 \quad (16)$$

$$\partial \mathcal{L} / \partial i_t \cdot i_t = -\varphi m_{2t} \cdot i_t = 0, \quad m_{2t} \geq 0, \quad i_t \geq 0 \quad (17)$$

$$\begin{aligned}
\partial \mathcal{L} / \partial \hat{p}_t = & -2(\hat{p}_t + x_t - x^*) - (\beta m_{1t} - \varphi m_{2t}) \cdot \partial E_t \pi_{t+1} / \partial \hat{p}_t \\
& + m_{2t} \cdot \partial E_t x_{t+1} / \partial \hat{p}_t - m_{3t} = 0.
\end{aligned} \quad (18)$$

A summary of the equilibrium conditions is provided in the following table:

Policy framework	Equilibrium conditions	State vector \mathbf{s}_t
Ramsey plan	(1), (2) and (8)-(10)	$(u_t, r_t^n, m_{1t-1}, m_{2t-1})$
Inflation targeting (discretion)	(1), (2) and (11)-(13)	(u_t, r_t^n)
Nominal GDP targeting (discretion)	(1), (2) and (14)-(18)	$(u_t, r_t^n, \hat{p}_{t-1})$
Taylor rule	(1), (2) and (6)	(u_t, r_t^n, i_{t-1}^u)
Nominal GDP rule	(1), (2), (7) and (14)	$(u_t, r_t^n, i_{t-1}^u, \hat{p}_{t-1})$

A.2 Permanent consumption loss

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

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t = \frac{U_c \bar{C}}{2} \frac{\alpha \theta (1 + \omega \theta)}{(1 - \alpha)(1 - \alpha \beta)} L, \quad (19)$$

where \bar{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

$$E_0 \sum_{t=0}^{\infty} \beta^t U_c \bar{C} \mu = \frac{1}{1 - \beta} U_c \bar{C} \mu. \quad (20)$$

Equating the right sides of (19) and (20) gives

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

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Table 1: Calibration of the model

Definition	Parameter	Numerical value
Discount factor	β	0.99
Real-rate elasticity of real GDP gap	φ	6.25
Share of firms keeping prices fixed	α	0.66
Price elasticity of demand	θ	7.66
Elasticity of a firms' marginal cost	ω	0.47
Slope of aggregate supply curve	κ	0.024
Weight on real GDP gap (Ramsey plan)	λ	0.003
Steady-state real interest rate	r_{ss}	1.00 percent
Standard deviation of real-rate shock	σ_r	0.75 percent
Standard deviation of mark-up shock	σ_u	0.10 percent
AR(1) parameter of real-rate shock	ρ_r	0.80
AR(1) parameter of mark-up shock	ρ_u	0.00

Note: Because in the model a period is one quarter, shown are parameter values corresponding to inflation and interest rates measured at a quarterly rate.

Table 2: Performance of optimal policies

Policy framework ^a	Inflation			Welfare loss relative to Ramsey ^e				
	target ^b	ZLB episodes		steady state		variability		Tot.
		freq. ^c	duration ^d	π	x	π	x	
Discretion								
Flexible inflation targeting	1.8	10	2	0.20	0.00	0.49	0.10	0.79
Nominal GDP targeting	0.1	12	2	0.00	0.00	0.04	0.04	0.08
Ramsey plan	θ	13	3					

a. If flexible inflation targeting, optimal weight $\lambda^d = 0.001$

b. Percent annualized

c. Expected percent of time at the ZLB

d. Expected number of consecutive quarters at the ZLB

e. Permanent consumption loss (percentage points)

Table 3: Performance of simple policy rules

Policy framework ^a	Inflation		Welfare loss relative to Ramsey ^e					
	target ^b	ZLB episodes		steady state		variability		Tot.
		freq. ^c	duration ^d	π	x	π	x	
Optimal coefficients								
Taylor rule	0.0	10	3	0.00	0.00	0.02	0.00	0.02
Nominal GDP rule	0.0	11	4	0.00	0.00	0.01	0.00	0.01
Suboptimal smoothing								
Taylor rule	1.3	8	2	0.10	0.00	0.06	0.01	0.17
Nominal GDP rule	0.1	11	3	0.00	0.00	0.02	0.01	0.03

a. If optimal coefficients, $\phi_j = 1$ for $j = i, \pi, x, y$. But if suboptimal smoothing, $\phi_i = 0.7$

