Nominal GDP Targeting and the Taylor Rule on an Even Playing Field

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Abstract

Standard monetary policy analysis built upon the New Keynesian model suggests that an optimal monetary policy rule is one which minimizes a weighted sum of the variance of inflation and the variance of the output gap. As one might expect, the Taylor rule evaluates well under this criteria. Recent calls for nominal GDP targeting therefore must contend with Taylor rule as an alternative approach to monetary policy. In this paper, we argue that the information requirements placed on a central bank by requiring policymakers to have real-time knowledge of the output gap need to be taken into account when evaluating alternative monetary policy rules. To evaluate the relevance of these informational restrictions, we estimate the parameters of an otherwise standard New Keynesian model with the exception that we assume the central bank has to forecast the output gap using lagged information. We then use the model to simulate data under different monetary policy rules. The monetary policy rule that performs best is the nominal GDP targeting rule.

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1 Introduction

Beginning with Rotemberg and Woodford (1999), the conventional way to evaluate the welfare effects of monetary policy is to derive a loss function by taking a second-order Taylor series approximation of the household utility function. The optimal monetary policy in this context is one that minimizes a weighted sum of the variance of inflation and the variance of the output gap. Unsurprisingly, the Taylor Rule, which calls for the central bank to adjust the nominal interest rate in response to deviations of inflation from its target and the output gap, performs well within this context. In addition, given the close connection between the mechanics of the Taylor Rule and the characteristics of the loss function, it is unlikely that other policies will outperform the Taylor Rule in model simulations.

Calls for a nominal GDP target therefore face an uphill battle in convincing economists and policymakers of the desirability of this policy. For example, Koenig (2012) argues that the Taylor Rule is a special case of a nominal GDP target and a rule that requires less discipline from policymakers. If the Taylor Rule requires less discipline on the part of central bankers and can be shown to have desirable welfare properties, it is unclear what benefit another variant of a nominal GDP target creates.

In fact, a Taylor Rule requires more information on the part of policymakers than is recognized in this discussion because it requires that the central bank have real-time knowledge of the output gap. This is potentially problematic given the evidence that the Federal Reserve's real-time estimates of the output gap have, at times, systematically differed from the actual gap (Orphanides 2000, 2002a, 2002b, 2004).[1]

The purpose of this paper is to argue that evaluating the desirability of a nominal GDP targeting rule relative to a Taylor Rule requires that the actual information set available to central bankers be taken into account in any model-based comparison. In order to accomplish this, we consider the welfare properties of a Taylor Rule and a nominal GDP targeting rule in the context of a standard New Keynesian model. Contrary with much of the previous literature, we assume that the central bank has imperfect information about the output gap. Specifically, we make the modest assumption that over the long-term, the Federal Reserve's estimate of the output gap is consistent with the actual gap. However, we assume that the Fed's estimate can differ from the actual gap and that this difference can persist for some time.

[1]The problem of identifying the natural level of output or the natural rate of unemployment is by now well-known. On the natural rate of unemployment, see Staiger, Stock, and Watson (1997) and Laubach (2001). On the natural rate of output, see Orphanides and van Norden (2002) and Lansing (2002). As a result, Staiger, Stock, and Watson (1997) and Orphanides and Williams (2002) argue that interest rate rules should include the change in the unemployment rate rather than deviations from the natural rate. The approach in this paper is to suggest nominal GDP targeting as an alternative.

We then estimate the size and persistence of the forecast error made by central banks using data on the Greenbook forecasts and Bayesian estimation of the New Keynesian model. Finally, we conduct simulations to determine the different welfare properties of the Taylor Rule and a nominal GDP targeting rule. It is our view that these simulations are better able to evaluate a comparison of the Taylor Rule and nominal GDP targeting since one of the main advantages of the latter is that policymakers needn't have real-time knowledge of the output gap in order to determine a path for policy.

Our results suggest that the variance of inflation is lower, but the variance of the output gap is higher under a nominal GDP target than it would be under Taylor rule under the assumption that the central bank knows the output gap in real time. However, both the variance of inflation and the variance of the output gap are lower under a nominal GDP target than under the Taylor rule when the central bank has imperfect information about the output gap. Given that there are periods during which the Federal Reserve's forecast of the output gap has systematically differed from the actual output gap, the evidence presented in this paper suggests that the adoption of a nominal GDP target would be welfare-increasing.

