

1 Introduction

What rule should a central bank follow in the formation of monetary policy? Despite extensive research about this topic, it remains an unsettled question. Although nominal output targeting has recently received attention in the popular press and within policy circles, it has not been scrutinized within the context of the quantitative frameworks commonly used by central banks. The objective of this paper is to study the desirability of nominal GDP targeting within the context of a New Keynesian model with both price and wage rigidity. In particular, we compare the welfare properties of nominal GDP targeting to two other popular targeting rules – inflation and output gap targeting – as well as to a conventional Taylor rule.

Although there is some disagreement on which type of rule central banks should follow, economists agree on several principles in the design of monetary policy. First, rules are preferred to discretion. Rules allow agents to better anchor expectations, which improves the inflation-output gap tradeoff. This is true in models of either ad hoc Phillips curves as in [Barro and Gordon \(1983\)](#) or in micro-founded Phillips curves as in [Woodford \(2003\)](#). Second, the policy objectives of central banks should be understandable to the public. As argued by [Bernanke and Mishkin \(1997\)](#), this requires the central bank to be more accountable. Even if monetary policy follows some strict rule, forming expectations is difficult if households do not understand it. Third, the central bank faces information constraints which should be taken into account in the formation of monetary policy. Responding to precisely measured variables is superior to responding to imprecisely measured variables or variables that are hypothetical constructs of a model. Finally, a desirable monetary policy rule ought to support a determinate equilibrium.

In the micro-founded welfare loss function from the simplest version of the New Keynesian model where only prices are sticky, a central bank ought to care about stabilizing both price inflation and the output gap (defined as the gap between the equilibrium level of output and the hypothetical equilibrium level of output which would obtain if prices were flexible). Inflation and output gap targeting are therefore easily motivated as potentially desirable policy rules. When nominal wages are flexible, the so-called “Divine Coincidence” ([Blanchard and Gali \(2007\)](#)) holds, and either targeting rule fully implements the flexible price allocation. In other words, stabilizing inflation also stabilizes the output gap, and vice-versa. Given that the output gap is a hypothetical model-based construct, whereas inflation is easily observed at high frequencies, inflation targeting is therefore often touted as a highly desirable and easily implemented policy rule.

Inflation targeting may be less desirable in versions of the model in which the Divine Coincidence does not hold. [Erceg, Henderson, and Levin \(2000\)](#) consider a version of the

model in which both prices and nominal wages are sticky, the combination of which breaks the equivalence between inflation and gap stabilization and renders it impossible for the central bank to fully implement the flexible price and wage allocation. For plausible values of the parameters governing price and wage stickiness, they find that inflation targeting tends to perform poorly from a welfare perspective. Output gap targeting, in contrast, does very well, coming close to implementing the flexible price and wage allocation.

Although nominal GDP targeting has recently gained attention as potential policy rule in the popular press and within policy circles, it has received relatively little attention within the context of the type of models in widespread use at central banks and among academics. Whereas inflation targeting focuses on nominal variables and gap targeting on real variables, nominal GDP targeting simultaneously targets both nominal and real variables. And unlike output gap targeting, it does not require the central bank to observe the hypothetical flexible price and wage level of output.

In Section 2 we study the merits of nominal GDP targeting relative to other policy rules using a standard parameterization of the sticky price and wage New Keynesian model developed by [Erceg et al. \(2000\)](#). We evaluate different rules on the basis of the average welfare loss relative to a hypothetical flexible price and wage allocation. Like [Erceg et al. \(2000\)](#), we find that output gap targeting does well, producing very small welfare losses that come close to implementing the flexible price and wage allocation. Nominal GDP targeting does almost as well as gap targeting. It is associated with smaller welfare losses than a conventionally parameterized Taylor rule and significantly outperforms inflation targeting. Nominal GDP targeting performs best in a relative sense when wages are sticky relative to prices and conditional on supply shocks. These results are consistent with the intuition laid out by [Sumner \(2014\)](#) in a textbook aggregate supply / aggregate demand model.

We consider a more elaborate medium scale version of the model in Sections 3 and 4. In addition to price and wage stickiness, the model features investment and capital accumulation, several sources of real inertia, and a number of different shocks. In Section 4, the parameters of the model are estimated using Bayesian methods to fit recent US data. The results of the medium scale model echo those from the small scale model. Output gap targeting produces the lowest welfare losses relative to the hypothetical flexible price and wage allocation. Nominal GDP targeting does almost as well, significantly better than both an estimated Taylor rule and inflation targeting. As in the small scale model, nominal GDP targeting performs best when wages are sticky relative to prices and conditional on supply shocks, although the relative desirability of nominal GDP targeting conditional on supply and demand shocks is not as stark as in the small scale model. In the medium scale model we also study the welfare properties of nominal GDP targeting conditional on realizations of

the state, as opposed to just unconditional welfare analysis as in the small scale model. We find that nominal GDP targeting is preferred to inflation targeting or a Taylor rule in all possible realizations of the state. Furthermore, though output gap targeting is preferred on average, there are some states in which nominal GDP targeting outperforms gap targeting.

Though we find output gap targeting to be the best performing (in an average sense) of the different policy rules under consideration, there are some reasons to be weary of actually implementing gap targeting as a policy rule. These reasons relate back to some of the basic principles of desirable monetary policy which are highlighted at the beginning of the Introduction. First, as a hypothetical model construct, gap targeting may be difficult to successfully communicate to the public, even if the central bank can observe the flexible price and wage level of output with precision. Second, it may be difficult for the central bank to observe the flexible price and wage level of output, particularly in real time. This point has been made by [Orphanides \(2001\)](#), [Orphanides and van Norden \(2002\)](#), and [Orphanides \(2003\)](#). Third, gap targeting may result in equilibrium indeterminacy. This point has been made in the context of sticky price New Keynesian models with positive trend inflation in [Hornstein and Wolman \(2005\)](#), [Ascari and Ropele \(2009\)](#), and [Coibion and Gorodnichenko \(2011\)](#).

We consider in Section 4 a couple of different exercises to address some of these points in the context of the estimated medium scale model. In one, we assume that the central bank observes the flexible price and wage level of output with noise, and compute the amount of noise which would equate the welfare losses associated with targeting the mis-measured gap and targeting nominal GDP. We find that if the noise in the observed flexible price and wage level of output is more than about one-third the volatility of the actual flexible price and wage level of output, then nominal GDP targeting produces a lower welfare loss than does gap targeting. In a second exercise, we suppose that the central bank adjusts its perceived flexible price and wage level of output to the actual flexible price and wage level of output slowly. If the central bank adjusts slowly enough, then gap targeting can result in significant welfare losses relative to nominal GDP targeting. Third, we investigate the determinacy properties of gap targeting when trend inflation is positive. We find that if trend inflation is greater than about 0.2 percent annually, then gap targeting results in equilibrium indeterminacy. Because in the long run the level of output is independent of monetary policy, nominal GDP targeting is equivalent to a price level target in the long run, and therefore supports a determinate equilibrium for any level of trend inflation.

Our paper is related to a large literature on optimal monetary policy. The relative merits of nominal GDP targeting versus inflation targeting have been recently revived by [Billi \(2014\)](#) and [Woodford \(2012\)](#), who discuss the rules within the context of the zero lower

bound. [Cecchetti \(1995\)](#) and [Hall and Mankiw \(1994\)](#) show in counterfactual simulations that nominal GDP targeting would lower the volatility of both real and nominal variables. Neither of these latter two papers have a structural model to conduct welfare analysis. [Mitra \(2003\)](#) studies nominal GDP targeting in a small scale New Keynesian model with adaptive learning. [Jensen \(2002\)](#) compares inflation and nominal GDP targeting in a linearized New Keynesian model with price stickiness and [Kim and Henderson \(2005\)](#) compare the two rules in a model of wage and price stickiness. While both of these papers include structural models similar to our own, [Jensen \(2002\)](#) does not include wage stickiness and [Kim and Henderson \(2005\)](#) use one period ahead price and wage contracts rather than the more common staggered price and wage contracts. Moreover, [Mitra \(2003\)](#), [Jensen \(2002\)](#), and [Kim and Henderson \(2005\)](#) do not analyze nominal GDP targeting in a medium scale model like [Smets and Wouters \(2007\)](#) or [Justiniano et al. \(2010\)](#) which are extensively used in central banks. [Schmitt-Grohe and Uribe \(2007\)](#) study optimal policy rule coefficients for a Taylor rule in a sticky price New Keynesian model with capital. They find that it is optimal to respond strongly to inflation and not at all to output, though they do not allow the central bank to target the output gap and their model does not feature wage rigidity. [Sims \(2013\)](#) studies the relative merits of a Taylor rule responding to the output gap or output growth.

Our conclusion concerning the desirable properties of nominal GDP targeting is related to recent work by [Gorodnichenko and Shapiro \(2007\)](#) and [Giannoni \(2014\)](#). Both of these papers consider interest rate rules (similar to a Taylor rule) in which the central bank can target the price level in addition to, or replacement of, inflation. Both papers find that targeting the price level in an interest rate rule is superior to targeting inflation. The essential intuition for why targeting the price level is desirable is that it introduces history dependence into monetary policy, which results in better anchoring of inflation expectations. Our analysis differs from these papers in that we consider a targeting rule for monetary policy as opposed to an instrument rule. Nevertheless, the intuition for the desirability of nominal GDP targeting is similar to the intuition for why price level targeting is desirable. As we discuss in [Section 2](#), in the long run a nominal GDP target is equivalent to a price level target since the long run level of output is independent of nominal features. This, like an explicit price level target, has the effect of better anchoring expectations by tying expectations of future price levels to the most recent price level. Compared to a price level target, in the short run, a nominal GDP target allows for greater flexibility in that it permits deviations in both output and the price level from their implicit long run targets. This flexibility is particularly desirable in a model with both price and wage rigidity, where strict price level targeting would be highly undesirable for the same reasons that strict inflation targeting is undesirable.

2 The Basic New Keynesian Model

We begin by studying a textbook New Keynesian model featuring both wage and price rigidity along the lines of [Erceg et al. \(2000\)](#). This model is a special case of the medium scale model we study in the next section. In the subsections below we briefly describe the problems of each type of agent in the model and discuss equilibrium and aggregation. We then use the model to develop some intuition for the relative benefits of different monetary policy rules. The full set of conditions characterizing the equilibrium are presented in [Appendix A](#).

2.1 Households

There exist a continuum of households indexed by $h \in [0, 1]$. These households are monopoly suppliers of differentiated labor, $N_t(h)$. There exists a labor aggregating firm which bundles differentiated labor input into an aggregate labor input, $N_{d,t}$, which is sold to firms at real wage w_t ; $w_t(h)$ denotes the real wage paid to household h . The technology which bundles labor input is given by:

$$N_{d,t} = \left(\int_0^1 N_t(h)^{\frac{\epsilon_w - 1}{\epsilon_w}} dh \right)^{\frac{\epsilon_w}{\epsilon_w - 1}}, \quad \epsilon_w > 1. \quad (1)$$

The parameter ϵ_w measures the degree of substitutability among different types of labor. Profit maximization by the labor aggregating firm gives rise to a downward sloping demand curve for each variety of labor and an aggregate real wage index:

$$N_t(h) = \left(\frac{w_t(h)}{w_t} \right)^{-\epsilon_w} N_{d,t} \quad (2)$$

$$w_t^{1-\epsilon_w} = \int_0^1 w_t(h)^{1-\epsilon_w} dh. \quad (3)$$

Households are not freely able to adjust their wage each period. In particular, each period there is a $1 - \theta_w$ probability, $\theta_w \in [0, 1)$, that a household can adjust its wage. This probability is independent of when a household last adjusted its wage. As in [Erceg et al. \(2000\)](#), we assume there exist state-contingent securities which insure households against idiosyncratic wage risk. We also assume that preferences are separable in consumption and labor. Combined with perfect insurance, this means that households will make identical non-labor market choices. We therefore suppress formal dependence on h in writing the problem of a particular household with the exception of labor market variables.

The problem of a particular household can be written:

$$\max_{\{C_t, B_t, w_t(h), N_t(h)\}_{t \geq 0}} E_0 \sum_{t=0}^{\infty} \beta^t \nu_t \left\{ \ln C_t - \psi \frac{N_t(h)^{1+\eta}}{1+\eta} \right\}$$

subject to

$$C_t + \frac{B_t}{P_t} \leq w_t(h) N_t(h) + \Pi_t + (1 + i_{t-1}) \frac{B_{t-1}}{P_t} \quad (4)$$

$$N_t(h) \geq \left(\frac{w_t(h)}{w_t} \right)^{-\epsilon_w} N_{d,t} \quad (5)$$

$$w_t(h) = \begin{cases} w_t^\#(h) & \text{if } w_t(h) \text{ chosen optimally} \\ (1 + \pi_t)^{-1} w_{t-1}(h) & \text{otherwise} \end{cases} \quad (6)$$

The discount factor is given by $\beta \in (0, 1)$, ψ is a scaling parameter on the disutility from labor, and η represents the inverse of the Frisch elasticity of labor supply. The exogenous variable ν_t is a preference shock common to all households. Constraint (4) is a standard flow budget constraint. A household enters the period with a stock of nominal bonds, B_{t-1} , and can choose a new stock of bonds, B_t , which pay out nominal interest rate i_t in period $t + 1$. Consumption is denoted by C_t and the price of goods is P_t . Real profit distributed from firms is Π_t . Constraint (5) requires that household labor supply meets demand. Wage-setting is described by (6). With probability $1 - \theta_w$ the household chooses a new real wage, denoted by $w_t^\#(h)$. With probability θ_w the household is unable to adjust its nominal wage, so the real wage it charges in period t is its period $t - 1$ real wage divided by the gross inflation rate between $t - 1$ and t , where $1 + \pi_t = P_t/P_{t-1}$. Optimization gives rise to a standard Euler equation for bonds that is the same across all households. It is straightforward to show that all households given the opportunity will adjust to a common wage, $w_t^\#$.