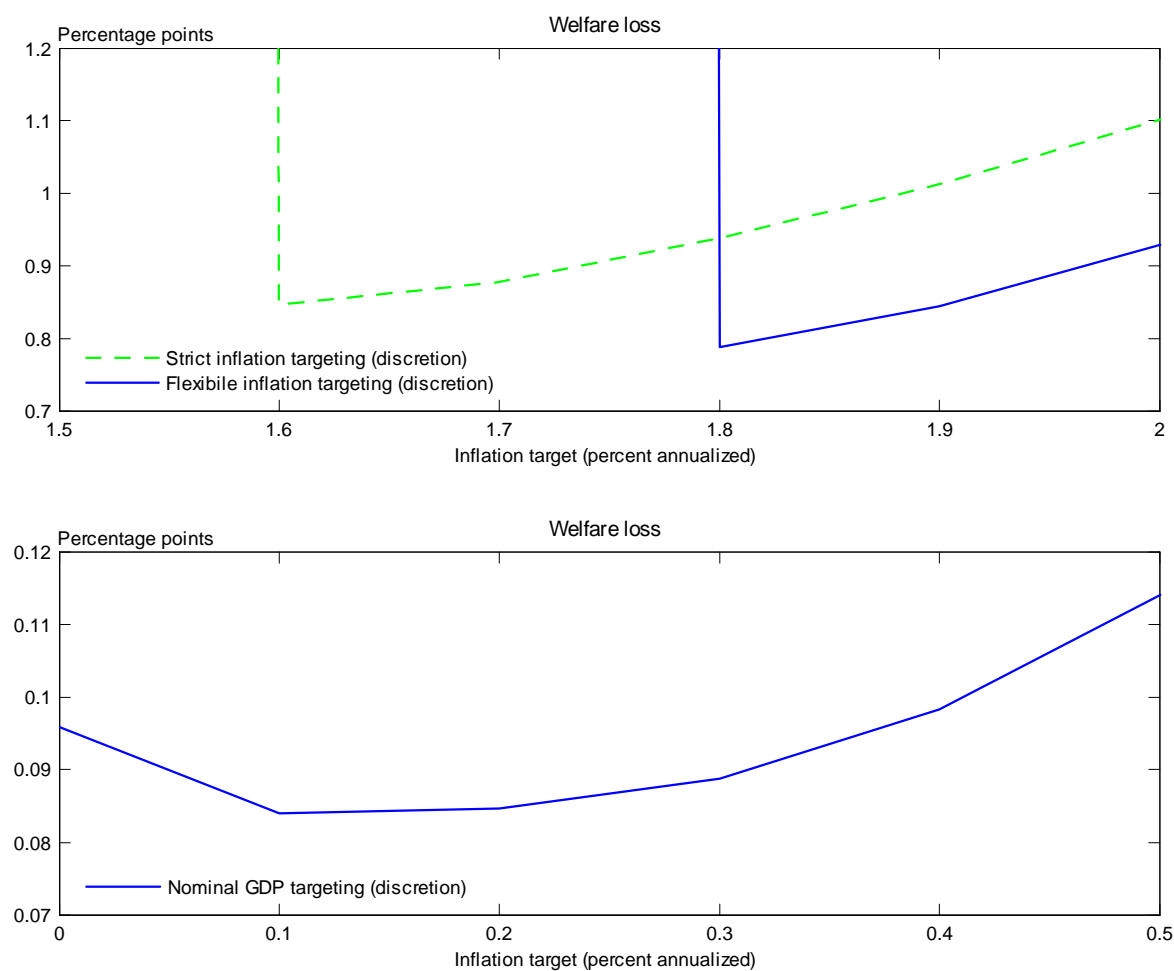
b. Percent annualized

c. Expected percent of time at the ZLB

d. Expected number of