ISSN 1518-3548

BANCO CENTRAL DO BRASIL

Working Paper Series 137

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May, 2007

ISSN 1518-3548
CGC 00.038.166/0001-05

Working Paper Series	Brasília	N. 137	May	2007	P. 1-40

Working Paper Series

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Monetary Policy Design under Competing Models of Inflation Persistence*

Solange Gouvea†
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Abstract

Most of the recent research in monetary policy has focused on the use of a single exogenously specified standard *ad hoc* loss function to evaluate policy performance. This literature has come to the conclusion that backward looking models are more difficult to control i.e. monetary policy performance deteriorates with an increase in inflation persistence. In this paper we test the validity of this conclusion using both a standard *ad hoc* loss function and a model consistent loss function across competing models of inflation persistence. We find that conclusions vary markedly with different types of loss functions. We also look into the case where the policymaker is uncertain about the pricing behavior of firms and investigate the presence of robust policy rules. We find that the existence of robust rules depend crucially on the type of loss function used to evaluate outcomes.

JEL Classification: E31; E52; D81
Keywords: Model Consistent Objectives; Inflation Persistence; Model Uncertainty

*We would like to thank Carl Walsh for his invaluable guidance. We would also like to thank seminar participants at University of California, Santa Cruz and India Development Form, New Delhi for their helpful comments. Financial assistance from the Graduate Division of University of California, Santa Cruz (both authors) and Central Bank of Brazil (Gouvea) is acknowledged with thanks. All remaining errors are our own responsibility

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1 Introduction

One of the most important recent developments in monetary policy analysis is the emergence of small scale monetary business cycle models, generally referred to as New Keynesian models. These models are notable for using microeconomic principles to describe the behavior of the households and firms, while allowing nominal rigidities and inefficient market outcomes, and being similar in structure to some of the traditional models used for policy analysis (such as the IS/LM model).

The New Keynesian models can be characterized primarily by two key equations. The first one is an aggregate demand equation that relates output gap negatively to the real interest rate and positively to future output gap. A rise in the real interest rate induces intertemporal substitution and reduces aggregate demand and the current output gap. The second key equation is the inflation adjustment equation, more commonly known as New Keynesian Phillips Curve (NKPC), and relates domestic inflation to the output gap and a supply shock. The baseline NKPC developed in Calvo (1983) has received a lot of attention in the literature as it is tractable and concisely summarizes the main mechanisms through which policy decisions affect the working of the economy. However, the baseline NKPC does a very poor job of explaining the dynamics of inflation, interest rate and output in the US as well as other developed countries. Specifically regarding price rigidities, the baseline NKPC does not match the inertia displayed in the inflation data of the main industrialized countries.[1] This has resulted in the development of a new generation of models that aimed at retaining the microeconomic approach to describing the behavior of the households and firms while trying to explain the movement in the inflation data. Several works in the literature have introduced alternative ways to model the behavior of price setters so that the inflation adjustment equation would incorporate an inertial component and therefore exhibit a better fit.

Most of the literature relies on these New Keynesian models to assess monetary policy performance. However, though the models incorporating inflation inertia have done well in matching the data, several papers like Levin and Williams (2003) and Adalid et al. (2005) have found these models to be more difficult to control. These papers look at model uncertainty and conclude that a higher loss would be achieved if the policymaker works with a more forward-looking model and the true model were characterized by a greater persistence. This policy advice is questioned in Walsh (2005) when model consistent loss function is used to assess the performance of monetary policy in a hybrid model. The model

[1] While the baseline NKPC predicts that current inflation depends only on current and future values of output gap and shock, a large econometric literature, including Nelson and Plosser (1992), Fuhrer and Moore (1995) and Pivetta and Reis (2004), conclude that postwar inflation in U.S. and other industrial countries exhibits high persistence. Other works like Baum et al. (1999) and Francisco and Bleaney (2005) have looked at developing countries and have found evidence for persistent inflation.

consistent loss function, popularized by Woodford (2003a), is derived from a second order approximation of the representative agent's welfare. In this loss function, both the relative weights on the variables in the loss function as well as the variables appearing in the loss function depend on the economic model. Walsh (2005) works with a hybrid model where current inflation depends on both lagged inflation as well as future expected inflation. He concludes that when policy outcomes are evaluated using model consistent welfare objectives, the overall loss declines with inflation inertia.

Given the different conclusions obtained about policy performance using different kinds of loss functions, it becomes imperative to investigate further the use of model consistent objectives in evaluating policy performance. For this purpose, we use two models of hybrid Phillips curve as derived by Gali and Gertler (1999) and Woodford (2003a). Our analysis differs from Walsh (2005) in several ways. We look at two varied models that exhibit different price setting behavior and evaluate policy outcomes using both standard *ad hoc* and model consistent objectives. The price setting behavior of these models have been analyzed in Gali and Gertler (1999) and Woodford (2003a). In this paper, the policymaker is assumed to follow a simple instrument rule to stabilize the economy. Finally, we also consider the case where the policymaker is uncertain about the exact pricing behavior of the firm and investigate the presence of robust rules using both model consistent and standard *ad hoc* objectives.

In the next section the baseline NKPC and two different hybrid versions of the Phillips curve are set out. Section 3 discusses the standard *ad hoc* loss and the model consistent loss function associated with the hybrid Phillips curves. The fourth section analyzes policy implications of using standard *ad hoc* versus model consistent loss function. The fifth section investigates the presence of robust policy rules in the face of model uncertainty. Finally, the sixth section concludes.

2 Setup of the Models

2.1 Modelling Inflation Inertia

2.1.1 Baseline Calvo Model

The baseline NKPC incorporating staggered price setting was introduced by Calvo (1983). A fraction $(1-\alpha)$ of firms are assumed to be able to choose new prices every period where as the remaining α firms have to keep their prices unchanged. For simplicity, the probability that any given price will be adjusted in any given period is assumed to be $(1-\alpha)$ and is independent of the length of time since the price was set and what the particular good's current price may be. Then it is possible to show that the log of the aggregate price level p_t evolves as a convex combination of the log of the lagged price level p_{t-1} and the log of optimal reset prices p_t^* as follows:

$$p_t = (1-\alpha)\ p_t^* + \alpha p_{t-1}. \tag{1}$$

Let mc_t^n be the firm's nominal marginal cost at time t and let β denote a subjective discount factor. Then for a firm that chooses price at t to maximize expected discounted profits subject to the Calvo pricing rule, the optimal reset price may be expressed as:

$$p_t^* = (1-\alpha\beta) \sum_{k=0}^{\infty} (\alpha\beta)^k E_t \left\{ mc_{t+k}^n \right\}. \tag{2}$$

In setting its price at t, the firm takes into account of the expected future path of nominal marginal cost, given the likelihood that its price may remain fixed for multiple periods. Combining equations (1) and (2) we can derive an inflation equation of the type:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa mc_t, \tag{3}$$

where $\kappa \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$ depends on the frequency of price adjustment α and subjective discount factor β. The real marginal cost is related to a measure of the output gap. The firm's real marginal cost is equal to the real wage it faces divided by the marginal product of labor. As a result, following Woodford (2003a) it can be shown that

$$mc_t = \left(\frac{\sigma + \omega}{1 + \omega\theta} \right) x_t, \tag{4}$$

where mc_t is the real marginal cost, σ is the inverse of the elasticity of substitution, θ is the price elasticity of demand, ω is the elasticity of labor and x_t is the output gap.

Thus equation (3) can be written as:

$$\pi_t = \beta E_t \pi_{t+1} + \tilde{\kappa} x_t + +\varepsilon_{\pi_t}, \tag{5}$$

where $\tilde{\kappa} = \kappa \left(\frac{\sigma+\omega}{1+\omega\theta} \right)$.