2 Monetary Policy and the Output Gap

One of the key challenges facing monetary policy authorities is the knowledge problem. As first noted by Hayek (1945), this problem arises because the information needed for optimal economic planning is distributed among many individual firms and households and therefore outside the knowledge of a central planning authority. This observation, when specifically applied to central banking, means that the information required to make activist countercyclical policies work is not available. Consequently, monetarists like Friedman (1953, 1968), Brunner (1985), and Meltzer (1987) argued early on against central bank discretion and instead called for simple rules that committed monetary authorities to stable money and nominal income growth.[2]

The knowledge problem was later shown by Orphanides (2000, 2002a, 2002b, 2004) to apply not only to central banks that conduct discretionary monetary policy, but also to ones follow a "constrained discretionary" approach to monetary policy. That is, even central banks that follow some kind of a Taylor Rule in a flexible inflation targeting regime are susceptible to the knowledge problem.

[2]Even if the knowledge problem could be overcome, Kydland and Prescott (1977), and later Barro and Gordon (1983) showed that central banks would still struggle with discretion due to the time inconsistency problem. This insight also points to a need for monetary policy rules.

To see why, consider a standard Taylor Rule:

$$r_t = r_t^* + \phi_\pi \pi_t + \phi_y \tilde{y}_t \qquad (1)$$

where r^* is the equilibrium nominal interest rate, π_t is inflation, $\tilde{y}_t$ is the output gap, and ϕ_π and ϕ_y are parameters.

Orphanides (2002a, 2002b) observes that the knowledge problem can arise in determining the response coefficients ϕ_π and ϕ_y as well as choosing the correct measure for π_t.[3] The biggest information challenge, though, comes from attempting to measure the output gap, $\tilde{y}_t$, in real time. The output gap is the difference between the economy's actual and potential level of output and is subject to two big measurement problems. First, real-time output data generally gets revised and often does so on the same order of magnitude as the estimated output gap itself. Second, potential output estimates are based on trends that rely on ever-changing end points. Orphanides finds the latter problem to be the biggest contributor to real-time misperceptions of the output gap. This means that even if real-time data improved so that there were fewer revisions, there would still be a sizable real-time output gap measurement problem.

To illustrate these problems, Figure 1 replicates Orphanides (2002b) construction of real-time output gap measures using vintage real output data and compares them to final output gap measures using both the Hodrick-Prescott and Baxter King filters. We construct this figure by taking the vintage real output data available for every quarter from 1965:Q1 to 2011:Q4 and applying the filters to the data. That is, we estimate for every quarter a real-time estimate of the output gap given the data available through that quarter.[4] We then add together all of the real-time output gap estimates for each quarter into one series and plot it against the output gap created by using the final data available.

The top panel in Figure 1 shows both the real-time and actual output gap measures. To help see how different these measures are, the second panel plots the "real-time output gap misperceptions," the difference between the real-time and final output gap measures. Both the Hodrick-Prescott (HP) and

[3]For example, should ϕ_t be based on current or forecasted values of inflation? Also, if the latter, what is the appropriate forecast horizon?

[4]Because these filters are sensitive to endpoints, we estimate for each vintage quarter time series its trend and then extrapolate it ahead five years. This horizon is far enough out to get pass the business cycle and arguably reflects where observers in real time expected trend real output to be headed. We add this forecasted path to the vintage real output series and apply the filters to it. This provides a better endpoint anchor. The vintage real output data comes from the Philadelphia Federal Reserve Bank and is comprised of vintage real GNP up through 1991 and thereafter real GDP.

Baxter-King filters reveal sizable measurement problems, particularly in the 1970s. The HP filter shows real-time output gap misperceptions reaching as much as 5 percentage points while the Baxter-King filter shows up to 2 percentage points in the 1970s.

Orphanides (2004) sees these large measurement errors as a key contributor to the unmooring of inflation in the 1970s. He shows that if one plugs in the real-time estimates of the output gap and inflation from the 1970s into a Taylor Rule like (1) you get pretty close to the actual monetary policy that occurred during this time. The "Great Inflation," in other words, was not the result of the Fed failing to properly respond to the economic developments during this time. It was the result of the Fed failing to properly measure the output gap.