2.2 Production

Production takes place in two phases. There exist a continuum of producers of differentiated output indexed by $j \in [0, 1]$, $Y_t(j)$. Differentiated output is transformed into final output, Y_t , by a competitive firm using the following technology:

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon_p - 1}{\epsilon_p}} dj \right)^{\frac{\epsilon_p}{\epsilon_p - 1}}, \quad \epsilon_p > 1. \quad (7)$$

The parameter ϵ_p measures the degree of substitutability among differentiated output. The price of the final output is P_t and the prices of differentiated outputs are denoted by $P_t(j)$. Profit maximization by the competitive firm gives rise to demand for each differentiated

output and an aggregate price index:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_p} Y_t \quad (8)$$

$$P_t^{1-\epsilon_p} = \int_0^1 P_t(j)^{1-\epsilon_p} dj. \quad (9)$$

The production function for producer j is given by:

$$Y_t(j) = A_t N_{d,t}(j). \quad (10)$$

The exogenous variable A_t is a productivity shock common across all producers of differentiated output. These firms are not freely able to adjust their price in a given period in an analogous way to household wage-setting. In particular, each period there is a $1 - \theta_p$ probability, $\theta_p \in [0, 1)$, that a firm can adjust its price, which we denote by $P_t^\#(j)$. Otherwise it charges its most recently chosen price:

$$P_t(j) = \begin{cases} P_t^\#(j) & \text{if } P_t(j) \text{ chosen optimally} \\ P_{t-1}(j) & \text{otherwise} \end{cases}. \quad (11)$$

Regardless of whether a firm can adjust its price, it will choose labor input to minimize cost, subject to the constraint of producing enough to meet demand, given by (8). Solving the cost minimization problem reveals that all firms face the same real marginal cost, given by $mc_t = w_t/A_t$. Firms given the opportunity to adjust their price will do so to maximize the expected present discounted value of profit returned to households. It is straightforward to show that all updating firms will choose a common reset price, $P_t^\#$.

2.3 Exogenous Processes

There are two exogenous variables in the model, the productivity shock, A_t , and the preference shock, ν_t . We assume that these both follow stationary AR(1) processes with non-stochastic means normalized to unity:

$$\ln A_t = \rho_A \ln A_{t-1} + \sigma_A \varepsilon_{A,t} \quad (12)$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \sigma_\nu \varepsilon_{\nu,t}. \quad (13)$$

The autoregressive parameters, ρ_A and ρ_ν , lie between zero and one. The innovations, $\varepsilon_{A,t}$ and $\varepsilon_{\nu,t}$, are drawn from standard normal distributions. These innovations are scaled by σ_A and σ_ν , which measure the standard deviations of the innovations.

2.4 Market-Clearing and Aggregation

Market-clearing requires that bond-holding is zero at all times, $B_t = 0$, and that the sum of labor demanded by producers of differentiated output equals total labor supplied by the labor aggregating firm. Integrating the flow budget constraints of households along with the definition of firm profits gives the aggregate resource constraint $Y_t = C_t$. The price and real wage indexes can be written without reference to household or firm subscripts as:

$$P_t^{1-\epsilon_p} = (1 - \theta_p)P_t^{\#,1-\epsilon_p} + \theta_p P_{t-1}^{1-\epsilon_p} \quad (14)$$

$$w_t^{1-\epsilon_w} = (1 - \theta_w)w_t^{\#,1-\epsilon_w} + \theta_w(1 + \pi_t)^{\epsilon_w-1}w_{t-1}^{1-\epsilon_w}. \quad (15)$$

Integrating over the demand curves for differentiated output, (8), gives rise to an aggregate production function:

$$Y_t = \frac{A_t N_{d,t}}{v_t^p} \quad (16)$$

where the variable v_t^p is a measure of price dispersion given by:

$$v_t^p = \int_0^1 \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_p} dj. \quad (17)$$

We define the hypothetical construct of the flexible price level of output (or sometimes “natural rate”) as the level of output which would obtain in the absence of price and wage stickiness. We denote this by Y_t^f , and can solve for it as the equilibrium level of output when $\theta_p = \theta_w = 0$. We then define the output gap, X_t , as the ratio of the level of output to the flexible price level, $X_t = Y_t/Y_t^f$.

Aggregate welfare is defined as the sum of the presented discounted value of flow utility across all households. This can be written recursively in terms of aggregate variables alone as:

$$\mathbb{W}_t = \nu_t \left[\ln C_t - \psi v_t^w \frac{N_{d,t}^{1+\eta}}{1+\eta} \right] + \beta E_t \mathbb{W}_{t+1}. \quad (18)$$

Recall that $N_{d,t}$ is aggregate labor supplied by the labor aggregating firm to production firms. This is only equal to aggregate labor supply (the sum of differentiated labor supply across households) in the special case that all households charge identical wages. In the more general case, there is a wedge between aggregate labor supply and labor used in production

due to wage dispersion. This is captured by the variable v_t^w , which can be written:

$$v_t^w = \int_0^1 \left(\frac{w_t(h)}{w_t} \right)^{-\epsilon_w(1+\eta)} dh. \quad (19)$$

2.5 Monetary Policy

Before fully characterizing the equilibrium it remains to specify the conduct of monetary policy. In addition to a nominal GDP targeting rule, we also consider inflation and output gap targeting rules. Each of these three targeting rules can be considered restricted cases of a generalized [Taylor \(1993\)](#) type instrument rule, which is often used in quantitative work to model the behavior of monetary policy.

The primary objective of the paper is to evaluate the performance of a nominal GDP targeting rule vis-à-vis other popular targeting rules. We write the nominal GDP targeting rule in growth rates as:

$$\pi_t + \ln Y_t - \ln Y_{t-1} = 0. \quad (20)$$

In this rule the nominal interest rate adjusts so that the growth rate of nominal GDP is equal to zero each period.¹ An implication of this rule is that inflation and output growth will be perfectly negatively correlated. The growth rate specification of the rule can be re-cast in terms of log levels of nominal GDP by noting that $\pi_t = \ln P_t - \ln P_{t-1}$:

$$E_t [\ln P_{t+s} + \ln Y_{t+s}] = \ln Y_{t-1} + \ln P_{t-1}, \quad \forall s \geq 0. \quad (21)$$

In other words, a nominal GDP growth rate target is equivalent to a nominal GDP level target, where the target level of nominal GDP in all future periods is its value in period $t-1$. In an unconditional sense, there is therefore no difference between a nominal GDP growth rate target and a strict level nominal GDP target, where the target level of nominal GDP is some exogenous value. In terms of transition dynamics, the distinction between a growth rate and level target might matter if the target level of nominal GDP differs from its most recent value. We return to this issue briefly in [Section 4.1.1](#). Since the long run level of GDP is independent of the monetary policy rule, in the long run the nominal GDP targeting rule is equivalent to a long run price level target.

The second rule we consider is a strict inflation targeting rule:

$$\pi_t = 0. \quad (22)$$

¹Here we follow convention in assuming no trend growth in output or trend inflation. It is straightforward to modify the nominal GDP targeting rule to account for these features.

Under an inflation targeting rule the central bank adjusts the nominal interest such that inflation hits its target each period (implicitly we have normalized the target inflation rate to zero, but could easily extend this to non-zero targets).

The final targeting rule we consider is an output gap targeting rule:

$$X_t = 1. \tag{23}$$

In this rule the nominal interest rate is adjusted in such a way that the equilibrium level of output always equals its flexible price level.

In a version of the model with flexible wages the so-called “Divine Coincidence” would hold (Blanchard and Gali (2007)), and in equilibrium inflation and gap targeting would be equivalent to one another, and would both implement the flexible price equilibrium. When prices and wages are simultaneously sticky this equivalence does not hold. Gap targeting requires that the central bank know the flexible price level of output, which is not directly observable, neither in real time nor ex-post. A potential advantage of inflation targeting is that inflation is observed at high frequencies and does not require a central bank to know anything about the underlying model. Whereas gap targeting focuses on a real variable and inflation targeting focuses solely on prices, nominal GDP targeting implicitly targets both nominal and real variables. It also only requires a central bank to observe endogenous variables, not hypothetical model constructs like the flexible price level of output.

Each of the three targeting rules can be understood to be special cases of a generalized Taylor rule of the following form:

$$\ln(1 + i_t) = (1 - \rho_i) \ln(1 + i^*) + \rho_i \ln(1 + i_{t-1}) + \phi_\pi \ln(1 + \pi_t) + \phi_x \ln X_t + \phi_y \ln\left(\frac{Y_t}{Y_{t-1}}\right). \tag{24}$$

Here $\rho_i \in [0, 1)$ is a smoothing parameter and ϕ_π , ϕ_x , and ϕ_y are non-negative coefficients on inflation, the output gap, and output growth, respectively. In writing this rule we have maintained an implicit assumption of zero trend inflation and no trend growth. Whereas the three rules discussed above are targeting rules, targeting the values of endogenous variables and adjusting the nominal rate to hit those targets, the Taylor rule is an instrument rule, directly specifying a process for the nominal interest rate as function of endogenous variables. Taylor rules of this form seem to provide an accurate account of observed monetary policy in the last several decades and tend to have good normative properties.² Each of the three

²As documented in Erceg et al. (2000) and Levin, Onatski, Williams, and Williams (2006), in models where both prices and wages are rigid, it is often desirable to stabilize nominal wage inflation as opposed to price inflation. This will certainly be true in the models we consider in this paper. However, as our objective is simply to compare nominal GDP targeting to a conventionally specified Taylor rule, which does not target nominal wage inflation, we omit a wage inflation targeting term in the Taylor rule.

targeting rules can be understood to be special cases of the Taylor rule. The Taylor rule would be isomorphic to an inflation targeting rule when $\phi_\pi \rightarrow \infty$ and $\rho_i = \phi_x = \phi_y$ and equivalent to a gap targeting rule when $\phi_x \rightarrow \infty$ and $\rho_i = \phi_\pi = \phi_y$. Because commitment to a nominal GDP targeting rule implies targeting the growth rate of nominal GDP each period, it is equivalent to the Taylor rule when $\phi_\pi = \phi_y \rightarrow \infty$ and $\rho_i = \phi_x = 0$.³

2.6 Quantitative Analysis

We adopt a standard parameterization of the model’s parameters; in the next section with a more empirically plausible model with capital accumulation we estimate them. The values of the parameters are listed in Table 1.

Table 1: Value of Parameters

Parameter	Description	Value
β	Discount rate	0.995
η	Inverse Frisch elasticity	1
ψ	Labor disutility	$N^* = 1/3$
ϵ_w	Elasticity of substitution – Labor	10
ϵ_p	Elasticity of substitution – Goods	10
θ_w	Wage stickiness	0–0.75
θ_p	Price stickiness	0–0.75
σ_A	Standard deviation – Productivity	0.006
σ_ν	Standard deviation – Preference	0.020
ρ_A	Persistence – Productivity	0.97
ρ_ν	Persistence – Preference	0.70

Notes: The table shows the values of the parameters uses in the quantitative analysis of the small scale model laid out in this section.

The discount factor is set to $\beta = 0.995$, which implies an annualized risk-free interest rate of two percent. The Frisch labor supply elasticity is set to unity, implying $\eta = 1$. The elasticities of substitution for goods and labor, ϵ_p and ϵ_w , are both set to 10, implying steady state price and wage markups of a little more than ten percent. The scaling parameter on the disutility from labor, ψ , is set so that steady state labor hours equal 1/3. Our baseline parameterization of the price and wage stickiness parameters is $\theta_w = \theta_p = 0.75$, which implies

³One could also map the Taylor rule into targeting rules that are not strict in the sense of featuring large but nevertheless finite coefficients on the target variables in the Taylor rule. In particular, an inflation targeting Taylor rule might feature a “large” value of ϕ_π (say, 10) and values of 0 for the other parameters, and similarly for a gap target and the coefficient on ϕ_x and a nominal GDP target with large and equal coefficients on ϕ_π and ϕ_y . We have experimented with these specifications and obtain similar results to the strict targeting rules considered.

that wages and prices both adjust once a year on average. We consider various different values of these parameters in the quantitative work below. The autoregressive parameter in the productivity process is set to $\rho_A = 0.97$ and the autoregressive parameter for the preference shock is $\rho_\nu = 0.70$. The standard deviations of the innovations to productivity and preferences are $\sigma_A = 0.006$ and $\sigma_\nu = 0.02$, respectively. When monetary policy is governed by a conventionally parameterized version of the Taylor rule with $\rho_i = 0.7$, $\phi_\pi = 0.45$, $\phi_y = 0.0375$, and $\phi_x = 0$,⁴ this parameterization generates a standard deviation of log output of 0.036, which is very close to the observed volatility of linearly detrended log GDP in postwar US data. Furthermore, the productivity and preference shocks each account for 50 percent of the unconditional variance of log output. In other words, our parameterization implies that supply and demand shocks are equally important in driving fluctuations in output.

We evaluate different policy rules by computing the unconditional mean of welfare for a particular policy rule and comparing that to the unconditional mean of welfare in a hypothetical economy where prices and wages are both flexible, i.e. $\theta_p = \theta_w = 0$. We compute these unconditional means by solving the model using a second order approximation of the equilibrium conditions about the non-stochastic steady state. We then calculate a compensating variation, computing the percent of consumption each period which would make a household indifferent between the flexible price and wage economy and the sticky price and wage economy. Formally, the compensating variation is given by:

$$\lambda = 100 [\exp(\mathbb{E} \mathbb{W}_{flex} - \mathbb{E} \mathbb{W}_0) - 1]$$

where $\mathbb{E} \mathbb{W}_{flex}$ is the expected present discounted value of utility under flexible prices and wages and $\mathbb{E} \mathbb{W}_0$ is the expected discounted value of utility in the sticky price and wage economy with a given monetary policy regime. We can interpret this compensating variation as a welfare loss from price and wage rigidity. More desirable monetary policy regimes therefore coincide with lower values of the compensating variation.

