Output Gaps and Robust Monetary Policy Rules

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Abstract

Policymakers often use the output gap, a noisy signal of economic activity, as a guide for setting monetary policy. Noise in the data argues for policy caution. At the same time, the zero bound on nominal interest rates constrains the central bank's ability to stimulate the economy during downturns. In such an environment, greater policy stimulus may be needed to stabilize the economy. Thus, noisy data and the zero bound present policymakers with a dilemma in deciding the appropriate stance for monetary policy. I investigate this dilemma in a small New Keynesian model, and show that policymakers should pay more attention to output gaps than suggested by previous research.

Keywords: output gap, measurement errors, monetary policy, zero lower bound

JEL: E52, E58

1 Introduction

In monetary policy analysis, a commonly used indicator of economic activity is the output gap, which is a gauge of how far the economy is from its productive potential. The output gap is conceptually appealing as an indicator to help guide policy, because it is an important determinant of inflation developments. A positive output gap implies an overheating economy and upward pressure on inflation. By contrast, a negative output gap implies a slack economy and downward pressure on inflation. Thus, if available, accurate and timely measures of the output gap can play a central role in the conduct of effective monetary policy. A positive output gap might prompt policymakers to cool an overheating economy by raising policy rates, while a negative output gap might prompt monetary stimulus.

In practice, the output gap is a noisy signal of economic activity. Estimates of the output gap are often subject to large revisions after the time policy is actually made. Given the possibility that the output gap could give an inaccurate signal in real time, there is interest in policies that are robust to errors in measuring the gap. As discussed by Taylor and Williams (2010), the consensus from the literature is that the optimal coefficient on the output gap in policy rules declines in the presence of errors in measuring the gap. The logic for this result is straightforward. The reaction to the mismeasured output gap adds unwanted noise to the setting of policy, which can cause unnecessary fluctuations in output and inflation. The adverse effects of noise can be reduced by lowering the coefficient on the output gap in the rule.

While measurement errors argue for a cautious policy response to output gaps, policy activism may be desirable when the zero lower bound (ZLB) on nominal interest rates constrains policy. A concern is that the inability to reduce interest rates below zero can impair the effectiveness of monetary policy to stabilize output and inflation. Reifschneider and Williams (2000) find that increasing the coefficient on the output gap in policy rules helps reduce the effects of the ZLB. Such an active response to output gaps prescribes greater monetary stimulus before and after episodes when the ZLB constrains policy, which helps lessen the effects when the ZLB constrains

policy. However, there are limits to this approach as it generally increases the variability of inflation and interest rates, which may be undesirable. Thus, too large a response to the output gap can be counterproductive.

Noisy data and the zero bound, therefore, present policymakers with a dilemma in deciding the appropriate stance for monetary policy. This article is the first to investigate this dilemma. To do so, I consider a small New Keynesian model, where the only policy instrument is a short-term nominal interest rate that occasionally hits the ZLB. To determine policy, I characterize the setting of the interest rate with simple policy rules. I acknowledge the belief shared by policymakers that simple rules serve as a useful benchmark for setting monetary policy. Rules are useful to the extent that they appropriately account for data imperfections. Using the actual historical data that were available to policymakers in real time, I am able to calibrate the degree of data imperfections to match the level of noise faced by policymakers in practice. I assume the private sector has full information about the state of the economy in real time, so the model can be treated as structurally invariant under different policies as in Aoki (2003) and Svensson and Woodford (2004). Comparison of the performance of alternative policies then presents a quantification of the impact of both the ZLB and measurement errors on monetary policy.

I find that, under robust optimal policy, the presence of the ZLB is associated with greater policy activism. With measurement errors fitted to historical revisions of the output gap, consideration of the ZLB causes the optimal coefficient on the gap in a simple rule to rise from 0.1 to 0.2 and the optimal coefficient on inflation to rise from 2.5 to 3.0. I also study less ambitious policies that forego the activism associated with responding to the level of the output gap, as I did in Billi (2011b). In my previous article, however, I did not consider optimal policy and instead provided a review for a broad audience. Here I find that less ambitious policies lead to worse economic performance than robust optimal policy. This paper is also related to Orphanides (2003) who is more sanguine about less ambitious policies but does not consider the ZLB.