The assumption in the baseline Calvo model that prices remain fixed in money terms between those occasions upon which they are optimized conforms with apparent practice of many firms. However, reconciling this Phillips Curve with the data proves to be a more complicated task. Fuhrer and Moore (1995) point out that the benchmark new Phillips curve implies that inflation should lead the output gap over the cycle. A rise (decline) in the current inflation should signal a subsequent rise (decline) in the output gap. However, one finds the opposite pattern in the data. The data suggests that current output gap moves positively with future inflation and negatively with lagged inflation.[2]

[2]See Gali and Gertler (1999) for empirical evidence.

Equation (5) also predicts that there is no short run trade off between output and inflation as it implies that the central bank can achieve a disinflation of any size costlessly by committing to set the path of future output gaps equal to zero. Historical evidence shows that disinflations involve a substantial loss in output.[3]

The empirical limitations of the baseline NKPC have resulted in the development of a number of hybrid versions of the Phillips curve, which take into account lagged inflation.[4]

2.1.2 Rule of Thumb Price Setters (ROT Model)

Monetary policy has real effects on the economy due to the assumption that within a given period not all suppliers are able to adjust their prices in response to fluctuations in demand. We follow Calvo (1983) in assuming that each period $(1-\alpha)$ fraction of suppliers are offered the opportunity to adjust to a new price. This is due to the costs of changing prices such as loss of goodwill and menu costs. However, we also assume that there are costs involved with optimization, and, as a result, not all firms who can adjust prices choose optimum price. A fraction λ of the adjusters (forward-looking firms) decide to optimize while the remaining fraction $(1-\lambda)$ of the adjusters (backward-looking firms) follow a rule of thumb. Those suppliers who do not set their prices in the optimal manner use the rule of thumb of Gali and Gertler (1999) by setting their price, which is denoted by p_t^b, according to:

$$p_t^b = p_{t-1}^* + \pi_{t-1}, \tag{6}$$

where p_{t-1}^* is the average price set in the most recent round of adjustment with a correction for inflation. The forward-looking firms set their prices exactly as in the baseline Calvo model. Accordingly their price is expressed as:

$$p_t^f = (1-\alpha\beta)\sum_{k=0}^{\infty}(\alpha\beta)^k E_t\left\{mc_{t+k}^n\right\}. \tag{7}$$

The index for the newly set prices maybe expressed as:

$$\bar{p}_t^* = (1-\lambda)\,p_t^b + \lambda p_t^f. \tag{8}$$

[3]Central banks all over the world pursue the common primary goal of achieving a low and stable level of price variability and have implemented disinflation policies in order to avoid the well known costs of inflation. This is specially true for developing countries, which have experienced high and volatile mean inflation. Nevertheless, countries with higher mean inflation have experienced a much lower inflation-output trade off than low inflation countries. Ball et al. (1988) look at sample of 43 developing and developed countries and find that there is a significantly strong negative relationship between mean inflation and inflation-output trade-off.

[4]Several papers like Gali and Gertler (1999), Amato and Laubach (2005), Woodford (2003a) have derived a version of the Phillips curve that accounts for lagged inflation.

The aggregate price level evolves according to:

$$p_t^* = (1-\alpha)\,\bar{p}_t^* + \alpha p_{t-1}. \tag{9}$$

Combing equations (6), (7), (8) and (9) we get the Gali and Gertler hybrid Phillips curve as:[5]

$$\pi_t = \gamma^f E_t \pi_{t+1} + \gamma^b \pi_{t-1} + \tilde{\kappa} x_t + \varepsilon_{\pi_t}. \tag{10}$$

where

$$\tilde{\kappa} \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha + (1-\lambda)(1-\alpha(1-\beta))}\frac{\lambda(\sigma+\omega)}{1+\omega\theta},$$

$$\gamma^b \equiv \frac{(1-\lambda)}{\alpha + (1-\lambda)(1-\alpha(1-\beta))},$$

$$\gamma^f \equiv \frac{\alpha\beta}{\alpha + (1-\lambda)(1-\alpha(1-\beta))}$$

Note that when $\lambda = 1$, we get $\gamma^b = 0$, $\gamma^f = \beta$ and $\tilde{\kappa} \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\frac{(\sigma+\omega)}{1+\omega\theta}$ and equation (10) collapses to (3), which is the standard New Keynesian Phillips Curve.

2.1.3 Indexation to Past Inflation (IPI Model)

An alternative way to incorporate past inflation is to correct in a simple way for increases in the general price index. Yun (1996) assumes that prices are increased automatically at the long run average rate of inflation between the occasions on which they are reconsidered. In countries where inflation has been high, indexation schemes are generally based on a measure of inflation over some short interval of time. Thus it becomes more plausible to assume automatic indexation of price commitments to the change in the overall price index over some recent period. It is not plausible to assume that firms would be able to index prices to the current price index as it will create a simultaneity problem. It is more plausible to assume indexation of price to the change in the overall price index over some past time interval. Woodford (2003b) assumes partial indexation and claims that this improves the empirical fit of the model.

It is assumed that each period a randomly chosen $(1-\alpha)$ of all prices are reoptimized. However, the prices of the goods that are not optimized are set according to the indexation rule:

$$p_t = p_{t-1} + \gamma \pi_{t-1}, \tag{11}$$

[5] This Phillips curve is identical to the one obtained by Gali and Gertler (1999) and Amato and Laubach (2005)

where $0 \leq \gamma \leq 1$ measures the degree of indexation to the most recently available inflation measure. The firms who get a chance to reoptimize set their prices exactly as in the original Calvo formulation given by:

$$\bar{p}_t^* = (1 - \alpha\beta) \sum_{k=0}^{\infty} (\alpha\beta)^k E_t \left\{ mc_{t+k}^n \right\}. \tag{12}$$

The aggregate price in every period is given as:

$$p_t^* = (1 - \alpha) \bar{p}_t^* + \alpha p_t. \tag{13}$$

Solving equation (11), (12) and (13) we obtain a Phillips curve of the following form:[6]

$$\pi_t - \gamma\pi_{t-1} = \beta E_t (\pi_{t+1} - \gamma\pi_t) + \tilde{\kappa} x_t + + \varepsilon_{\pi_t}, \tag{14}$$

where $\tilde{\kappa} = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} \frac{(\sigma+\omega)}{1+\omega\theta}$.

Note that when $\gamma = 0$, equation (14) collapses to (3), which is the standard New Keynesian Phillips Curve.

2.2 Rest of the Model

The remaining model consists of an aggregate demand equation. The utility maximization of the representative agent yields the equation:

$$x_t = E_t x_{t+1} - \frac{1}{\sigma} (i_t - E_t \pi_{t+1}) + \varepsilon_{x_t}. \tag{15}$$

Recently some works like Gali et al. (2004) and Amato and Laubach (2005) have also looked at rule of thumb consumers and habit formation, which yield a variant of the aggregate demand equation. These works have been motivated by papers like Campbell and Mankiw (1989), which find empirical support of non-Ricardian behavior among a significant fraction of households in US and other industrialized countries. However, since the main objective of this paper is to investigate inflation dynamics, we follow works like McCallum and Nelson (1999), Clarida et al. (1999), Woodford (2003a), and Walsh (2003) and work with the benchmark aggregate demand equation, given by equation (15).

The shock process follow an AR(1) process of the following type:

$$\varepsilon_{\pi_{t+1}} = \rho_\pi \varepsilon_{\pi_t} + \xi_{\pi_{t+1}}, \text{and} \tag{16}$$

$$\varepsilon_{x_{t+1}} = \rho_x \varepsilon_{x_t} + \xi_{x_{t+1}}. \tag{17}$$

We obtain a well specified general equilibrium model that consists of equations (15), (16), (17) and either (10) or (14).