Table 2 present compensating variations for the three different targeting rules for different combinations of price and wage stickiness parameters. For point of comparison we also show the compensating variation for the Taylor rule parameterized as described above. Focus first on the case where the price and wage rigidity parameters are both 0.75. The most desirable policy regime is the output gap targeting rule, which produces a compensating variation of only 0.02 percent of consumption. Nominal GDP targeting does almost as well, generating a welfare loss of only 0.03 percent of consumption. Inflation targeting performs very poorly, with a welfare loss of nearly 20 percent of consumption. The Taylor rule performs fairly

⁴Note that our rule is not written as one of partial adjustment. The long run response of the interest rate to inflation and output growth is $\phi_\pi/(1 - \rho_i)$ and $\phi_y/(1 - \rho_i)$, or 1.5 and 0.125, respectively.

well, albeit substantially worse than either nominal GDP or output gap targeting, with a compensating variation of 0.3 percent.

We now turn attention to different combinations of price and wage stickiness parameters. The output gap targeting rule at least weakly dominates the other two targeting rules as well as the Taylor rule for all combinations of price and wage rigidity. The output gap targeting rule implements the flexible price allocation (i.e. the compensating variation is zero) if either prices or wages are flexible. Inflation targeting tends to perform very poorly except in the case where wages are fully flexible, when strict inflation targeting also fully implements the flexible price allocation. The compensating variation associated with the Taylor rule is roughly the same at all combinations of price and wage rigidity under consideration. Nominal GDP targeting tends to perform very well, yielding compensating variations less than 0.04 percent of consumption for all combinations of price and wage stickiness parameters under consideration.

Table 2: Consumption Equivalent Welfare Losses from Different Policy Rules

	$\theta_p = 0.75$	$\theta_p = 0.00$	$\theta_p = 0.50$	$\theta_p = 0.75$	$\theta_p = 0.75$
	$\theta_w = 0.75$	$\theta_w = 0.75$	$\theta_w = 0.75$	$\theta_w = 0.50$	$\theta_w = 0.00$
NGDP	0.0314	0.0000	0.0127	0.0352	0.0398
Inflation	20.3694	20.3694	20.3694	0.8618	0.0000
Output Gap	0.0190	0.0000	0.0090	0.0166	0.0000
Taylor Rule	0.2880	0.2908	0.2902	0.2506	0.1601

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule. The parameterization of the model is as described in Table 1. The first three rows consider strict targeting rules. The row labeled “Taylor rule” considers the Taylor rule, (24), parameterized with $\rho_i = 0.7$, $\phi_\pi = 0.45$, $\phi_x = 0$, and $\phi_y = 0.0375$.

That inflation targeting performs poorly, and output gap targeting does very well, when both prices and wages are rigid has been well-known since Erceg et al. (2000). The novel result here is that nominal GDP targeting seems to have desirable properties. Nominal GDP targeting is associated with substantially lower compensating variations than the Taylor rule, and significantly outperforms inflation targeting except in the case where wages are flexible. While nominal GDP targeting is always weakly worse than output gap targeting, the differences in the compensating variations associated with these two targeting rules are very small. From the table it appears as though nominal GDP targeting is relatively better the stickier are wages relative to prices – when wages are rigid and prices are flexible, nominal GDP targeting is equivalent to gap targeting, while when wages are flexible and prices rigid, inflation targeting outperforms nominal GDP targeting.

Figure 1 shows the loci of wage (horizontal axis) and price (vertical axis) rigidity parameters where nominal GDP targeting and inflation targeting generate the same compensating variation. The area shaded green shows parameter combinations where nominal GDP targeting strictly dominates inflation targeting. For wage stickiness parameters in excess of 0.3 nominal GDP targeting strictly dominates inflation targeting for any value of the parameter governing price rigidity. Furthermore, at low levels of wage stickiness inflation targeting only dominates nominal GDP targeting if prices are very rigid.

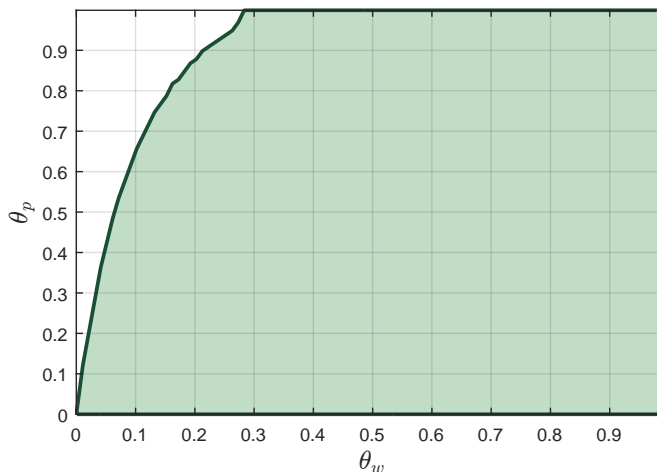


Figure 1: Nominal GDP vs. Inflation Targeting

Notes: This figure traces out the loci of wage stickiness parameters, (θ_w, θ_p) for which nominal GDP targeting and inflation targeting yield the same compensating variation. The area shaded green depicts combinations of (θ_w, θ_p) for which nominal GDP targeting strictly dominates inflation targeting.

We next consider the role of the two different shocks in the model in driving the relative performance of the different monetary policy regimes. Tables 3 and 4 repeat the exercises in Table 2 conditioning on only the productivity or the preference shock, respectively. For this exercise, we set the standard deviation of one of the shocks to zero, and re-parameterize the standard deviation of the remaining shock to generate the same volatility of log output as in the baseline model when policy is characterized by a Taylor rule.⁵ The impulse responses to a productivity shock are included in Appendix A.1.⁶

The compensating variations for the different policy regimes when there are only productivity shocks are qualitatively similar to the compensating variations when both shocks are included in the model. Output gap targeting always weakly dominates the other policies

⁵When conditioning on the productivity shock, this implies a value of $\sigma_A = 0.0085$ and $\sigma_\nu = 0$. When conditioning on the preference shock, $\sigma_A = 0$ and $\sigma_\nu = 0.0285$.

⁶As we discuss in the next paragraph, the main differences between the different policy rules are conditional on the productivity shock, so we focus on that in the Appendix.

and inflation targeting does poorly unless wages are flexible. Nominal GDP targeting is significantly more desirable than inflation targeting unless wages are flexible, and performs better than the Taylor rule for most parameter configurations. Inflation targeting performs worse conditional on productivity shocks relative to the case where both shocks are in the model. When there are only preference shocks, each of the three targeting regimes implements the flexible price allocation for any combination of price and wage rigidity parameters, while the Taylor rule performs similarly to when both shocks are in the model. This equivalence of the three targeting regimes obtains because of the absence of capital in the model and our assumptions about preferences. Given that preferences are separable in consumption and labor and that consumption must equal output, in the flexible price allocation neither output nor real wages change in response to a preference shock.⁷ This has the implication that stabilizing prices (inflation targeting), real activity (gap targeting), or a mix of both (nominal GDP targeting) are equivalent in equilibrium.

Table 3: Consumption Equivalent Welfare Losses from Different Policy Rules, Only Productivity Shocks

	$\theta_p = 0.75$	$\theta_p = 0.00$	$\theta_p = 0.50$	$\theta_p = 0.75$	$\theta_p = 0.75$
	$\theta_w = 0.75$	$\theta_w = 0.75$	$\theta_w = 0.75$	$\theta_w = 0.50$	$\theta_w = 0.00$
NGDP	0.0629	0.0000	0.0254	0.0707	0.0800
Inflation	45.0747	45.0747	45.0747	1.7372	0.0000
Output gap	0.0382	0.0000	0.0180	0.0333	0.0000
Taylor rule	0.2740	0.2767	0.2767	0.0937	0.0178

Notes: The table contains the compensating variations of the policies described in the text in a specification of the model in which there are only productivity shocks. In particular, the standard deviation of the productivity shock is chosen to produce the same volatility under a Taylor rule as in the version of the model with both shocks, while the standard deviation of the preference shock is set to zero. The standard deviation of the productivity shock is $\sigma_A = 0.0085$.

The results in Tables 3 and 4 suggest that the choice of monetary regime is far more relevant for welfare conditional on supply shocks (i.e. the productivity shock) than demand shocks (i.e. the preference shock). This confirms the simple aggregate demand - supply intuition in Sumner (2014). Our baseline parameterization assigns the productivity and preference shocks equal weight in accounting for output fluctuations, and therefore takes

⁷A simple way to see this is to note that the price and wage markups are fixed when both prices and wages are flexible. Given our assumptions on preferences, this means that consumption and labor must co-move negatively absent a change in A_t . But since $C_t = Y_t = A_t N_{d,t} / v_t^p$, consumption and labor cannot co-move negatively absent a change in A_t (holding v_t^p fixed, which is valid to a first order approximation). Hence, in the flexible price allocation consumption, hours, output, and the real wage do not react to a preference shock.

a relatively agnostic stand on the relative importance of supply and demand shocks. In the next section we consider an empirically realistic medium scale model and estimate the relative importance of several different kinds of shocks. In the simple model of this section, the demarcation between supply and demand shocks is clear, because the preference shock does not impact the flexible price level of output. But when capital and other features are added to the model, the distinction between “supply” and “demand” can become blurry. While the basic intuition about the choice of policy regime conditional on supply and demand shocks will indeed carry over largely intact, some caution is in order when extrapolating from the simple model to the more realistic one in the next section.

Table 4: Consumption Equivalent Welfare Losses from Different Policy Rules, Only Preference Shocks

	$\theta_p = 0.75$ $\theta_w = 0.75$	$\theta_p = 0.00$ $\theta_w = 0.75$	$\theta_p = 0.50$ $\theta_w = 0.75$	$\theta_p = 0.75$ $\theta_w = 0.50$	$\theta_p = 0.75$ $\theta_w = 0.00$
NGDP	0.0000	0.0000	0.0000	0.0000	0.0000
Inflation	0.0000	0.0000	0.0000	0.0000	0.0000
Output gap	0.0000	0.0000	0.0000	0.0000	0.0000
Taylor rule	0.3094	0.3105	0.3094	0.4144	0.3078

Notes: The table contains the compensating variations of the policies described in the text in a version of the model in which there are only preference shocks. In particular, the standard deviation of the preference shock is chosen to produce the same volatility under a Taylor rule as in the version of the model with both shocks, while the standard deviation of the productivity shock is set to zero. The standard deviation of the preference shock is $\sigma_\nu = 0.0285$.

3 Medium Scale Model

While the previous section demonstrates some desirable welfare properties of nominal GDP targeting, especially relative to inflation targeting and a Taylor rule, it did so within the context of a very simplified framework. In this section, we consider a medium scale version of the model. The simple economy of the previous section is a special case of the more realistic model in this section. In addition to price and wage rigidity, the model allows for capital accumulation, habit formation in consumption, variable capital utilization, wage and price indexation to lagged inflation, and several more stochastic shocks. Such a model has been shown to capture the dynamic effects of monetary policy shocks and the most salient business cycle facts.⁸ Where different from the simpler model of Section 2, in the subsections below

⁸See [Christiano, Eichenbaum, and Evans \(2005\)](#) as an example of the former and [Smets and Wouters \(2007\)](#) for the latter.

we lay out the details of the medium scale model. The full set of conditions characterizing the equilibrium are presented in Appendix B.

3.1 Households

The basic structure of the household side of the model is very similar to the simpler model. There again exist a continuum of households indexed by $h \in [0, 1]$. The labor aggregating firm is the same, giving rise to the same downward-sloping demand for each household's labor, (2), and the same aggregate real wage index, (3). The medium scale model departs from the simpler model in allowing for internal habit formation in consumption, capital accumulation and capital utilization, and indexation of wages to lagged inflation. The problem of a particular household is:

$$\max_{\{C_t, B_t, u_t, I_t, K_{t+1}, w_t(h), N_t(h)\}_{t \geq 0}} E_0 \sum_{t=0}^{\infty} \beta^t \nu_t \left\{ \ln (C_t - bC_{t-1}) - \psi \frac{N_t(h)^{1+\eta}}{1+\eta} \right\}$$

subject to

$$C_t + I_t + \frac{B_t}{P_t} + \left[\gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2 \right] K_t \leq w_t(h)N_t(h) + R_t u_t K_t + \Pi_t - T_t + (1+i_{t-1}) \frac{B_{t-1}}{P_t} \quad (25)$$

$$K_{t+1} = Z_t \left[1 - \frac{\tau}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t + (1 - \delta) K_t \quad (26)$$

$$N_t(h) \geq \left(\frac{w_t(h)}{w_t} \right)^{-\epsilon_w} N_{d,t} \quad (27)$$

$$w_t(h) = \begin{cases} w_t^\#(h) & \text{if } w_t(h) \text{ chosen optimally} \\ (1 + \pi_t)^{-1} (1 + \pi_{t-1})^{\zeta_w} w_{t-1}(h) & \text{otherwise} \end{cases} \quad (28)$$

Relative to the simpler model, the preference specification is identical with the exception of the inclusion of internal habit formation, which is governed by the parameter $b \in [0, 1]$. In the flow budget constraint, (25), I_t denotes investment, K_t physical capital, u_t capital utilization, R_t the rental rate on capital services (where capital services is understood to represent the product of utilization and physical capital), and T_t is a lump sum tax paid to a government. There is a convex resource cost of capital utilization given by $\gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2$. This cost is measured in units of physical capital. The law of motion for physical capital is given by (26). Z_t is an exogenous shock to the marginal efficiency of investment along the lines of Justiniano et al. (2010) and $\tau \geq 0$ is an investment adjustment cost in the form proposed by Christiano et al. (2005). The depreciation rate on physical capital is given by $\delta \in (0, 1)$. A household is required to supply as much labor as is demanded at its wage, just as in

the simpler model. The wage-setting process is virtually the same as in the simpler model. With probability $1 - \theta_w$ a household can adjust to a new optimal wage, which we denote in real terms as $w_t^\#(h)$. Otherwise a household must charge its most recently chosen nominal wage. Differently than the simple model, here we permit partial indexation of nominal wages to lagged inflation as measured by the parameter $\zeta_w \in [0, 1]$. It is again the case that all updating households will adjust to the same reset real wage, which we denote by $w_t^\#$.

