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# Do inflation targeting central banks behave asymmetrically? Evidence from Australia and New Zealand

## Abstract<sup>1,2</sup>

This paper tests the standard quadratic approximation to central bank preferences on data from Australia and New Zealand, two of the earliest explicit inflation targeting countries. The standard linear-quadratic monetary policy model assumes central bank preferences over key macroeconomic variables, such as inflation and output, can be usefully approximated by a quadratic function. This approximation implies that a deviation from a target is considered to be equally costly irrespective of whether the deviation is positive or negative. Combined with a linear model of the economy, quadratic preferences are useful because they yield a first order condition that implies a linear interest rate reaction function. This paper relaxes the assumption of quadratic preferences by allowing central banks to regard the costs associated with positive and negative output gaps differently. Our models also test for the possibility that positive and negative deviations of inflation from target to be treated differently. During the inflation targeting period in both countries, evidence suggests that we cannot reject quadratic preferences over inflation deviations (from target). We cannot reject that New Zealand's preferences regarding deviations of output from trend are quadratic, but Australia's behaviour does not appear to be consistent with quadratic preferences. Instead, the preferences of the Reserve Bank of Australia appear to be more accurately modelled with an asymmetric loss such that the Reserve Bank of Australia views negative output gaps as more costly than positive output gaps.

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<sup>2</sup> The views expressed in the paper are those of the authors. No inference should be drawn from the paper regarding the views of the Reserve Bank of New Zealand. We thank David Archer, Nils Björkstén, Clive Granger, Arthur Grimes, Adrian Pagan, Christie Smith and seminar participants at the NZESG and the Reserve Bank of New Zealand, for useful comments.  
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## 1 Introduction

It is well-recognised that inflation targeting central banks pay attention to more than just inflation. Indeed, the adjective 'flexible' has gradually crept in to precede inflation targeting in most instances. In practice this means that central banks care about output deviations from potential output as well as inflation deviations from target. But are positive output gaps as distasteful as negative output gaps? And is undershooting the inflation target as bad as overshooting it? In principle, the preferences of monetary policy decision can be inferred from interest rate decisions.

When analysing monetary policy, central bank preferences are usually approximated with a quadratic loss function such that deviations of inflation (from target) and output (from trend) are ranked according to a quadratic function (for example Barro and Gordon 1983). Quadratic loss functions imply that positive deviations of inflation (from target) are just as unpalatable as negative deviations of inflation of the same magnitude, and that positive output gaps are of as much concern as negative output gaps of the same size. These findings are critically important to quantitative monetary policy analysis because the linear-quadratic framework is routinely used to analyse many important questions, such as about the efficacy of simple policy rules, how to conduct policy under uncertainty, and the benefits of commitment to a monetary policy rule relative to discretion. If the central banks have non-quadratic preferences, the conclusions drawn from the linear-quadratic approach to monetary policy analysis would be undermined.

Recently, several papers have found evidence that many central banks do not behave in a manner consistent with quadratic preferences. Cukierman and Gerlach (2002) and Cukierman and Muscatelli (2003) state that central banks may employ a 'precautionary demand for expansions', that is, when policymakers are uncertain about the state of the economy, central banks may respond relatively more aggressively to negative output gaps than to positive output gaps of the same magnitude. In addition, central banks probably attract more criticism when contracting the economy compared with stimulating the economy. Such possibilities imply

that central bank preferences may not be symmetric, as is usually assumed. Bec, Salem and Collard (2002), Ruge-Murcia (2002) and Surico (2003) come to similar conclusions for different countries that there exists some evidence in favour of non-quadratic loss functions for central banks. Orphanides and Wieland (2000) argue that the existence of inflation target zones indicates central bank preferences may not be accurately approximated with a quadratic function.