Interestingly, Figure 1 also indicates that the "Great Moderation" period of 1984-2007 was one characterized by relatively smaller real-time output gap misperceptions. This suggests that the claims of Taylor (1999), Clarida, Gali, and Gertler (2000), and others the FOMC after Paul Volker was not necessarily more disciplined in its response to inflation than in the 1970s might be without merit. As Walsh (2009: 216) notes, it may be that the success of inflation targeting during this time has as much to do with "good luck" coming from a "benign economic environment" as it does with monetary policy itself.

The final panel in Figure 1 plots the real-time output gap misperceptions against a total factor productivity (TFP) forecast error series. This latter measure comes from running a rolling regression on the trend of the Fernald (2009) TFP series and using it to construct a forecast for each period. The difference between actual and forecasted TFP is the forecast error.[5]

This final panel shows, especially for the HP filter, a close relationship between the TFP forecast error and real-time output gap misperceptions. This suggests that supply-side shocks are key to the knowledge problem facing central bankers. Such shocks affect potential real output and thus the output gap, but are notoriously hard to measure in real time. Selgin et al. (2015), for example, show that a key contributor the housing boom in the early 2000s was the failure of the FOMC to recognize and properly respond to the large productivity boom of 2002-2004. This failure to recognize this large positive supply shock can explain why monetary policy continued to ease after 2002 even though housing prices, credit growth, and nominal spending were accelerating.

Recognizing the measurement problems supply shocks make for monetary policy, Selgin et al. (2015)

[5]The data starts in 1947:Q1 and we forecasts based on the assumption of a slowly changing long-term trend in the data. Hence, we use a rolling sample of 92 observations which means the first forecast is for 1970:Q1. The regression takes the natural log of the Fernald (2009) total factor productivity and regresses it on a time trend.

advocate a nominal GDP target as a way to deal with this knowledge problem. Specifically, they note that monetary authorities can step back from worrying about the size of the output gap by focusing on anchoring the path of nominal spending. Doing so keeps total dollar spending stable while removing the need for the Fed to respond to changes in the composition of this spending from supply shocks.

Nominal GDP targeting, in other words, is a work around for the knowledge problem facing central bankers. It the reason Woodford (2012) endorsed it in his much-publicized Jackson Hole speech and is the reason Koenig (2012) is wrong to characterize the Taylor Rule as a special case of nominal GDP targeting. From the knowledge problem perspective, the Taylor Rule is a fundamentally different approach to monetary policy than a nominal GDP targeting. The former imposes an information requirement on central bankers that the latter does not.

3 A Framework For Analysis

As noted above, within the standard New Keynesian framework, the relative performance of monetary policy rules are evaluated in terms of their ability to minimize a weighted sum of the variance of inflation and the output gap. Given the fact that the Taylor rule adjusts policy to the contemporaneous inflation rate and output gap, it is perhaps unsurprising that the Taylor rule performs rather well using this criteria. Nonetheless, the assumption that the central bank is accurately able to estimate the output gap in real time is contrary to existing empirical evidence. As a result, it is important to incorporate this characteristic into the evaluation of alternative monetary policy rules.

In this section, we evaluate monetary policy rules in the following way. First, we outline a New Keynesian model in which the central bank forms an estimate of the output gap based on previous values of the actual output gap. The central bank then uses their estimate in the determination of policy. We estimate the parameters of this model using Bayesian estimation techniques. We then generate data with this model and use the welfare function to evaluate policy.

Second, given the parameter estimates from the initial model, we generate data using two alternative models which differ only in terms of assumptions regarding the conduct of monetary policy. The first alternative is the standard New Keynesian model in which the central bank has perfect information about the output gap. The second alternative is a standard New Keynesian model in which monetary policy adjusts to deviations of nominal GDP from some arbitrary target.[6]

Finally, we use the simulations from each model to evaluate monetary policy under these different assumptions. The results will then allow us to compare the performance of the nominal GDP targeting rule to the Taylor rule under different assumptions about the information set of the central bank.

