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Abstract

We investigate the optimality of monetary policy targeting rules in a macroeconomic model based on explicit micro-foundations for intrinsic persistence in inflation and real output. For the corresponding social welfare loss function to be minimized by the central bank, inertia arises endogenously in both the inflation and output gap stabilization objectives. In this framework, inflation targeting closely approximates the optimal precommitment policy for empirically relevant parameter values. Alternative policy rules, such as nominal income growth targeting, "speed-limit" targeting, or price level targeting, do not perform as well. Previous research has demonstrated lower social welfare losses with these alternative targeting rules; such findings are shown to be primarily a consequence of assuming the central bank minimizes a simple social loss function that is not consistent with the micro-foundations of a model with intrinsic persistence.

JEL Categories: E52, E58.

Keywords: Habit formation, inflation persistence, targeting rules, time consistency, institutional design of monetary policy.

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1 Introduction

A number of central banks have implemented some form of inflation targeting over the past few decades, and an extensive amount of research has investigated this approach to monetary policy. Goodfriend and King (1997) and Clarida et al. (1999) develop formal support for inflation targeting in dynamic stochastic general equilibrium (DSGE) models that feature nominal rigidities. The subsequent literature that investigates optimal monetary policy in such a "New Keynesian" or "New Neo-Classical Synthesis" paradigm is vast; Woodford (2003) provides an extensive exposition.

Recently in this journal, Jensen (2002) and Walsh (2003) have challenged the desirability of inflation targeting (hereafter "IT") in a discretionary policy environment. When the effectiveness of policy depends on agents' expectations about future macroeconomic aggregates, such as inflation, the inability of monetary policy makers to completely and credibly precommit to future policy actions creates a time-inconsistency problem. Jensen (2002) and Walsh (2003) propose targeting rules that create intertemporal linkages in a discretionary environment, such as nominal income growth targeting or price-level targeting, as a means to mitigate this "stabilization bias."[1]

Jensen (2002) and Walsh (2003) simulate the relative performance of IT versus these alternative targeting rules in a simplified macroeconomic model that entails an important departure from the standard micro-founded approach mentioned above: both inflation and the output gap are assumed to be functions of their own lagged values as well as expected future values. For empirical plausible degrees of inflation persistence, these authors document that the stabilization bias problem is exacerbated, further driving a wedge between the performance of IT and the alternative targeting rules they investigate.

Jensen (2002) and Walsh (2003) introduced persistence into their modeling framework in a fairly *ad hoc* manner. Recent theoretical work has provided more explicit microeconomic foundations that make these persistence terms an intrinsic part of the model. For example, Fuhrer (2000) incorporates habit formation in consumption to generate persistence in real output, while Steinsson (2003) shows how allowing a proportion of firms to index their prices to past averages can yield a "hybrid" Phillips curve. Smets and Wouters (2003) and Christiano et al. (2005) have integrated these sources of persistence into more extensive general equilibrium macroeconomic models. In section 2, we summarize a small, micro-

[1] For additional perspectives on stabilization bias, see Dennis and Söderström (2002) and McCallum and Nelson (2004). Notice that this source of bias is distinct from the "average inflation bias" studied by Barro and Gordon (1983), which is not present in the models examined herein.

founded "New Keynesian" model with intrinsic persistence that closely resembles the approaches of Giannoni and Woodford (2003), Woodford (2003), and Amato and Laubach (2004).

These authors have shown that the microeconomic behavioral assumptions that yield intrinsic persistence in the dynamics of inflation and the output gap (derived from the log-linearized first-order conditions describing optimal behavior by the representative household) also impact the second-order approximation to the welfare of the representative agent. That is, the popular quadratic loss function in inflation and the output gap — which has been utilized by Jensen (2002) and Walsh (2003), as well as numerous other researchers — is not appropriate for a model with persistent dynamics in either variable. Recently, Walsh (2005) has studied how inflation persistence affects the derivation of the second-order approximation to the social welfare function.[2] In our model, the appropriate social loss function features "endogenous inertia," in which quasi-differences in inflation and the output gap appear in the loss function, with the relative importance of these lagged terms increasing in the structural parameters that generate intrinsic persistence. In section 3 we explore the differences between the common quadratic social loss function and the specification consistent with intrinsic persistence in the model.

Given this coherence between the model dynamics and the loss function, in section 4 we simulate the consequences of different targeting rules under discretion. Two important and novel results emerge from that investigation. First, variation in the degree of habit formation plays a particularly important role, as it affects the dynamics for inflation and the relative importance of the output gap stabilization objective in the social loss function. Second, we find that inflation targeting often comes closest to the precommitment ideal, once the model is calibrated to plausible degrees of persistence. The apparent superiority of the alternative targeting rules that has been cited elsewhere in the literature can be traced to the use of a simple, but model-inconsistent, specification of the loss function. Section 5 concludes.

2 Model Specification

Below we briefly outline the key dynamic equations that result from a micro-founded "New Keynesian" model that features intrinsic persistence. Appendix A further develops the model specification. For simplicity, the economy is assumed to be closed, and there is no capital accumulation. The representative household derives utility from an aggregate consumption good that is composed of differentiated inter-

[2] Walsh (2005) does not investigate the consequences of using a micro-founded social loss function for the success of various targeting rules in mitigating stabilization bias under discretion, which is the focus of this paper.

mediate goods, each produced by a monopolistically competitive firm that is owned by the household.

The household chooses its consumption and labor supply to maximize the present discounted value of utility. Let γ and $-\eta$ be isoelastic utility parameters for consumption and labor supply, respectively. The parameter $h \in [0,1]$ measures the degree of habit persistence in consumption; $h = 0$ returns a more standard time-separable specification in which only the current value of household consumption enters into each period's utility.[3] Log-linearizing the first-order conditions for the household's problem yields a variation of an Euler equation for consumption. In the presence of habit formation, lagged as well as expected future consumption appear in the Euler equation.

Assuming exogenous stochastic processes for government spending and for productivity allows the Euler equation to be re-written as an aggregate demand relationship in terms of the (log) real output gap, $x_t = y_t - y_t^n$:

$$x_t = \theta_{-1} x_{t-1} + \theta_{+1} \mathrm{E}_t x_{t+1} - \theta_{+2} \mathrm{E}_t x_{t+2} - \widetilde{\sigma}(i_t - \mathrm{E}_t \pi_{t+1} - r_t^n), \tag{1}$$

where i_t is the nominal interest rate (the policy instrument of the central bank), $\mathrm{E}_t \pi_{t+1}$ is the expectation of next period's inflation rate, and r_t^n is the natural or "Wicksellian" real rate of interest, defined as:

$$r_t^n = \widetilde{\gamma}\left(\mathrm{E}_t \widetilde{y}_{t+1}^n - \widetilde{y}_t^n + \mathrm{E}_t \widetilde{g}_{t+1} - \widetilde{g}_t\right). \tag{2}$$

$\widetilde{y}_t^n$ and $\widetilde{g}_t$ are transformations of the (log) natural level of output and the exogenous fiscal policy innovation, respectively, and $\widetilde{\gamma} = \gamma/(1-\beta h)$. (See appendix A for details.)

The coefficients on the output gap terms on the right-hand side of equation (1) are reduced-form functions of the structural parameters h, the degree of habit formation, and β, the discount factor. $\widetilde{\sigma}$ is a generalized representation of the intertemporal elasticity of substitution that is decreasing in h. Recall that $h = 0$ produces a standard forward-looking AD (or IS) relationship; in this case both θ_{-1} and θ_{+2} are zero, $\theta_{+1} = 1$, and $\widetilde{\sigma} = \gamma^{-1}$.

On the aggregate supply side, firms are monopolistically competitive price setters for their differentiated products. We assume Calvo-type nominal price rigidity with α being the probability that a firm does not adjust its price in a given period. We augment this specification by assuming that a proportion ω of firms who do not adjust in a period index their prices to the aggregate price level. This additional

[3] Consistent with Fuhrer (2000), Giannoni and Woodford (2003), and Amato and Laubach (2004), similar approaches, we incorporate "internal" habit formation into our model in appendix A to generate persistence in aggregate consumption and output. Dennis (2004) finds small empirical differences between "internal" and "external" specifications of habit formation.

assumption yields persistence in the New-Keynesian Phillips Curve via a lagged inflation term:

$$\pi_t = \phi_{-1}\,\pi_{t-1} + \phi_{+1}\,\mathrm{E}_t\pi_{t+1} + \widetilde{\kappa}\,x_t - \widetilde{\kappa}_{-1}\,x_{t-1} - \widetilde{\kappa}_{+1}\,\mathrm{E}_t x_{t+1} + \mu_t\,. \tag{3}$$

In the absence of price indexation by firms, ω would be zero and the coefficient on lagged inflation, ϕ_{-1}, would be zero as well, while the coefficient on next period's expected inflation, ϕ_{+1}, would be β.

The lack of inflation persistence when $\omega = 0$, however, does not reproduce the standard New-Keynesian Phillips Curve: the presence of habit formation in consumption impacts the labor supply decisions of the representative household, which therefore has an impact on production and price setting behavior of firms in equilibrium. One important consequence of incorporating habit formation is the introduction of the lag and expected lead of the output gap into the above aggregate supply relationship. Each of $\widetilde{\kappa}$, $\widetilde{\kappa}_{-1}$, and $\widetilde{\kappa}_{+1}$ are positive and increasing in h, heightening the volatility of inflation for any exogenous shock to the model, all else equal. However, the cumulative output gap elasticity for inflation (that is, the sum of the $\widetilde{\kappa}$ terms) is declining in h. Only in the special case of intrinsic persistence in neither output nor inflation does equation (3) reduce to a canonical forward-looking New-Keynesian Phillips Curve.

Equations (1) and (3) above each differ in important ways from an *ad hoc* specification of persistence, such as the models used by Jensen (2002) and Walsh (2003). The stylized aggregate demand (or IS) equation with *ad hoc* persistence takes the form:

$$x_t = \theta\,x_{t-1} + (1-\theta)\,\mathrm{E}_t x_{t+1} - \sigma\,(i_t - E_t\pi_{t+1}) + u_t\,, \tag{4}$$

in which θ governs the degree of persistence in the output gap; $\theta = 0$ corresponds with a forward-looking IS equation that can be derived from the Euler equation for aggregate consumption in a micro-founded model. Similarly, the aggregate supply (or Phillips Curve) equations typically have a "hybrid" form:

$$\pi_t = \phi\,\pi_{t-1} + (1-\phi)\,\beta\,\mathrm{E}_t\pi_{t+1} + \kappa\,x_t + e_t\,, \tag{5}$$

where ϕ measures the degree of intrinsic persistence in inflation; $\phi = 0$ returns the standard New Keynesian Phillips Curve that can be derived, for example, from a Calvo model of price setting. Both u_t and e_t are assumed to follow exogenous stationary AR(1) processes.