The quadratic approximation to central bank preferences can be tested using a revealed preference concept similar to the method Salemi (1995), Söderlind (1999) and Dennis (2003), use to parameterise quadratic preferences for the US Federal Reserve, based on the estimation of linear reaction functions. The method assumes that the central bank conducts monetary policy optimally, given their knowledge about the model of the economy. If the economy can be approximated by a linear model and the central bank preferences are not closely approximated by a quadratic loss function, then the reaction function the central bank uses to set the nominal interest rate will be nonlinear. Hence researchers can reveal deviations from the quadratic approximation to central bank preferences based on inference from the reaction function. It is perhaps unsurprising if central bank preferences are not well approximated by a quadratic loss function. While the costs associated with low or negative inflation deviations (deflation) may be approximately equal to the costs associated with positive inflation deviations (including increased price signal uncertainty for firms associated with a negative growth effect, income tax distortions, menu costs and shoe leather costs), the costs associated with positive output gaps (including, but not limited to asset price inflation) appear markedly lower than the costs associated with negative output gaps (for example, unemployment, bankruptcies and lower investment).

In this paper, we test the hypothesis of quadratic preferences for Australia and New Zealand. Both Australia and New Zealand adopted inflation targeting in the early 1990s. Inflation targeting has been a successful monetary policy framework — in terms of reducing both the level and volatility of inflation. Although New Zealand and Australia share many common characteristics, their

economies are quite different in many respects and the two countries have made many quite different policy choices. The differences in policy choices might reflect their different economic structures or, alternatively, they might reflect different preferences for different outcomes. Consequently, even though both countries are explicitly inflation targeters committed to keeping inflation within their stated target ranges, the central banks may not have ‘preferences’ that are exactly alike.

The paper proceeds as follows. Section 2 reviews the standard framework for the central bank’s problem. Section 3 estimates linear reaction functions and conducts residual-based tests that are indicative of potential non-linearity in the reaction function. Section 4 estimates reaction functions for two classes of non-linear models to back up central bank preferences. Section 5 concludes.

## 2 The framework

### 2.1 The linear quadratic framework

We can think of the job of the central bank as setting the interest rate to achieve a good set of outcomes for the macroeconomy. The linear-quadratic framework formalises a mirror image of this problem, and assumes that the central bank minimises a loss function that summarizes a bad set of outcomes for the macroeconomy. The central bank sets the interest rate to minimise this loss function intertemporally, represented mathematically:

$$\min_i E_0 \sum_{t=0}^{\infty} \delta^t L_t \quad (1)$$

where  $\delta$  is the discount factor and  $0 > \delta \geq 1$ ,  $t$  is the time subscript,  $E$  is the expectations operator and  $L_t$  represents the period or a temporal loss function which ascribes quadratic preferences over particular macroeconomic variables to the central bank. This period loss function can be represented as:

$$L_t^{cb} = \{x_t' R x_t + i_t' Q i_t\} \quad (2)$$

where it represents the policy instrument for the central bank, most commonly the interest rate and  $x_t$  represents the other variables in the model, the state variables. The matrices  $Q$  and  $R$  ascribe weights to particular state variables — common representations of inflation targeting ascribe positive weights to inflation, the output gap and the change in the nominal interest rate.

When setting the interest rate to achieve good outcomes, the central bank must take account of the role of economy in translating interest rate decisions to actual outcomes for the macroeconomy. Thus the central bank's model of the economy constrains the extent to which the central bank can achieve their objectives. A general representation of the economy can take the following form:

$$\begin{bmatrix} x_{1t+1} \\ E_t x_{2t+1} \end{bmatrix} = A \begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} + B i_t + \begin{bmatrix} \varepsilon_{t+1} \\ 0_{n2 \times 1} \end{bmatrix} \quad (3)$$

with  $x_{1t}$  denoting predetermined variables and  $x_{2t}$  denoting expectational or forward-looking variables.