[6]This Phillips curve is identical to the one obtained by Woodford (2003a)

3 Welfare Implications of Inflation Inertia and the Instrument Rule

3.1 Standard *ad hoc* Loss Function

In the standard literature, majority of researchers consider the case where the policymaker tries to stabilize both inflation and the output gap around steady state values, which are assumed to be zero for simplicity. This kind of consideration gives rise to a loss function of the type:

$$L_t = \pi_t^2 + \lambda_x x_t^2, \tag{18}$$

where λ_x is the weight the policymaker puts on output gap stabilization relative to inflation.[7]. If $\lambda_x = 0$ then we have a policymaker that has been described by Mervyn King as "inflation nutter" i.e. the policymaker only cares about inflation fluctuations and not output gap fluctuations. On the other hand if $\lambda_x = 1$ then the policymaker is equally concerned about output gap and inflation stabilization.

3.2 Model Consistent Loss Function

Rotemberg and Woodford (1997) and Woodford (2003b) have shown that under certain conditions, a local approximation to the expected utility of the representative household is inversely related to the expected discounted value of a conventional quadratic loss function. The variables and the weights entering such a loss function depend on the behavior of the consumers and the price setters.

In this section we look at the structural loss functions that correspond to the two types of inflation inertia that was introduced in Section 2.

3.2.1 Rule of Thumb Price Setters

The use of rule of thumb behavior described in Section 2.1.2 does affect the objective of the policymaker. The policymaker chooses at some point t=0 a plan that maximizes the representative agent's welfare defined by:

$$V_t = U\left(Y_t, z_t\right) - \int_0^1 v\left(y_t\left(i\right), z_t\right) di, \tag{19}$$

where $v\left(y_t\left(i\right), z_t\right)$ is the disutility of producing good $y_t\left(i\right)$ and z_t is a vector of exogenous shocks. A second order approximation of equation (19) around the zero steady state yields a loss function of the type:

$$W = \sum_{t=0}^{\infty} \beta^t E_0 L_t. \tag{20}$$

[7]Several papers like Levin and Williams (2003) and Svensson (2000) also include an interest rate smoothing objective which can be justified on the basis of financial stability concerns

where the period loss L_t is given as:[8].

$$L_t = \pi_t^2 + \lambda_x x_t^2 + \lambda_{\Delta\pi} \left(\pi_t - \pi_{t-1}\right)^2 , \tag{21}$$

where $\lambda_x = \frac{\tilde{\kappa}}{\theta}$ and $\lambda_{\Delta\pi} = \frac{1-\lambda}{\alpha\lambda}$. Since a fraction $(1-\lambda)$ of price setters are learning about the optimal price by observing the average of prices set in the previous period, there is a reason for reducing variability in the change in inflation. This additional term increases the weight on inflation stabilization relative to output gap stabilization, as any reduction in inflation variability reduces the variability of the change in the inflation.

3.2.2 Indexation to Past Inflation

When the inflation inertia is due to backward indexation as shown in Section 2.1.3, and the utility of the representative agent is given by equation (19), then the structural period loss function is given as:[9]

$$L_t = \left(\pi_t - \gamma\pi_{t-1}\right)^2 + \lambda_x x_t^2, \tag{22}$$

where $\lambda_x = \frac{\tilde{\kappa}}{\theta}$ and $\tilde{\kappa}$ and θ have same definition as in Section 2.1.3.

We define $z_t \equiv \pi_t - \gamma\pi_{t-1}$. When $\gamma = 1$ i.e. we have full indexation then equation (22) points out that the the policymaker must stabilize the rate of inflation acceleration $\Delta\pi_t$ around zero rather than the rate of inflation itself. Due to the complete indexation to past inflation, constant inflation does not introduce any distortions in the economy. The distortions are only due to changes in rate of inflation.

3.3 Instrument Rule

Following the approach in Levin and Williams (2003) and Adalid et al. (2005) we consider a three parameter family of simple interest rate rule, where the nominal interest rate reacts to current inflation, output gap and lagged interest rate:

$$i_t = \tilde{\alpha}\pi_t + \tilde{\beta}x_t + \tilde{\rho}i_{t-1}. \tag{23}$$

The coefficients $\tilde{\alpha}$ and $\tilde{\beta}$ represent the policymaker's short term reactions to the deviation of inflation and output gap from their target values. The coefficient $\tilde{\rho}$ characterizes the inertia of the interest rate response also interpreted as the desired degree of policy smoothing. The above rule is what Levin et al. (1999) refer to as outcome rules. i.e. rules involving a small subset of current and lagged variables. They conclude that this class of simple rules perform as well as more complicated rules involving forecasts of inflation and output gap, across

[8]A detailed derivation of the structural loss function is provided in Amato and Laubach (2005)

[9]A detailed derivation of the structural loss function is provided in Walsh (2003) and Woodford (2003b)

different models of the US economy. These simple rules tend to be more robust to model uncertainty than more complicated rules. According to optimal control theory, policy rules should incorporate all the available information, and hence include all the state variables of the specific economic model. However, this rule which is optimal for a particular model may perform disastrously, if the economy is described by another model, which involves a different set of state variables.[10]

From an institutional point of view, simple rules have the advantage of greater transperancy; as a result they can be monitored by and communicated to the public sector. Even from an empirical point of view Clarida et al. (1998) show that simple interest rate rules match well the data for the United States and a number of European countries. Gerdesmeier and Roffia (2004) provide evidence for the euro area as a whole and conclude that Taylor-like rules estimated over the last two decades appear to be able to capture on average, substantial elements of past monetary policy behavior.

4 Policy Implications of Using Model Consistent Objectives

Recently several papers like Levin and Williams (2003), Adalid et al. (2005) etc. have employed a single loss function to evaluate the consequences of employing a policy rule that is optimal for one model when the economy is described by structural equations, which are very different from the ones that were used to obtain the optimal rule. However, there are several problems associated with using a single loss function. Giannoni and Woodford (2003) and Ireland (2003) point out that as one moves from a forward looking model to a relatively backward looking model, not only does the parameters of the welfare-theoretic loss function changes, but there is also a dramatic change in the basic functional form itself. When dealing with microfounded models, the loss function can represent an approximation of the representative households welfare. In such a scenario, both, parameters entering the loss function, as well as the functional form of the loss function itself, depend on the deep parameters of the model and the structural equations that describe the behavior of the economy.

Walsh (2005) considers the New Keynesian model developed by Benigno and Woodford (2005), which explicitly incorporates the case of a distorted steady state. They assume away the existence of employment subsidy that has been assumed in the literature to offset the distortion due to monopolistic competition. Walsh (2005) shows that in this model one reaches very different conclusions using a standard loss function like (18) than when one uses a welfare-theoretic

[10]Levin and Williams (2003) show that optimal targeting rules, which have complicated formulation in terms of leads and/or lags of target variables perform disastrously if the economy is described by a competing model.

loss function. In this section, we extend the analysis of Walsh (2005) to include two models incorporating inflation inertia reviewed in Section 2. These models incorporate very different price setting behavior.

We look at the implications of evaluating policy performance using a standard *ad hoc* loss function versus a model consistent loss function. We first consider the case where the policymaker is interested in minimizing the standard *ad hoc* loss function. We obtain the optimized interest rate rule for each of the models. The optimized interest rate rule includes optimized coefficients on current inflation, output gap and lagged interest rate that minimizes the standard *ad hoc* loss function.[11]. Finally, we report the performance in terms of the central bank loss function. We then repeat this procedure for the case where the policymaker seeks to minimize the model consistent loss function. To explore these cases we consider a calibrated version of the model. The baseline parameters for the ROT and the IPI models have been taken from Amato and Laubach (2005) and Woodford (2003b) respectively. These parameter values have been reproduced in Table 1.