3.2 Production

The production process again takes place in two phases. The final output aggregator, demand curve for each differentiated output, and expression for the aggregate price level are the same as in the simpler model, given by equations (7), (8), and (9), respectively.

The production function of firms who produce differentiated output is given by:

$$Y_t(j) = \max \{ A_t \widehat{K}_t(j)^\alpha N_{d,t}(j)^{1-\alpha} - F, 0 \}. \quad (29)$$

Here \widehat{K}_t is capital services leased from households. The parameter α lies between 0 and 1. There is also a fixed cost of production given by $F \geq 0$. Cost-minimization by firms implies that all firms face the same real marginal cost and hire capital services and labor in the same ratio. As in the simpler model, firms face a probability of $1 - \theta_p$ that they can adjust their price in a given period. Differently than the simpler model, we permit indexation of non-updated prices to lagged inflation, governed by the parameter $\zeta_p \in [0, 1]$. A firm's price in any period therefore satisfies:

$$P_t(j) = \begin{cases} P_t^\#(j) & \text{if } P_t(j) \text{ chosen optimally} \\ (1 + \pi_{t-1})^{\zeta_p} P_{t-1}(j) & \text{otherwise} \end{cases}. \quad (30)$$

Updating firms will choose their prices to maximize the present discounted value of flow profits, where discounting is by the stochastic discount factor of households.⁹ It is again straightforward to show that all updating firms choose an identical price, denoted by $P_t^\#$.

⁹Though there is heterogeneity among households, because of separability and perfect insurance the marginal utility of income is identical across households, so it is safe to talk about one stochastic discount factor in spite of the heterogeneity among households.

3.3 Fiscal Policy

In the medium scale model we allow for government spending. Government spending is assumed to be exogenous and obeys the following stationary stochastic process:

$$\ln G_t = (1 - \rho_G) \ln G^* + \rho_G \ln G_{t-1} + \sigma_G \varepsilon_{G,t}. \quad (31)$$

Here G^* is the steady state level of government spending, the parameter ρ_G lies between zero and one, and the innovation $\varepsilon_{G,t}$ is drawn from a standard normal distribution. The innovation is scaled by the standard deviation parameter σ_G . We assume that the only source of government revenue is lump sum taxes, T_t . This means that it is innocuous to assume that the government balances its budget each period, with $G_t = T_t$.

3.4 Exogenous Processes

The exogenous processes for productivity, A_t , and the preference shock, ν_t , are the same as in Section 2. We assume that the investment shock, Z_t , also obeys a stationary stochastic process with steady state value normalized to unity:

$$\ln Z_t = \rho_Z \ln Z_{t-1} + \sigma_Z \varepsilon_{Z,t}. \quad (32)$$

The parameter ρ_Z lies between zero and one, $\varepsilon_{Z,t}$ is drawn from a standard normal distribution, and σ_Z is the standard deviation of the innovation.

3.5 Monetary Policy

Our ultimate objective is to again consider and compare the three different targeting rules discussed in Section 2. For the purposes of estimation, however, we assume that the central bank sets policy according to the same Taylor rule described above, but augment this to include a policy innovation, $\varepsilon_{i,t}$, which is drawn from a standard normal distribution with standard deviation σ_i :

$$\ln(1+i_t) = (1 - \rho_i) \ln(1+i^*) + \rho_i \ln(1+i_{t-1}) + \phi_\pi \ln(1 + \pi_t) + \phi_x \ln X_t + \phi_y \ln \left(\frac{Y_t}{Y_{t-1}} \right) + \sigma_i \varepsilon_{i,t}. \quad (33)$$

3.6 Aggregation

Since we assume that the government issues no debt, in equilibrium bond-holding is always zero, $B_t = 0$. Combining this with the definition for firm profit and the government's

budget constraint gives rise to the aggregate resource constraint:

$$Y_t = C_t + I_t + G_t + \left[\gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2 \right] K_t. \quad (34)$$

The expressions for the aggregate price and wage indexes are similar to Section 2, but account for indexation:

$$P_t^{1-\epsilon_p} = (1 - \theta_p)P_t^{\#,1-\epsilon_p} + \theta_p(1 + \pi_{t-1})^{\zeta_p(1-\epsilon_p)}P_{t-1}^{1-\epsilon_p} \quad (35)$$

$$w_t^{1-\epsilon_w} = (1 - \theta_w)w_t^{\#,1-\epsilon_w} + \theta_w(1 + \pi_t)^{\epsilon_w-1}(1 + \pi_{t-1})^{\zeta_w(1-\epsilon_w)}w_{t-1}^{1-\epsilon_w}. \quad (36)$$

The aggregate production function is given by:

$$Y_t = \frac{A_t (u_t K_t)^\alpha N_{d,t}^{1-\alpha} - F}{v_t^p}. \quad (37)$$

The variable v_t^p is the same measure of price dispersion as in the simpler model, defined by (17).

Aggregate welfare is defined similarly as in Section 2, but takes into account internal habit formation:

$$\mathbb{W}_t = \nu_t \left[\ln(C_t - bC_{t-1}) - \psi v_t^w \frac{N_{d,t}^{1+\eta}}{1+\eta} \right] + \beta E_t \mathbb{W}_{t+1}. \quad (38)$$

The variable v_t^w is again a measure of wage dispersion, defined above by (19).

4 Quantitative Analysis

In this section we analyze the welfare properties of nominal GDP targeting, inflation targeting, output gap targeting, and the Taylor rule in the medium scale model. Quantitatively evaluating different policy regimes requires selecting values for the parameters of the model. We calibrate some parameters to match long run moments of the data and estimate the remaining parameters so as to ensure that the model provides an empirically realistic fit to observed data.

The calibrated parameters and their values are listed in Table 5. As in the simpler model of Section 2, the discount factor is set to $\beta = 0.995$, and the elasticities of substitution for goods and labor, ϵ_p and ϵ_w , are set to 10. The steady state level of government spending is chosen so that the steady state ratio of government spending to output is $G^*/Y^* = 0.20$. The scaling parameter on the disutility of labor is set to $\psi = 6$, which implies steady state

labor hours of between one-third and one-half for reasonable values of the Frisch elasticity and habit persistence parameter. To a first order approximation, this scaling parameter is irrelevant for equilibrium dynamics. The parameter on the linear term in the utilization adjustment cost function, γ_1 , is chosen to be consistent with a steady state normalization of utilization to one. Capital's share is set to $\alpha = 1/3$, and the depreciation rate on physical capital is $\delta = 0.025$. The fixed cost, F , is set so that profits are zero in steady state.

The remaining parameters are estimated via Bayesian maximum likelihood. The observable variables in the estimation are the log first differences of real output, real consumption, and real investment, and the levels of the inflation rate and the nominal interest. To facilitate comparison with the model, we define nominal GDP as the sum of consumption (non-durables and services consumption), investment (the sum of durables consumption and private fixed investment), and government spending (government consumption expenditures and gross investment). These series are all taken from the [NIPA tables](#). We deflate nominal output, as well as the individual components, by the GDP implicit price deflator. We then divide by the civilian non-institutionalized population, take logs, and first difference. Inflation is defined as the log first difference of the GDP deflator. Our measure of the nominal interest rate is the effective Federal Funds Rate, aggregated to a quarterly frequency by averaging monthly observations. We use data from the first quarter of 1984 through the third quarter of 2007. The start date is chosen to account for the large break in volatility associated with the Great Moderation, while the end date is chosen so as to exclude the recent zero lower bound period.

Table 5: Calibrated Parameters, Medium Scale Model

Parameter	Description	Value
β	Discount rate	0.995
ψ	Labor disutility	6
ϵ_w	Elasticity of substitution – Labor	10
ϵ_p	Elasticity of substitution – Goods	10
G^*	SS Government Spending	$G^*/Y^* = 0.2$
α	Capital Share	1/3
F	Fixed cost	$\Pi^* = 0$
γ_1	Utilization linear cost	$u^* = 1$
δ	Depreciation rate	0.025

Notes: The table shows the values of the calibrated parameters in the medium scale model.

Table 6 presents the prior and posterior distributions of the estimated parameters. These results are broadly consistent with [Smets and Wouters \(2007\)](#) and [Justiniano et al. \(2010\)](#). There is significant rigidity in both prices and wages. The average duration between prices

changes is roughly three quarters, while the average duration between wage changes is about a year. The latter is consistent with the micro evidence presented in [Barattieri et al. \(2014\)](#).

Table 6: Estimated Parameters

Parameter	Prior			Posterior			
	Dist.	Mean	SD	Mode	Mean	SD	90% Probability Interval
b	Beta	0.70	0.10	0.7508	0.7606	0.0713	[0.6634, 0.8759]
τ	Normal	4.00	0.20	3.9676	3.9927	0.2007	[3.6661, 4.3288]
η	Normal	1.50	0.20	1.6244	1.6290	0.2165	[1.3075, 1.9141]
γ_2	Beta	0.10	0.10	0.3783	0.4143	0.1226	[0.2372, 0.6042]
θ_p	Beta	0.70	0.10	0.6762	0.6852	0.0556	[0.6008, 0.7659]
θ_w	Beta	0.70	0.10	0.7887	0.7701	0.0780	[0.6517, 0.9054]
ζ_p	Beta	0.50	0.10	0.3236	0.3417	0.0894	[0.1982, 0.4783]
ζ_w	Beta	0.50	0.10	0.5252	0.5263	0.1071	[0.3610, 0.6990]
ρ_i	Beta	0.70	0.10	0.8814	0.8804	0.0197	[0.8470, 0.9135]
ϕ_π	Normal	0.50	0.10	0.4495	0.4540	0.0478	[0.3747, 0.5330]
ϕ_x	Normal	0.05	0.10	0.0000	0.0000	0.0000	[0.0000, 0.0000]
ϕ_y	Normal	0.20	0.10	0.1469	0.1504	0.0276	[0.1036, 0.1971]
ρ_A	Beta	0.70	0.10	0.8472	0.8295	0.0485	[0.7506, 0.9125]
ρ_ν	Beta	0.70	0.10	0.6916	0.6579	0.1201	[0.4885, 0.8276]
ρ_Z	Beta	0.70	0.10	0.6820	0.6733	0.0575	[0.5840, 0.7708]
ρ_G	Beta	0.70	0.10	0.9506	0.9488	0.0001	[0.9267, 0.9706]
σ_A	Inv. Gamma	0.01	0.01	0.0064	0.0073	0.0015	[0.0046, 0.0100]
σ_ν	Inv. Gamma	0.01	0.01	0.0181	0.0203	0.0041	[0.0128, 0.0282]
σ_Z	Inv. Gamma	0.01	0.01	0.0389	0.0405	0.0040	[0.0330, 0.0468]
σ_G	Inv. Gamma	0.01	0.01	0.0098	0.0100	0.0001	[0.0087, 0.0113]
σ_i	Inv. Gamma	0.002	0.01	0.0013	0.0013	0.0001	[0.0011, 0.0015]

Notes: The variables used in the estimation are the growth rates of output, consumption, and investment, and the levels of inflation and the nominal interest rate. Construction of these series is as described in the text. The posterior is generated with 100,000 Metropolis-Hastings draws.

We find moderate levels of wage and price indexation. The investment adjustment cost parameter, τ , and the parameter governing internal habit formation, b , imply significant real inertia. The estimate of the parameter η implies a Frisch labor supply elasticity of about two-thirds. The monetary policy rule features significant inertia and a large response to inflation (the implied long run response of the interest rate to inflation is about four). The policy rule features a positive response to output growth and no response to the output gap,

the latter of which is estimated precisely at zero. This is consistent with the evidence in [Coibion and Gorodnichenko \(2011\)](#) that the Fed moved away from responding to the output gap and toward a much stronger reaction to output growth in the post-Volcker period.

The estimated model produces second moments which align closely with their counterparts in the data. Consumption growth is less volatile than output growth, while investment growth is about three times more volatile than output growth. Output, consumption, and investment are strongly positively correlated, while the nominal interest rate is roughly uncorrelated with output growth and the inflation rate is mildly negatively correlated with output growth. The first order autocorrelations of output, consumption, and investment growth are all significantly positive. In terms of contributions to business cycle dynamics, the investment shock is the most important disturbance. It accounts for about 50 percent of the unconditional variance of output growth. The productivity shock explains about 30 percent of the variance of output growth. The preference and government spending shocks each contribute a little less than 10 percent, while the monetary shock accounts for about 5 percent of the unconditional variance of output growth. This variance decomposition is very much in line with the results in [Justiniano et al. \(2010\)](#).

The fact that the posterior distribution for τ is virtually identical to the prior suggests that this parameter is poorly identified, at least in the region of where we place the mean of the prior distribution. The apparent poor identification of τ seems consistent with the literature, where parameter estimates of the equivalent of τ range from a low near 1 to higher than 10, with a central tendency around 4. In experimenting with different values of this parameter, we find that the model is incapable of generating positive autocorrelation in the growth rates of output and investment, and generates acyclical consumption, if the investment adjustment cost is dropped from the model and the remaining parameters are re-estimated. Once τ is above 1 or so, the fit of the model relative to several moments in the data is roughly invariant to the value of τ .

4.1 Evaluating Monetary Policy Rules

We solve the medium scale model using the calibrated or estimated values listed in [Tables 5 and 6](#) using a second order approximation about the non-stochastic steady state. Compensating variations are constructed comparing average welfare under different policy regimes to the hypothetical flexible price and wage equilibrium. These exercises are identical to the ones carried out in [Section 2](#). When evaluating the welfare performance of the estimated Taylor rule, we set the standard deviation of the policy innovation to zero so as to facilitate comparison with the other targeting rules, which feature no shocks.