Deriving intrinsic persistence in the output gap from habit formation in consumption affects both aggregate demand and aggregate supply in the micro-founded model. The micro-founded aggregate demand specification of equation (1) features different dynamics and a more complex innovation process than equation (4). (See appendix A for details.) But the important difference is in the specification of aggregate supply. In the above *ad hoc* model specification, variation in the degree of persistence in equation (4) has no effect on equation (5). In the micro-founded model, on the other hand, habit formation directly impacts the aggregate supply relationship in equation (3), as noted above. It also influences the nature of the social loss function as well, as we discuss in the next section. Thus, monetary policy is affected in important ways by variation in intrinsic persistence in output, due to variation in the degree of habit persistence. Such a relationship does not occur with the *ad hoc* model: Jensen (2002), for example, emphasizes that variation in θ is irrelevant for determining optimal monetary policy.[4]

3 Loss Functions and Policy Regimes

As Giannoni and Woodford (2003) have shown (see also Amato and Laubach, 2004), intrinsic persistence in a macroeconomic model of the form described in the previous section leads to lagged values of inflation and the output gap appearing in the social loss function: policy is inherently inertial.[5] In particular, the second-order approximation to the social loss function in appendix A takes the form:

$$\mathscr{L} = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[(\pi_t - \omega \pi_{t-1})^2 + \widetilde{\lambda} (x_t - \delta x_{t-1})^2 \right] , \tag{6}$$

where δ measures the contribution of lagged output to the loss function, and $\widetilde{\lambda}$ is the relative weight on the quasi-differenced output gap term vis-à-vis a similar quasi-differenced term for inflation. The larger the degree of habit formation, h, the greater the relative weight on the quasi-differenced output gap term, $\widetilde{\lambda}$, and the more prominent the lag of the output gap, δ, in equation (6). On the other hand, variation in the degree of price indexation only affects the weight on the lagged inflation term: $\widetilde{\lambda}$ is independent of ω, as in Walsh (2005).

[4] The micro-founded model of Walsh (2005) yields a similar result, as only inflation is modeled as persistent.

[5] Amato and Laubach (2003) analyze similar models that feature either rule-of-thumb price setting behavior by firms, or rule-of-thumb consumption choices by households — thereby inducing persistence in either the AS or AD equation, respectively — and show that lagged values of the variable determined by the rule-of-thumb behavior appear in the social loss function.

In contrast, many authors presume the central bank minimizes a loss function of the form:

$$\mathscr{L}^S = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\pi_t^2 + \lambda x_t^2 \right], \tag{7}$$

subject to the dynamic constraints imposed by equations (4) and (5). However, as documented in Woodford (2003), this loss function is only consistent with a model that lacks any persistence.[6] That is, equation (7) is only the appropriate second-order approximation to social welfare when $\theta = 0$ in equation (4) and $\phi = 0$ in equation (5). This mismatch between the specification of the model and of the loss function has implications for the performance of the various targeting rules studied by Jensen (2002) and Walsh (2003), who presume $\lambda = 0.25$ in their baseline specifications. These authors conduct simulations in which the parameters of the model are varied while those of the loss function are held fixed, and vice versa; their approaches do not recognize the relationship between the model equations and loss function parameters. In section 4 we investigate the consequences of using a model-consistent loss function versus the simple quadratic loss of equation (7).

3.1 Optimal Policy: Discretion vs. Precommitment

Optimal monetary policy under precommitment can be characterized by the first-order conditions that result from minimizing the objective function in equation (6) subject to the Phillips curve in equation (3):

$$2(\pi_t - \omega \pi_{t-1}) - 2\beta\omega(\mathrm{E}_t \pi_{t+1} - \omega \pi_t) - \ell_t + \beta \phi_{-1} \mathrm{E}_t \ell_{t+1} + \beta^{-1} \phi_{+1} \ell_{t-1} = 0 \tag{8}$$

$$2\widetilde{\lambda}(x_t - \delta x_{t-1}) - 2\beta\widetilde{\lambda}\delta(\mathrm{E}_t x_{t+1} - \delta x_t) + \widetilde{\kappa}\ell_t - \beta\widetilde{\kappa}_{-1} \mathrm{E}_t \ell_{t+1} - \beta^{-1}\widetilde{\kappa}_{+1} \ell_{t-1} = 0 \tag{9}$$

where ℓ_t is the Lagrange multiplier associated with the Phillips Curve constraint. Notice that in the absence of endogenous persistence the optimal precommitment policy still would be inertial: ℓ_{t-1} is a consequence of the central bank taking into account the agents' (rational) expectations of future variables under a credible precommitment policy.

On the other hand, the optimal policy under discretion is a simpler "leaning against the wind" rule. In the absence of any intrinsic persistence (i.e. with $h = \omega = 0$), the optimal discretionary policy solution lacks any inertial terms.[7] In the microfounded model of section 2, however, optimal discretionary policy

[6] In the absence of any intrinsic persistence (i.e., $h = \omega = 0$), the loss function in equation (6) reduces to that in equation (7).
[7] That is, the discretionary policy solution of Clarida et al. (1999) is obtained when $h = \omega = 0$.

has the form:

$$(\pi_t - \omega\,\pi_{t-1}) = -\frac{\widetilde{\lambda}}{\widetilde{\kappa}}(x_t - \delta\,x_{t-1})\,, \tag{10}$$

in which inertial components of policy arise endogenously from the micro-founded model. The derivations in appendix A reveal that $\widetilde{\lambda}/\widetilde{\kappa}$ is decreasing in h but increasing in ω. The fact that inertia arises endogenously in both the precommitment and discretionary policy solutions as a result of intrinsic persistence plays an important role for the relative desirability of the various targeting rules we consider.

3.2 Simple Targeting Rules

Rogoff (1985) was among the first in this literature to establish that having the central bank minimize an objective other than the social loss function could improve economic outcomes. In the presence of average inflation bias from discretionary policy, per Barro and Gordon (1983), a "conservative" central bank could more closely approach the ideal precommitment policy by placing lower weight on the output stabilization objective than society's preferences would suggest. Although discretionary policy in the model considered here does not exhibit average inflation bias, stabilization bias is a potentially important issue.[8] Jensen (2002) shows that while a "conservative" inflation-targeting central bank can mitigate some of the loss in social welfare due to stabilization bias under discretion, an inertial policy such as nominal income growth targeting can perform better for moderate degrees of inflation persistence.[9] Walsh (2003) shows that for "empirically relevant" degrees of inflation persistence, speed limit targeting or price level targeting can do even better in terms of minimizing the social loss in equation (7).

These various targeting rules are summarized in table 1, using the same notation as Walsh (2003).[10] Notice that only inflation targeting is not inertial in the sense of involving lags of real output or the output gap.[11] Based on analyses using a simple quadratic loss function combined with the *ad hoc* specification of persistence in equations (4) and (5), both Jensen (2002) and Walsh (2003) demonstrate that the last three targeting regimes listed in table 1 outperform pure discretionary policy and "optimal" inflation targeting regimes.

[8] Using the simple quadratic loss function of equation (7), McCallum and Nelson (2004) find stabilization bias yields quantitatively significant welfare costs for a purely discretionary policy relative to a "timeless-perspective" one.

[9] A "conservative" central banker is willing to respond to a positive cost-push shock with a deeper recession, thereby stabilizing inflation — and inflation expectations — relative to the pure discretionary case.

[10] The relationship between targeting rules and instrument rules is beyond the scope of this paper. Clarida et al. (1999) and Woodford (2003) show how instrument rules can be derived from targeting rules. McCallum and Nelson (2004) describe how targeting rules can be nested within instrument rules.

[11] Differencing the price level targeting rule reveals its inertial nature.

Table 1: Categorization of Targeting Regimes

Regime		Loss Function	Implied Rule
Inflation Targeting	IT	$\pi_t^2 + \lambda_{IT} x_t^2$	$\pi_t = -\frac{\lambda_{IT}}{\widetilde{\kappa}} x_t$
Nominal Income Growth Targeting	NIGT	$\pi_t^2 + \lambda_{NIGT}(\pi_t + y_t - y_{t-1})^2$	$\pi_t = -\frac{\lambda_{NIGT}(1+\widetilde{\kappa})}{\widetilde{\kappa}(1+\lambda_{NIGT})+\lambda_{NIGT}}(y_t - y_{t-1})$
Speed Limit Targeting	SLT	$\pi_t^2 + \lambda_{SLT}(x_t - x_{t-1})^2$	$\pi_t = -\frac{\lambda_{SLT}}{\widetilde{\kappa}}(x_t - x_{t-1})$
Price Level Targeting	PLT	$p_t^2 + \lambda_{PLT} x_t^2$	$p_t = -\frac{(1+\beta)\lambda_{PLT}}{\widetilde{\kappa}} x_t$

These findings reflect the fact that the optimal precommitment policy takes into account the effects on inflation expectations of a (credible) commitment to a future time path for monetary policy. That is, even in the absence of any inertia in the dynamic equations for inflation or the output gap, the first-order condition for optimal precommitment involves the difference in the output gap and not just its current value, as demonstrated in Clarida et al. (1999). Thus the first-order condition for precommitment in a non-inertial model has exactly the same form as the first-order condition that yields the implied policy rule for speed-limit targeting (and the first difference of the implied rule for price-level targeting) in the final column of table 1. In contrast with the policy rule under IT, these inertial targeting rules imply discretionary policy rules that resemble the precommitment ideal, which is why they mitigate the stabilization bias problem.

In the presence of intrinsic persistence, additional inertial terms arise in the precommitment solution, as seen in equations (8) and (9). These terms appear because of the corresponding inertia in the model-consistent social loss function. In the next section we simulate the various policy rules in this environment, and study how variation in the degree of intrinsic persistence affects the relative desirability of the targeting rules listed in table 1. Recall that the model-consistent loss function in equation (6) only reduces to the simple quadratic form in equation (7) if $h = \omega = 0$ — that is, if there is no persistence in the micro-founded model.

4 Simulation Results

Optimal policy is determined by minimizing the social loss function subject to the constraints imposed by equations (1) and (3). Given the calibrated parameter values, numerical simulations are used to determine the optimal value of λ_{TR}, where $TR = \{IT, NIGT, SLT, PLT\}$ stands for each of the targeting rules listed in table 1 above. The corresponding social loss under each optimal policy also is computed. Simulations were conducted using the solution technique of Dennis (2003), which is outlined in appendix B. Initially we choose values for the structural parameters by examining the existing research using similar micro-founded models. We conclude this section with an alternative calibration that more closely matches the reduced-form specification of equations (4) and (5) used by Jensen (2002) and Walsh (2003).