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

2 The model

I consider a small New Keynesian model, widely used in recent studies of monetary policy and discussed in depth in Clarida, Galí and Gertler (1999), Woodford , and Galí (2008). I focus on a simple policy rule along the lines of Taylor (1993), with rule parameters chosen optimally as to maximize welfare for the representative household. In determining the optimal rule parameters, I take into account that the nominal interest rate occasionally hits the ZLB.

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.

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

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

where E_t denotes the expectations operator conditional on information available at time t. x_t is the real output gap, i.e., the deviation of real output from its flexible-price steady state. π_t is the inflation rate. i_t is the nominal interest rate. And r_t^n is a natural rate of interest shock.[1] The parameter $\varphi > 0$ represents the real-rate elasticity of the output 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 setting as in Calvo (1983), is given by

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

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

where u_t is a mark-up shock, resulting from variation over time in the degree of monopolistic competition between firms. The parameter $\beta \in (0, 1)$ 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 $\omega > 0$ is the elasticity of a firm's real marginal cost with respect to its own output level. 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 given by

$$r_t^n = (1 - \rho_r) r_{ss} + \rho_r r_{t-1}^n + \sigma_{\varepsilon r} \varepsilon_{rt}$$

$$u_t = \rho_u u_{t-1} + \sigma_{\varepsilon u} \varepsilon_{ut},$$

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 $\sigma_{\varepsilon j} \geq 0$ for $j = r, u$.

2.2 Policy

The policymaker uses a Taylor rule to set the nominal interest rate. It is reasonable to assume that commitment to a simple policy rule of this kind represents the only feasible form of commitment. This is because optimal plans, derived from optimal control theory, tend to be complicated and potentially difficult to communicate to the public, relative to simple rules.

The policymakers's decision rule is then given by

$$i_t = \max\left[0, r_{ss} + \pi^* + \phi_\pi\left(\pi_t - \pi^*\right) + \phi_x\left(x_t - x^* + z_t\right)\right], \tag{3}$$

where $\phi_\pi, \phi_x, \geq 0$ are the rule parameters on inflation and the output gap in deviation from their goals. π^* is the steady-state inflation goal. And x^* is the steady-state output gap, which is consistent with an inflation rate of π^* in Phillips curve (2), that is $x^* = (1 - \beta)\kappa^{-1}\pi^*$. In addition, z_t represents noise or errors in measuring the output gap. The measurement errors are assumed to follow an AR(1) stochastic process, normally distributed.[2]

As a consequence of measurement errors, the policymaker faces the following problem. By choosing a positive response parameter on the output gap, as is appropriate for the stabilization of output and inflation, the policymaker inadvertently also reacts to the noise process. Responding to the noise introduces undesirable movements in the interest rate, which feed back to the economy and generate unnecessary fluctuations in output and inflation. As a result, naive adoption of policies that are optimal when measurement errors are ignored results in worse economic performance, relative to robust optimal policies that appropriately account for measurement errors. However, robust optimal policies might seek a balance and call for a lower parameter on the output gap in the rule than would be appropriate in the absence of measurement errors.

The max operator in rule (3) captures the restriction that the rule cannot violate the ZLB constraint. Ignoring the existence of the ZLB, the model could be solved with standard linear-quadratic methods. By contrast, a global numerical procedure must be used to find a solution that accounts for the ZLB and a stochastic process like the one studied here.[3] When the ZLB threatens, the mere possibility of hitting the ZLB causes expectations of a future decline in output below potential and inflation below its goal. As a result, as showed in Adam and Billi (2006, 2007), optimal policy calls for greater monetary stimulus than would be appropriate in the absence of the ZLB. But those papers did not consider measurement errors.

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[2] As my scope is to highlight the implications of mistakenly ignoring errors in measuring the output gap, in this analysis inflation is assumed to be observed without error. In actuality, inflation is also measured with error.

[3] See Billi (2011a) for a description of the numerical procedure.