The compensating variations for the different monetary policy rules in the estimated model are summarized in the first main column of Table 7. The relative performance of the different targeting rules is the same as in the small scale model from Section 2. The welfare loss associated with nominal GDP targeting is 0.11 percent of consumption. This is not as good as output gap targeting, which has a welfare loss of 0.03 percent of consumption, but outperforms the estimated Taylor rule (welfare loss of 0.24 percent of consumption) and does significantly better than inflation targeting, which produces a compensating variation of 0.86 percent of consumption.

The remaining columns of Table 7 consider different values of the parameters governing price and wage stickiness. For these exercises all but the listed parameter are fixed at their estimated or calibrated values. The patterns in the Table again echo those from the small scale model. If either prices or wages are completely flexible, the output gap targeting rule implements the flexible price and wage allocation with a compensating variation of zero. If wages are perfectly flexible then inflation targeting also implements the flexible price allocation. Nominal GDP targeting performs very well, producing a lower welfare loss than the Taylor rule in all specifications and outperforming inflation targeting by a wide margin in all but the case where wages are flexible. As in the small scale model, the relative performance of nominal GDP targeting to inflation targeting depends on the relative stickiness of wages to prices.

Table 7: Consumption Equivalent Welfare Losses from Different Policy Rules
Medium Scale Model

	Estimated Model	$\theta_p = 0.00$	$\theta_p = 0.50$	$\theta_w = 0.50$	$\theta_w = 0.00$
NGDP	0.1056	0.0950	0.0976	0.1276	0.0755
Inflation	0.8630	0.8630	0.8630	0.6182	0.0000
Output Gap	0.0343	0.0000	0.0277	0.0312	0.0000
Taylor Rule	0.2439	0.1998	0.2325	0.1286	0.1132

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model. The column labeled “Estimated Model” uses the parameter values described in Tables 5 and 6. When evaluating the compensating variation for the Taylor rule the standard deviation of the monetary policy shock is set to zero. The other columns describe values of the price or wage rigidity parameters. For the exercises described in these columns all other parameters are fixed at their calibrated or estimated values.

In Table 8 we compare the compensating variations for different policy rules conditional on specific shocks. For these exercises we solve for the standard deviation of the listed shock that would generate the same volatility of log output as in the baseline model when all

other shocks have standard deviations of zero. The output gap targeting rule produces the smallest welfare losses conditional on each of the four considered shocks. Nominal GDP targeting is the second best rule conditional on three of the four shocks, with the exception being the government spending shock. Though nominal GDP targeting produces a fairly high compensating variation conditional on the government spending shock, this shock is estimated to be a relatively unimportant driver of fluctuations. Inflation targeting does very poorly conditional on productivity shocks, but produces fairly small compensating variations conditional on investment and preference shocks. The Taylor rule performs fairly well conditional on all but the preference shock.

Table 8: Consumption Equivalent Welfare Losses from Different Policy Rules, Shock Specific Medium Scale Model

	Shocks			
	Productivity	Investment	Preference	Government Spending
NGDP	0.1141	0.0872	0.2012	0.5507
Inflation	1.7684	0.1266	0.3379	0.4828
Output Gap	0.0684	0.0062	0.0173	0.0209
Taylor Rule	0.1562	0.2779	1.1869	0.1075

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model. We solve for the standard deviation of the listed shock that would generate the same volatility of log output as in the baseline model when all other shocks have standard deviations of zero. The resulting shock standard deviations are $\sigma_A = 0.0096$ for the productivity shock only case, $\sigma_Z = 0.0537$ when there are only investment shocks, $\sigma_\nu = 0.1175$ when conditioning on only preference shocks, and $\sigma_G = 0.1103$ for government spending shocks. All other parameters are fixed at their calibrated or estimated values.

In the estimated model the productivity shock is a “supply” shock in that it moves output and inflation in opposite directions, while the other three shocks are “demand” shocks in that they result in output and inflation co-moving positively (these statements are conditional on the estimated model where policy is governed by the estimated Taylor rule). In the medium scale model there is not a clean demarcation between “demand” and “supply” because the investment, preference, and government spending shocks would affect output when prices and wages are flexible. Nevertheless, some of the intuition from the simple model does carry over to this setting. In particular, the difference between nominal GDP and inflation targeting is starkest conditional on the productivity shock, with inflation targeting producing a compensating variation more than fifteen times bigger than nominal GDP targeting. Further, the welfare differences between nominal GDP and inflation targeting are smaller conditional on the three demand shocks. Unlike the simple model, inflation targeting does not implement

the flexible price and wage allocation conditional on these three shocks, and nominal GDP targeting outperforms inflation targeting conditional on two of the three demand shocks.

We consider some robustness to different values of parameters unrelated to the shock processes and nominal price and wage stickiness in Table 9.¹⁰ For these exercises all parameters but the one listed in the column are set to their baseline values. The basic pattern of results is consistent with our previous analysis – the output gap targeting rule is always the best-performing rule, while nominal GDP targeting is typically the second best. When there is an infinite Frisch labor supply elasticity ($\eta = 0$) or no variable utilization ($\gamma_2 = \infty$), nominal GDP targeting performs slightly worse and inflation targeting a little better than in the baseline estimated model, though nominal GDP targeting is still more desirable than inflation targeting by a wide margin. The compensating variations for both nominal GDP targeting and inflation targeting are slightly smaller with no habit formation ($b = 0$) and lower elasticities of substitution ($\epsilon_p = \epsilon_w = 5$), though again nominal GDP targeting is preferred to inflation targeting. The Taylor rule produces compensating variations similar to the baseline estimated model. Assuming full indexation of non-updated prices and wages to lagged inflation ($\gamma_p = \gamma_w = 1$) makes very little difference for any of the welfare losses associated with different policies relative to the baseline estimated model.

Table 9: Consumption Equivalent Welfare Losses from Different Policy Rules, Parameter Robustness Medium Scale Model

	$b = 0$	$\eta = 0$	$\gamma_2 = \infty$	$\epsilon_p = \epsilon_w = 5$	$\gamma_p = \gamma_w = 1$
NGDP	0.0919	0.2051	0.1056	0.0745	0.3020
Inflation	0.4683	0.4577	0.8021	0.6240	0.8630
Output Gap	0.0292	0.0374	0.0346	0.0141	0.0265
Taylor Rule	0.2654	0.0996	0.2463	0.1093	0.3152

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model for different values of select parameters. The value of a parameter(s) different than in our baseline is indicated in each column; the remaining parameters are set at their calibrated or estimated values listed in Tables 5 and 6.

Above we noted that the parameter τ , which governs the investment adjustment cost,

¹⁰We consider several additional robustness exercises which are relegated to Appendix C. In Table 12 we compute the compensating variations for the different policy rules when all estimated parameters are set at either the 10th or 90th percentiles of the posterior distribution. In Tables 13 and 14 we set each parameter to either the 10th or 90th percentile of the posterior distribution, respectively, while holding all other parameters fixed at the posterior mode, and compute compensating variations for the different policy rules. Qualitatively the relative ranking of different policy rules obtains in all the different parameter configurations considered.

seems to be poorly identified in our estimation. Table 10 summarizes welfare comparisons of different policy rules from exercises wherein we fix τ at different levels and re-estimate the remaining parameters of the model conditional on the fixed level of τ .¹¹ While there is a big improvement in model fit going from $\tau = 0$ to $\tau = 1$, moments from the model vary little with τ for values of 1 or higher, and other parameters are similar to what we estimate in the baseline model. In the table one sees that the compensating variation associated with nominal GDP targeting is roughly invariant to the value of τ . The same is not true for the other rules under consideration. While output gap targeting is always the most desirable rule, and nominal GDP the second most, there is a significant impact of τ on the compensating variations associated with inflation targeting and the Taylor rule. Inflation targeting performs best when τ is low and is significantly worse than in our baseline analysis when τ is very large. The reverse is true for the Taylor rule.

Table 10: Consumption Equivalent Welfare Losses from Different Policy Rules
Medium Scale Model, Different Values of τ

	$\tau = 0$	$\tau = 1$	$\tau = 2$	$\tau = 3$	$\tau = 5$	$\tau = 6$	$\tau = 10$
NGDP	0.1011	0.1061	0.1052	0.1100	0.1199	0.1264	0.1481
Inflation	0.4573	0.6010	0.7281	0.8855	1.1029	1.2163	1.3945
Output Gap	0.0074	0.0281	0.0330	0.0376	0.0406	0.0427	0.0486
Taylor Rule	0.3497	0.2948	0.2644	0.2487	0.2341	0.2366	0.1923

Notes: This table shows consumption equivalent welfare losses for the four different policy rules under consideration. The first inner column shows the welfare losses in the estimated model. The remaining columns compute welfare losses when τ is restricted to the value indicated in the column heading and the remaining parameters are re-estimated.

4.1.1 Conditional vs. Unconditional Welfare Comparisons

Our baseline comparison of different policy rules is based on unconditional compensating variations. That is, we compare the unconditional mean of welfare under one policy rule to the unconditional mean of welfare in a hypothetical economy with flexible prices and wages. We then compare these compensating variations for different policy rules. This exercise may convey misleading information when comparing different policy rules to one another. This is because the economy fluctuates about potentially different means under different policy rules. Put another way, our baseline exercise shows that households would prefer to be in an economy with nominal GDP targeting to an economy where monetary policy is conducted

¹¹We are grateful to an anonymous associate editor for bringing the poor identification of τ to our attention and encouraging us to think about the effect of τ on our results.

according to a Taylor rule. But our baseline exercise does not tell us whether a household in an economy where policy is governed by a Taylor rule would prefer switching to an economy with nominal GDP targeting, for example, since the realization of states in the two economies might be different.

To address the issue of conditional versus unconditional welfare, we consider the following quantitative experiment. Using the parameter values from the estimated model, we simulate 5,000 periods of data assuming the central bank follows a Taylor rule.¹² Each period in the simulation represents a “beginning state” for the economy on which we condition. For each beginning state, we compare the welfare of staying in the Taylor rule to the welfare from switching to one of the three other rules. The compensating variations are again compared to a hypothetical economy with flexible prices and wages. This experiment allows us to answer the question: Under what circumstances would households prefer to switch to a strict targeting rule *given* that we start in some state of the world generated by a Taylor rule? This approach takes into account any costs of transition dynamics, which is important since the Fed’s recent history suggests they follow a Taylor rule.

Table 11 presents summary statistics from the conditional welfare exercises. In particular, at each realization of the state vector, we compute the compensating variation associated with each of the four monetary policy rules. The entries in the table summarize the difference between the compensating variation associated with nominal GDP targeting and other rules. The first row presents the differences averaged across all states. Negative entries mean that nominal GDP targeting is preferred (i.e the compensating variation with nominal GDP targeting is smaller than with the other rule). The numbers presented in this row are very close to the differences in unconditional compensating variations presented in Table 7. On average, nominal GDP targeting is preferred to the Taylor rule by about 0.10 and to inflation targeting by about 0.75 percent of consumption. Gap targeting is preferred to nominal GDP targeting on average by about 0.07 percent of consumption.

The rows labeled “min” and “max” show the minimum and maximum differences between the compensating variations from nominal GDP targeting and other rules across the 4,500 simulated values of states. Relative to inflation targeting, the compensating variation from nominal GDP targeting is preferred by as much as 0.9 percent of consumption or as little as 0.7 percent of consumption. Consequently, nominal GDP targeting is preferred to inflation targeting in 100 percent of states (as indicated in the bottom row of the table). A similar story emerges when comparing nominal GDP targeting to the Taylor rule, albeit the differences are not as stark. Nominal GDP targeting is preferred to the Taylor rule in all realizations of the state. In other words, regardless of initial conditions, households in the economy would

¹²We “burn in” the first 500 observations.

always prefer to switch from the estimated Taylor rule to a nominal GDP targeting regime. Interestingly, even though gap targeting is preferred on average, there are some states in which nominal GDP targeting is preferred to gap targeting. In particular, in 0.5 percent of simulated states the compensating variation associated with nominal GDP targeting is smaller than the compensating variation with output gap targeting.

Table 11: NGDP Targeting vs. Alternatives: Conditional Compensating Variations
Medium Scale Model

	Relative to		
	Inflation Targeting	Taylor Rule	Gap Targeting
Average	-0.7593	-0.1276	0.0672
Min	-0.8972	-0.1786	-0.0179
Max	-0.6818	-0.0764	0.1880
Std	0.0250	0.0120	0.0278
% of Periods NGDP is Preferred	100	100	0.50

Notes: The entries in the table show the difference between the compensating variation associated with nominal GDP targeting and other rules. Parameters are set at their calibrated or estimated values listed in Tables 5 and 6.

Finally, we return briefly to an issue brought up in Section 2 concerning the difference between a nominal GDP growth rate target and a level target. As noted there, a nominal GDP growth rate targeting rule is equivalent to a level targeting rule, where the level target going forward is the log level of nominal GDP in the most recent period. Hence, unconditionally, there is no difference between a nominal GDP targeting rule in growth rates or levels. This is not necessarily the case in a conditional sense if the level target for nominal GDP differs from the most recent log level of nominal GDP. In the exercises considered in this section, data are simulated from an economy governed by a Taylor rule. In this economy the log level of nominal GDP is not constant (and indeed is not stationary, as the Taylor rule does not generate a stationary price level). Switching from a Taylor rule to a nominal GDP level target can be quite costly if the level target of nominal GDP is far from the existing level of nominal GDP. For example, if the target level of nominal GDP is lower than current nominal GDP, switching from a Taylor rule to a nominal GDP target necessitates a large increase in interest rates so as to implement an immediate and large reduction in nominal GDP. This issue does not arise with the nominal GDP growth rate target, which is equivalent to a level target going forward where the level target is flexible in the sense of equaling the most recent value of nominal GDP.