Table 1: Calibrated Parameters for the Two Models

Structural Parameters	**Implied Parameters**	**Innovations**
$\alpha = 0.66$	$\kappa = 0.024$	$\rho_\pi = 0.5$
$\beta = 0.99$		$\rho_x = 0.5$
$\sigma = 0.157$		$\sigma^2_{(\xi,x)} = 1$
$\omega = 0.473$		$\sigma^2_{(\xi,\pi)} = 1$
$\theta = 7.88$		

4.1 Rule of Thumb Price Setters

The value of the loss function, when the policymaker implements an optimized rule, is reported below in Table 2. Here $\mathfrak{L}^{MC}_{MC}$ is the value of the model consistent loss function when the policymaker implements a rule optimized for this loss function, while $\mathfrak{L}^{Std}_{Std}$ is the value of the standard *ad hoc* loss function when an optimized rule for this loss function is implemented.

[11]The optimized coefficients on the lagged interest rate, current inflation and current output gap is obtained using the method outlined in Söderlind (1999) and the *fminsearch* routine in Matlab. The set up of the model and the method used to calculate the value of the loss function is described in greater detail in Appendix A and B

Table 2: Performance of Optimized Policy in the Rule of Thumb Behavior Model

Inertia	**Weights**		**Standard *ad hoc* Loss**				**Model Consistent Loss**			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$1-\lambda$	λ_x	$\lambda_{\Delta\pi}$	$\mathfrak{L}_{Std}^{Std}$	Var_π	Var_x	$Var_{\Delta\pi}$	$\mathfrak{L}_{MC}^{MC}$	Var_π	Var_x	$Var_{\Delta\pi}$
0.20	0.0297	0.387	1272.80	12.77	0.18	12.95	938.33	4.01	135.69	4.10
0.40	0.0181	1.01	3418.09	32.12	2.95	35.06	1286.83	3.22	386.65	2.92
0.60	0.0102	2.28	8887.78	63.28	29.24	92.52	1269.14	1.48	846.08	1.26
0.80	0.0044	6.3	14845.21	80.84	76.10	156.94	827.99	0.23	1609.84	0.18
1.00	0.00	∞	17879.88	91.24	100.74	191.88	NaN	NaN	NaN	NaN

As shown in column (4) of Table (2), $\mathfrak{L}_{Std}^{Std}$ increases with degree of indexation. This outcome is in concurrence with the standard result in the literature that greater persistence is associated with higher loss. Looking at columns (5) and (6), we observe that both components of the standard *ad hoc* loss, variance of inflation and the variance of output gap, increase with the degree of inflation inertia, thereby generating a higher loss. However, looking at column (8) we find that when loss is calculated using the model consistent loss function, we obtain a non monotonic result. The decomposition of the loss function shows that the magnitude of the variability of inflation and inflation gap are significantly less than the variability of output gap. Thus the outcomes are influenced mainly by the variability of the output gap. From columns (9) and (11) it is clear that in a higher indexed environment both inflation and inflation gap are less volatile. Intuitively, when a cost push shock hits these economies, inflation takes longer time to accommodate. In this case, the policymaker would have to impose a deeper recession in order to stabilize inflation. Therefore output gap becomes more volatile as the degree of indexation increases. On the other hand, in economies characterized by high inertia, the policymaker puts a smaller weight on on output gap. Interaction of the increasing variance with the decreasing weight on output gap implies that economies with medium levels of indexation incur greater loss.

4.2 Indexation to Past Inflation

The consequences of using a model consistent loss function versus a standard *ad hoc* loss function, when the firms set their prices according to the indexation to past inflation rule, are reported in Table 3. If the policymaker was to evaluate outcome using a standard *ad hoc* loss function, we again obtain the standard result that backward looking models are more difficult to control. Both the variance of inflation and output gap increase with degree of indexation, thereby yielding a higher loss. In contrast, if the policymaker was to follow a model consistent loss, he would infer that that the performance of the monetary policy improves substantially with the degree of inertia (γ). Thus models that exhibit higher intrinsic persistence, generates lower loss. This contradicts the common perception that performance of monetary policy decreases with inertia.

Table 3: Performance of Optimized Policy in the Indexation to Past Inflation Model

Structural Parameter	**Implied Parameter**	**Standard *ad hoc* Loss**			**Model Consistent Loss**		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
γ	λ_x	$\mathfrak{L}_{Std}^{Std}$	Var_π	Var_x	$\mathfrak{L}_{MC}^{MC}$	Var_z	Var_x
0.20	0.0486	651.28	6.57	0.04	467.28	4.60	5.72
0.40	0.0486	904.08	9.10	0.11	462.09	4.17	10.59
0.60	0.0486	1422.10	14.06	0.52	447.91	4.00	11.15
0.80	0.0486	2662.00	23.78	3.84	419.84	3.65	12.70
1.00	0.0486	5123.40	33.93	20.35	386.62	3.67	6.95

In the standard *ad hoc* loss the policymaker's objective is to minimize the volatility of inflation and output gap. As the degree of indexation increases it becomes more difficult to stabilize inflation around a zero steady state. In other words, in highly indexed economies it takes longer for inflation to return to its steady state level after a cost push shock. On the other hand, the model consistent loss incorporates a different inflation gap represented by $(\pi_t - \gamma\pi_{t-1})$. Here the policymaker is concerned about the dispersion caused by the difference between current inflation and γ times the lagged inflation. By reacting to deviations of inflation from the steady state the policymaker is able to reduce this inflation gap. Moreover, a higher value of γ implies that lagged inflation would be closer to current inflation which results in a lower loss.

The decomposition of the loss into the variance of its two components explains the decreasing trend of the $\mathfrak{L}_{MC}^{MC}$. Its clear from Column (7) in Table 3 that variance of z_t decreases with an increase in γ. Even though the volatility of the output gap is not monotonic, its weight in the computation of the loss is relatively small thereby not influencing the loss to a great extent. Similarly, the increasing trend of the $\mathfrak{L}_{Std}^{Std}$ reflects the increasing variability of both its components π_t and x_t as shown in Column (4) and (5) in Table 3.

5 Model Uncertainty

The degree of inflation inertia has been a focus of a great deal of theoretical as well as empirical research. While most researchers agree that the purely forward looking Phillips curve does not fit the data, there is a great deal of debate on which is the correct way to model inflation inertia. Gali and Gertler (1999) and Gali et al. (2001, 2002) find that the Phillips curve based on the rule of thumb behavior is consistent with inflation dynamics in United States as well as the Euro area. On the other hand Christiano et al. (2005) and Smets and Wouter (2002) assume partial or full indexation to lagged inflation and argue that this extension of the basic Calvo model improves the empirical fit.

In this section we consider the case where the central bank is aware that the true Phillips curve is a hybrid one but is uncertain about the exact pricing behavior of the firm. We investigate the presence of robust simple rules using a procedure similar to Levin and Williams (2003), Côté et al. (2002) and Adalid et al. (2005). We measure the relative performance of a specified rule in a model by looking at the relative loss. The relative loss, $\%\Delta L$, is defined as the percent difference between the loss under a specified policy rule and the optimal commitment rule.

$$\%\Delta L = \frac{L^{Opt\ \ Simp\ Rule} - L^{Commitment}}{L^{Commitment}} \times 100$$

Following the literature, we consider a rule generating $\%\Delta L$ significantly below 100 percent to yield satisfactory performance. In contrast, a rule yielding $\%\Delta L$ well above 100 percent is unacceptable.