4.1 Baseline Calibration

Our baseline parameter values are summarized in table 2. Macroeconomic evidence on the degree of habit formation in U.S. data generally yields values of h close to the upper limit of one: Fuhrer (2000) estimates values between 0.8 and 0.9; Bouakez et al. (2005) estimate h to be 0.982. Dennis (2004) surveys the literature and finds estimates of h between 0.54 and 1, while his own estimates on U.S. data are just below our baseline assumption of 0.9. This value also lies midway between Amato and Laubach (2004), who adopt Fuhrer's (2000) estimate of $h = 0.8$, and Giannoni and Woodford (2003), who assume $h = 1$.

Estimates of the elasticity parameters for household utility, γ and η, are more diffuse. Fuhrer (2000) estimates γ to be roughly between 6 and 13 for quarterly consumption data in a model that does not include labor supply; Dennis (2004) estimates even larger values. On the other hand, Giannoni and Woodford (2003) assume a value of γ of 0.16, based on Rotemberg and Woodford (1997). Part of the difference may be due to a lower interest sensitivity of aggregate output than of non-durable consumption. Bouakez et al. (2005) assume $\gamma = 2$ as they are unable to get tight estimates of that parameter in their maximum likelihood framework; they suggest that values between 0.5 and 5 are plausible. We follow Amato and Laubach (2004) and set our baseline value of γ to 1.1.

These values of h and γ yield a value for $\widetilde{\sigma}$, the intertemporal elasticity of substitution, that is much lower than the 1.5 posited by Jensen (2002) and used in Walsh (2003). (We investigate this difference further below.) Lower values of either parameter would lead to a larger value for $\widetilde{\sigma}$, although our implied value of 0.037 is broadly consistent with estimates on U.S. data by Yogo (2004) and slightly higher than those reported by Cho and Moreno (2005).

We set the value of η, the Frisch labor supply elasticity, to 0.8 per Dennis (2004), who in turn cites estimates from Smets and Wouters (2003). Amato and Laubach (2004) assume $\eta = 0.6$. Notice that η affects the model simulations in three ways: it mediates the impact of technology and aggregate demand shocks

Table 2: Baseline Calibration

Structural Parameters						
β	h	γ	η	α	ω	ε
0.99	0.9	1.1	0.8	0.75	0.8	8
Implied Parameters						
	θ_{-1}	θ_{+1}	θ_{+2}	$\widetilde{\sigma}$		
	0.333	0.997	0.330	0.037		
	ϕ_{-1}	ϕ_{+1}	$\widetilde{\kappa}$	$\widetilde{\kappa}_{-1}$	$\widetilde{\kappa}_{+1}$	
	0.446	0.553	0.909	0.435	0.431	
Exogenous Shock Processes						
ρ_g	σ_g	ρ_z	σ_z	ρ_μ	σ_μ	
0.3	0.015	0.97	0.005	0	0.015	

on the natural level of output (equation 2), it influences the slope of the Phillips curve (equation 3), and it affects the relative weight of the output gap in the social loss function (equation 6).

On the aggregate supply side, the value of ω, the fraction of firms that index their prices to the aggregate price level, determines the relative weights given to lagged inflation, ϕ_{-1}, and expected future inflation, ϕ_{+1}, in equation (3). While Giannoni and Woodford (2003) assume that $\omega = 1$ in their simulations, estimates of ω are generally lower: Rabanal and Rubio-Ramírez (2005) use Bayesian methods to estimate $\omega = 0.77$ — close to our baseline assumption of 0.8. Cho and Moreno (2005) report FIML estimates of ϕ_{+1} that are very close to our implied value of 0.553 when $\omega = 0.8$. Not all authors find strong evidence of persistence in inflation: Galí and Gertler (1999) report GMM estimates of ω between 0.077 and 0.522, depending on the empirical specification. Below we investigate the sensitivity of our findings to variation in ω.

Dennis (2004) estimates the rate of non-adjustment of prices in a Calvo framework to be about 0.78; he also notes that estimates of α tend to range between 0.63 and 0.92. A common assumption in the literature is for prices to be fixed for roughly a year on average; in a Calvo model of price setting, this degree of stickiness would suggest $\alpha = 0.75$ at a quarterly frequency. It is worth noting that evidence on the degree of price stickiness at the firm or product level is more diffuse.

The final structural parameter listed in table 2 is ε, the elasticity of substitution between varieties in the Dixit-Stiglitz aggregator for production. While ε does not play a direct role in the dynamics of aggregate demand or aggregate supply, it does influence $\widetilde{\lambda}$, the relative weight given to the output gap terms in the inertial social loss function of equation (6). Our choice of $\varepsilon = 8$ implies an equilibrium markup for the monopolistically competitive firms to be approximately 15%, which coincides with the implied value of Giannoni and Woodford (2003).

Lastly, the autoregressive parameters and the standard deviations of the exogenous shock processes are taken from Jensen (2002) and Walsh (2003), in order to facilitate comparisons. Most significantly, the cost-push shock, which is the source of a trade-off for the stabilization objectives of monetary policymakers, is assumed to be serially uncorrelated. Thus, any persistence in the macroeconomic variables following a cost-push shock is due to propagation through the intrinsic persistence channels of habit formation and staggered price setting with indexation.

4.2 Baseline Results

Table 3 reports the simulated results for the baseline parameter values, under the assumption that for each policy regime specification, the central bank minimizes the social loss function in equation (6). The first column of results, labeled PC, reports the simulation results under the assumption that the central bank were capable of fully credible precommitment. In the presence of cost-push shocks to equation (3), even a credible precommitment policy cannot completely stabilize inflation and the output gap. As it does not suffer from stabilization bias, the precommitment result forms the basis for comparison across the various discretionary targeting regimes. The second column of results, labeled PD, reports the simulation results for the "pure discretionary" policy; that is, if the social loss function also served to prescribe the policy rule for the central bank. The remaining columns correspond with the optimal (i.e. loss minimizing) policies for each targeting regime listed in table 1.

The second row of table 3 lists the "premium" resulting from stabilization bias for the discretionary policies we examine, relative to the social loss achieved under this precommitment ideal. In the third row we report the value of λ_{TR} that minimizes this inertial social loss of equation (6), for each of the targeting regimes listed in table 2. The final two rows of table 3 list the standard deviations of inflation (π_t) and the output gap (x_t) that correspond to each policy regime.

In contrast with the results of both Jensen (2002) and Walsh (2003), inflation targeting is the best discretionary policy regime in our baseline simulations, in that it comes closest to achieving the precommitment value. Surprisingly, the pure discretionary policy is the next best. Speed limit and price level

Table 3: Baseline Calibration, Inertial social loss function

		Discretionary Policy Regime				
	PC	PD	IT	NIGT	SLT	PLT
Social Loss	0.7407	0.7520	0.7470	0.7951	0.7623	0.7660
% loss relative to precommitment	—	1.53	0.85	7.34	2.92	3.42
Optimal λ_{TR}	—	—	0.10	0.02	0.07	0.15
St. Dev. (π_t)	0.3505	0.4710	0.4259	0.1490	0.2105	0.2123
St. Dev. (x_t)	3.3627	3.3219	3.3238	3.6221	3.5372	3.5651

Social loss is multiplied by 100. Standard deviations are in percentages. For this loss function, $\omega = 0.8$, $\widetilde{\lambda} = 0.1330$, and $\delta = 0.7327$.

Table 4: Baseline Calibration, Simple social loss function

		Discretionary Policy Regime				
	PC	PD	IT	NIGT	SLT	PLT
Perceived Loss	2.6729	2.8591	2.7933	3.0878	2.8372	2.9192
% loss relative to precommitment	—	6.97	4.50	15.52	6.15	9.21
Optimal λ_{TR}	—	—	0.18	0.11	0.34	1.01
Actual Loss	0.8683	0.8725	0.7831	1.0322	1.1079	1.0510
% loss relative to precommitment	—	0.48	−9.81	18.88	27.59	21.04
St. Dev. (π_t)	0.7422	0.9288	0.6942	0.5100	0.7055	0.7070
St. Dev. (x_t)	2.9551	2.8710	3.0814	3.4053	3.1017	3.1570

Loss values are multiplied by 100. Standard deviations are in percentages. For the "perceived" loss function, $\lambda = 0.25$. For the "actual" loss function, $\omega = 0.8$, $\widetilde{\lambda} = 0.1330$, and $\delta = 0.7327$.

targeting rank third and fourth, respectively, although the premium over the precommitment outcome of these two targeting rules is substantially greater than that of the inflation targeting regime. Nominal income growth targeting performs noticeably worse than the other policy regimes. Interestingly, table 3 suggests that for the parameterized loss function in equation (6), all three of these targeting regimes are too aggressive in stabilizing inflation, at the cost of greater volatility in the output gap.

In table 4, we simulate the consequences of the central bank incorrectly perceiving the social loss function to have the simple form in equation (7) rather than the model-consistent and inertial form in equation (6). The values reported under "Perceived Loss" in the first row of table 4 evaluate the different policies under the assumption that this simple loss function is the appropriate metric. As in table 3, inflation targeting is the preferred discretionary policy and the relative ranking of the targeting rules is unchanged. However, the use of the simple but model-inconsistent loss function both to solve for the "optimal" targeting rules and to evaluate the effects of each of these rules implies significantly higher values of the loss function, and much larger stabilization bias premia.

The third row of table 4 lists the values of λ_{TR} for each discretionary policy rule that minimize the loss function in equation (7). The values of λ_{TR} are higher in table 4 than in table 3 (where λ_{TR} was chosen to minimize equation 6), suggesting that the use of the simple loss function also may overstate the appropriate weight to be placed on the non-inflation (or non-price level) objective for these alternative targeting rules. This finding likely is due to the fact that for our baseline value of h — which, as argued above, is most consistent with the empirical evidence — the weight on the output objective, $\widetilde{\lambda}$, in equation (6) is nearly half the $\lambda = 0.25$ typically assumed in the literature and used in table 4. Notice that across the regimes, the standard deviation of inflation is uniformly higher — and the standard deviation of the output gap lower — when the central bank is modeled as minimizing a simple quadratic loss function (table 4) rather than the model-consistent one (table 3).

The model-consistent social loss function also can be used to evaluate the actual social loss that would arise from "optimal" targeting rules derived under the incorrect specification of the loss function. These values are reported in the fourth row of table 4 as the "Actual Loss" for each policy. In this case IT minimizes the model-consistent social loss — indeed, it even outperforms the precommitment policy that is derived under the simple but incorrect loss function of equation (7). Conversely, SLT is undoubtedly the worst policy when evaluated in accordance with the model-consistent social loss. These results illustrate how misspecification of the loss function can lead to a mistaken assessment of the relative performance of different policy rules for society.