4.2 Gap or NGDP Targeting: Measurement Difficulties

In both the small and medium scale versions of the model, we find that output gap targeting is the most desirable policy rule. Nominal GDP targeting typically performs very well, in many instances almost as well as gap targeting. A potential advantage of nominal GDP targeting over gap targeting is that the former is easily observed, whereas the gap is based on a hypothetical model construct that is likely difficult to observe even ex-post, much less in real time. A nominal GDP target is likely also far easier to communicate to the public than a gap targeting rule.

There exists a large literature that studies the difficulties of observing the output gap and the implications for monetary policy. [Orphanides and van Norden \(2002\)](#) find that the measurement of the output gap in real time is acutely affected by the method of detrending. Moreover, the ex post revisions in the output gap are on the same order of magnitude as the output gap itself. Combining this uncertainty about the trend with conventional measurement error implies that the real time measurement of the output gap is an unreliable measure of the true output gap. [Orphanides \(2001\)](#) shows that inputting real time data in to a Taylor rule with standard coefficients consistently under predicts the Fed Funds rate and [Orphanides \(2003\)](#) shows that smaller coefficients in the Taylor rule are in fact welfare improving in the presence of measurement error. Since any reaction to observed deviations of the output gap and inflation is in fact a reaction to their true deviations plus measurement error, the optimally behaved central bank is more prudent. In recent work, [Beckworth and Hendrickson \(2015\)](#) show that a rule where the nominal interest rate is a linear function of nominal GDP growth outperforms the conventional Taylor rule when real time forecasts are used for the output gap. This corroborates the results of [Orphanides \(2003\)](#), who finds that policy rules that respond to growth rates of economic variables rather than their misperceived deviations from their natural rates are welfare improving.

We consider a couple of different exercises to examine the relative desirability of gap versus nominal GDP targeting when the gap is difficult to observe. In the first, we assume that the central bank observes the flexible price and wage level of output with noise. In particular, we assume:

$$\ln Y_t^{f,obs} = \ln Y_t^f + n_t. \quad (39)$$

In this specification Y_t^f is the flexible price and wage level of output, while $Y_t^{f,obs}$ is the central bank's observed flexible price and wage level of output. The two differ by n_t , which is a noise process which we assume obeys a mean-zero stationary AR(1) process:

$$n_t = \rho_n n_{t-1} + \sigma_n \varepsilon_{n,t}. \quad (40)$$

Here $0 < \rho_n < 1$ is a persistence parameter, $\varepsilon_{n,t}$ is a shock drawn from a standard normal distribution, and σ_n is the standard deviation of the shock. These noise shocks capture in a tractable yet realistic way the idea that the central bank may have difficulty in observing the true flexible price and wage level of output. The central bank’s observed output gap is the ratio of the actual level of output to the observed flexible price and wage level of output, i.e. $X_t = Y_t/Y_t^{f,obs}$. Noise shocks cause an output gap targeting central bank to target the wrong measure of the gap. One would expect that gap targeting would be less desirable the noisier is the observed flexible price and wage level of output.

We consider the following experiment. We find the pairs of (ρ_n, σ_n) for which gap targeting (with the mis-measured output gap) and nominal GDP targeting produce the same welfare loss. Figure 2 plots in the left panel these combinations for which a central bank would be indifferent between gap and nominal GDP targeting. At parameter combinations above this frontier (areas shaded green) nominal GDP targeting is preferred to gap targeting. The right panel plots the overall standard deviation of noise (i.e. the standard deviation of n_t) at the (ρ_n, σ_n) pairs plotted in the left panel. Areas shaded green represent standard deviations of the noise process for which nominal GDP targeting produces a lower welfare loss than does gap targeting.

The standard deviation of the noise shock to the observed flexible price and wage level of output which would equate the welfare losses of nominal GDP and gap targeting is always less than 0.66 percent for any value of the persistence parameter. For levels of persistence in excess of 0.9 the amount of noise required to equate the two targeting rules is less than 0.25 percent. It is interesting to note that the relationship between ρ_n and the standard deviation of the noise shock which equates gap targeting to NGDP targeting is non-monotonic – for low values of persistence, as ρ_n increases the standard deviation of the noise shock increases. We surmise that this has to do with a smoothing motive – if the noise shocks are i.i.d., then the central bank’s perceived flexible price and wage level of output fluctuates substantially period-to-period, imparting significant volatility to interest rates. For very high levels of persistence, however, the amount of noise required to equate nominal GDP and gap targeting is smaller the bigger is ρ_n . The right panel plots the overall standard deviation of the noise process for the parameter combinations in the left panel. The overall standard deviation of the noise process necessary for output gap and nominal GDP targeting to produce the same compensating variations is always less than 1 percent, and is often substantially less than that. To put this number into perspective, the standard deviation of the log flexible price and wage level of output in the estimated model is 1.8 percent. Roughly speaking, if volatility of noise is greater than 1/3-1/2 the volatility of the flexible price and wage level of

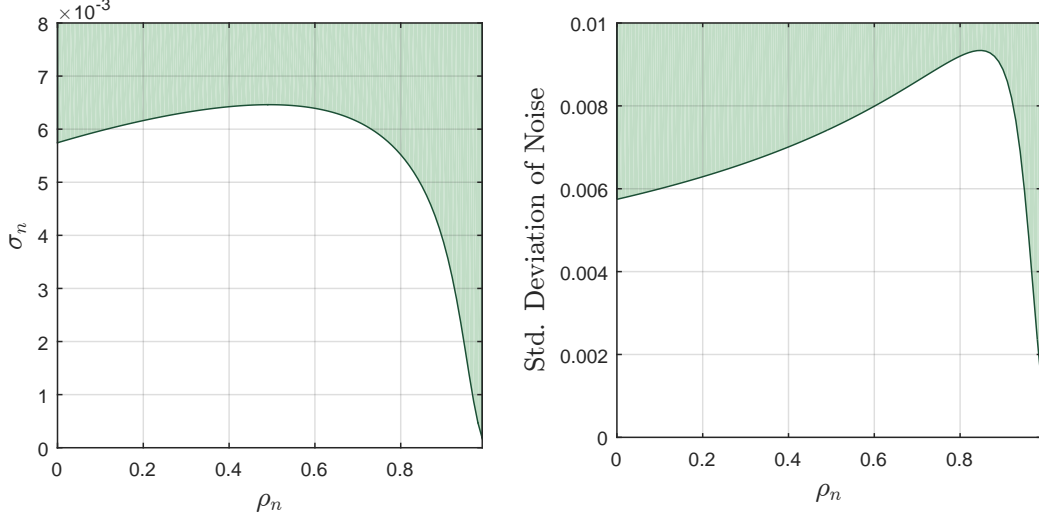


Figure 2: Measurement Error and Gap Targeting vs. NGDP Targeting

Notes: The left panel of the figure plots the combinations of (ρ_n, σ_n) for which output gap and nominal GDP targeting produce the same compensating variation in the estimated medium scale model. The right panel plots the standard deviation of the noise process, n_t , at the parameter values plotted in the left panel. The areas shaded green correspond to parameter configurations where NGDP targeting is preferred to gap targeting.

output itself, nominal GDP targeting dominates output gap targeting.

We also consider a second specification in which, rather than being observed with noise, the central bank's perceived measure of the flexible price and wage level of output adjusts slowly to actual movements in the flexible price and wage level of output. In particular:

$$\ln Y_t^{f,obs} = \omega \ln Y_{t-1}^{f,obs} + (1 - \omega) \ln Y_t^f. \quad (41)$$

The parameter ω is restricted to lie strictly between 0 and 1. In this specification ω governs the speed with which the flexible price and wage level of output adjusts to its true level. A specification like this could be motivated as reduced form way to model an optimal filtering problem solved by a central bank. As $\omega \rightarrow 1$, this rule would be equivalent to an output targeting rule, since the perceived flexible price and wage level of output would always equal its non-stochastic steady state, which is the same as the steady state level of actual output.

In Figure 3 we calculate the compensating variation of gap targeting (when the gap is constructed using the observed flexible price and wage level of output) for different values of the parameter ω . For comparison, we also show the compensating variation associated with nominal GDP targeting.

Output gap targeting produces a smaller welfare loss than nominal GDP targeting for values of ω less than about 0.8. This is fairly high and suggests that the perceived flexible price and wage level of output must adjust slowly to its true value for nominal GDP targeting

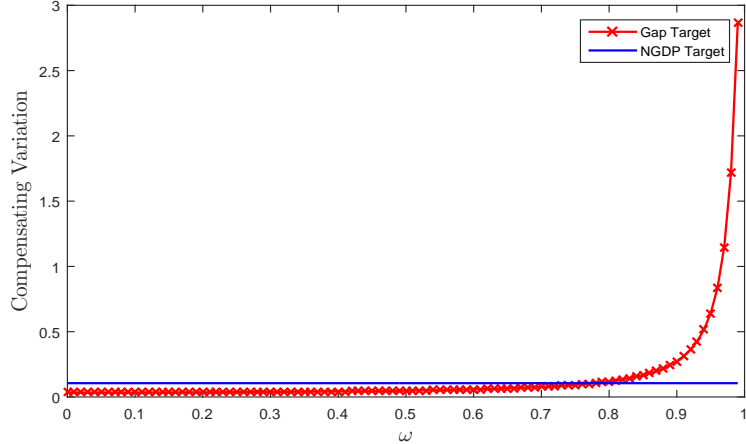


Figure 3: Slow-Moving Gap Target

Notes: The solid blue line plots the compensating variation associated with nominal GDP targeting in the estimated medium scale model. The ride line marked with “x” plots the compensating variation associated with gap targeting for different values of the parameter ω when the perceived flexible price and wage level of output follows the process described in (41).

to be preferred to gap targeting. Nevertheless, there is significant downside risk to output gap targeting in the event that ω is high. The compensating variation associated with gap targeting rises quickly at values of ω above 0.8. Once above about $\omega = 0.9$ or so output gap targeting performs worse than inflation targeting, and produces compensating variations in excess of 1 percent. Since when $\omega \rightarrow 1$ this specification is equivalent to an output target, these results are consistent with the analysis in [Schmitt-Grohe and Uribe \(2007\)](#), who find that it is non-optimal to target the deviation of output from its steady state in a Taylor rule.

4.3 Gap vs NGDP Targeting: Equilibrium Determinacy

There exists a literature which emphasizes that a central bank strongly responding to the output gap could result in equilibrium indeterminacy. This point has been made in the context of the Taylor rule in a sticky price New Keynesian model by [Hornstein and Wolman \(2005\)](#), [Ascari and Ropele \(2009\)](#), and [Coibion and Gorodnichenko \(2011\)](#). These authors show that the standard Taylor principle for a Taylor rule to support a determinate equilibrium may break down when trend inflation is positive. In particular, strong responses to the output gap can result in equilibrium indeterminacy even if the long run response of the interest rate to inflation is greater than one. Furthermore, the minimum required response to inflation is increasing in the coefficient on the gap for positive levels of trend inflation.

Whereas these papers focus on determinacy within the context of an instrument rule, to our knowledge no paper has studied the issue of determinacy with trend inflation for strict targeting rules. We find that gap targeting results in an indeterminate equilibrium at trend

inflation rates higher than 0.2 percent annualized, which is far below the observed average level of inflation of about 2 percent over the last thirty years. Nominal GDP targeting, in contrast, supports a determinate equilibrium for any level of trend inflation. This is because in the long run nominal GDP targeting is isomorphic to a price level target, which always ensures equilibrium determinacy.¹³

5 Conclusion

The design of monetary policy has been the subject of a voluminous and influential literature. In spite of widespread discussion in the press and policy circles, the normative properties of nominal GDP targeting have not been subject to scrutiny within the context of the quantitative frameworks commonly used at central banks and among academic macroeconomists. The objective of this paper has been to analyze the welfare properties of nominal GDP targeting in comparison to other popular policy rules in an empirically realistic New Keynesian model with both price and wage rigidity.

We find that nominal GDP targeting performs well in this model. It typically produces small welfare losses and comes close to fully implementing the flexible price and wage allocation. It produces smaller welfare losses than an estimated Taylor rule and significantly outperforms inflation targeting. It tends to perform best relative to these alternative rules when wages are sticky relative to prices and conditional on supply shocks. While output gap targeting always at least weakly outperforms nominal GDP targeting in an average sense, the differences in welfare losses associated with the two rules are small. Furthermore, there are some states of the world in which nominal GDP targeting is preferred to output gap targeting in a conditional sense. Nominal GDP targeting may produce lower welfare losses than gap targeting if the central bank has difficulty measuring the output gap in real time. Nominal GDP targeting always supports a determinate equilibrium, whereas output gap targeting may result in indeterminacy if trend inflation is positive. Overall, our analysis suggests that nominal GDP targeting is a policy alternative that central banks ought to take seriously.

There are a number of possible extensions of our analysis. Three which immediately come to mind are financial frictions, the zero lower bound, and secular stagnation. Though our medium scale model includes investment shocks, which have been interpreted as a reduced form for financial shocks in [Justiniano et al. \(2011\)](#), it would be interesting to formally model financial frictions and examine how nominal GDP targeting interacts with those. Second,

¹³We also find that inflation targeting supports a determinate equilibrium for any level of trend inflation. Though we do not report the results here, we continue to find that nominal GDP targeting produces significantly lower welfare losses than inflation targeting (and the Taylor rule) in the model when trend inflation is positive.

our analysis abstracts from the zero lower bound on nominal interest rates. It would be interesting to study how a commitment to a nominal GDP target might affect the frequency, duration, and severity of zero lower bound episodes. Third, there has been much recent interest in “Secular Stagnation,” a situation in which the economy finds itself stuck in a low growth, low inflation regime. It would be interesting to study how nominal GDP targeting affects the susceptibility of an economy to secular stagnation, as well as to how switching to nominal GDP targeting might help to lift an economy out of secular stagnation. These issues are beyond the scope of the present paper, which aims to compare nominal GDP targeting to other popular policy rules in a reasonably conventional DSGE model. We plan to take up a thorough examination of these and related issues in subsequent work.