However, a common feature of the literature is to carry out this robustness analysis using exogenous loss function only. As pointed out by Ireland (2003) this procedure might not be consistent. When dealing with microfounded models, the loss function can represent an approximation of the representative households welfare and parameters of the loss function then depend on the deep parameters of the model itself. In addition, for each of the hybrid models we work with, the correspondent functional form of the loss function itself changes. In order to address this concern, we incorporate both standard *ad hoc* and model consistent loss in our analysis.

We restrict our attention to three different degrees of inflation inertia. An economy is assumed to exhibit low inertia if either $\gamma = 0.2$ in the IPI model or $(1-\lambda) = 0.2$ in the ROT model. While a value of $\gamma = 0.5$ or $(1-\lambda) = 0.5$ implies medium inflation inertia, high inflation inertia is characterized by $\gamma = 0.8$ and $(1-\lambda) = 0.8$.

5.1 Robustness of Optimized Interest Rate Rule

We use an instrument rule of the type described in Section 3.3. For different degrees of inflation inertia, we obtain the optimized interest rate rule that minimizes the model consistent loss function obtained using one model of inflation inertia. Then we evaluate the performance of this rule when the inflation inertia is described by the competing model. We then repeat this analysis using the standard *ad hoc* loss function for both the models.

Table 4: Robustness of Optimized Policy Rules

Inertia	**Persistence**		**Comm. Loss**		**Indexation to Past Inflation**				**Rule of Thumb**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	γ	$1-\lambda$	$\mathfrak{L}^{IPI}_{comm}$	$\mathfrak{L}^{ROT}_{comm}$	$\mathfrak{L}^{IPI}_{IPI}$	%ΔL	$\mathfrak{L}^{IPI}_{ROT}$	%ΔL	$\mathfrak{L}^{ROT}_{ROT}$	%ΔL	$\mathfrak{L}^{ROT}_{IPI}$	%ΔL
	Model Consistent Loss											
Low	0.20	0.20	387	840	467	20.86	626	61.98	938	11.67	1336	59.02
Medium	0.50	0.50	387	1323	457	18.12	1736	348.95	1338	0.78	4737	258.06
High	0.80	0.20	387	828	420	8.59	6127	1484.95	828	0.01	17437	2006.23
	Standard *ad hoc* Loss											
Low	0.20	0.20	608	1154	651	7.07	654	7.59	1273	10.33	1276	10.57
Medium	0.50	0.50	996	4735	1113	11.73	1497	50.34	5704	20.47	6952	46.83
High	0.80	0.20	2192	14411	2662	21.45	3953	80.34	14845	3.01	62442	333.29

In the IPI model, the model consistent loss under optimum commitment rule is constant across different degrees of indexation while the ROT model yields a non monotonic loss as we increase the degree of inflation inertia.[12] Table 4 reports the losses and the relative losses

Looking at Table 4, we find that the optimized rule performs nearly as well as the optimal commitment rule. Looking at columns (6) and (10) we find that both across different levels of inertia as well as different loss functions the relative loss is less than 25 percent when we use an optimized rule instead of the optimal rule.

The top panel shows that when the policymaker knows that the economy is characterized by low inflation inertia then it is quite easy to obtain a robust policy rule. Column (7) shows that a rule optimized for the ROT model yields a relative loss of slightly more than 60 percent in the competing model where as column (9) shows that a rule that was optimized for the IPI model yields a relative loss of less than 60 percent. The reason for this robustness is very easy to see. In the case where inflation inertia is low, the Phillips curves in both the models are similar to baseline forward looking Phillips curve. Moreover, in the case of low inflation inertia, the model consistent loss functions given by equations (21) and (22) also become similar. In the extreme case when $\gamma = 0$ and $(1-\lambda) = 0$ equations (10) and (14) collapses to (3) and the loss functions given by (21) and (22) collapse to the standard loss function (18).

However, if the economy is characterized by medium or high inertia then it becomes very difficult to obtain a robust rule. In both cases when an optimized rule is simulated in the competing model, the relative loss turns out to be very high. As inflation becomes more and more persistent, the way inflation inertia is modeled becomes important. Moreover, the loss function also becomes significantly different. While the structural loss function from the ROT behavior

[12] Walsh (2005) using targeting rules obtains a constant loss across different degrees of inertia for the IPI model with a distorted steady state.

model comprise of inflation, output gap and inflation gap stabilization, the loss from the IPI model seeks to stabilize output gap and a quasi difference of inflation.

To look into this issue in more detail, we decompose the loss into the variance of the target variables. Table 5 explains the reason for the different values of the loss functions. Columns (1) and (2) display the variance of the quasi difference of inflation and output gap when the policymaker uses the optimized rule for the IPI model and the economy is characterized by the IPI model. In contrast, columns (3) and (4) exhibits the variances when the policymaker uses a competing rule optimized for the ROT model. Similarly, columns (5), (6) and (7) show the variance of inflation, the output gap and the inflation gap when the policymaker implements the rule from the ROT model and the economy is described by the ROT model while columns (8), (9) and (10) display the variance when a competing rule from the IPI model is used.

Table 5: Decomposition of the Model Consistent Loss

Inertia	**Indexation to Past Inflation**				**Rule of Thumb**					
	Opt Rule		**Comp Rule**		**Opt Rule**			**Comp Rule**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Var_z	Var_x	Var_z	Var_x	Var_π	Var_x	$Var_{\Delta\pi}$	Var_π	Var_x	$Var_{\Delta\pi}$
Low	4.60	5.72	2.27	85.79	4.01	135.69	4.10	10.54	12.26	7.05
Medium	4.12	10.67	0.95	346.59	2.38	588.03	2.07	33.96	37.19	9.27
High	3.65	12.71	0.12	1280.22	0.23	1609.84	0.18	126.94	47.62	9.26

Comparing column (1) and (2) with (3) and (4) we find that when the economy is actually described by the IPI model, the competing rule stabilizes the quasi difference of inflation much more than the optimizing rule. While both under the optimized and the competing rule, the variance of the quasi difference of the inflation decreases as inflation inertia increases, the decreases is more dramatic under the competing rule. One reason why the competing rule stabilizes quasi difference more is to do with the different functional form of the loss functions. The competing rule is obtained from the ROT model and aims to minimize variation of the inflation, output gap and inflation gap. In the the ROT model as degree of inflation inertia increases, the policymaker becomes more concerned about smoothing inflation than stabilizing inflation since the weight on $\pi_t - \pi_{t-1}$ increases with inflation inertia. Thus the optimized rule for the ROT model smooths inflation more than stabilizing it. When this rule is implemented in the IPI model and the loss function is given by equation (22) it stabilizes the quasi difference of inflation which is a deviant of the inflation gap.

However, under the competing rule, the variance of output gap is significantly higher compared to the optimized rule. We find that the variance of output gap increases both under the optimized and the competing rule as the economy becomes more indexed, and the increase under the competing rule is more dramatic. Again this divergence is due to the different functional form of the loss function. In the ROT model the policymaker is less and less concerned about output gap stabilization as the degree of inflation inertia increases. Thus the optimized rule for the ROT model does not attempt to stabilize output gap much. As a result when this rule is implemented in the IPI model we have a higher variance of the output gap. From Table 2 and Table 3 we can see that for any level of inflation inertia the policymaker following the IPI model is always more concerned about output stabilization than when he follows the ROT model. The higher variance of output gap when the competing rule is implemented combined with higher weight on output gap variation in the IPI model results in the higher loss.