3.1 The New Keynesian Model With Uncertainty Regarding the Output Gap

In this section we present the standard New Keynesian model modified by the assumption that the central bank does not have real time knowledge of the output gap. Specifically, we assume that the central bank can observe the previous period's true output gap and uses it to forecast the current period output gap. The standard New Keynesian model consists of the following log-linearized equations:

$$c_t = E_t c_{t+1} - \frac{1}{\sigma}(r_t - E_t \pi_{t+1}) + e_t^c \tag{2}$$

$$y_t = c_t + g_t \tag{3}$$

$$g_t = \rho_g g_t + e_t^g \tag{4}$$

$$\pi_t = \beta E_t \pi_{t+1} + \left(\frac{(1-\theta)(1-\beta\theta)(1-\alpha)}{\theta(1-\alpha+\alpha\epsilon)} \right) \left(\sigma + \frac{\psi+\alpha}{1-\alpha} \right) \tilde{y}_t + e_t^{PC} \tag{5}$$

$$y_t^n = \frac{1+\psi}{\sigma(1-\alpha)+\psi+\alpha} a_t \tag{6}$$

$$a_t = \rho_a a_{t-1} + e_t^a \tag{7}$$

$$\tilde{y}_t = y_t - y_t^n \tag{8}$$

where c_t is consumption, g_t is an aggregate spending/demand shock, y_t is real GDP, π_t is the rate of inflation, r_t is the nominal interest rate, $\tilde{y}_t$ is the output gap, y_t^n is the natural level of output, a_t is productivity, e_t^c is a consumption shock, e_t^{PC} is a shock to the New Keynesian Phillips curve, and σ, β, κ, ϕ_n, and ρ_a are parameters. Thus, equation (2) is the consumption Euler equation, (3) defines real GDP as the sum of consumption and an aggregate demand shock, (5) is the New Keynesian Phillips curve, (6)

[6] This latter model is similar to the model used in Hendrickson (2012). The assumption in this model is that monetary policy responds to deviations of nominal GDP growth from the steady state growth rate. The particular steady state growth rate, however, has no bearing on the results, hence the use of the term arbitrary. We view this as an advantage of our analysis since it does not require the stipulation of a particular target for nominal GDP and therefore applies to nominal GDP targeting generally.

defines the natural rate of output, and (8) defines the output gap.

Our framework differs from the standard model in the following way. We assume that the central bank follows a Taylor rule. However, the central bank sets the nominal interest rate based on their estimate of the current period output gap:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)(\phi_\pi \pi_t + \phi_y \tilde{y}_t^{CB}) + e_t^r \tag{9}$$

where ρ_r is an autoregressive parameter, ϕ_π is the coefficient on inflation, ϕ_y is the coefficient on the estimate of the output gap, e_t^r is a monetary policy shock, and $\tilde{y}_t^{CB}$ is the central bank's estimate of output gap and satisfies:

$$\tilde{y}_t^{CB} = \Theta(\tilde{y}_{t-1}^{CB} - \tilde{y}_{t-1}) + e_t^{gap} \tag{10}$$

Equations (2) - (10) represent a system of nine equations that solve for nine unknowns: c_t, g_t, y_t, r_t, π_t, $\tilde{y}_t$, y_t^n, a_t, and $\tilde{y}_t^{CB}$. We estimate the parameters of the model using Bayesian estimation techniques. The estimated parameters are then held constant in the model simulations used to evaluate the welfare properties of alternative monetary policy rules.

3.2 Estimation Details

Bayesian estimation relies on the fact that the posterior distribution of the parameters is approximately equal to the product of the likelihood of the model and the prior distribution of the parameters. This subsection outlines the prior distribution of the parameters and discusses how to estimate the likelihood and characterize the posterior distribution.

Four of the model parameters are calibrated. The remaining parameters are estimated. The calibrated parameters are as follows. The discount factor, β, is set equal to 0.99. For quarterly observations, this is consistent with a real interest rate of 4%. The fraction of firms that are able to change their prices, θ, is set to 2/3, consistent with parameterizations used to match the timing of price changes in the literature. The labor share of income for the model is $1 - \alpha$. Thus, we set $\alpha = 1/3$, consistent with empirical observations. Finally, the parameter ϵ is set equal to 6, which is a standard used in the literature.

The prior distribution of the parameters are shown in Table 1. The prior mean of the parameter σ is set equal to one. This is consistent with an assumption of log utility over consumption. We assume that this parameter follows a Gamma distribution with a standard deviation of 0.5. The parameter, ψ, is the inverse Frisch labor supply elasticity. We assume that ψ follows a Gamma distribution with a mean of 1 and a standard deviation of 0.5. Θ measures the responsiveness of the central bank to their previous period's forecast error. We assume that Θ follows a uniform distribution on the interval $[-2, 2]$. The parameters ϕ_π and ϕ_y are the Taylor rule coefficients. We assume that ϕ_π follows a Gamma distribution with a mean of 1.5 and a standard deviation of 0.5 and ϕ_y follows a Beta distribution with a mean of 0.125 and a standard deviation of 0.05. The parameters ρ_g, ρ_a and ρ_r represent the autoregressive parameters of the aggregate demand shock, productivity and the nominal interest rate, respectively. For each of these parameters, we assume they follow a Beta distribution with a mean of 0.5 and a standard deviation of 0.2. Finally, we assume that each of the shocks follow an Inverse Gamma distribution with a mean of 0.01 and a standard deviation of 2.0.