Under quadratic preferences, solutions methods to obtain linear reaction functions for the interest rate exist for both forward-looking models (see Söderlind (1999) or Dennis (2001) for solution methods to a slightly more general set of models) and backward-looking models (see Ljungqvist and Sargent (2000), for example). For the forward-looking model in equation (4), optimal monetary policy, under discretion, can be expressed as:

$$i_t = -F x_{1t} \quad (4)$$

such that the interest rate is a function of the observed state variables. Note also one key feature of the linear-quadratic framework — certainty equivalence — such that the optimal interest rate setting is not a function of the size of the errors in equation (3).

However, the assumption of quadratic preferences is critical in generating linear first order conditions. If quadratic preferences are not used to model central bank preferences, first order conditions imply a non-linear reaction function without certainty equivalence

and thus a non-linear model of the evolution of the economy. Clearly, the assumption of quadratic preferences yields simpler, more tractable expressions for optimal policy.

## 2.2 Relaxing the assumption of quadratic preferences

To test the assumption of quadratic preferences we firstly relax a version of equation (2) that contains inflation and output gap to take the form:

$$L_t = h(\pi_t - \pi^*) + \lambda f(\tilde{y}_t) \quad (5)$$

where  $h(\cdot)$  and  $f(\cdot)$  are general functions that encompass the policymaker's preferences over inflation deviations from a target,  $(\pi_t - \pi^*)$ , and the output gap,  $\tilde{y}_t$ . The coefficient  $\lambda$  parameterises the policymaker's concern for the output gap relative to deviations of inflation from target. Equation (5) is the very general specification used in Cukierman and Muscatelli (2003), who test four G7 countries for asymmetric behaviour. Much of this paper follows the method of that paper.

Restricting preferences to a quadratic function implies that the second order derivatives,  $h''(\cdot)$  and  $f''(\cdot)$ , are positive and the third order derivatives,  $h'''(\cdot)$  and  $f'''(\cdot)$ , are zero. Relaxing the assumption of quadratic preferences allows non-zero third order derivatives, which permits the asymmetric central bank preferences.

Suppose that policymakers prefer negative output gaps in comparison to positive output gaps of the same magnitude. This implies that negative deviations of output from trend are weighted more strongly in the loss function than are positive deviations. Hence,  $f'''(\cdot)$ , the third derivative of the output argument in the loss function, is negative. Why would the central bank weight positive output deviations less strongly than negative ones? Negative output gaps are more likely to be associated with unemployment, bankruptcies and lower investment. Conversely, positive output gaps

may be associated with asset price inflation which may induce higher inflation in the future, above and beyond the standard channel of transmission from output to inflation.<sup>3</sup>

Furthermore, volatility in output may be associated with uncertainty and reduced investment. We take the position that the costs from below-trend output could outweigh the costs to above-trend output. Blinder (1997) notes that: "...Academic macroeconomists tend to use quadratic loss functions for reasons of mathematical convenience without thinking about their substantive implications."<sup>4</sup> This appears to be particularly true of modelling central bank preferences over output deviations. Why would the central bank weight positive inflation deviations more strongly than negative ones? The literature (see, for example, Okun, (1975), Hall (1984) and Diamond (1993)) identifies three main costs of high inflation: (i) shoe leather costs which represent the cost of attempting to minimise money holdings in a high inflation environment; (ii) menu costs that are the costs associated with changing prices; and (iii) distortions that arise within the tax and transfer system (Feldstein, 1983). With respect to the rate of inflation, suppose that policymakers weight positive deviations of inflation from target more strongly than negative deviations. This assumption implies that  $h'''(\cdot)$ , the third derivative of the inflation argument in the loss function, is positive.

Akerlof, Dickens and Perry (1996 and 2000) argue that a low rate of inflation may be detrimental to the economy. This is because firms find it difficult to introduce nominal wage reductions: a positive rate of inflation gives some flexibility in the real wage, that helps insulate firms from lower product demand during recessions. That said, several researchers find very little evidence of downward nominal wage rigidity and argue that this effect is small (see for example, Card and Hyslop (1997), Hogan (1997) and Kahn (1997)).