The lower variance of the quasi difference of inflation under the competing rule is more than offset by the higher variance of the output gap thereby resulting in a higher loss. The higher variance of the output gap under the competing rule means that the performance of the competing rule deteriorates significantly as the economy becomes more indexed.

Columns (5) to (7) display the variance of the target variables when the policymaker implements an optimized rule from the ROT model and the firms set their prices according to the rule of thumb. We find that as the degree of inflation inertia increases, variability in both inflation and inflation gap decreases whereas the variance of output gap increases. However, when a competing rule, which is optimized for the IPI model, is simulated in the ROT model, variance of all the three target variables increase with the degree of inflation inertia. The increase in variance is maximum in the case of inflation as the rule from IPI model does not seek to stabilize inflation explicitly. The competing rule is aimed at stabilizing the output gap and quasi difference of inflation and therefore when this rule is implemented in the ROT model it is able to stabilize the output gap and inflation gap, which is a deviant of the quasi difference of inflation. The higher variance of inflation when the competing rule is implemented in the ROT model results in the higher loss. Thus we find that when the policymaker attempts to maximize the welfare of the representative individual and there is uncertainty about how firms update their prices one can obtain a robust rule only in the case where the economy is characterized by low inflation inertia.

Next, we focus on the case where the policymaker's objectives are characterized by equation (18). We follow the literature like Walsh (2005) and Levin and Williams (2003) in assuming that this loss function is fixed as we vary the pricing behavior. The results from using this loss function is displayed in the lower panel of Table 4 and Table 6. Looking at Table 4 we find that even when the policymaker evaluates the loss using a standard *ad hoc* loss function, the optimized interest rate rules perform well relative to the optimal commitment rule across the different models and different degrees of inertia.

Column (8) and (12) in Table 4 show that optimized rules from either model will work well in the other model if the economy is characterized by low or medium inertia. The relative loss is less than 10 percent when the economy is characterized by low inertia and around 50 percent when the economy is characterized by medium inertia. However, when the economy is characterized by high inflation inertia then a rule from the ROT model performs reasonably well in the IPI model but not the other way around. The reason for this can be found in Table 6. We find that when the true economy is given by the IPI model then both the components of the loss, variance of inflation and variance of output gap, are of similar magnitudes across different degrees of inflation inertia. While the optimized rule stabilizes output gap more, the competing rule does a better job of stabilizing inflation.

Table 6: Decomposition of the Standard *ad hoc* Loss

Inertia	**Indexation to Past Inflation**				**Rule of Thumb**			
	Opt Rule		**Comp Rule**		**Opt Rule**		**Comp Rule**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Var_π	Var_x	Var_π	Var_x	Var_π	Var_x	Var_π	Var_x
Low	6.58	0.04	6.52	0.13	12.77	0.18	12.90	0.08
Medium	11.14	0.23	9.63	5.68	48.48	10.42	71.20	0.59
High	23.79	3.84	15.25	25.65	80.84	76.10	751.16	9.22

When the true economy is characterized by the ROT model and it is characterized by low inflation inertia then both the optimized and the competing rule yield similar variance of output gap and inflation. However, if the economy is characterized by medium inflation inertia then even though the resulting loss is similar the components of the loss are dissimilar. The optimizing rule stabilizes inflation more while the competing rule stabilizes output gap more. Finally, if the economy is characterized by high inertia then the competing rule performs disastrously. Even though under the competing rule output gap is stabilized, inflation becomes extremely volatile and this results in a very high loss.

Thus we conclude that in the case of model uncertainty if the policymaker aims to minimize the welfare theoretic loss then a robust policy rule is obtained only when the economy is characterized by low inertia. It is not easy to obtain a robust rule if the economy is characterized by medium or high inflation inertia. On the other hand if the policymaker aims to minimize the standard *ad hoc* loss function then optimized policy rules from the ROT model perform very all in both the models i.e. these rules are robust to model uncertainty. Thus if the policymaker is uncertain about the price setting behavior of the firms then it would be safe for the policymaker to use an optimized rule from the ROT model.

5.2 Fault Tolerance

The results from the previous section show that it is not possible to obtain robust optimized simple interest rate rules when the economy is characterized by moderate and high inflation inertia, and the policy performance is evaluated using the model consistent loss function. In order to investigate further the presence of robustness, in this section we use an alternative method, following Levin and Williams (2003). This method, known as 'Fault Tolerance', considers deviations of a given parameter of the rule from its optimized value, and computes the change in relative loss. A model exhibits high tolerance if large deviations of the parameters from their optimized values imply a small change (below 100 percent) in relative loss. Robustness is obtained when a range of parameters values for the three coefficients of the rule, corresponds to relative loss below 100 percent in both models. In other words, one should look for common areas of high tolerance across the two models.

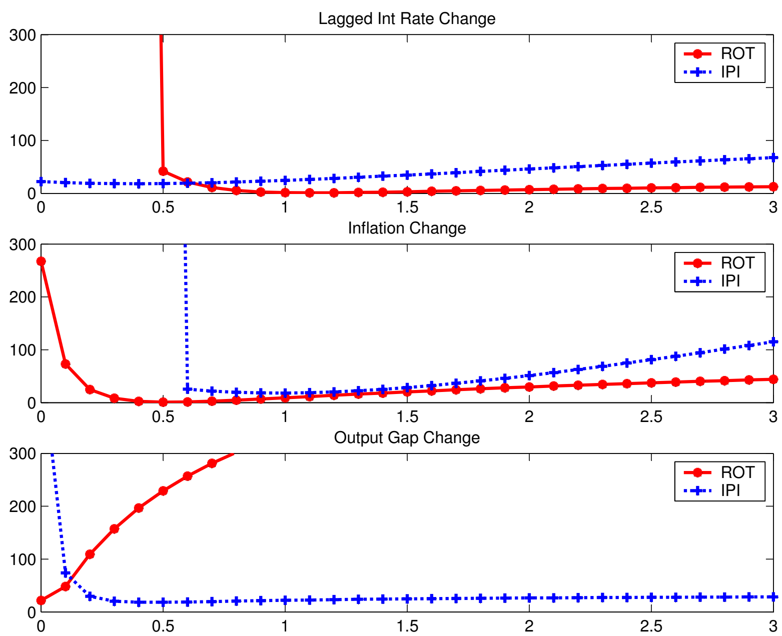

Figure 1: Fault Tolerance of both Models under Moderate Inflation Inertia

Figure 1 shows the fault tolerance of the two models under moderate inflation inertia. The two models display high fault tolerance to the coefficients on lagged interest rate and inflation. The ROT model is quite intolerant with respect to the deviations of the coefficient on the output gap. On the other hand, the IPI model shows high fault tolerance to the same coefficient. Therefore, it is possible to find a small common range of the coefficient on the output gap that corresponds to low relative loss. Robust policy rules can be found provided that the coefficients on lagged interest rate and inflation is not below 0.5 and 0.6 respectively. The coefficient on output gap should be restricted between 0.1 and 0.2.