In determining the optimal parameters in the policy rule, the policymaker's objective function is given by

$$\min_{\{\pi_t, x_t, i_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_t^2 + \lambda_x x_t^2 + \lambda_i i_t^2 \right], \tag{4}$$

where $\lambda_x, \lambda_i > 0$ are weights assigned to the stabilization of the output gap and the nominal interest rate, respectively. This objective function can be derived as a second-order approximation of the lifetime utility function of the representative household. The concern for interest variability reflects welfare costs of transactions. The approximation of the utility function allows to determine the weights in terms of the structure of the economy. For instance, λ_x is equal to κ/θ, where $\theta > 1$ is the price elasticity of demand substitution among differentiated goods produced by firms in monopolistic competition.

The policymaker faces two tradeoffs in objective (4). First, the mark-up shock is responsible for a tradeoff between the stabilization of inflation and the stabilization of the output gap, and the tradeoff depends on the weight λ_x.[4] In the absence of mark-up shocks, both inflation and the output gap could be completely stabilized by letting the nominal interest rate track the natural rate of interest shock. But in the presence of mark-up shocks, the policymaker cannot completely stabilize both inflation and the output gap. Second, transactions introduce a tension between stabilizing inflation and the output gap on one side and stabilizing the nominal interest rate on the other side, and the tension depends on the weight λ_i.

2.3   Equilibrium

In equilibrium, the policymaker chooses a policy based on a response function $\mathbf{y}(\mathbf{s}_t)$ and a state vector $\mathbf{s}_t$. Because $\mathbf{y}(\mathbf{s}_t)$ does not have an explicit representation, only numerical results are available. Before turning to the numerical results, I first explain some features of the equilibrium and then provide a formal definition.

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[4]Such a tradeoff would not be present without mark-up shocks, as is the case in Billi (2011b).

The response function is

$$\mathbf{y}\left(\mathbf{s}_t\right) = \left(\pi_t, x_t, i_t\right) \subset R^3.$$

Based on $\mathbf{y}\left(\mathbf{s}_t\right)$, the policymaker chooses a policy. The policy decision includes the inflation rate, the output gap, and the nominal interest rate.

The state vector is

$$\mathbf{s}_t = \left(u_t, r_t^n, z_t\right) \subset R^3.$$

It includes the exogenous shocks in the structural equations that summarize the behavior of the private sector. It also includes the errors in measuring the output gap in the Taylor rule.

In addition, the law of motion,

$$\mathbf{s}_{t+1} = g(\mathbf{s}_t, \mathbf{y}\left(\mathbf{s}_t\right), \boldsymbol{\varepsilon}_{t+1}),$$

describes how the future state of the economy unfolds. The future state $\mathbf{s}_{t+1}$ depends on the current state $\mathbf{s}_t$ and on current policy $\mathbf{y}\left(\mathbf{s}_t\right)$, which are known to both the policymaker and the private sector. It also depends on future innovations in the exogenous shocks and the measurement errors, $\boldsymbol{\varepsilon}_{t+1} = \left(\varepsilon_{ut+1}, \varepsilon_{rt+1}, \varepsilon_{zt+1}\right) \subset R^3$, which are unknown.

Based on the current choice of policy, the private sector forms expectations about future policy decisions. Thus, associated with the response function, there is an expectations function that describes how expectations about future policy are formed.

The expectations function is given by

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

where $f\left(\cdot\right)$ is a probability density function of the future innovations in the exogenous shocks and the measurement errors. The expectations about future policy decisions are formed over the

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current choice of policy.

Based on the above considerations, the following definition is proposed:

Definition 1 (SREE) *Assume $\sigma_{\varepsilon j} \geq 0$ for $j = u, r, z$. A "stochastic, rational-expectations equilibrium" is a response function $\mathbf{y}\left(\mathbf{s}_t\right)$ that satisfies equilibrium conditions (1), (2) and (3).*

2.4 Calibration and measurement errors

I now calibrate the model to the U.S. economy, and obtain estimates of the stochastic process describing the measurement errors.