The nine equation system of equations described above has a rational expectations solution of the form:

$$S_t = AS_{t-1} + B\varepsilon_t \tag{11}$$

$$Y_t = CS_t \tag{12}$$

where Y_t is a vector of control variables, S_t is a vector of state variables, ϵ_t is a vector of structural shocks, and A, B, and C are parameter matrices. Define $X_t = [Y_t' \;\; S_t']$. One can then re-write (11) and (12) as

$$X_t = DX_{t-1} + E\varepsilon_t \tag{13}$$

where D, E are functions of A, B, and C, and (13) is the state-space representation of the model.

Define $\mathcal{Y}_t$ to be a vector of observable variables. The observable variables can be written in terms of the states defined in (13) as

$$\mathcal{Y}_t = F + GS_t + \Xi_t \tag{14}$$

where F is a vector of the mean of the observable variables, G is a matrix of zeros and ones that relates the observables to the variables in the system, and Xi_t is a vector of measurement errors.

Define Γ as a vector that contains the parameters of the model. The likelihood of the model is given as

$$\mathcal{L}(\mathcal{Y}_T|\Gamma) = \sum_{t=1}^{T} \mathcal{L}(\mathcal{Y}_t|\mathcal{Y}_{t-1}, \Gamma)$$

where $\mathcal{L}(\mathcal{Y}_t|\mathcal{Y}_{t-1}, \Gamma)$ is the likelihood conditional on information up to time $t-1$. Given (13) and (14), we can use the Kalman filter to compute the likelihood function.

The posterior distribution of the parameters is characterized using the Metropolis-Hastings algorithm. The algorithm operates as follows. Given some initial vector of parameters, $\Gamma_{1,0}$, the Kalman filter can be used to estimate the likelihood. A new parameter vector is then generated according to

$$\Gamma_{1,1} = \Gamma_{1,0} + jc\varepsilon_1$$

where c is the Choleski decomposition of the covariance matrix of Γ, j is a jump scalar, and ε_1 is a vector of elements drawn from a standard normal distribution. The Kalman filter is then used to construct the likelihood given the new parameter vector $\Gamma_{1,1}$. The Metropolis-Hastings algorithm is then used to either accept or reject this parameter vector. The steps are repeated for a specified number of draws, N, to determine the posterior density of the model.

Both the number of draws, N, and the jump scalar, j, are important for characterizing the posterior. The jump scalar j should be chosen such that the acceptance rate for the Metropolis-Hastings algorithm is between 20 - 30%. The size of the sample is also important for convergence of the Metropolis-Hastings algorithm. The R statistic proposed by Gelman et al. (2004) can be used to evaluate convergence of each parameter. An R statistic less than 1.1 represents evidence of convergence. In our estimation, we set $j = 0.55$, which produces an acceptance rate of 24.9%. We set the number of draws to $250{,}000$ and drop the first $50{,}000$ draws. The resulting R statistic is less than 1.1 for each of the parameters.

3.3 Results

The model is estimated using data on five variables: real GDP, the output gap, the Federal Reserve's forecast of the output gap, the federal funds rate, and the inflation rate. Real GDP is measured by the log-difference of real GDP. The output gap is measured by the percentage difference between real GDP and the Congressional Budget Office's estimate of real potential GDP. The inflation rate is measured by the percentage change in the implicit GDP deflator from a year ago. The federal funds rate is the effective federal funds rate. Each of these variables were obtained from the St. Louis Federal Reserve's FRED database. The Federal Reserve's estimate of the output gap is the forecast of the current period output gap taken from the Federal Reserve's Greenbook forecast. The Greenbook forecasts were obtained from the Federal Reserve Bank of Philadelphia's Greenbook database. All data is quarterly and is estimated over the sample 1987:Q3 - 2007:Q3. This is the sample over which the Federal Reserve's forecast of the output gap is available.