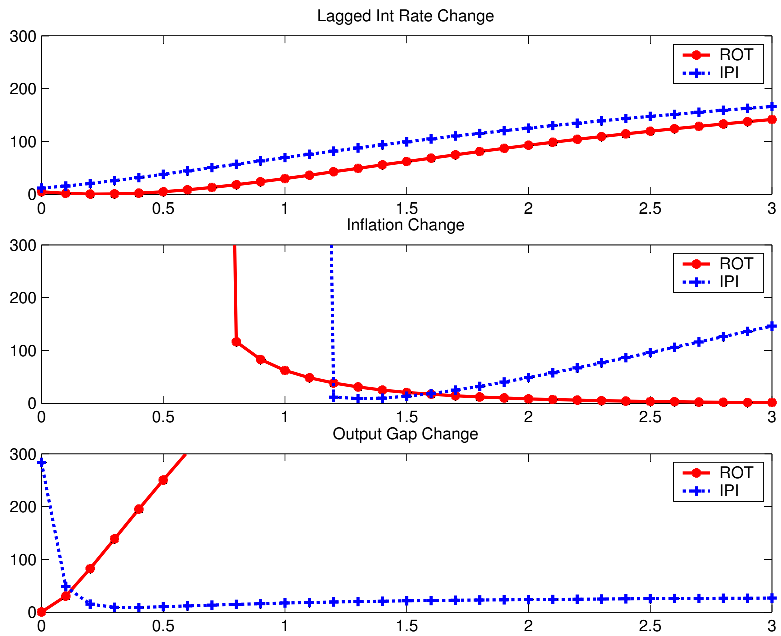

Figure 2: Fault Tolerance of both Models under High Inflation Inertia

Economies described by high inflation inertia are relatively less fault tolerant to the coefficients on lagged interest rate and inflation. In this case, robustness requires $\tilde{\rho}$ to be less than 1.3 and $\tilde{\alpha}$ to be limited between 1.2 and 2.2. Again, the overlapping region of low relative loss for the coefficient on the output gap is restricted between 0.1 and 0.2.

Beginning with the change in the coefficient on lagged interest rate, we find that optimal degree of interest rate smoothing is modest in case of moderate inflation inertia and extremely small for high inflation inertia. This result is coherent with the fact that interest rate smoothing does not play an important role in backward looking models. In these economies, monetary policy performance does not improve with inertial adjustment of the policy instrument due to the absence of the expectation channel. As we deviate the coefficient from the optimized value, there is a deterioration of the relative loss across both models, especially for high degree of inflation inertia. Typically, backward looking models require a more forceful reaction to shocks in inflation and output gap. Therefore, a higher concern for smoothing the interest rate prevents the policymaker to be as forceful resulting in a higher relative loss.

According to Figure 1 and 2 the more backward looking versions of the models require a stronger reaction to inflation. As noted above, the weak expectation channel in these models forces the policymaker needs to be more aggressive. This explains why under higher inflation inertia, the stability range shifts to the right. In addition, one can notice that the relative loss increases less rapidly with the coefficient on inflation in the ROT model. This may be due to the higher concern of the policymaker on inflation stabilization relative to output gap stabilization in the ROT model.

The overall fault tolerance analysis indicates that if the policymaker responds more aggressively to the output gap, there is an increase in the relative loss. In the ROT model, the weight on the inflation gap is much higher than on the output gap. Therefore, a higher volatility in inflation caused by a stronger reaction to output gap explains the rise in the relative loss. However, comparing Figure 1 and 2 we see that for moderate inflation inertia, the ROT model shows marginally higher fault tolerance. This can be explained by the difference in weights placed on inflation gap and output gap stabilization across the two different levels of inertia. In the case of high inflation inertia, the weight on inflation gap (6.06) is significantly higher than the weight on the output gap (0.0044), i.e. the policymaker shows approximately 1400 times more concern with inflation gap stabilization. On the other hand, under moderate inflation inertia, this difference is relatively smaller implying that the weight on inflation is about 110 times higher than the weight on output gap stabilization. Therefore, relative loss under moderate inflation inertia increases at a lower rate.

6 Conclusion

In this paper we look at the two different ways inflation inertia has been modeled in the literature. We also look into the use of both a standard *ad hoc* loss function and a welfare theoretic model consistent loss function to evaluate policy outcomes. Using the standard *ad hoc* loss function we obtain the standard result that policy performance deteriorates as the structural inflation process becomes more inertial in both the ROT and IPI model. However, this results breaks down when we use a model consistent loss function. In the IPI model the policy performance improves as the degree of indexation increases. On the other hand in the ROT model we get a non monotonic result with the loss being highest in the case of medium inertia.

Next we focus on the case where the policymaker is uncertain about the price setting behavior of the firms. We find that if the policymaker is evaluating outcomes using a welfare theoretic loss function then only in the case of low inflation inertia, the policymaker is able to obtain a robust rule. However, if he uses a standard *ad hoc* loss function with equal weight on inflation and output gap stabilization then an optimized rule from ROT model proves to be robust to model uncertainty.

Investigating further, the fault tolerance analysis of the two models under model consistent loss indicates that it is possible to find a range of parameter values for each coefficient of the instrument rule over which both models perform reasonably well. These ranges are fairly broad for the coefficients on lagged interest rate and inflation. However, the two models exhibit low relative loss over an extremely narrow interval for the coefficient on output gap.

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Appendix

A Setup of the Two Hybrid Models

The two models outlined in the paper have been solved following the method outlined in Söderlind (1999). The method requires the model to be set up in the following form.

$$\left[\begin{array}{c} x_{1_{t+1}} \\ E_t x_{2_t+1} \end{array}\right] = A \left[\begin{array}{c} x_{1_t} \\ x_{2_t} \end{array}\right] + B i_t + \left[\begin{array}{c} \varepsilon_{t+1} \\ 0_{n2*1} \end{array}\right] \tag{A.1}$$

where x_{1_t} is the set of predetermined or backward looking variables and x_{2_t} is the set of jump or forward looking variables. The loss function can then be written as

$$\mathfrak{L}_t = x_t' Q\, x_t \; + 2x_t' U\, u_t \; + u_t' R\, u_t \tag{A.2}$$

where $x_t = [x_{1_t}, x_{2_t}]'$ and u_t is the instrument used by the policymaker.

A.1 Model Consistent Loss

A.1.1 Rule of Thumb Price Setters Model

The ROT Price Setters model is made up of n1 = 4 predetermined variables $[\varepsilon_{\pi_t}, \varepsilon_{x_t}, \pi_{t-1}, i_{t-1}]$ and n2 = 2 forward looking variables $[\pi_t, x_t]$. Equations (15), (16), (17) and (10) along with trivial equations for π_t and i_t yield.

$$A_0 = \left[\begin{array}{cccccc} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma^f & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\sigma} & 1 \end{array}\right] \qquad A_1 = \left[\begin{array}{cccccc} \tau_\pi & 0 & 0 & 0 & 0 & 0 \\ 0 & \tau_x & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & -\gamma^b & 0 & 1 & -\kappa \\ 0 & -1 & 0 & 0 & 0 & 1 \end{array}\right] \qquad B_1 = \left[\begin{array}{c} 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ \frac{1}{\sigma} \end{array}\right]$$

where $A = A_0^{-1} A_1$ and $B = A_0^{-1} B_0$.