Table 1 shows the baseline calibration. The values of the parameters of the Euler equation and Phillips curve are derived from Woodford (2003) tables 5.1 and 6.1 based on U.S. data, with two modifications. First, the value of φ represents a lower degree of interest-sensitivity of aggregate expenditure, to not exaggerate the size of the output contraction when the nominal interest rate hits the ZLB. As a consequence, κ and λ_x change as well. Second, the value of ρ_r represents a more persistent real-rate shock, to make the economic dynamics more persistent.[5] In addition, σ_u is set close to its upper bound when assuming all supply shifts are inefficient as in Giannoni (2012). Finally, the weights in the policymaker's objective function are derived from Woodford (2003) as well.[6]

[Table 1 about here]

The process for the measurement errors is obtained from fitting historical revisions of the output gap, as in Billi (2011b). Figure 1 shows the Congressional Budget Office (CBO) estimates for the past two decades. The figure shows real-time estimates, which reflect information available to policymakers at the time decisions were actually made. It also shows revised estimates, which

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[5] The value of ρ_r is slightly lower than in Billi (2011b), to not exaggerate the incidence of hitting the ZLB. In that article, for numerical convenience, the procedure added a bias term to the notional inflation goal to ensure that, on average, inflation reached the goal. The bias term limited the incidence of hitting the ZLB.

[6] The value assigned to λ_i preserves the ratio λ_i/λ_x. The ratio is roughly 26 in Woodford (2003) table 6.1 when interest rates are measured at a quarterly rate.

reflect information available with the benefit of hindsight. The difference between the revised and real-time estimates represents historical revisions, which are described quite well with a standard, first-order autoregressive process. Estimates of the process are reported in Table 1.

[Figure 1 about here]

3   Policy evaluation

Employing the small New Keynesian model calibrated to U.S. data together with estimates of errors present in the data, I next provide comparisons of the performance of naive policy, robust optimal policy, as well as less ambitious policies.

3.1   Naive policy

The starting point for the evaluation is the outcome when the policymaker follows rule (3) and the parameters are optimal in the absence of measurement errors. The policymaker uses the same parameters in the rule irrespective of the presence of measurement errors. In this sense, the resulting policy is naive because it neglects errors present in the data.

Table 2 shows the performance of the naive policy as the level of the measurement errors is varied. The analysis considers a case with measurement errors of normal size, namely, the baseline calibration. The analysis also considers a case with measurement errors of small size, in which the errors are assumed to have a standard deviation 50 percent smaller than the baseline. The table reports the optimal rule parameters.[7] It also reports the consumption loss associated with volatility in the output gap, inflation, and the nominal interest rate, respectively.[8] And it reports the incidence of hitting the ZLB. In the top panel the analysis ignores the ZLB and

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[7]The rule parameters are found searching over nonnegative values, with step size for ϕ_π equal to 0.5 and step size for ϕ_x equal to 0.1.

[8]Welfare is evaluated using objective (4) and averaging across 10,000 stochastic simulations each 1,000 periods long after a burn-in period. This value is then converted into a steady-state consumption loss, which is reported in the tables. See Appendix A.1 for further details.

allows the nominal interest rate to fall below zero, while in the bottom panel the ZLB is present.

[Table 2 about here]

When the analysis ignores the ZLB, the presence of measurement errors leads to deterioration of performance of naive policy. Moreover, the performance deterioration is not proportional to the size of the measurement errors, as discussed in Orphanides (2003). As the top panel of Table 2 shows, the consumption loss associated with output gap volatility is 0.03 percent in the absence of measurement errors. The loss remains roughly 0.03 percent as small errors are considered, but rises to 0.05 percent with normal errors. At the same time, the consumption loss due to inflation volatility rises from 0.12 percent to 0.20 percent (67 percent increase) as small errors are considered, but rises to 0.41 percent (242 percent increase) with normal errors. Given that the rule parameters stay unchanged, consideration of measurement errors does not cause a noticeable change in the consumption loss associated with interest rate volatility. Overall, naive policy results in disproportionately worse performance the larger the measurement errors the policymaker is mistakenly reacting to.

Also in the presence of the ZLB, consideration of measurement errors causes a disproportionate deterioration of performance of naive policy. As the bottom panel of Table 2 shows, the consumption loss associated with output gap volatility and inflation volatility rises relatively by more with normal errors. By contrast, the presence of the ZLB leads to a lower consumption loss in terms of interest rate volatility. This occurs because the long-run, or stationary, distribution of the nominal interest rate "piles up" at the ZLB, as discussed in Billi (2011a). As a result, the consumption loss due to interest rate volatility falls from 1.15 percent (ZLB absent) to 0.88 percent (ZLB present).