4.3 Robustness to Variation in Intrinsic Persistence

With rational, forward-looking agents, standard micro-founded New Keynesian (or New Neo-Classical Synthesis) models do not exhibit any intrinsic persistence. In our structural model of section 2, this standard class of models corresponds with $h = \omega = 0$. The problem of stabilization bias occurs even in this case, but both Jensen (2002) and Walsh (2003) show that the degree of inflation persistence in their reduced-form specification (ϕ in equation 5) affects the relative performance of the various policy rules listed in table 1. Jensen (2002) finds that for moderate degrees of inflation persistence, the larger the value of ϕ in equation (5), the more favorable is NIGT relative to IT. However, once ϕ exceeds about $\frac{2}{3}$, inflation becomes sufficiently backward-looking that the time-inconsistency problem fades in importance, and the gains from avoiding stabilization bias with NIGT disappear. Walsh (2003) reports that PLT is most preferred for values of $\phi < 0.35$, and that IT is most preferred for $\phi > 0.7$, with SLT most preferred in the "empirically relevant" middle range.

Our approach differs from those in Jensen (2002) and Walsh (2003) in two significant ways. First, our microfounded model implies that the maximum possible value for ϕ_{-1}, given $\beta = 0.99$, is just above $\frac{1}{2}$; the larger values of ϕ considered by Jensen (2002) and Walsh (2003) are not relevant. (Recall that the empirical estimates cited above suggest the coefficient on lagged inflation is close to, but less than, $\frac{1}{2}$.) Second, our approach is cognizant of the inertial nature of the social loss function that arises endogenously as a result of intrinsic persistence in inflation and output. This relationship accounts for much of the differences in results between tables 3 and 4. Recognizing this linkage, Walsh (2005) also has investigated the impact of varying degrees of inflation persistence in a micro-founded model that incorporates the consequences of inflation persistence in the specification of the social loss function.

Our paper extends the model of Walsh (2005) to explicitly consider the contribution of intrinsic persistence in output as well as inflation.[12] Recall that in our framework, changes in the degree of habit formation not only alter the specification of aggregate demand (equation 1), but also the output gap–inflation trade-off in equation (3). Furthermore, in the model-consistent social loss function of equation (6), both δ and $\widetilde{\lambda}$ are increasing functions of h. As a result, variation in h has a substantial effect on

[12] Notice that Walsh (2005) represents a special case of our specification in which $h = 0$. Also, Walsh (2005) does not investigate the performance of the various discretionary targeting rules in the model with a micro-founded social welfare objective.

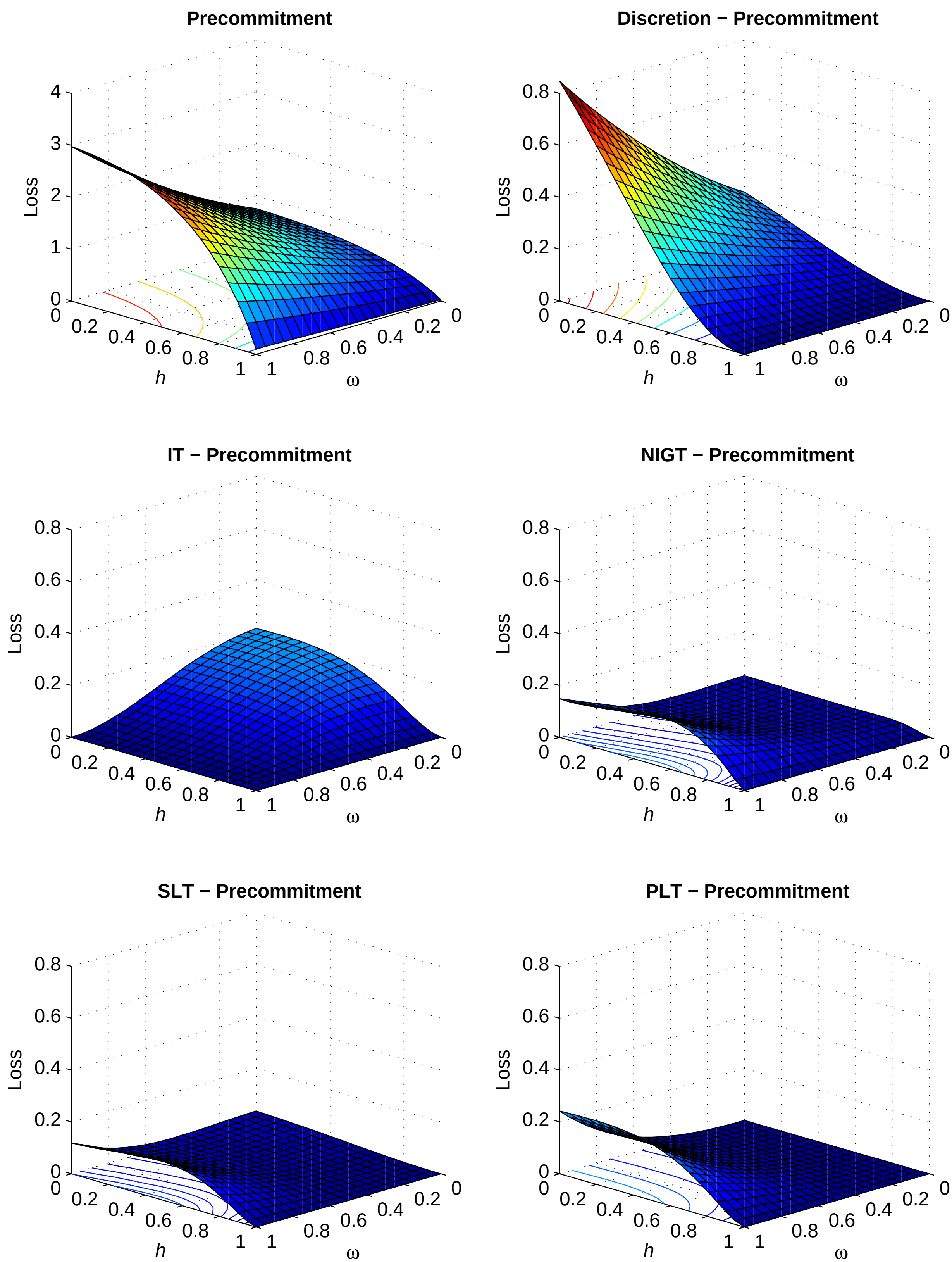

Figure 1: Model-Consistent Social Loss under Precommitment, and Additional Loss due to Stabilization Bias under Various Discretionary Policies

the simulated social loss for our structural parameter values, and interacts with variation in ω.

Figure 1 illustrates how variation in the terms that generate intrinsic persistence, h and ω, affect conclusions about optimal monetary policies. The upper-left plot of figure 1 quantifies the social loss under precommitment, as a function of the values of h and ω. As in table 3, equation (6) is used to evaluate the model-consistent social loss function. As ω increases from 0 to 1, the intrinsic persistence of inflation in the micro-founded model increases from $\phi_{-1} = 0$ to roughly $\phi_{-1} = 0.5$. Furthermore, both the instantaneous elasticity of inflation with respect to the output gap ($\widetilde{\kappa}$ in equation 3) and the "long-run" elasticity ($\widetilde{\kappa}_{-1} + \widetilde{\kappa} + \widetilde{\kappa}_{+1}$) decline as ω rises. These two effects each make inflation less responsive to a given change in the interest rate, thereby requiring larger policy actions — and deeper recessions — to stabilize inflation in response to a μ_t shock. This attenuation of the central bank's ability to stabilize the economy results in higher values of the social loss function for the optimal (but time-inconsistent) precommitment policy as ω rises.

Higher values of h lead to greater persistence in the output gap, as well as lower values of $\widetilde{\sigma}$ in equation (1). These two effects would tend to make the output gap more difficult to stabilize through interest rate changes. But the degree of habit formation also has important and direct effects on the Phillips Curve (equation 3). In our micro-founded model, higher values of h act to increase the instantaneous output gap elasticity of consumption, which "improves" the immediate trade-off between inflation variability and output gap variability in response to a one-time cost-push shock, all else equal. As a result, less aggressive policy actions are necessary to stabilize inflation, all else equal. In contrast, higher values of ω, as discussed in the previous paragraph, have the opposite effect. Put another way, larger values of h represent greater real rigidity (what King, 2000, calls "macro rigidity") in the economy, due to the consequences that habit formation in consumption have for the labor supply decisions of the optimizing representative agent. Conversely, higher values of ω represent greater nominal rigidity in this framework ("micro rigidity" in King, 2000), which leads to a lower value of $\widetilde{\kappa}$ in equation (3), all else equal.[13]

Additionally, as h rises, the relative weight on the output gap terms, $\widetilde{\lambda}$, and the contribution of the lagged output gap, δ, in the social loss function (equation 6) rise as well. Thus, under precommitment the central bank optimally places greater weight on stabilizing the output gap as the degree of habit persistence increases. $\widetilde{\lambda}$ is strongly convex in h, remaining below 0.05 for h less than about 0.7, and below

[13]Higher values for α, which measures the degree of price stickiness in a Calvo specification, also represent greater nominal rigidity. Walsh (2005) investigates how variation in α affects the nature of optimal policy.

0.25 for h less than 0.95. These factors, in conjunction with those mentioned in the previous paragraph, imply that the standard deviations of inflation and the output gap are both monotonically declining in h for any value of ω under the precommitment policy, as illustrated in figure 1.

The remaining panels in figure 1 illustrate how the values of h and ω affect the stabilization bias from discretionary policies. The upper-right corner displays the additional loss, beyond that under the precommitment policy, from a pure discretionary policy. The lower four panels show the incremental loss over the precommitment solution of each of the targeting rules listed in table 1. For low values of ω — for which there would be minimal persistence in inflation — the three other targeting rules all preform better than IT. This result is especially true if h is low as well; i.e., if there is not much persistence in the output gap, either. Conversely, for "empirically relevant" values of both h and ω — generally in the 0.8 to 0.9 range — the model-consistent social loss is lower with IT than with the other three rules.

To understand why our results differ so significantly from others in the literature — particularly those of Jensen (2002) and Walsh (2003) — we repeat the above investigation, this time with the model-inconsistent simple social loss function of equation (7) for both the choice of the "optimal" policy and the evaluation of the loss to society from this policy. These results are shown in figure 2.

Notice that the loss under precommitment, plotted in the upper-left panel of figure 2, is broadly similar in shape to that in figure 1, but larger in magnitude. The main differences between the results with the model-consistent loss function (figure 1) and those with the simple loss function (figure 2) are in the targeting rules. In particular, inflation targeting is bested by SLT and PLT for most values of h and ω, and even NIGT does better than IT over a broad range of parameter values.

However, as figure 3 demonstrates, these findings are due almost entirely to the use of the simple model-inconsistent loss function to evaluate the loss to society under the various policy regimes. In figure 3, the simple loss function (equation 7) still is used to determine the "optimal" policy in each case — in effect, the central bank minimizes the wrong loss function. However, the consequences of each of these policies is evaluated according to the model-consistent loss function of equation (6). Again, the effects of variation in the intrinsic persistence parameters on the social loss under precommitment are qualitatively similar to the prior figures, although naturally the evaluated loss tends to be higher when "optimal" policy is determined with the simple loss function (equation 7) than with the appropriate model-consistent social loss (equation 6).