The estimated parameters are shown in Table 2 along with the posterior mean, mode, and 90% probability interval. Figure 1 plots the prior density of each parameter, the posterior density of each parameter, and the mode of the distribution. The prior density is plotted in gray, the posterior density is plotted in black, and the mode is represented by a vertical line.

As shown the intertemporal elasticity of substitution for consumption, σ is estimated to be 2.21. The inverse Frisch elasticity of the labor supply is estimated to be 0.85. The parameters on inflation and the output gap in the Taylor rule are estimated to be 2.03 and 0.29, respectively. The responsiveness of the central bank's forecast of the output gap to its previous forecast error is 0.25. For most of the estimated parameters, the variance of the posterior distribution is narrower than the prior distribution.

Shocks to consumption and to monetary policy are small. The largest shock is the aggregate demand shock. The shock to technology and to the New Keynesian Phillips curve are of similar magnitude. We use the estimated parameters and the estimated standard deviations of the shocks in the simulations in the next section.

4 Evaluating Alternative Monetary Policies

As we outlined above, a distinct difference between a nominal income growth target and a Taylor rule is that the latter requires knowledge of the output gap in real time. While a target for nominal income growth would no doubt be informed by long-run averages of real GDP growth and the central bank's desired rate of inflation, the choice of a nominal income growth target need not require any knowledge of the output gap or potential GDP. Traditional analysis of Taylor rules assume that the central bank has real-time knowledge of the output gap. If this is not true, as historical experience would seem to suggest, then the welfare properties of the Taylor rule are potentially biased. In this section we present evidence from simulations to analyze the welfare properties under four different assumptions regarding the economy. The four frameworks are described as follows:

1. *The Taylor Rule with Standard New Keynesian Assumptions.* This is the standard analysis in the literature. The framework consists of equations (2) - (9) under the assumption that the central bank has perfect real-time knowledge of the output gap ($\tilde{y}_t^{CB} = \tilde{y}_t$). In addition, the parameters of the Taylor rule, ϕ_π and ϕ_y, are set equal to 1.5 and 0.5, respectively, as in Taylor (1993).

2. *The Taylor Rule with Imperfect Knowledge of the Output Gap.* This framework consists of equations (2) - (10) as outlined above. However, we impose Taylor rule parameters $\phi_\pi = 1.5$ and $\phi_y = 0.5$.

3. *A Difference Rule.* The framework consists of equations (2) - (9). However, (9) is modified to replace the output gap with the change in real GDP: $y_t - y_{t-1}$. This modification was first suggested by Staiger, Stock, and Watson (1997). Similarly, Orphanides and Williams (2002) showed that a rule that included the change in the unemployment rate was robust to a world in which the central bank is uncertain about the natural rate of unemployment. Since this policy is also immune to information problems associated with the output gap, this provides a Taylor rule alternative to nominal GDP targeting that is immune from our critique.

4. *A Nominal Income Growth Target.* This framework consists of equation (2) - (8), an identity that defines nominal income growth, and a nominal income target. The monetary policy rule is expressed in log-deviations as

$$r_t = \rho_r r_{t-1} + (1 - \rho_r)\Omega\Delta x_t + e_t^r \tag{15}$$

   where Δx_t is nominal income growth, e_t^r is the monetary policy shock, and Ω is a parameter. Consistent with the estimates in Hendrickson (2012) from the post-Volcker era, we assume that $\Omega = 1.78$.

Each framework is simulated by generating 100,000 observations. We keep only the last 200 observations. All of the parameters and the standard deviations of the shocks used to simulate data are identical to the estimates obtained in the previous section. Each of the simulated series are HP-filtered under standard assumptions. Thus, the only difference in the data generating process across each different framework are the assumptions regarding monetary policy.

Finally, the welfare function is derived using a second-order approximation the household utility function. As shown in Gali (2008), the welfare loss per period is the weighted sum of the variance of the output gap and the variance of inflation:

$$\mathcal{W} = \frac{1}{2}\left[\left(\sigma + \frac{\psi+\alpha}{1-\alpha}\right)\text{var}(\tilde{y}_t) + \frac{\epsilon\theta(1-\alpha+\alpha\epsilon)}{(1-\theta)(1-\beta\theta)(1-\alpha)}\text{var}(\pi_t)\right] \tag{16}$$

We will use this loss equation to evaluate the welfare effects of each model.