Still, the presence of the ZLB leads to greater policy activism, especially in terms of the response to inflation. As can be seen in Table 2, the parameter on the output gap in the rule remains 0.6 irrespective of the ZLB. However, the presence of the ZLB causes the rule parameter on inflation to rise from 1.0 to 2.0. The stronger response to inflation provides greater stimulus

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and helps lessen the effects of the ZLB. It also leads to a higher incidence of hitting the ZLB. The nominal interest rate falls to zero 8 percent of the time if the analysis ignores the ZLB. However, it falls to zero 19 percent of the time if the analysis takes account of the ZLB. In summary, naive policy argues for greater monetary stimulus in the presence of the ZLB.

3.2 Robust optimal policy

Policymakers who take account of measurement errors may improve upon naive policy. I thus consider the outcome when the policymaker follows rule (3) and the parameters are optimal reflecting the level of measurement errors. The resulting policy is then robust to potential errors in measuring the output gap.

Table 3 shows the performance of the robust policy as the level of the measurement errors is varied. Under the robust policy, consideration of measurement error leads to a weaker response to the output gap, but leads to a stronger response to inflation. When the analysis ignores the ZLB, the parameter on the output gap in the rule falls from 0.6 to 0.3 as small errors are considered, and falls to 0.1 with normal errors. This occurs because the robust policy seeks a balance and calls for a weaker response to the output gap in the rule than would be appropriate in the absence of measurement errors. By contrast, the rule parameter on inflation rises from 1.0 to 2.0 as small errors are considered, and rises to 2.5 with normal errors. However, the rise in the parameter on inflation in the rule depends on the model and the weights in the objective function, as noted in Taylor and Williams (2010).

[Table 3 about here]

In the presence of the ZLB, in contrast, the robust policy is associated with greater policy activism, in terms of the responses to inflation and the output gap. Comparing the top and bottom panels of Table 3, the rule parameters are generally larger when the analysis takes account of the ZLB. With normal measurement errors in particular, consideration of the ZLB causes the parameter on the output gap in the rule to rise from 0.1 to 0.2 and the parameter on

inflation to rise from 2.5 to 3.0. The stronger responses to the output gap and inflation prescribe greater monetary stimulus, which helps reduce the effects of the ZLB. It also leads to a higher incidence of hitting the ZLB. With normal measurement errors, the incidence of hitting the ZLB rises from 7 percent of the time (ZLB absent) to 12 percent of the time (ZLB present). In sum, robust policy calls for greater monetary stimulus when the zero bound threatens.

3.3   Less ambitious policies

The output gap is an important concept in monetary policy analysis, but the accuracy with which it is measured is suspect. Recognizing such errors in measuring the output gap, some policymakers favor less ambitious policies that forego the activism associated with responding to the level of the output gap altogether, see Plosser (2010). To study less ambitious policies, I consider the following two families of policy rules that are based on the Taylor rule.

I consider an *inflation rule* that takes the form:

$$i_t = \max\left[0, r_{ss} + \pi^* + \phi_\pi \left(\pi_t - \pi^*\right)\right]. \tag{5}$$

I also consider a *growth rule* given by:

$$i_t = \max\left[0, r_{ss} + \pi^* + \phi_\pi \left(\pi_t - \pi^*\right) + \phi_x \left(g_t - g^* + v_t\right)\right], \tag{6}$$

where now $\phi_x \geq 0$ is the rule parameter on the growth gap, or the deviation of real GDP growth from trend, instead of the output gap.[9],[10] In addition, v_t represents errors in measuring GDP

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[9]Because the sum of inflation and real GDP growth is simply the growth of nominal income, this strategy is closely related to nominal income growth targeting, as discussed in Orphanides (2003) and Walsh (2003). An argument against the latter strategy, however, is that the timing of the effects of monetary policy on inflation and output are quite different, with monetary policy affecting inflation with a longer lag. Because it allows policymakers to react differently to inflation and real GDP growth, the growth rule may be a more-effective strategy.