References

- ASCARI, G. AND T. ROPELE (2009): “Trend Inflation, Taylor Principle, and Indeterminacy,” *Journal of Money, Credit and Banking*, 41, 1557–1584.
- BARATTIERI, A., S. BASU, AND P. GOTTSCHALK (2014): “Some Evidence on the Importance of Sticky Wages,” *American Economic Journal: Macroeconomics*, 6, 70–101.
- BARRO, R. J. AND D. B. GORDON (1983): “Rules, Discretion and Reputation in a Model of Monetary Policy,” *Journal of Monetary Economics*, 12, 101 – 121.
- BECKWORTH, D. AND J. R. HENDRICKSON (2015): “Nominal GDP Targeting and the Taylor Rule on an Even Playing Field,” Tech. rep.
- BERNANKE, B. S. AND F. S. MISHKIN (1997): “Inflation Targeting: A New Framework for Monetary Policy?” *Journal of Economic Perspectives*, 11, 97–116.
- BILLI, R. M. (2014): “Nominal GDP Targeting and the Zero Lower Bound: Should We Abandon Inflation Targeting?” Tech. Rep. 270, Sveriges Riksbank Working Paper Series.
- BLANCHARD, O. AND J. GALI (2007): “Real Wage Rigidities and the New Keynesian Model,” *Journal of Money, Credit and Banking*, 39, 35–65.
- CECCHETTI, S. G. (1995): “Inflation Indicators and Inflation Policy,” NBER Working Papers 5161, National Bureau of Economic Research, Inc.
- CHRISTIANO, L. J., M. EICHENBAUM, AND C. L. EVANS (2005): “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy,” *Journal of Political Economy*, 113, 1–45.
- COIBION, O. AND Y. GORODNICHENKO (2011): “Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation,” *American Economic Review*, 101, 341–70.
- ERCEG, C. J., D. W. HENDERSON, AND A. T. LEVIN (2000): “Optimal Monetary Policy with Staggered Wage and Price Contracts,” *Journal of Monetary Economics*, 46, 281–313.
- GIANNONI, M. P. (2014): “Optimal Interest-Rate Rules and Inflation Stabilization Versus Price-Level Stabilization,” *Journal of Economic Dynamics and Control*, 41, 110–129.
- GORODNICHENKO, Y. AND M. D. SHAPIRO (2007): “Monetar Policy When Potential Output is Uncertain: Understanding the Growth Gamble of the 1990s,” *Journal of Monetary Economics*, 54, 1132–1162.

- HALL, R. E. AND N. G. MANKIW (1994): “Nominal Income Targeting,” Tech. rep.
- HORNSTEIN, A. AND A. L. WOLMAN (2005): “Trend Inflation, Firm-Specific Capital, and Sticky Prices,” *Economic Quarterly*, 57–83.
- JENSEN, H. (2002): “Targeting Nominal Income Growth or Inflation?” *American Economic Review*, 92, 928–956.
- JUSTINIANO, A., G. E. PRIMICERI, AND A. TAMBALOTTI (2010): “Investment Shocks and Business Cycles,” *Journal of Monetary Economics*, 57, 132 – 145.
- (2011): “Investment Shocks and the Relative Price of Investment,” *Review of Economic Dynamics*, 14, 101–121.
- KIM, J. AND D. W. HENDERSON (2005): “Inflation Targeting and Nominal-Income-Growth Targeting: When and Why are They Suboptimal?” *Journal of Monetary Economics*, 52, 1463 – 1495.
- LEVIN, A. T., A. ONATSKI, J. WILLIAMS, AND N. WILLIAMS (2006): “Monetary Policy Under Uncertainty in Micro-Founded Macroeconomic Models,” in *NBER Macroeconomics Annual 2005, Volume 20*, MIT Press, 229–312.
- MITRA, K. (2003): “Desirability of Nominal GDP Targeting under Adaptive Learning,” *Journal of Money, Credit, and Banking*, 35, 197–220.
- ORPHANIDES, A. (2001): “Monetary Policy Rules Based on Real-Time Data,” *American Economic Review*, 91, 964–985.
- (2003): “Monetary Policy Evaluation with Noisy Information,” *Journal of Monetary Economics*, 50, 605–631.
- ORPHANIDES, A. AND S. VAN NORDEN (2002): “The Unreliability of Output-Gap Estimates in Real Time,” *The Review of Economics and Statistics*, 84, pp. 569–583.
- SCHMITT-GROHE, S. AND M. URIBE (2007): “Optimal Simple and Implementable Monetary and Fiscal Rules,” *Journal of Monetary Economics*, 54, 1702–1725.
- SIMS, E. (2013): “Growth or the Gap? Which Measure of Economic Activity Should be Targeted in Interest Rate Rules?” Tech. rep.
- SMETS, F. AND R. WOUTERS (2007): “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach,” *The American Economic Review*, 97, 586–606.

SUMNER, S. (2014): “Nominal GDP Targeting: A Simple Rule to Improve Fed Performance,” *Cato Journal*, 34, 315–337.

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

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

——— (2012): “Methods of Policy Accommodation at the Interest-Rate Lower Bound,” Tech. rep.

A Basic New Keynesian Model

The equations below characterize the equilibrium of the simple New Keynesian model described in Section 2.

$$\frac{1}{C_t} = \beta E_t \frac{\nu_{t+1}}{\nu_t} \frac{1}{C_{t+1}} \frac{1+i_t}{1+\pi_{t+1}} \quad (42)$$

$$w_t^\# = \frac{\epsilon_w}{\epsilon_w - 1} \frac{H_{1,t}}{H_{2,t}} \quad (43)$$

$$H_{1,t} = \psi \nu_t \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w(1+\eta)} N_{d,t}^{1+\eta} + \theta_w \beta E_t \left(\frac{w_{t+1}^\#}{w_t^\#} \right)^{\epsilon_w(1+\eta)} (1+\pi_{t+1})^{\epsilon_w(1+\eta)} H_{1,t+1} \quad (44)$$

$$H_{2,t} = \nu_t \frac{1}{C_t} \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w} N_{d,t} + \theta_w \beta E_t \left(\frac{w_{t+1}^\#}{w_t^\#} \right)^{\epsilon_w} (1+\pi_{t+1})^{\epsilon_w-1} H_{2,t+1} \quad (45)$$

$$mc_t = \frac{w_t}{A_t} \quad (46)$$

$$\frac{1+\pi_t^\#}{1+\pi_t} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{X_{1,t}}{X_{2,t}} \quad (47)$$

$$X_{1,t} = \nu_t \frac{1}{C_t} mc_t Y_t + \theta_p \beta E_t (1+\pi_{t+1})^{\epsilon_p} X_{1,t+1} \quad (48)$$

$$X_{2,t} = \nu_t \frac{1}{C_t} Y_t + \theta_p \beta E_t (1+\pi_{t+1})^{\epsilon_p-1} X_{2,t+1} \quad (49)$$

$$Y_t = C_t \quad (50)$$

$$Y_t = \frac{A_t N_{d,t}}{v_t^p} \quad (51)$$

$$(1+\pi_t)^{1-\epsilon_p} = (1-\theta_p)(1+\pi_t^\#)^{1-\epsilon_p} + \theta_p \quad (52)$$

$$w_t^{1-\epsilon_w} = (1-\theta_w) w_t^{\#,1-\epsilon_w} + \theta_w (1+\pi_t)^{\epsilon_w-1} w_{t-1}^{1-\epsilon_w} \quad (53)$$

$$v_t^p = (1+\pi_t)^{\epsilon_p} \left[(1-\theta_p)(1+\pi_t^\#)^{-\epsilon_p} + \theta_p v_{t-1}^p \right] \quad (54)$$

$$\ln(1+i_t) = (1-\rho_i) \ln(1+i^*) + \rho_i \ln(1+i_{t-1}) + \phi_\pi \ln(1+\pi_t) + \phi_y \ln X_t + \phi_y \ln \left(\frac{Y_t}{Y_{t-1}} \right)$$

or

$$\pi_t = 0$$

or

$$\pi_t + \ln Y_t - \ln Y_{t-1} = 0$$

or

$$X_t = 1$$

(55)

$$\ln A_t = \rho_A \ln A_{t-1} + \sigma_A \varepsilon_{A,t} \quad (56)$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \sigma_\nu \varepsilon_{\nu,t} \quad (57)$$

$$\mathbb{W}_t = \nu_t \left[\ln C_t - \psi v_t^w \frac{N_{d,t}^{1+\eta}}{1+\eta} \right] + \beta E_t \mathbb{W}_{t+1} \quad (58)$$

$$v_t^w = (1 - \theta_w) \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w(1+\eta)} + \theta_w \left(\frac{w_t}{w_{t-1}} (1 + \pi_t) \right)^{\epsilon_w(1+\eta)} v_{t-1}^w. \quad (59)$$

Equation (42) is the consumption Euler equation and equations (43) - (45) describe optimal wage-setting for households given the opportunity to adjust their wage. Equation (46) describes real marginal cost and comes from firms minimizing cost. Equations (47) - (49) describe optimal price-setting. Here we have defined $1 + \pi_t^\# = \frac{P_t^\#}{P_{t-1}}$ as reset price inflation. Equation (50) is the aggregate resource constraint and (51) is the aggregate production function. Equations (52) and (53) describe the evolution of aggregate inflation and the aggregate real wage, respectively. The process for price dispersion is given by (54). Monetary policy is characterized by (55), which either follows the Taylor rule, inflation targeting, or nominal GDP targeting. Equations (56) and (57) are the stochastic processes for the productivity and preference shocks. Aggregate welfare obeys (58), while the expression for wage dispersion is given by (59). Given initial values of the state variables and current realizations of the innovations in the shock processes, an equilibrium consists of a non-explosive sequence of $\{C_t, i_t, \pi_t, \nu_t, w_t^\#, H_{1,t}, H_{2,t}, w_t, N_{d,t}, mc_t, A_t, \pi_t^\#, X_{1,t}, X_{2,t}, v_t^p, \mathbb{W}_t, v_t^w, Y_t\}$ such that equations (42)-(59) all hold.

A.1 Impulse Response Functions

Figure 4 presents the impulse response functions of several endogenous variables following a one standard deviation shock to aggregate productivity. In generating these responses we use the parameter values listed in Table 1, and assume that $\theta_w = \theta_p = 0.75$.

Panel 4a focuses on responses when policy is governed by a Taylor rule, NGDP targeting, or output gap targeting. After a productivity increase, output and the real wage rise and the inflation rate falls. For these variables, the dynamics are similar across all three policy rules. Output responds the least on impact under NGDP targeting and the most when policy is governed by the Taylor rule. The inflation response is most negative and most persistent under the Taylor rule compared to the other two rules. The reason that NGDP targeting outperforms inflation targeting conditional on this shock is because the approximate weight on inflation in the welfare loss function is significantly higher than the weight on the output gap.¹⁴ An interesting difference across the three policy rules centers on the behavior of the nominal interest rate. While the nominal rate drops under the Taylor rule and output gap

¹⁴See, for example, the discussion in Chapter 6 of Woodford (2003) for a derivation of the approximate quadratic loss function in the textbook model.

targeting, it is constant under nominal GDP targeting. The intuition for this comes from the Euler equation. The nominal GDP target forces inflation and output growth to move in opposite directions at equal magnitudes. Under log preferences, this implies the nominal interest rate stays fixed.

Panel 4b presents the responses when the central bank follows a strict inflation target. Following a positive productivity shock, the nominal rate must decrease significantly on impact to hold inflation constant. The large drop in nominal interest rates causes output to respond on impact significantly more than it would if prices and wages were both flexible. There is also a large increase in the aggregate real wage. With prices fixed, this necessitates a marked increase in nominal wage inflation. The increase in wage inflation is the main source of the large welfare costs of inflation targeting.

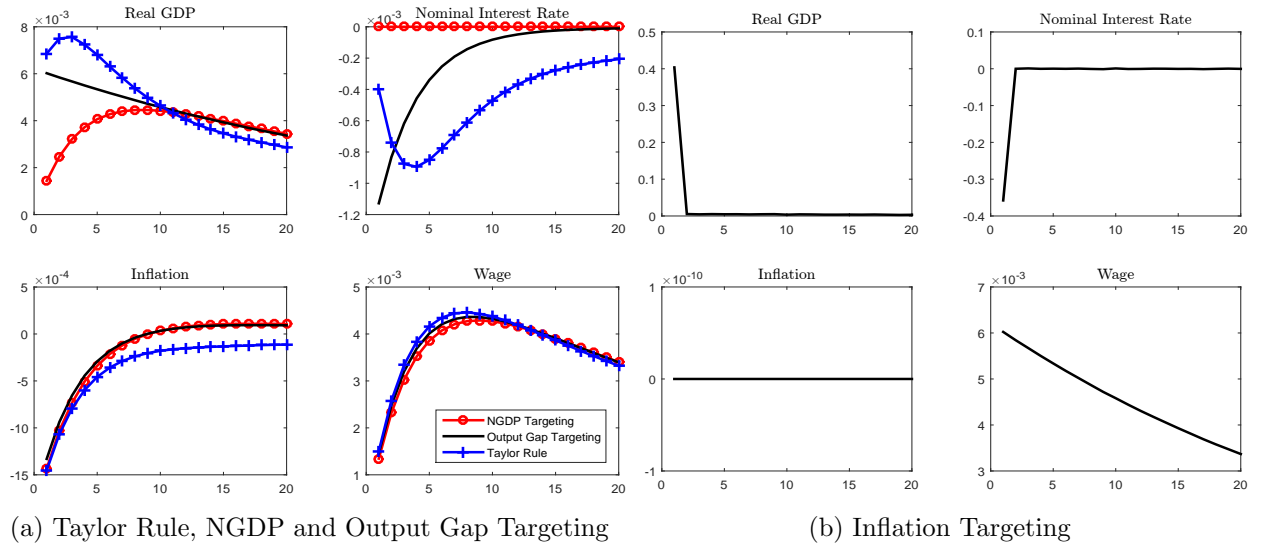


Figure 4: Impulse Response to a Productivity Shock

Notes: This Figure shows the response of some endogenous variables to a one standard deviation productivity shock. The scale in the vertical axis represents percentage deviations from the non-stochastic steady state.