<sup>3</sup> The standard argument that above trend output leads to higher inflation and should therefore be included in the loss function is fallacious. In an intertemporal context, future inflation appears in the central bank's loss function. Including contemporaneous positive deviations of output from trend would constitute double counting.

<sup>4</sup> Chadha and Schellekens (1999) use this quote to motivate examining the costs of inflation.

However, there exist additional reasons why low inflation may be costly. Low rates of inflation may lead to an increased probability of deflation, associated with the costs of a downward spiral of weak consumer spending and weak investment. Finally, the Consumer Price Index may overstate the true rate of inflation because of quality improvement and partly because of the introduction of new goods into the index.<sup>5</sup>

There is no particular reason to suppose that the costs of below target inflation are of the same magnitude as the costs of above target inflation. Policymakers could form a coherent argument in favour of asymmetric preferences based on the literature on the costs of inflation.<sup>6</sup>

### 2.3 The economy

The model of the economy takes the form of the structural, closed economy model of Clarida, Galí and Gertler (1999), presented below:

$$\tilde{y}_t = -\phi(i_t - E_t \pi_{t+1}) + E_t \tilde{y}_{t+1} + \hat{g}_t \quad (6)$$

$$\pi_t = \xi \tilde{y}_t + \theta E_t \pi_{t+1} + \hat{u}_t \quad (7)$$

where  $\tilde{y}_t$  is the output gap,  $\pi_t$  is inflation and  $\hat{g}_t$  and  $\hat{u}_t$  are autoregressive demand and cost shocks. The model also benefits from foundations drawn from the optimising behaviour of agents. In particular, the aggregate demand equation is founded on a consumption Euler equation, while the aggregate supply equation can be supported by Calvo-type price setting behaviour and indeed other optimising behaviour (see Roberts (1995) for discussion).

<sup>5</sup> Lebow and Rudd (forthcoming) estimate that these effects imply the Consumer Price Index may overstate the true rate of inflation by approximately 60 basis points for the US.

<sup>6</sup> There are also costs associated with volatility of inflation *per se*, such as increased uncertainty, reduced investment and the associated resources lost through devoting resources to forecasting inflation. However, at the margin, the argument against symmetric preferences still holds.

Following Cukierman and Muscatelli (2003), we make the assumption that the shocks consist of two components — one component that is known at time  $t$  and one that is not known and cannot be forecast at time  $t$ . Thus the shocks can be defined:

$$\hat{g}_t = g_t + \tilde{g}_t \quad (8)$$

$$\hat{u}_t = u_t + \tilde{u}_t \quad (9)$$

where  $g_t$  and  $u_t$  are the known components and  $\tilde{g}_t$  and  $\tilde{u}_t$  are the random components assumed to be mean zero, independent processes.

## 2.4 The reaction function

The reaction function specifies a plan for setting the interest rate that generates good outcomes for the given model of the economy. In the Clarida, Galí and Gertler (1999) model, the reaction function is reduced to arguments over expected inflation and expected output only. However, in practice, the observed behaviour of interest rates show considerable interest rate smoothing (see for example, Lowe and Ellis (1997), Sack and Wieland (2000), and Drew and Plantier (2000)).<sup>7</sup>

Under interest rate smoothing, the reaction function takes the form:

$$i_t = \rho i_{t-1} + (1 - \rho) i_t^* \quad (10)$$

where  $i_t^*$  represents the desired interest rate and  $\rho$  parameterises the degree of interest rate smoothing. The interest rate smoothing term comes from the observed inertia in the interest rates across many countries. Cukierman and Muscatelli (2003) show that under symmetric preferences the desired reaction function under the closed

<sup>7</sup> Nevertheless, the issue of interest rate smoothing is subject to a considerable debate, as some argue that the empirical findings in favour of interest rate smoothing are either the serial correlation in residuals or the serial correlation in the output gap revisions (Rudebusch 2002, Lansing 2002).