[10]Real growth is simply the change in real GDP, which implies $g_t - g^* = x_t - x_{t-1}$. With the additional state variable x_{t-1} in the model, the state vector becomes $\mathbf{s}_t = (u_t, r_t^n, v_t, x_{t-1}) \subset R^4$. In the presence of the ZLB, the higher dimension of the state vector makes finding a numerical solution more challenging when the policymaker uses the growth rule rather than the Taylor rule.

growth. The measurement errors are assumed to follow an AR(1) stochastic process, normally distributed. As in Billi (2011b), the process for the measurement errors is obtained from fitting historical revisions of GDP growth for the past two decades, with estimates reported in Table 1. As can be seen in the table, historical revisions and thereby measurement errors are typically smaller for GDP growth, relative to output gaps.

In typical macro models used for monetary policy analysis, the output gap is a key determinant of the behavior of the private sector and therefore inflation. As a result, in the absence of measurement errors the optimal rule requires a response to the level of the output gap, and the performance of less ambitious rules, such as the inflation rule and growth rule, will be clearly inferior, relative to the Taylor rule. It is not clear, however, which rule will lead to superior performance when measurement errors are appropriately taken into account.

Table 4 compares the performance of the Taylor rule and less ambitious rules. The table shows the performance that can be achieved, under naive policy and robust policy, in the presence of measurement errors of normal size as in the data. When the analysis ignores the ZLB, the rule parameter on the growth gap is zero, because reacting to GDP growth would lead to a consumption loss. As a result, the inflation rule and growth rule result in the same performance. Admittedly, not reacting to growth in the rule depends on the model and the weights in the objective function. At the same time, the less ambitious rules seek a balance and call for a stronger response to inflation than the Taylor rule. Under robust policy in particular, the parameter on inflation in the Taylor rule is 2.5, but rises to 3.0 in the less ambitious rules. As a result, the consumption loss associated with inflation volatility is lower when the policymaker adopts less ambitious rules instead of the Taylor rule. The less ambitious rules, however, result in a higher consumption loss associated with interest rate volatility.

[Table 4 about here]

Also in the presence of the ZLB, in the bottom panel of table 4, the less ambitious rules call for a stronger response to inflation, relative to the Taylor rule. Under robust policy, the parameter

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on inflation in the Taylor rule is 3.0, but rises to 3.5 in the less ambitious rules. By forcing the policymaker to move the interest rate more vigorously to offset disturbances to aggregate demand, the less ambitious rules generally result in a higher consumption loss. They also result in a lower incidence of hitting the ZLB. This occurs because under optimal policy the long-run distribution of the nominal interest rate is less piled up at the ZLB when the policymaker adopts less ambitious rules.[11] In conclusion, under robust policy, adopting less ambitious policies results in worse economic performance.

4   Conclusion

A central question in monetary policy analysis is whether policymakers should focus on the output gap as an indicator of economic activity to assess economic conditions and set an appropriate stance for monetary policy. The output gap is a key determinant of the behavior of the private sector and inflation in typical macro models used for monetary policy analysis. In practice, the output gap is a noisy signal of economic activity. The consensus from the literature is that policymakers should respond less to the output gap in policy rules than would be appropriate in the absence of noise in the data. This line of research, however, has ignored the ZLB by implicitly assuming policymakers can normally set policy rates below zero.

To address this limitation in previous research, I use a small New Keynesian model and take account of the ZLB. I find that policymakers should pay more attention to output gaps than suggested by previous research. In particular, if the analysis takes account of the ZLB, robust optimal policy is associated with a stronger response to the output gap. The stronger response to the output gap prescribes greater monetary stimulus and helps stabilize the economy when the ZLB threatens.

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[11] Under sub-optimal policy, however, less ambitious rules can result in a higher incidence of hitting the ZLB, as discussed in Billi (2011b)

A Appendix

A.1 Consumption loss

The expected lifetime utility of the representative household, as shown in chapter 6 of Woodford (2003), is validly approximated by

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t = \frac{U_c \overline{C}}{2} \frac{\alpha\theta(1+\omega\theta)}{(1-\alpha)(1-\alpha\beta)} L, \tag{7}$$

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 (4).