Most striking in figure 3 is the fact that each of the discretionary policies actually does better than

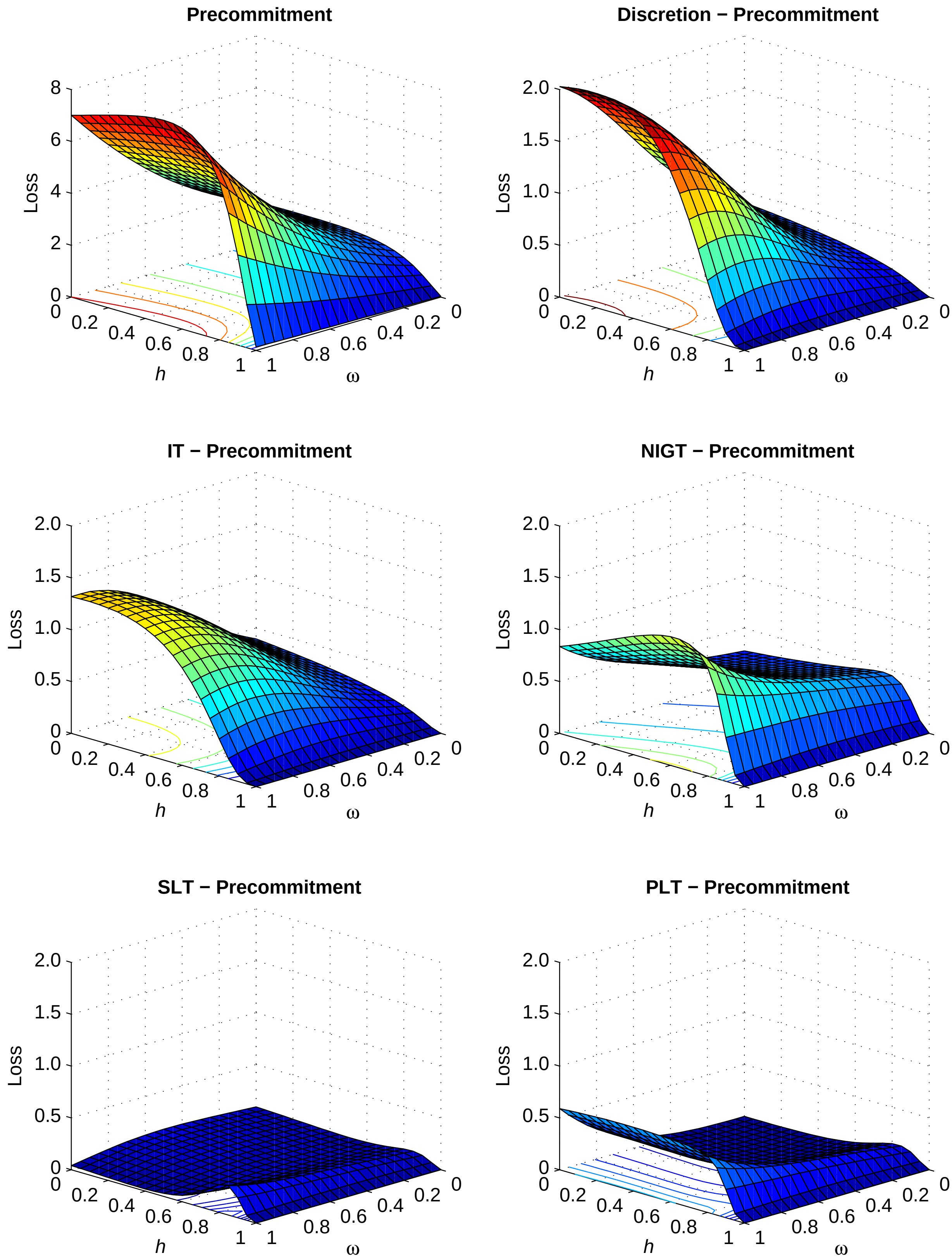

Figure 2: Simple Loss under Precommitment, and Additional Loss due to Stabilization Bias under Various Discretionary Policies

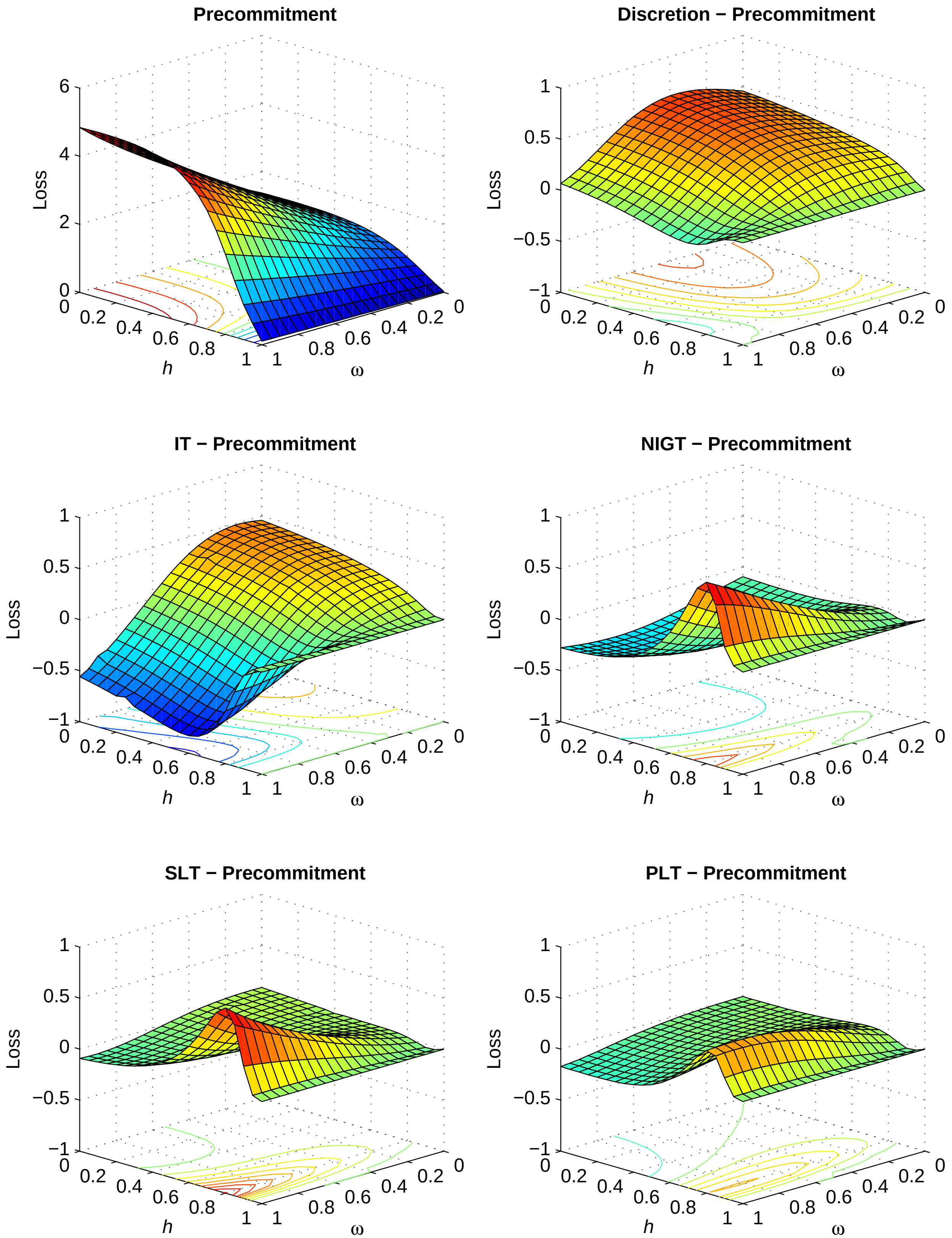

Figure 3: Simple Loss under Precommitment, and Additional Loss due to Stabilization Bias under Various Discretionary Policies, all evaluated with Model-Consistent Social Loss

Table 5: Alternative Calibration

Structural Parameters						
β	h	γ	η	α	ω	ε
0.99	0.9	0.0269	0.8	0.7582	0.9901	8
Implied Parameters						
	θ_{-1}	θ_{+1}	θ_{+2}	$\widetilde{\sigma}$		
	0.333	0.997	0.330	1.5		
	ϕ_{-1}	ϕ_{+1}	$\widetilde{\kappa}$	$\widetilde{\kappa}_{-1}$	$\widetilde{\kappa}_{+1}$	
	0.5	0.5	0.05	0.009	0.009	

precommitment for some values of h and ω: the precommitment policy that minimizes the simple loss function is so inferior from the standpoint of the model-consistent social loss that instructing the central bank to follow one of the targeting rules under discretion actually can yield better outcomes. However, the various targeting rules are not symmetric in their ability to improve upon the suboptimal precommitment policy. In particular, IT dramatically out-performs not only precommitment but also all the other targeting rules when ω exceeds roughly 0.6 (ϕ_{-1} larger than roughly 0.36). For the "empirically relevant" ranges of h and ω, the social loss with SLT or PLT is about twice that with IT. Thus, IT is more robust to this particular type of mispecification than the alternative targeting regimes, which tend to exacerbate the social loss in the empirically relevant region.

4.4 Alternative Calibration and Results

As an alternative to our baseline parameter values in table 2, we also consider parameter values chosen to match as closely as possible the reduced-form specification of the model simulated by Walsh (2003). These values are shown in table 5. The main difference with respect to the baseline values in table 2 is the much smaller value for γ. Given $h = 0.9$ and $\beta = 0.99$, this value of γ is necessary to match the value of the intertemporal elasticity of substitution of 1.5 in Walsh (2003) (as well as Jensen, 2002). As noted in table 5, these values of β and h yield an estimate of θ_{-1} no larger than one-third, well below the assumed value of $\theta = 0.5$ in equation (4) of both Jensen (2002) and Walsh (2003).

The second main difference between the parameter values in table 5 versus table 2 is the value of ω. In order to match the coefficient on lagged inflation (ϕ_{-1}) of 0.5, we had to choose a value for ω that was nearly one. As a result, we also had to assume a slightly higher value for α in order to match the value of $\widetilde{\kappa} = 0.05$ on the output gap in the aggregate supply relationship. The remaining structural parameter values are the same as in table 2. Our objective in this exercise is to replicate the specification of the dynamic equations in Jensen (2002) and Walsh (2003) as closely as possible given the micro-foundations of the model, while changing the fewest number of parameters from our baseline specification.