B Medium Scale Model

The equations below characterize the equilibrium of the medium scale model described in Section 3.

$$\lambda_t = \frac{\nu_t}{C_t - bC_{t-1}} - \beta b E_t \frac{\nu_{t+1}}{C_{t+1} - bC_t} \quad (60)$$

$$\lambda_t = \beta E_t \lambda_{t+1} \frac{1 + i_t}{1 + \pi_{t+1}} \quad (61)$$

$$R_t = \gamma_1 + \gamma_2(u_t - 1) \quad (62)$$

$$\mu_t = \beta E_t \lambda_{t+1} \left[R_{t+1} u_{t+1} - \left(\gamma_1(u_{t+1} - 1) + \frac{\gamma_2}{2}(u_{t+1} - 1)^2 \right) \right] + \beta(1 - \delta) E_t \mu_{t+1} \quad (63)$$

$$\lambda_t = \mu_t Z_t \left[1 - \frac{\tau}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \tau \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta \tau E_t \mu_{t+1} Z_{t+1} \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \quad (64)$$

$$w_t^\# = \frac{\epsilon_w}{\epsilon_w - 1} \frac{H_{1,t}}{H_{2,t}} \quad (65)$$

$$H_{1,t} = \psi \nu_t \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w(1+\eta)} N_{d,t}^{1+\eta} + \theta_w \beta E_t \left(\frac{w_{t+1}^\#}{w_t^\#} \right)^{\epsilon_w(1+\eta)} (1 + \pi_t)^{-\zeta_w \epsilon_w(1+\eta)} (1 + \pi_{t+1})^{\epsilon_w(1+\eta)} H_{1,t+1} \quad (66)$$

$$H_{2,t} = \lambda_t \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w} N_{d,t} + \theta_w \beta E_t \left(\frac{w_{t+1}^\#}{w_t^\#} \right)^{\epsilon_w} (1 + \pi_t)^{\zeta_w(1-\epsilon_w)} (1 + \pi_{t+1})^{\epsilon_w - 1} H_{2,t+1} \quad (67)$$

$$\frac{u_t K_t}{N_{d,t}} = \frac{\alpha}{1 - \alpha} \frac{w_t}{R_t} \quad (68)$$

$$m c_t = \frac{w_t^{1-\alpha} R_t^\alpha}{A_t} (1 - \alpha)^{\alpha-1} \alpha^{-\alpha} \quad (69)$$

$$\frac{1 + \pi_t^\#}{1 + \pi_t} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{X_{1,t}}{X_{2,t}} \quad (70)$$

$$X_{1,t} = \lambda_t m c_t Y_t + \theta_p \beta E_t (1 + \pi_t)^{-\zeta_p \epsilon_p} (1 + \pi_{t+1})^{\epsilon_p} X_{1,t+1} \quad (71)$$

$$X_{2,t} = \lambda_t Y_t + \theta_p \beta E_t (1 + \pi_t)^{\zeta_p(1-\epsilon_p)} (1 + \pi_{t+1})^{\epsilon_p - 1} X_{2,t+1} \quad (72)$$

$$Y_t = C_t + I_t + G_t + \left[\gamma_1(u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2 \right] K_t \quad (73)$$

$$K_{t+1} = Z_t \left[1 - \frac{\tau}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t + (1 - \delta) K_t \quad (74)$$

$$Y_t = \frac{A_t (u_t K_t)^\alpha N_{d,t}^{1-\alpha} - F}{v_t^p} \quad (75)$$

$$(1 + \pi_t)^{1-\epsilon_p} = (1 - \theta_p) (1 + \pi_t^\#)^{1-\epsilon_p} + \theta_p (1 + \pi_{t-1})^{\zeta_p(1-\epsilon_p)} \quad (76)$$

$$w_t^{1-\epsilon_w} = (1 - \theta_w) w_t^\#{}^{1-\epsilon_w} + \theta_w (1 + \pi_t)^{\epsilon_w - 1} (1 + \pi_{t-1})^{\zeta_w(1-\epsilon_w)} w_{t-1}^{1-\epsilon_w} \quad (77)$$

$$v_t^p = (1 + \pi_t)^{\epsilon_p} \left[(1 - \theta_p) (1 + \pi_t^\#)^{-\epsilon_p} + \theta_p (1 + \pi_{t-1})^{-\epsilon_p \zeta_p} v_{t-1}^p \right] \quad (78)$$

$$\begin{aligned}
& \ln(1 + i_t) = (1 - \rho_i) \ln(1 + i^*) + \rho_i \ln(1 + i_{t-1}) + \phi_\pi \ln(1 + \pi_t) + \phi_x \ln X_t + \phi_y \ln\left(\frac{Y_t}{Y_{t-1}}\right) \\
\text{or} & \quad \quad \quad \pi_t = 0 \\
\text{or} & \quad \quad \quad \pi_t + \ln Y_t - \ln Y_{t-1} = 0 \\
\text{or} & \quad \quad \quad X_t = 1
\end{aligned} \tag{79}$$

$$\ln A_t = \rho_A \ln A_{t-1} + \sigma_A \varepsilon_{A,t} \tag{80}$$

$$\ln \nu_t = \rho_\nu \ln \nu_{t-1} + \sigma_\nu \varepsilon_{\nu,t} \tag{81}$$

$$\ln Z_t = \rho_Z \ln Z_{t-1} + \sigma_Z \varepsilon_{Z,t} \tag{82}$$

$$\ln G_t = (1 - \rho_G) \ln G^* + \rho_G \ln G_{t-1} + \sigma_G \varepsilon_{G,t} \tag{83}$$

$$\mathbb{W}_t = \nu_t \left[\ln(C_t - bC_{t-1}) - \psi v_t^w \frac{N_{d,t}^{1+\eta}}{1+\eta} \right] + \beta E_t \mathbb{W}_{t+1} \tag{84}$$

$$v_t^w = (1 - \theta_w) \left(\frac{w_t^\#}{w_t} \right)^{-\epsilon_w(1+\eta)} + \theta_w \left(\frac{w_t}{w_{t-1}} (1 + \pi_t) \right)^{\epsilon_w(1+\eta)} (1 + \pi_{t-1})^{-\zeta_w \epsilon_w(1+\eta)} v_{t-1}^w. \tag{85}$$

In these expressions λ_t is the Lagrange multiplier on the flow budget constraint of a household and μ_t is the multiplier on the capital accumulation equation. Equation (60) defines the marginal utility of income, while (61) is a standard Euler equation for bonds. The first order condition for capital utilization is given by (62). Equation (63) is the Euler equation for physical capital and (64) is the optimality condition for the choice of investment. Equations (65)-(67) describe optimal wage-setting. Expressions (68) and (69) come out of cost-minimization for firms and establish that all firms face the same real marginal cost and hire capital services and labor in the same ratio, equal to the aggregate ratio. Equations (70)-(72) describe optimal price-setting. The aggregate resource constraint is given by (73), the law of motion for physical capital by (74), and the aggregate production function by (75). Equations (76) and (77) describe the evolution of inflation and the real wage. The law of motion for price dispersion is (78). Monetary policy is characterized by one of the three rules in (79). The exogenous processes for productivity, the preference shock, the investment shock, and government spending are given by (80)-(83). Aggregate welfare is given by (84) and the process for wage dispersion is (85). Given initial values of the state variables and current realizations of the innovations in the shock processes, an equilibrium consists of a non-explosive sequence of $\{\lambda_t, \nu_t, C_t, i_t, \pi_t, R_t, u_t, \mu_t, Z_t, I_t, w_t^\#, H_{1,t}, H_{2,t}, w_t, N_{d,t}, K_t, mc_t, \pi_t^\#, X_{1,t}, X_{2,t}, G_t, A_t, v_t^p, \mathbb{W}_t, v_t^w, Y_t\}$ such that equations (60)–(85) all hold.

C Parameter Robustness

Table 12 shows compensating variations associated with different policy rules in the medium scale model when all parameter values are set at the 10th percentile of the posterior distribution. The 10th percentiles of the posterior distribution of the parameters are shown in Table 6.

Table 12: Consumption Equivalent Welfare Losses from Different Policy Rules
Medium Scale Model, Parameter Robustness

	Estimated Model	10th Percentile, All Parameters	90th Percentile, All Parameters
NGDP	0.1056	0.0424	0.7731
Inflation	0.8630	0.2865	7.3909
Output Gap	0.0343	0.0115	0.1777
Taylor Rule	0.2439	0.0838	2.0121

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model when all parameters are set to the 10th percentile of the posterior distribution. When evaluating the compensating variation for the Taylor rule the standard deviation of the monetary policy shock is set to zero. The other columns describe values of the price or wage rigidity parameters. For the exercises described in these columns all other parameters are fixed at their calibrated or estimated values.

Table 13 shows compensating variations associated with different policy rules in the medium scale model when parameters are set at the 10th percentile of the posterior distribution one at a time. For this exercise only the listed parameter is set at the 10th percentile of its posterior distribution; all non-listed parameters are set at the mode of the posterior. Because the parameters of the estimated Taylor rule are irrelevant for the compensating variations associated with the different targeting rules, the compensating variations are listed as “n/a” in this portions of the table.

Table 13: Consumption Equivalent Welfare Losses from Different Policy Rules, 10th Percentiles of Parameters Medium Scale Model

	NGDP	Inflation	Output Gap	Taylor rule
$b = 0.6634$	0.0981	0.7458	0.0329	0.2452
$\tau = 3.6661$	0.1084	0.8432	0.0343	0.255
$\chi = 1.3075$	0.1077	0.7940	0.0348	0.2101
$\gamma_2 = 0.2372$	0.1056	0.9000	0.0342	0.2426
$\theta_p = 0.6008$	0.1012	0.863	0.0319	0.2386
$\theta_w = 0.6517$	0.1126	0.7395	0.0332	0.1587
$\zeta_p = 0.1982$	0.1107	0.8630	0.0398	0.2507
$\zeta_w = 0.3610$	0.0920	0.8630	0.0275	0.2618
$\rho_i = 0.8470$	n/a	n/a	n/a	0.2980
$\phi_\pi = 0.3747$	n/a	n/a	n/a	0.2653
$\phi_x = 0.0000$	n/a	n/a	n/a	0.2439
$\phi_y = 0.1036$	n/a	n/a	n/a	0.2591
$\rho_A = 0.7506$	0.0886	0.7350	0.0249	0.2137
$\rho_\nu = 0.4885$	0.1018	0.8575	0.0340	0.2327
$\rho_Z = 0.5840$	0.0897	0.8388	0.0329	0.1793
$\rho_G = 0.9267$	0.1046	0.8624	0.0343	0.2438
$\sigma_A = 0.0046$	0.0814	0.4887	0.0198	0.2107
$\sigma_\nu = 0.0128$	0.1032	0.8589	0.0341	0.2299
$\sigma_Z = 0.0330$	0.0928	0.8443	0.0334	0.2031
$\sigma_G = 0.0087$	0.1047	0.8622	0.0343	0.2437

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model when each parameter is set at the 10th percentile of its post distribution holding all other parameters fixed at the mode of the posterior.

Table 14 shows compensating variations associated with different policy rules in the medium scale model when parameters are set at the 90th percentile of the posterior distribution one at a time. For this exercise only the listed parameter is set at the 90th percentile of its posterior distribution; all non-listed parameters are set at the mode of the posterior. Because the parameters of the estimated Taylor rule are irrelevant for the compensating variations associated with the different targeting rules, the compensating variations are listed as “n/a” in this portions of the table.

Table 14: Consumption Equivalent Welfare Losses from
Different Policy Rules, 90th Percentiles of Parameters
Medium Scale Model

	NGDP	Inflation	Output Gap	Taylor rule
$b = 0.8759$	0.1250	1.0646	0.0373	0.2484
$\tau = 4.3288$	0.1025	0.8861	0.0343	0.2322
$\eta = 1.9141$	0.1048	0.9274	0.0339	0.2754
$\gamma_2 = 0.6042$	0.1056	0.8400	0.0344	0.2447
$\theta_p = 0.7659$	0.1136	0.8630	0.036	0.2544
$\theta_w = 0.9054$	0.1140	1.3226	0.0347	0.5346
$\zeta_p = 0.4783$	0.1008	0.8630	0.0281	0.2368
$\zeta_w = 0.6990$	0.1346	0.8630	0.0476	0.2384
$\rho_i = 0.9100$	n/a	n/a	n/a	0.2080
$\phi_\pi = 0.5330$	n/a	n/a	n/a	0.2292
$\phi_x = 0.0000$	n/a	n/a	n/a	0.2439
$\phi_y = 0.1971$	n/a	n/a	n/a	0.2291
$\rho_A = 0.9125$	0.1317	1.0937	0.0458	0.3196
$\rho_\nu = 0.8276$	0.1153	0.8755	0.0351	0.2576
$\rho_Z = 0.7708$	0.1346	0.9103	0.0371	0.3628
$\rho_G = 0.9706$	0.1073	0.8636	0.0343	0.2442
$\sigma_A = 0.0100$	0.1792	2.0089	0.0784	0.3448
$\sigma_\nu = 0.0282$	0.1124	0.8746	0.0349	0.2842
$\sigma_Z = 0.0468$	0.1260	0.8929	0.0358	0.3091
$\sigma_G = 0.0113$	0.1070	0.8643	0.0344	0.2442

Notes: The table contains the compensating variations of three different targeting rules as well as a Taylor rule in the medium scale model when each parameter is set at the 10th percentile of its post distribution holding all other parameters fixed at the mode of the posterior.