The model consistent loss in this model is given by equation (21). This loss function can be written as equation (A.2) with

$$Q = \left[\begin{array}{cccccc} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda_{\Delta\pi} & 0 & -\lambda_{\Delta\pi} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\lambda_{\Delta\pi} & 0 & 1+\lambda_{\Delta\pi} & 0 \\ 0 & 0 & 0 & 0 & 0 & \lambda_x \end{array}\right] \qquad U = \left[\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{array}\right] \qquad R = [0]$$

Finally the instrument rule can be written as

$$i_t = -F \begin{bmatrix} x_{1_t} \\ x_{2_t} \end{bmatrix} \tag{A.3}$$

where the F matrix is given as $[0, 0, 0, \tilde{\rho}, \tilde{\alpha}, \tilde{\beta}]$

A.1.2 Indexation to Past Inflation

The IPI model also has n1 = 4 predetermined variables $[\varepsilon_{\pi_t}, \varepsilon_{x_t}, \pi_{t-1}, i_{t-1}]$ and n2 = 2 forward looking variables $[\pi_t, x_t]$. Again, equations (15), (16), (17) and (14) along with trivial equations for π_t and i_t yield.

$$A_0 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -\beta\gamma & 0 & \beta & 0 \\ 0 & 0 & 0 & 0 & \sigma & 1 \end{bmatrix} \quad A_1 = \begin{bmatrix} \tau_\pi & 0 & 0 & 0 & 0 & 0 \\ 0 & \tau_\pi & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & -\gamma & 0 & 1 & -\kappa \\ 0 & -1 & 0 & 0 & 0 & 1 \end{bmatrix} \quad B_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ \sigma \end{bmatrix}$$

where $A = A_0^{-1} A_1$ and $B = A_0^{-1} B_0$. The model consistent loss function of this model is given by equation (22) which can also be written in the form of equation (A.2) with

$$Q = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma^2 & 0 & -\gamma & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\gamma & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & \lambda_x \end{bmatrix} \quad U = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad R = [0]$$

The instrument rule is given by the equation (A.3) where the F matrix is given as $[0, 0, 0, \tilde{\rho}, \tilde{\alpha}, \tilde{\beta}]$.

A.2 Standard *ad hoc* Loss

A.2.1 Rule of Thumb Price Setters Model

The standard *ad hoc* loss function is given by equation 18. Since there is no change in the structural equations of the model the A and B matrices are same as in Section A.1.1. In the Q matrix we impose the condition $\lambda_x = 1$ and that $\lambda_{\Delta\pi} = 0$ so that equation (A.2) corresponds to equation 18. The R and U matrices continue to be same as above

A.2.2 Indexation to Past Inflation

The A and B matrices continue to be same as in section A.1.2. However, since now we have π_t instead of z_t in the loss function the Q matrix changes to

$$Q = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & \lambda_x \end{bmatrix}$$

while the U and R matrices are same as above.

B Solving the Models

Given, the structural matrices A and B and the instrument rule matrix F the dynamics of each of the model can be written as

$$x_{1_{t+1}} = Mx_{1_{t+1}} + \varepsilon_{t+1} \tag{A.4}$$

$$x_{2_t} = Cx_{1_t} \tag{A.5}$$

and the loss function is given by

$$J_0 = x'_{10}Vx_{10} + \frac{\beta}{1-\beta}tr\left(V\Sigma\right) \tag{A.6}$$

where x_{10} is the value of the predetermined variables at time t = 0, Σ is the variance covariance matrix of ϵ_{t+1} and where V_s is determined by

$$V_s = P' \begin{bmatrix} Q & U \\ U' & R \end{bmatrix} P + \beta M' V_{s+1} M \tag{A.7}$$

where P = $\begin{bmatrix} I_{n_1} \\ \mathrm{C} \\ -F \begin{bmatrix} I_{n_1} \\ C \end{bmatrix} \end{bmatrix}$

C Calculating the Loss under Commitment

This subsection describes the procedure used to calculate the loss under the commitment. The models need to be set up in the form shown in equation (A.1. Define n1 as the dimension of x_{1_t}, n2 as the dimension of x_{2_t} and finally n = n1 + n2. Let ρ_{1_t} be an $n1 \times 1$ vector of Lagrangian multipliers associated with the predetermined variables and ρ_{2_t} be an $n2 \times 1$ vector of Lagrangian multipliers associated with the forward looking variables. The rational expectations equilibrium under the optimal commitment policy is given by (see Söderlind (1999))

$$\begin{bmatrix} x_{1_{t+1}} \\ \rho_{2_{t+1}} \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} x_{1_t} \\ \rho_{2_t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{t+1} \\ 0_{n2\times 1} \end{bmatrix} \tag{A.8}$$

and

$$\begin{bmatrix} x_{2_t} \\ i_t \\ \rho_{1_t} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \\ C_{31} & C_{32} \end{bmatrix} \begin{bmatrix} x_{1_t} \\ \rho_{2_t} \end{bmatrix} = \bar{C} \begin{bmatrix} x_{1_t} \\ \rho_{2_t} \end{bmatrix} \tag{A.9}$$

where $\bar{C}$ is of the dimension $(n2 + 1 + n1) \times (n1 + n2)$

Let the loss function be given by

$$\mathfrak{L}_t = Z_t' W Z_t + \beta E_t \mathfrak{L}_{t+1} \tag{A.10}$$

where

$$Z_t = \begin{bmatrix} x_{1_t} \\ x_{2_t} \\ i_t \end{bmatrix} \qquad W = \begin{bmatrix} Q & U \\ U' & R \end{bmatrix}$$

Using equation (A.9)we obtain

$$Z_t = \begin{bmatrix} x_{1_t} \\ x_{2_t} \\ i_t \end{bmatrix} = \begin{bmatrix} x_{1_t} \\ S \begin{bmatrix} x_{2_t} \\ i_t \\ \rho_{1_t} \end{bmatrix} \end{bmatrix} = \begin{bmatrix} x_{1_t} \\ S\bar{C} \begin{bmatrix} x_{1_t} \\ \rho_{2_t} \end{bmatrix} \end{bmatrix} \tag{A.11}$$

or

$$Z_t = \begin{bmatrix} I_{n1\times n1} & 0_{n1\times n1+n2} \\ 0_{n1\times n1} & S\bar{C} \end{bmatrix} \begin{bmatrix} x_{1_t} \\ x_{1_t} \\ \rho_{2_t} \end{bmatrix} = \Gamma \begin{bmatrix} x_{1_t} \\ x_{1_t} \\ \rho_{2_t} \end{bmatrix} \tag{A.12}$$

where $S = [I_{n2+1} \quad 0_{n2+1\times n1}]$

Next we add the following equation to the system given by A.8

$$x_{1_{t+1}} = M_{11} x_{1_t} + M_{12} \rho_{2_t} + \varepsilon_{t+1} \tag{A.13}$$

Then the new system can be written as

$$\begin{bmatrix} x_{1_{t+1}} \\ x_{1_{t+1}} \\ \rho_{2_{t+1}} \end{bmatrix} = \begin{bmatrix} 0_{n1\times n1} & M_{11} & M_{12} \\ 0_{n1\times n1} & M_{11} & M_{12} \\ 0_{n2\times n1} & M_{21} & M_{22} \end{bmatrix} \begin{bmatrix} x_{1_t} \\ x_{1_t} \\ \rho_{2_t} \end{bmatrix} = \Omega \begin{bmatrix} x_{1_t} \\ x_{1_t} \\ \rho_{2_t} \end{bmatrix} \tag{A.14}$$

Given the linear quadratic structure the loss function L can be expressed as $X_t' V X_t + d$ where

$$X_t' V X_t = X_t' \Gamma' W \Gamma X_t + \beta E_t \left[X_{t+1}' V X_{t+1} + d \right]$$

$$X_t' V X_t = X_t' \Gamma' W \Gamma X_t + \beta [X_t' \Omega' V \Omega X_t] + \beta trace(V \Sigma_\phi) \tag{A.15}$$

or V satisfies

$$V = \Gamma' W \Gamma + \beta \Omega' V \Omega \tag{A.16}$$

and d satisfies

$$d = \beta [trace(V \Sigma_\phi) + d] = (\frac{\beta}{1-\beta}) trace(V \Sigma_\phi) \tag{A.17}$$

where Σ_ϕ is the variance covariance matrix with the variance of $[x_{1_t}, x_{1_t}, x_{2_t}]$ on the diagonal. Equation (A.16) can be solved for the value of V and then equation (A.17) can be used to obtain d.

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