Table 6 reports the losses under precommitment and each of the discretionary policies, under the assumption that each optimal policy is chosen to minimize the model-consistent social loss of equation (6). That is, the results in table 6 parallel those in table 3, but for the alternative calibration given in table 5. Note that for those values, chosen to match the reduced-form model equations of Jensen (2002) and Walsh (2003) as closely as possible, the parameterized model-consistent social loss function looks very different than the simple loss function assumed by those authors. For example, the lagged inflation rate does not enter equation (7), whereas the assumption of $\omega = 0.9901$ — necessary to make the reduced-form inflation persistence $\phi_{-1} = 0.5$ — implies a high degree of inflation inertia in the model-consistent loss. Similarly, the lagged output gap does not enter equation (7), whereas the parameter values in table 5 imply $\delta = 0.1844$ in equation (6). Finally, while Jensen (2002) and Walsh (2003) assume that $\lambda = 0.25$ in equation (7), the above parameter values imply a substantially lower value of $\widetilde{\lambda} = 0.012$ for equation (6).

Even under this alternative parameterization, inflation targeting remains the discretionary policy regime that comes closest to the precommitment ideal. Indeed, in this case stabilization bias is nearly absent. Table 6 reveals SLT, NIGT, and PLT to be the next-best policies, in that order, although there is a sizable difference between the social loss under each of these policies and the loss under IT.

Conversely, when the simple loss function is used both to determine the loss-minimizing policy and to evaluate that policy, we are able to reproduce the qualitative results of Walsh (2003), in which IT appears much worse than SLT or PLT: compare the perceived losses from the simple loss function in the first row of table 7. In this case, SLT appears very close to the precommitment loss, and IT appears to perform dramatically worse. But when the model-consistent social loss is used to evaluate the policies chosen under the simple loss function, the ranking is nearly reversed: the actual loss from IT is quite a bit lower than that from SLT, which itself is bested by both NIGT and PLT. (See the fourth row of table 7.) The use of the simple but model-inconsistent loss function leads to fundamentally different — and arguably incorrect — conclusions about the relative desirability of the targeting rules we consider here, just as in

Table 6: Alternative Calibration, Inertial social loss function

		Discretionary Policy Regime				
	PC	PD	IT	NIGT	SLT	PLT
Social Loss	3.9803	4.9451	3.9817	4.2554	4.2178	4.2884
% loss relative to precommitment	—	24.24	0.04	6.91	5.97	7.74
Optimal λ_{TR}	—	—	0.01	0.01	0.01	0.03
St. Dev. (π_t)	1.5803	11.9802	1.5574	1.2962	1.3168	1.4125
St. Dev. (x_t)	12.6784	13.6882	12.9150	13.7326	13.5182	13.4204

Social loss is multiplied by 100. Standard deviations are in percentages. For this loss function, $\omega = 0.9901$, $\widetilde{\lambda} = 0.0120$, and $\delta = 0.1844$.

Table 7: Alternative Calibration, Simple social loss function

		Discretionary Policy Regime				
	PC	PD	IT	NIGT	SLT	PLT
Perceived Loss	12.8790	18.0070	15.4680	16.8214	12.9442	14.0950
% loss relative to precommitment	—	39.82	20.10	30.61	0.51	9.44
Optimal λ_{TR}	—	—	0.10	0.89	0.73	2.59
Actual Loss	6.0674	6.2579	5.4657	5.5500	6.0189	5.8486
% loss relative to precommitment	—	3.14	−9.92	−8.53	−0.80	−3.61
St. Dev. (π_t)	2.9640	4.0475	3.2243	2.3941	2.9676	3.1110
St. Dev. (x_t)	4.2039	2.9302	4.6553	6.8038	4.2173	4.4411

Loss values are multiplied by 100. Standard deviations are in percentages. For the "perceived" loss function, $\lambda = 0.25$. For the "actual" loss function, $\omega = 0.9901$, $\widetilde{\lambda} = 0.0120$, and $\delta = 0.1844$.

table 4 above. These results overturn those in the existing published literature.

4.5 Interpretation

The above results demonstrate that conclusions about the desirability of the monetary policy targeting rules we consider are sensitive to various modeling assumptions. First, the specification of the loss function itself has a substantial effect on the extent of stabilization bias in the simulations. Second, any ranking of the policy rules depends upon the magnitudes of the relative weights in the social welfare function, which in turn depend on the structural parameter values. In particular, we find evidence against the superiority of simple inertial targeting rules like NIGT or SLT — as advocated by Jensen (2002) or Walsh (2003), for example — once the specification of the social loss function is derived from a micro-founded model featuring intrinsic persistence. Indeed, for empirically plausible degrees of inflation persistence, a discretionary IT regime appears to closely match the precommitment ideal.

Recall that, in the absence of any persistent dynamics, a pure discretionary policy would still suffer from stabilization bias. Under discretion a policy maker takes the expectations of the public as given, and is incapable of credibly committing to a future path of policy in a manner that can convince the public to set its expectations of future inflation accordingly. Thus, Clarida et al. (1999), for example, have demonstrated that the first-order condition that describes the optimal precommitment policy in a basic New Keynesian model (i.e., one lacking persistence) sets the inflation rate as a function of the one-period change in the output gap, rather than as a function of the contemporaneous output gap alone as in the optimal discretionary policy case. This lag of the output gap appears in the first-order condition for precommitment as a consequence of a credible central bank's ability to influence the formation of inflation expectations. Such a precommitment policy, however, is not time consistent.

By incorporating a lagged value of the real activity objective (either output or the output gap) into the policy rule, the first-order conditions under discretion for the targeting rules other than IT in table 1 resemble those under precommitment, and in particular, exhibit a form of history dependence. Table 1 summarizes the implied rules derived from the first-order conditions for optimal discretionary policy under each targeting regime: as noted in section 3, NIGT, SLT and PLT all have lagged output (y_{t-1}) or output gap (x_{t-1}) terms. Jensen (2002) and Walsh (2003) demonstrate that for a moderate degree of inertia in the inflation dynamics equation (ϕ in the range of $\frac{1}{3}$ to $\frac{1}{2}$ in equation 5), the stabilization bias under pure discretion — and under inflation targeting — worsens relative to the other targeting rules. We find similar results, as can be seen when comparing the "Preceived Loss" values reported in table 7. In a similiar vein, notice that with our micro-founded calibration as illustrated in figure 2, the gap between the losses under pure discretion or IT and the other targeting rules are increasing in ω for $h = 0$.

Introducing intrinsic persistence into the model changes the specification of the loss function significantly from the simple quadratic form of equation 7 that is commonly assumed in the literature. Thus, the appropriate first-order conditions for optimal policy differ as well, as highlighted in section 3. Equations (8) and (9) reveal the lack of a closed-form expression for the form of optimal precommitment policy once both sources of persistence are introduced. Nonetheless, we can glean some insight into the relative performance of the various targeting rules by noting first that the other three targeting rules tend to over-stabilize inflation at the cost of output gap variability. Implicitly, by fixing a weight of one on the lagged output (gap) term, these targeting rules appear to be "overweighting" x_{t-1} relative to its actual weight in the social loss function of $\delta < 1$. To compensate, these other targeting rules tend to underweight the output stabilization objective, leading to a socially sub-optimal degree of variability in real activity. For the baseline calibration illustrated in table 3, such policies lead to higher social losses than with precommitment — or with inflation targeting.

The flip side of this analysis comes into play as ω approaches one. In that case, the difference of inflation rather than the level enters into the social loss function and thus the specification of the optimal precommitment policy. The other targeting rules link the level of inflation to the first difference of the output gap, but when inflation is intrinsically highly inertial, the difference of inflation should respond to the difference in the output gap (to a first approximation). The first difference of the implied targeting rule for IT more closely resembles the optimal precommitment policy in the case of relatively high inflation persistence; differencing the other targeting rules effectively over-differences the output gap terms. In this sense, there is an intuitive parallel between the performance of PLT in the standard, non-presistent model and the performance of IT in the intrinsically persistent model. Recall that the first difference of PLT yields a close approximation of first-order condition for optimal precommitment in the absence of inflation persistence (see, e.g., Walsh, 2003); with an empirically-plausible degree of inflation persistence arising intrinsically in the micro-founded model, the first difference of IT more closely approximates the corresponding first-order condition for optimal precommitment in the presence of inflation persistence than do any of the other targeting rules we consider.

This result can be seen in the case of our baseline calibration, in which $\frac{\tilde{\kappa}_{-1}}{\tilde{\kappa}} \approx \phi_{-1}$ and $\frac{\tilde{\kappa}_{+1}}{\tilde{\kappa}} \approx \phi_{+1}$. In this case — which holds over a relatively wide range of (h, ω) pairs given the other parameter values — the lag polynomials on the Langrange multiplier ℓ_t in equations (8) and (9) are approximately equal. Then the first-order condition for the optimal precommitment policy with intrinsic persistence can be written as:

$$(\pi_t - \omega\pi_{t-1}) - \beta\omega(\mathrm{E}_t\pi_{t+1} - \omega\pi_t) = -\frac{\widetilde{\lambda}}{\widetilde{\kappa}}\left[(x_t - \delta x_{t-1}) - \beta\delta(\mathrm{E}_t x_{t+1} - \delta x_t)\right]. \tag{11}$$

For values of δ in the neighborhood of ω, quasi-differencing the implied targeting rule for IT very closely approximates this equation. More generally, when ω is low, the level of inflation appears on the left-hand side of equation (11) and the other targeting rules perform relatively well, as shown in figure 1. When ω is relatively high, IT outperforms the other targeting rules.

5 Conclusion

The evaluation of optimal monetary policy in the face of macroeconomic persistence has received significant attention recently. Following others in the literature, in this paper we make persistence an intrinsic part of a "New Keynesian" dynamic stochastic general equilibrium model by incorporating habit formation in consumption and price indexation by firms. In this framework, both the log-linearized equations for the model dynamics and the second-order approximation to the social loss function vary with the structural parameters that determine the extent of intrinsic persistence. The specification and calibration of this micro-founded model has important consequences for the relative desirability of various targeting rules for monetary policy.

In a discretionary policy environment, uncertainty about the central bank's willingness to deliver on past promises for the future path of policy yields a problem of "stabilization bias," in which private agents' expectations about subsequent inflation rates are higher than they would be under a credible — but time-inconsistent — precommitment policy. Jensen (2002) and Walsh (2003) have suggested that inertial policies, such as nominal income growth targeting or price-level targeting, address this problem better than inflation targeting. Our simulations reveal their results to be a direct consequence of the *ad hoc* nature of persistence and simple specification of the social loss function that they use.

In contrast, use of the appropriate model-consistent loss function yields inflation targeting as the best discretionary policy of those considered. We obtain these results both with a calibration based on a review of the empirical evidence as well as with another chosen to replicate the persistent dynamics of Jensen (2002) or Walsh (2003) as closely as possible. This model-consistent specification of the social loss function features inertial terms in both inflation and the output gap stabilization objectives. This inertia arises endogenously from the same model assumptions that generate intrinsic persistence in the inflation and output gap equations.