consecutive quarters at the ZLB

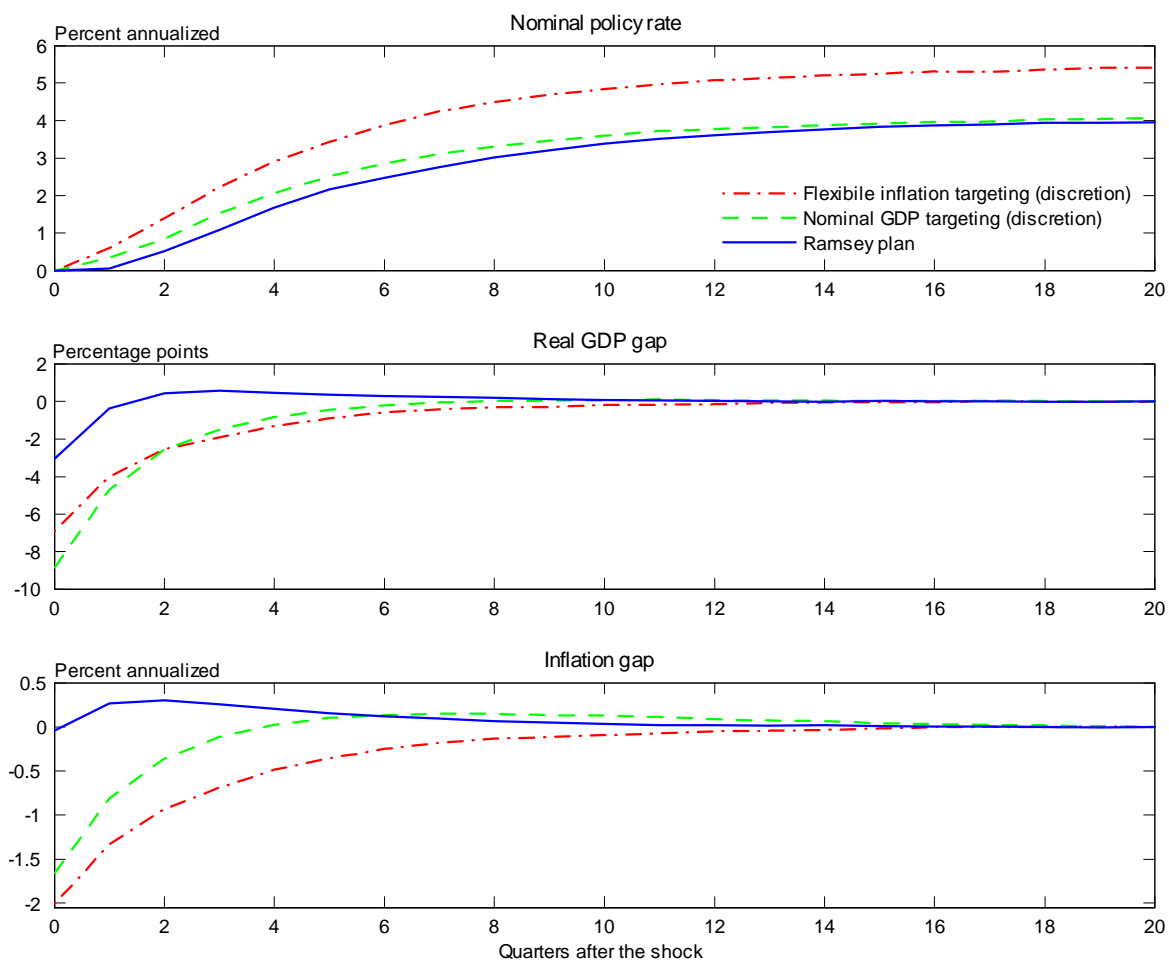
e. Permanent consumption loss (percentage points)