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

$$E_0 \sum_{t=0}^{\infty} \beta^t U_c \overline{C} \mu = \frac{1}{1-\beta} U_c \overline{C} \mu. \tag{8}$$

Then, equating the right side of (7) and (8) gives

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

References

ADAM, K., AND R. M. BILLI (2006): "Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates," *Journal of Money, Credit, and Banking*, 38(7), 1877–1905.
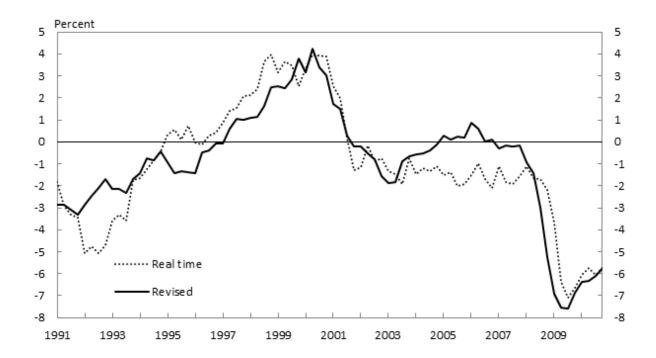
——— (2007): "Discretionary Monetary Policy and the Zero Lower Bound on Nominal Interest Rates," *Journal of Monetary Economics*, 54(3), 728–752.

AOKI, K. (2003): "On the Optimal Monetary Policy Response to Noisy Indicators," *Journal of Monetary Economics*, 50(3), 501–23.

BILLI, R. M. (2011a): "Optimal Inflation for the U.S. Economy," *American Economic Journal: Macroeconomics*, 3(3), 29–52.

——— (2011b): "Output Gaps and Monetary Policy at Low Interest Rates," *Federal Reserve Bank of Kansas City, Economic Review*, First Quarter.

CALVO, G. A. (1983): "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12(3), 383–98.

CLARIDA, R., J. GALÍ, AND M. GERTLER (1999): "The Science of Monetary Policy: Evidence and Some Theory," *Journal of Economic Literature*, 37(4), 1661–1707.

GALÍ, J. (2008): *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework*. Princeton University Press.

GIANNONI, M. P. (2012): "Optimal Interest Rate Rules and Inflation Stabilization versus Price-Level Stabilization," *Federal Reserve Bank of New York, Staff Report no. 546.*

ORPHANIDES, A. (2003): "Monetary Policy Evaluation with Noisy Information," *Journal of Monetary Economics*, 50(3), 605–31.

PLOSSER, C. I. (2010): "Output Gaps and Robust Policy Rules," *Speech given at the 2010 European Banking & Financial Forum, Czech National Bank, Prague, The Czech Republic, March 23*, available at http://www.philadelphiafed.org.

REIFSCHNEIDER, D., AND J. C. WILLIAMS (2000): "Three Lessons for Monetary Policy in a Low-Inflation Era," *Journal of Money, Credit, and Banking*, 32(4), 936–966.

SVENSSON, L. E. O., AND M. WOODFORD (2004): "Indicator Variables for Optimal Policy under Asymmetric Information," *Journal of Economic Dynamics & Control*, 28(4), 661–90.

TAYLOR, J. B. (1993): "Discretion versus Policy Rules in Practice," *Carnegie-Rochester Conference Series on Public Policy*, 39, 195–214.

TAYLOR, J. B., AND J. C. WILLIAMS (2010): "Simple and Robust Rules for Monetary Policy," in *Handbook of Monetary Economics*, ed. by B. M. Friedman, and M. Woodford, vol. 3, chap. 15, pp. 829–59. Elsevier B.V.

WALSH, C. E. (2003): "Implications of a Changing Economic Structure for the Strategy of Monetary Policy," *Federal Reserve Bank of Kansas City, Jackson Hole Economic Symposium*, pp. 297–348.

WOODFORD, M. (2003): *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton University Press.