The need for coherence between the social loss function and the rest of the model specification has been emphasized by several authors recently, including Amato and Laubach (2003, 2004), Giannoni and Woodford (2003), and Woodford (2003). In a micro-founded model with inflation persistence, Walsh (2005) has demonstrated how misspecification of the policy objectives of the central bank affects determination of the optimal monetary policy and the evaluation of the social loss from such policies. Our approach is similar, although by adding intrinsic persistence in real activity, we can extend his results. In contrast with models of *ad hoc* persistence in the output gap, variation in the degree of habit formation affects the inflation dynamics and the relative weights on current and lagged values of the output gap in the objective function. Variation in this source of persistence is shown to impact more significantly the relative performance of various targeting rules than does inflation persistence alone.

While our specific results depend upon a particular set of assumptions for the micro-foundations of our model, any framework that features intrinsic persistence in inflation and output likely will feature endogenous inertial in the model-consistent specification of the social welfare function as well. In such a case, the relationship among the first-order conditions that describe optimal discretionary policy for each of the targeting regimes is likely to favor inflation targeting if the model is calibrated to the degree of persistence observed in U.S. data. Recent work by Smets and Wouters (2003) and Christiano et al. (2005), amongst others, have introduced additional frictions and potential sources of persistence that could impact the relative performance of the targeting rules we examine. Given the increasing popularity of inflation targeting regimes around the globe, additional research into these issues seems warranted.

A Model Specification

Our investigation utilizes what has become the workhorse model for monetary policy analysis, a micro-founded "New Keynesian" model with business cycle dynamics due to less than perfectly flexible product prices. We draw extensively upon previous work in this area by Giannoni and Woodford (2003) and Woodford (2003), and summarize the key components of the model below.[14]

A representative household solves the utility maximization problem:

$$\max_{\{C_t, N_t, D_{t+1}\}} \mathrm{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{1-\gamma} (C_t - h\, C_{t-1})^{1-\gamma} - \frac{N_t^{1+\eta}}{1+\eta} \right\} \right] \tag{A1}$$

subject to their intertemporal budget constraint. C_t, N_t, and D_t represent consumption, labor supply, and debt holdings at time t, respectively. Equation (A1) includes lagged consumption in the specification of utility: $h \in [0, 1]$ measures the extent of habit persistence in consumption.

The log-linearized version of the Euler equation that follows from the first-order conditions of the consumer's maximization problem has the form:

$$\widetilde{c}_t = \mathrm{E}_t \widetilde{c}_{t+1} - \widetilde{\gamma}^{-1} (i_t - \mathrm{E}_t \pi_{t+1}), \tag{A2}$$

where $\widetilde{c}_t$ is defined as:

$$\widetilde{c}_t = (c_t - h\, c_{t-1}) - \beta\, h (\mathrm{E}_t c_{t+1} - h\, c_t), \tag{A3}$$

and c_t is the log of consumption. $\widetilde{\gamma} = \gamma \big/ (1 - \beta\, h)$ measures the sensitivity of consumption to the real interest rate; γ is the inverse of the intertemporal elasticity of substitution for consumption. Notice that in the absence of habit formation, $h = 0$ and equation (A2) reduces to the consumption Euler equation commonly found in the literature that lacks endogenous persistence in consumption.

Assuming the government consumes a fixed share of output, subject to mean zero (in logs) stochastic disturbances, equation (A2) can be re-written in terms of real output:

$$\widetilde{y}_t = \mathrm{E}_t \widetilde{y}_{t+1} - \widetilde{\gamma}^{-1} (i_t - \mathrm{E}_t \pi_{t+1}) + \mathrm{E}_t \widetilde{g}_{t+1} - \widetilde{g}_t. \tag{A4}$$

The expected change in $\widetilde{g}$, the (transformed) innovation to fiscal policy, acts as an aggregate demand

[14] Additional details on the model derivation are available from the authors upon request.

shock in this specification. Here, $\widetilde{y}_t$ and $\widetilde{g}_t$ are defined analogously to $\widetilde{c}_t$ in equation (A3).[15]

To rewrite equation (A4) in terms of the output gap requires a model of aggregate supply. We assume a simple linear production function, $y_t = z_t + n_t$ (in log terms), in which the common technological shock, z_t, is assumed to follow an exogenous first-order autoregressive process.[16] Equating labor demand and labor supply under flexible prices yields an implicit relationship for the natural level of real output:

$$\eta\, y_t^n + \widetilde{\gamma}\, \widetilde{y}_t^n = (1+\eta) z_t - \widetilde{\gamma}\, \widetilde{g}_t\,, \tag{A5}$$

where $\widetilde{y}_t^n$ also is defined analogously to $\widetilde{c}_t$ in equation (A3).

With equation (A5) we can express equation (A4) in terms of the (transformed) output gap, $\widetilde{x}_t \equiv \widetilde{y}_t - \widetilde{y}_t^n$:

$$\widetilde{x}_t = \mathrm{E}_t \widetilde{x}_{t+1} - \widetilde{\gamma}^{-1}(i_t - \mathrm{E}_t \pi_{t+1} - r_t^n)\,, \tag{A6}$$

where r_t^n is the corresponding natural or "Wicksellian" real rate of interest, defined as:

$$r_t^n \equiv \widetilde{\gamma}\left(\mathrm{E}_t \widetilde{y}_{t+1}^n - \widetilde{y}_t^n + \mathrm{E}_t \widetilde{g}_{t+1} - \widetilde{g}_t\right). \tag{A7}$$

To facilitate comparison with the *ad hoc* persistent aggregate demand formulation of equation (4), we can expand the definition of $\widetilde{x}_t$ in equation (A6) using the transformation of equation (A3) and the law of iterated expectations to give:

$$x_t = \theta_{-1} x_{t-1} + \theta_{+1} \mathrm{E}_t x_{t+1} - \theta_{+2} \mathrm{E}_t x_{t+2} - \widetilde{\sigma}(i_t - \mathrm{E}_t \pi_{t+1} - r_t^n)\,, \tag{A8}$$

where $\theta_{-1} = \left(\frac{h}{1+h+\beta h^2}\right)$, $\theta_{+1} = \left(\frac{1+\beta h+\beta h^2}{1+h+\beta h^2}\right)$, $\theta_{+2} = \left(\frac{\beta h}{1+h+\beta h^2}\right)$, and $\widetilde{\sigma} = \left(\frac{1-\beta h}{(1+h+\beta h^2)\gamma}\right)$.

Returning to the supply side of the model, firms are monopolistically competitive price setters for their differentiated products. We assume Calvo-type nominal price rigidity with α being the probability that a firm does not adjust its price in a given period. Thus, the average price is fixed for $1/(1-\alpha)$ periods. We augment this specification by assuming that a proportion ω of firms who do not adjust in a period index their prices to the aggregate price level. This additional assumption yields persistence in the New-

[15] We model the exogenous fiscal process as $g_t = \rho_g g_{t-1} + \zeta_t^g$, with $\zeta_t^g \sim (0, \sigma_g^2)$ and $0 \le \rho_g < 1$.
[16] That is, the technology shock is modeled as $z_t = \rho_z z_{t-1} + \zeta_t^z$, with $\zeta_t^z \sim (0, \sigma_z^2)$ and $0 \le \rho_z < 1$.

Keynesian Phillips Curve via a lagged inflation term:

$$\pi_t = \phi_{-1}\,\pi_{t-1} + \phi_{+1}\,\mathrm{E}_t\pi_{t+1} + \widetilde{\kappa}\,x_t - \widetilde{\kappa}_{-1}\,x_{t-1} - \widetilde{\kappa}_{+1}\,\mathrm{E}_t x_{t+1} + \mu_t\,, \tag{A9}$$

where $\phi_{-1} = \frac{\omega}{1+\omega\beta}$ and $\phi_{+1} = \frac{\beta}{1+\omega\beta}$ are the coefficients on lagged and expected future inflation, respectively. $\widetilde{\kappa} = \frac{(1-\alpha\beta)(1-\alpha)}{\alpha}\frac{\eta+\widetilde{\gamma}}{1+\omega\beta}$ measures the response of inflation to variation in the output gap; $\widetilde{\kappa}_{-1} = \widetilde{\kappa}\widetilde{\gamma}h\big/(\eta+\widetilde{\gamma})$ and $\widetilde{\kappa}_{+1} = \widetilde{\kappa}\beta\widetilde{\gamma}h\big/(\eta+\widetilde{\gamma})$ measure the contributions, respectively, of lagged and expected output gaps for current inflation. The cost-push shock, μ_t, can be derived as a stochastic deviation from the steady-state monopolistic markup or taxes as in Steinsson (2003). We assume that the cost-push shock also follows an exogenous stationary first-order autoregressive process.[17]

For $\omega = 0$ the lagged inflation term disappears from equation (A9) and ϕ_{+1} equals β, as in the canonical forward-looking New Keynesian Phillips Curve. However, habit formation in consumption yields a micro-founded Phillips Curve with both $\mathrm{E}_t x_{t+1}$ and x_{t-1} on the right-hand side of equation (A9), even in the absence of any intrinsic persistence in inflation. Only if $h = 0$ and $\omega = 0$ does equation (A9) reduce to the standard New Keynesian Phillips Curve derived from a Calvo price-setting framework. Thus this price setting relationship also is qualitatively different than the *ad hoc* specification in equation (5), and cannot be reconciled with the micro-foundational model for permissible parameter values.

Giannoni and Woodford (2003) and Woodford (2003) demonstrate that the second-order approximation to the social loss function based on equation (A1) takes the form:

$$\mathscr{L} = \mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \left[(\pi_t - \omega\,\pi_{t-1})^2 + \widetilde{\lambda}\,(x_t - \delta\,x_{t-1})^2\right], \tag{A10}$$

where $\delta = \frac{h}{\vartheta}$ measures the contribution of lagged output to the loss function, and $\widetilde{\lambda} = \frac{\vartheta\widetilde{\gamma}\widetilde{\kappa}(1+\omega\beta)}{\varepsilon(\eta+\widetilde{\gamma})}$ is the relative weight on the quasi-differenced output gap term vis-à-vis a similar quasi-differenced term for inflation.[18] Notice that the larger the degree of habit formation, the greater the relative weight on the quasi-differenced output gap term, and the more prominent the lag of the output gap in equation (6). On the other hand, variation in the degree of price indexation only affect the weight on the lagged inflation

[17] Formally, we assume $\mu_t = \rho_\mu\,\mu_{t-1} + \zeta_t^\mu$, with $\zeta_t^\mu \sim (0, \sigma_\mu^2)$ and $0 \le \rho_\mu < 1$. The cost-push shock represents deviations to the relationship between real marginal cost and the output gap, and conceptually should be multiplied by $\widetilde{\kappa}/(\eta+\widetilde{\gamma})$. In the simulations below we calibrate the standard deviation of this composite term to be a constant, consistent with Jensen (2002) and Walsh (2003), but in contrast with Walsh (2005). Results in which σ_μ varies with ω are available from the authors.