Figure 1: Optimal discretion: deflationary trap versus firmly anchored inflation



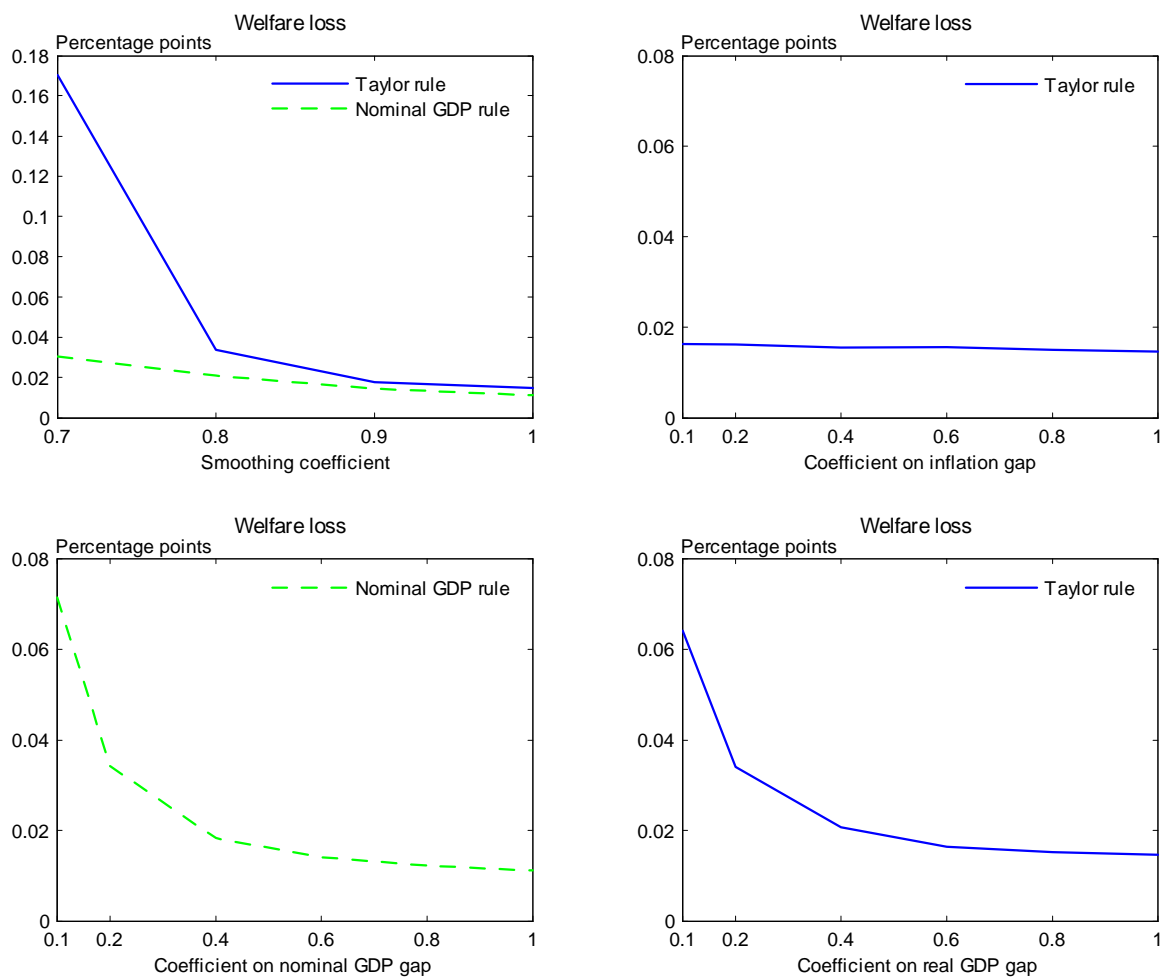
Notes: The welfare loss is measured as the permanent consumption loss relative to the Ramsey plan. The flexible inflation targeter assigns optimal weight to stabilizing real GDP relative to inflation.