In Table 3, the variance of the output gap and inflation as well as the welfare loss associated with those values are shown for each of the frameworks outlined above. The welfare loss is measured as the percentage of consumption relative to the steady state. The variances are shown in percentages. As shown the variance of inflation is lower under a nominal GDP target than the Taylor rule under the standard assumptions. However, the variance of the output gap is considerably lower under the Taylor rule in this comparison. The welfare loss is lower under the nominal GDP targeting rule than under the Taylor rule given the large relative weight that is placed on inflation.

Our argument in this paper is that the relevant comparison for analysis is between the Taylor rule under imperfect information and the nominal GDP targeting rule since central banks do not know the output gap in real time. Under imperfect information, the variance of inflation and the output gap are higher than when the central bank has perfect information – as one would expect. However, it is also true that the assumption of imperfect information implies that the variance of both inflation and the output gap under a Taylor rule would be higher than under a nominal GDP target. Thus, on an equal playing field, the nominal GDP target outperforms the Taylor rule. Moving from a Taylor rule with imperfect knowledge of the output gap to a nominal GDP target would reduce the welfare loss by 19%.

Finally, the performance of the nominal GDP target is also favorable in comparison to the difference rule. Some have argued that a Taylor rule modified to include the change in the real output rather than the output gap would be robust to the issues raised in this paper. Our results are important because they suggest that a nominal GDP target would be welfare-improving even in comparison to the difference specification of the Taylor rule.

5 Conclusion

Standard monetary policy analysis built upon the New Keynesian model suggests that an optimal monetary policy rule is one which minimizes a weighted sum of the variance of inflation and the variance of the output gap. As one might expect, the Taylor rule evaluates well under this criteria. Recent calls for nominal GDP targeting therefore must contend with Taylor rule as an alternative approach to monetary policy. In this paper, we have argued that the information requirements placed on a central bank by requiring policymakers to have real-time knowledge of the output gap need to be taken into account when evaluating alternative monetary policy rules.

To evaluate the relevance of these informational restrictions, we estimated the parameters of an otherwise standard New Keynesian model with the exception that we assumed the central bank has to forecast the output gap using lagged information. We then used the estimated parameters to simulate data under different monetary policy rules. The monetary policy rule that performed best was the nominal GDP targeting rule. Thus, nominal GDP targeting outperforms the Taylor rule on an even playing field.

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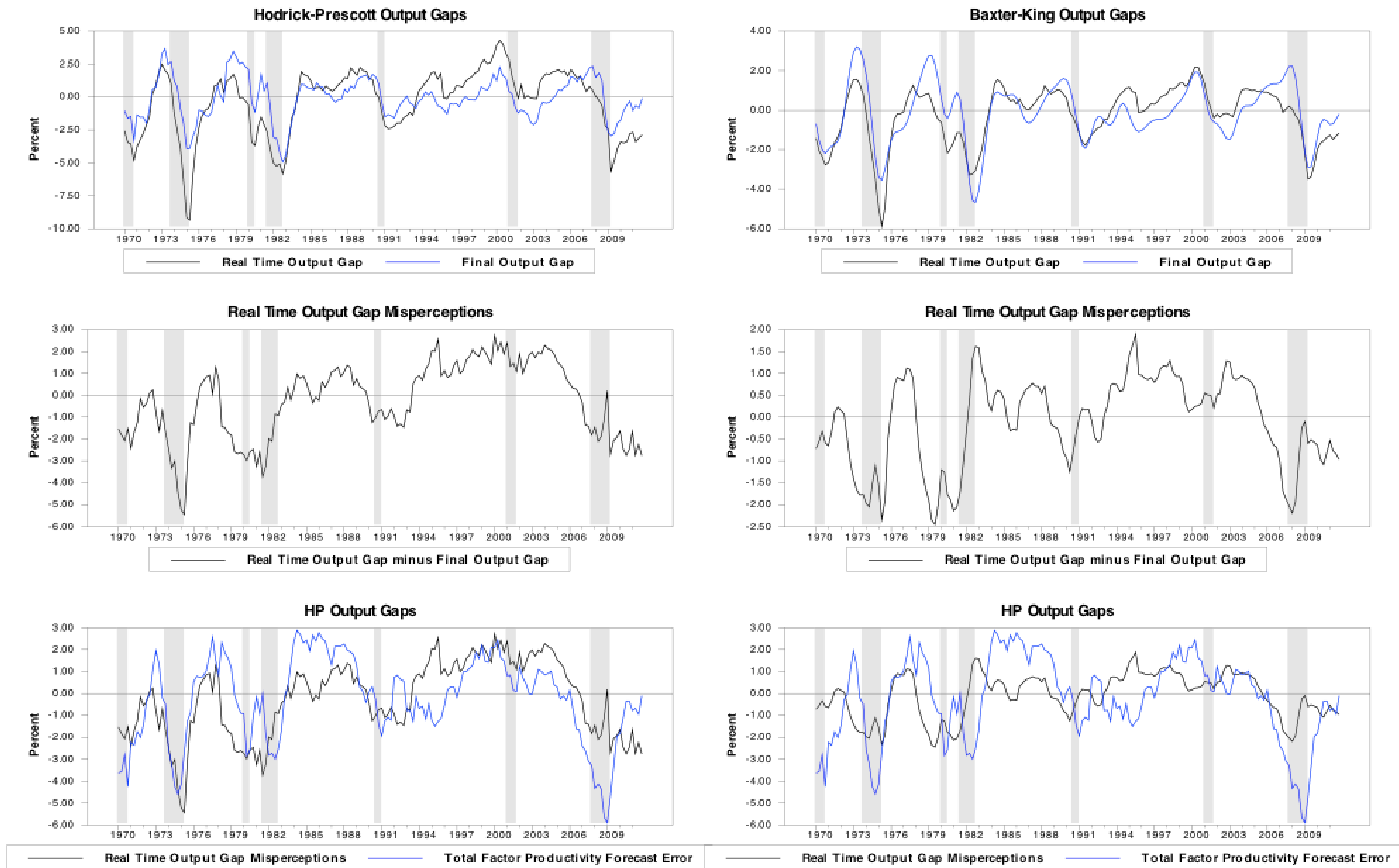