[18] $\vartheta = \frac{\beta}{2}\left(\chi + \sqrt{\chi^2 - 4\,h^2\,\beta^{-1}}\right)$ is a composite of the structural parameters, with $\chi = \frac{\eta+\widetilde{\gamma}(1+\beta\,h^2)}{\beta\widetilde{\gamma}}$. This specification of the loss function is conditioned upon the distortions associated with monopolistic competition being arbitrarily close to zero.

term: $\widetilde{\lambda}$ is independent of ω, as in Walsh (2005).[19]

B Solution Algorithm for Simulations

To investigate the nature of optimal policy under both precommitment and discretion, and to better understand how the optimal policy solutions are sensitive to the model specification, we use computational techniques to simulate the model. In particular, we use a version of the technique developed by Dennis (2003) for finding optimal policy in rational expectations models that involve both expectational leads and lags of the endogenous variables.[20] The solution technique proceeds as follows: first, collect the relevant dynamic equations of section 2, as well as any identities necessary to close the model, into the following matrix representation of the structural model:[21]

$$\mathbf{A}_0\,\mathbf{y}_t = \mathbf{A}_1\,\mathbf{y}_{t-1} + \mathbf{A}_2\,E_t\mathbf{y}_{t+1} + \mathbf{A}_3\,\mathbf{x}_t + \mathbf{A}_4\,E_t\mathbf{x}_{t+1} + \mathbf{A}_5\,\mathbf{v}_t\,, \tag{B1}$$

where $\mathbf{y}_t$ is the $(n \times 1)$ vector of endogenous variables and $\mathbf{x}_t$ represents the $(p \times 1)$ vector of policy variables. In the simulations reported below, the nominal interest rate, i_t, is assumed to be the sole instrument of policy (i.e., $p = 1$). The three structural shocks in the model — the aggregate demand shock, g_t, the technology shock, z_t, and the cost-push shock, μ_t — are included in the $\mathbf{y}_t$ vector and assumed to have exogenous AR(1) representations:

$$\begin{aligned} g_t &= \rho_g\, g_{t-1} + \zeta_t^g \\ z_t &= \rho_z\, z_{t-1} + \zeta_t^z \\ \mu_t &= \rho_\mu\, \mu_{t-1} + \zeta_t^\mu \end{aligned}$$

The $(s \times 1)$ matrix $\mathbf{v}_t$ of the independent white-noise forcing shocks (ζ_t^g, ζ_t^z, and ζ_t^μ) is distributed as:

$$\mathbf{v}_t \sim iid(\mathbf{0}, \mathbf{\Omega})\,,$$

in which the diagonal elements of $\mathbf{\Omega}$ are σ_g^2, σ_z^2, and σ_μ^2, respectively.

[19] We compute the values of the social loss function under different targeting rules using the method discussed in appendix B. Adam and Billi (2005) discuss a monotonic transformation to convert these values into consumption units. As we are interested in the relative performance of each policy regime, our results are invariant to the units in which the losses are expressed.

[20] The simulations were computed with code written by the authors for MATLAB version 7 (release 14).

[21] The primary equations of the simulation are (1) and (3), along with the definitions of the flexible-price equilibrium variables in equations (A5) and (A7). The definitions for the "quasi-differenced" variables, as in equation (A3), are included as well.

The social loss functions of equations (7) and (6) can be expressed in the following general quadratic form:

$$\mathscr{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left[\mathbf{y}_t' \mathbf{W} \mathbf{y}_t\right]. \tag{B2}$$

The central bank then optimally chooses $\mathbf{x}_t$ to solve the above linear-quadratic problem, subject to the constraints summarized in equation (B1).

While we report both the optimal precommitment and various optimal discretionary policies in the main text, we are most interested in the discretionary solutions. In this case, a stationary solution to the model has the form:

$$\mathbf{y}_t = \mathbf{H}_1 \mathbf{y}_{t-1} + \mathbf{H}_2 \mathbf{v}_t \tag{B3}$$

$$\mathbf{x}_t = \mathbf{F}_1 \mathbf{y}_{t-1} + \mathbf{F}_2 \mathbf{v}_t, \tag{B4}$$

where equation (B3) defines the dynamic updating equation for the variables in the model, and equation (B4) represents the (implicit) policy rule as a function of the "state" variables (namely, the exogenous disturbances and the lagged endogenous variables.)

Minimizing the loss function (B2) subject to (B3) and (B4) yields:

$$\begin{aligned}
\mathbf{H}_1 &= \mathbf{D}^{-1}(\mathbf{A}_1 + \mathbf{A}_3 \mathbf{F}_1) \\
\mathbf{H}_2 &= \mathbf{D}^{-1}(\mathbf{A}_5 + \mathbf{A}_3 \mathbf{F}_1) \\
\mathbf{F}_1 &= -(\mathbf{A}_3' \mathbf{D}'^{-1} \mathbf{P} \mathbf{D}^{-1} \mathbf{A}_3)^{-1} \mathbf{A}_3' \mathbf{D}'^{-1} \mathbf{P} \mathbf{D}^{-1} \mathbf{A}_1 \\
\mathbf{F}_2 &= -(\mathbf{A}_3' \mathbf{D}'^{-1} \mathbf{P} \mathbf{D}^{-1} \mathbf{A}_3)^{-1} \mathbf{A}_3' \mathbf{D}'^{-1} \mathbf{P} \mathbf{D}^{-1} \mathbf{A}_5
\end{aligned}$$

where

$$\begin{aligned}
\mathbf{D} &\equiv \mathbf{A}_0 - \mathbf{A}_2 \mathbf{H}_1 - \mathbf{A}_4 \mathbf{F}_1 \\
\mathbf{P} &\equiv \mathbf{W} + \beta \mathbf{H}_1' \mathbf{P} \mathbf{H}_1.
\end{aligned}$$

In this case, Dennis (2003) shows that the loss function (B2) under discretion can be computed as:

$$\mathscr{L} = \mathbf{y}_t' \mathbf{P} \mathbf{y}_t + \tfrac{\beta}{1-\beta} \operatorname{tr}\left[\left(\mathbf{H}_2' \mathbf{P} \mathbf{H}_2\right) \boldsymbol{\Omega}\right]. \tag{B5}$$

The standard errors of the endogenous variables in $\mathbf{y}_t$ can be recovered from equation (B3), expressed in moving average form.

References

Adam, Klaus and Roberto M. Billi, "Discretionary Monetary Policy and the Zero Lower Bound on Nominal Interest Rates," November 2005. Forthcoming, Journal of Monetary Economics.

Amato, Jeffery D. and Thomas Laubach, "Rule-of-Thumb Behaviour and Monetary Policy," *European Economic Review*, October 2003, *47* (5), 791–831.

__ **and** __ , "Implications of Habit Formation for Optimal Monetary Policy," *Journal of Monetary Economics*, March 2004, *51* (2), 305–325.

Barro, Robert J. and David B. Gordon, "A Positive Theory of Monetary Policy in a Natural Rate Model," *Journal of Political Economy*, August 1983, *91* (4), 589–610.

Bouakez, Hafedh, Emanuela Cardia, and Francisco J. Ruge-Murcia, "Habit Formation and the Persistence of Monetary Shocks," *Journal of Monetary Economics*, September 2005, *52* (6), 1073–1088.

Cho, Seonghoon and Antonio Moreno, "A Small Sample Study of the New-Keynesian Macro Model," September 2005. Manuscript.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, February 2005, *113* (1), 1–45.

Clarida, Richard, Jordi Galí, and Mark Gertler, "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature*, December 1999, *37* (4), 1661–1707.

Dennis, Richard, "Optimal Policy Rules in Rational Expectations Models: New Solution Algorithms," January 2003. Federal Reserve Bank of San Francisco Working Paper #2001-09.

__ , "Specifying and Estimating New Keynesian Models with Instrument Rules and Optimal Monetary Policy," September 2004. Federal Reserve Bank of San Fransisco Working Paper #2004-17.

__ **and Ulf Söderström**, "How Important is Precommitment for Monetary Policy?," September 2002. Federal Reserve Bank of San Francisco Working Paper #2002-10.

Fuhrer, Jeffrey C., "Habit Formation in Consumption and Its Implications for Monetary-Policy Models," *American Economic Review*, June 2000, *90* (3), 367–390.

Galí, Jordi and Mark Gertler, "Inflation Dynamics: A Structural Econometric Analysis," *Journal of Monetary Economics*, October 1999, *44* (2), 195–222.

Giannoni, Marc P. and Michael Woodford, "Optimal Inflation Targeting Rules," August 2003. Columbia University manuscript.

Goodfriend, Marvin and Robert King, "The New Neoclassical Synthesis and the Role of Monetary Policy," in Ben Bernanke and Julio Rotemberg, eds., *NBER Macroeconomic Annual*, 1997, pp. 231–283.

Jensen, Henrik, "Targeting Nominal Income Growth or Inflation?," *American Economic Review*, September 2002, *92* (4), 928–956.

King, Robert G., "The New IS-LM Model: Language, Logic, and Limits," *Federal Reserve Bank of Richmond Economic Quarterly*, Summer 2000, *86* (3), 45–103.

McCallum, Bennett T. and Edward Nelson, "Timeless Perspective vs. Discretionary Monetary Policy in Forward-Looking Models," *Federal Reserve Bank of St. Louis Review*, March/April 2004, *86* (2), 43–56.

Rabanal, Pau and Juan F. Rubio-Ramírez, "Comparing New Keynesian Models of the Business Cycle: A Bayesian Approach," *Journal of Monetary Economics*, September 2005, *52* (6), 1151–1166.

Rogoff, Kenneth, "The Optimal Degree of Commitment to an Intermediate Monetary Target," *Quarterly Journal of Economics*, November 1985, *100* (4), 1169–1189.

Rotemberg, Julio J. and Michael Woodford, "An Optimizing-Based Econometric Model for the Evaluation of Monetary Policy," in Ben S. Bernanke and Julio J. Rotemberg, eds., *NBER Macroeconomic Annual*, Cambridge MA: MIT Press 1997, pp. 297–346.

Smets, Frank and Raf Wouters, "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, September 2003, *1* (5), 1123–1175.

Steinsson, Jón, "Optimal Monetary Policy in an Economy with Inflation Persistence," *Journal of Monetary Economics*, October 2003, *50* (7), 1425–1456.

Walsh, Carl E., "Speed Limit Policies: The Output Gap and Optimal Monetary Policy," *American Economic Review*, March 2003, *93* (1), 265–278.

__ , "Endogenous Objectives and the Evaluation of Targeting Rules for Monetary Policy," *Journal of Monetary Economics*, July 2005, *52* (5), 889–911.

Woodford, Michael, *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton, NJ: Princeton University Press, 2003.

Yogo, Motohiro, "Estimating the Elasticity of Intertemporal Substitution When Instruments Are Weak," *The Review of Economics and Statistics*, August 2004, *86* (3), 797–810.