Figure 2: ZLB episode with optimal policies



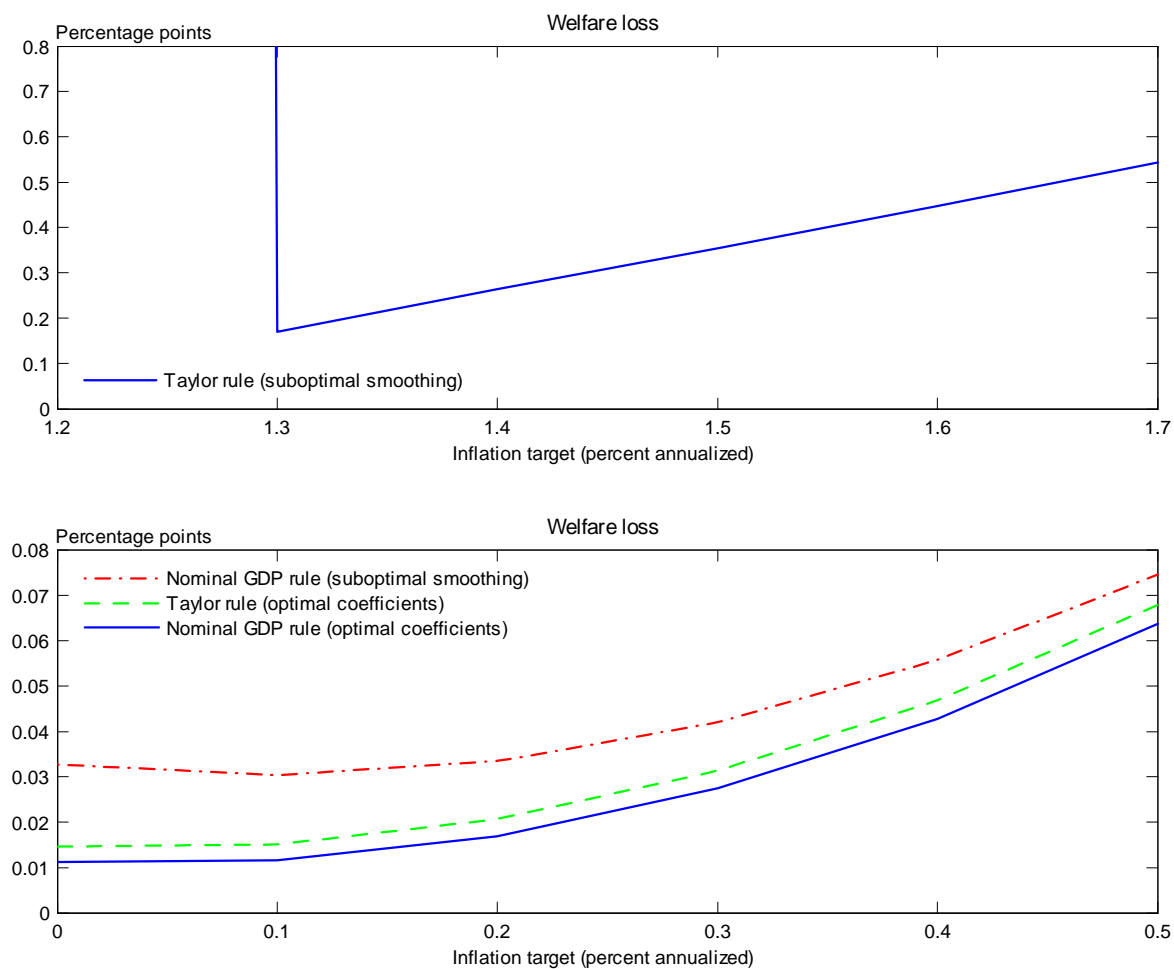
Notes: Shown is the expected path after a -2 standard deviation real-rate shock, with optimal inflation targets. The flexible inflation targeter assigns optimal weight to the stabilization of real GDP relative to inflation.