Figure 1: **Real-Time Estimates and Final Estimates of the Output Gap**. The top row shows estimates of the output gap using real-time data and the final data available. The second row shows the difference between the estimates. The third row shows misperceptions along with the forecast errors for total factor productivity alongside the output gap misperceptions.

Table 1: Prior Distribution

Parameter	Distribution	Mean	Standard Dev.
σ	Gamma	1.00	0.50
ψ	Gamma	1.00	0.50
ϕ_π	Gamma	1.50	0.50
ϕ_y	Gamma	0.125	0.05
Θ	Uniform	0.00	1.15
ρ_g	Beta	0.50	0.20
ρ_a	Beta	0.50	0.20
ρ_r	Beta	0.50	0.20
stddev(e^{IS})	Inv. Gamma	0.01	2.00
stddev(e^{PC})	Inv. Gamma	0.01	2.00
stddev(e^{a})	Inv. Gamma	0.01	2.00
stddev(e^{r})	Inv. Gamma	0.01	2.00
stddev(e^{gap})	Inv. Gamma	0.01	2.00
stddev(e^{g})	Inv. Gamma	0.01	2.00

Table 2: Posterior Estimates

Parameter	Mean	Mode	90% Prob. Interval
σ	2.21	2.27	[1.58, 2.85]
ψ	0.85	0.61	[0.19, 1.47]
ϕ_π	2.03	2.01	[1.89, 2.17]
ϕ_y	0.29	0.29	[0.12, 0.44]
Θ	0.25	0.26	[-0.02, 0.55]
ρ_g	0.98	0.98	[0.97, 0.99]
ρ_a	0.98	0.99	[0.97, 0.99]
ρ_r	0.76	0.76	[0.71, 0.80]
stddev(e^{c})	0.003	0.003	[0.002, 0.004]
stddev(e^{PC})	0.02	0.02	[0.015, 0.021]
stddev(e^{a})	0.03	0.03	[0.02, 0.04]
stddev(e^{r})	0.005	0.01	[0.004, 0.006]
stddev(e^{gap})	0.02	0.02	[0.015, 0.020]
stddev(e^{g})	0.09	0.07	[0.03, 0.16]

Table 3: Welfare Implications

Model	var(π)	var($\tilde{y}$)	Welfare Loss
Taylor Rule, Standard Assumptions	4.12	2.32	2.95
Taylor Rule with Imperfect Information	4.45	4.05	3.22
Nominal GDP Target	3.60	3.12	2.60
Difference Rule	4.38	3.73	3.16