Figure 1: Output gap based on real-time and revised data

Notes: The period is 1991:Q1 to 2010:Q4. The output gap is calculated as the deviation of real GDP from potential, as a fraction of potential using seasonally adjusted data. Real-time data reflect information actually available each quarter. Revised data reflect information available in January 2011.

Sources: Bureau of Economic Analysis (GDP) and Congressional Budget Office (potential)

Table 1: Baseline calibration of the model

Definition	Parameter	Numerical value
Discount factor	β	0.99
Real-rate elasticity of the output gap	φ	1.00
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 the aggregate-supply curve	κ	0.057
Weight on output gap in the objective	λ_x	0.008
Weight on nominal interest rate in the objective	λ_i	0.194
Steady-state real interest rate	r_{ss}	1.00 percent
Std. dev. of real-rate shock	σ_r	0.93 percent
Std. dev. of mark-up shock	σ_u	0.10 percent
Std. dev. of output-gap measurement error	σ_z	1.33 percent
Std. dev. of GDP-growth measurement error	σ_v	0.79 percent
AR(1)-parameter of real-rate shock	ρ_r	0.65
AR(1)-parameter of mark-up shock	ρ_u	0.00
AR(1)-parameter of output-gap measurement error	ρ_z	0.81
AR(1)-parameter of GDP-growth measurement error	ρ_v	0.79

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

Table 2: Naive policy performance

	Rule parameters		Consumption loss[a]			Frequency[b]
	ϕ_x	ϕ_π	x	π	i	$i \leq 0$
ZLB absent						
Measurement errors						
absent	0.6	1.0	0.03	0.12	1.15	8
small	0.6	1.0	0.03	0.20	1.15	8
normal	0.6	1.0	0.05	0.41	1.15	8
ZLB present						
Measurement errors						
absent	0.6	2.0	0.04	0.28	0.88	19
small	0.6	2.0	0.04	0.32	0.88	19
normal	0.6	2.0	0.05	0.46	0.88	19

Notes: Shown are results when policy follows Taylor rule (3) and the parameters

are optimal in the absence of measurement errors.

a Annualized percentage points

b Quarterly percentage points

Table 3: Robust policy performance

	Rule parameters		Consumption loss[a]			Frequency[b]
	ϕ_x	ϕ_π	x	π	i	$i \leq 0$
ZLB absent						
Measurement errors						
absent	0.6	1.0	0.03	0.12	1.15	8
small	0.3	2.0	0.04	0.17	1.12	8
normal	0.1	2.5	0.05	0.20	1.09	7
ZLB present						
Measurement errors						
absent	0.6	2.0	0.04	0.28	0.88	19
small	0.5	2.0	0.04	0.26	0.95	16
normal	0.2	3.0	0.04	0.20	1.07	12

Notes: Shown are results when policy follows Taylor rule (3) and the parameters are optimal reflecting the level of measurement errors.

a Annualized percentage points

b Quarterly percentage points

Table 4: Performance of Taylor rule and less ambitious policies

	Rule parameters		Consumption loss[a]			Frequency[b]
	ϕ_x	ϕ_π	x	π	i	$i \leq 0$
ZLB absent						
Naive policy						
Taylor rule	0.6	1.0	0.05	0.41	1.15	8
inflation rule	n/a	3.0	0.05	0.19	1.11	7
growth rule	0.0	3.0	0.05	0.19	1.11	7
Robust policy						
Taylor rule	0.1	2.5	0.05	0.20	1.09	7
inflation rule	n/a	3.0	0.05	0.19	1.11	7
growth rule	0.0	3.0	0.05	0.19	1.11	7
ZLB present						
Naive policy						
Taylor rule	0.6	2.0	0.05	0.46	0.88	19
inflation rule	n/a	3.5	0.05	0.20	1.08	10
growth rule	0.0	3.5	0.05	0.20	1.08	10
Robust policy						
Taylor rule	0.2	3.0	0.04	0.20	1.07	12
inflation rule	n/a	3.5	0.05	0.20	1.08	10
growth rule	0.0	3.5	0.05	0.20	1.08	10

Notes: Shown are results when policy follows Taylor rule (3), inflation rule (5) or growth rule (6), in the presence of measurement errors of normal size.

a Annualized percentage points

b Quarterly percentage points

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