Figure 3: Optimal, simple policy rules



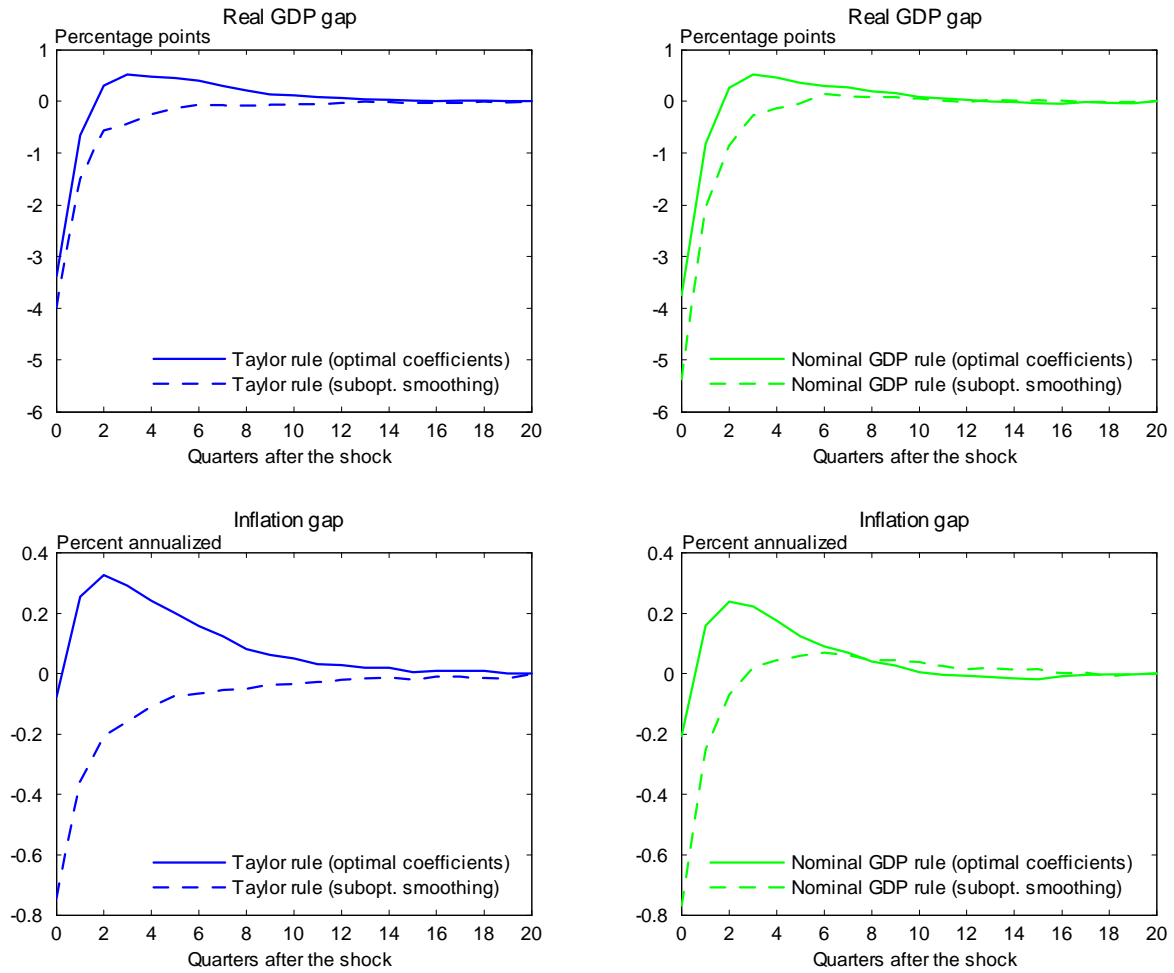
Notes: The welfare loss is measured as the permanent consumption loss relative to the Ramsey plan. In each panel a single rule coefficient is changed, while the other rule coefficients and the inflation target are at their optimal values.

Figure 4: Anchoring effect of smoothing in simple policy rules



Notes: The welfare loss is measured as the permanent consumption loss relative to the Ramsey plan. The optimal rule coefficients are equal to 1. But if suboptimal smoothing then ϕ_i is lowered to 0.7.

Figure 5: Smoothing in simple policy rules in a ZLB episode



Notes: Shown is the expected path after a -2 standard deviation real-rate shock, with optimal inflation targets. The optimal rule coefficients are equal to 1. But if suboptimal smoothing then ϕ_i is lowered to 0.7.

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