economy model of Clarida, Galí and Gertler (1999) reduces to the following linear equation under interest rate smoothing:

$$i_t = (1 - \rho) \left\{ \alpha + \beta (E\pi_{t,k} | \Omega_t - \pi^*) + \gamma E\tilde{y}_{t,q} | \Omega_t \right\} + \rho i_{t-1} + v_t \quad (11)$$

where  $\alpha$  is the constant or the neutral nominal interest rate,  $\beta$  is the response to the deviations of inflation from its target,  $\gamma$  is the response to the output gap and  $v_t$  is the expectational error.<sup>8</sup> Adding and subtracting the terms  $\beta E[\pi_{t,k} | \Omega_t]$  and  $\gamma E[\tilde{y}_{t,q} | \Omega_t]$  to both sides of equation (11) yields to the following:

$$i_t = (1 - \rho) \left\{ \alpha + \beta (\pi_{t+1} - \pi^*) + \gamma \tilde{y}_{t+1} \right\} + \rho i_{t-1} + \xi_t \quad (12)$$

This equation lends itself to preliminary tests for evidence of asymmetric preferences. If the residuals from this regression are well behaved then we cannot reject a quadratic approximation of central bank preferences. However, Granger and Teräsvirta (1993) state that specific nonlinearities in the residuals are indicative of nonlinear behaviour, which within our model implies that the central bank behave asymmetrically. The following section begins by estimating equation (12) and conducting these indicative residual-based tests, before proceeding to examine nonlinear reaction functions.

## 3 Residual-based tests

In this section we examine the actions of the central banks of Australia and New Zealand over the inflation targeting period, to make inferences about whether their preferences can fairly be described as quadratic. New Zealand's legislative framework for inflation targeting came into effect in February, 1990. However, it took some time for inflation to fall to low levels. This disinflation period was also associated with a large recession in New Zealand, with output not recovering until early 1993. We wished to exclude

<sup>8</sup> Cukierman and Muscatelli's (2003) derivation is shown in the Appendix to this paper, which also examines the second and third order derivatives of the reaction function.

this disinflationary period from our analysis and focus on a stable inflation targeting regime from 1993q1.<sup>9</sup>

Australia adopted a more gradual approach to inflation targeting and the appropriate starting date for the inflation targeting period is more ambiguous. However, researchers favour dating early 1993 as the inflation targeting period in Australia and this is the date used within this paper (see Bernanke et al. (1999) for support on this view and Grenville (1997) for a wider discussion on dating the inflation targeting period in Australia).

### 3.1 Linear reaction functions

Without recourse to survey data, ordinary least squares is not an appropriate technique to estimate equation (12) because future expected values of the output gap and inflation appear on the right hand side of the equation; this is analogous to an errors-in-variables problem. Because the estimated reaction function contains expected values of the output gap and inflation, estimation of the reaction function is conducted by GMM.<sup>10</sup> We use a standard set of instruments for the regressions. We used three lags of inflation, output gap and the interest rate as instruments.<sup>11</sup> For Australia and New Zealand, the output gap is constructed from seasonally adjusted constant price production GDP with the signal-to-noise ratio set to 1600. Weighted median consumer price inflation is used for Australia and New Zealand with the New Zealand median measure adjusted for excess skew in the CPI distribution.<sup>12</sup> The interest rate is the 90-day bank bill rate for both Australia and New Zealand.

<sup>9</sup> Initially we ran regressions for New Zealand from 1993q1, but settled on beginning from 1994q1. This yielded stable coefficient estimates. We believe that regressions containing earlier data suffer from trying to exclude the disinflation and associated recession, or from using the disinflation and associated recession as instruments.

<sup>10</sup> Because the moment conditions are to minimise the square of the residuals, this approach is, in essence, IV estimation.

<sup>11</sup> We also tested this approach against other instruments, such as the real time output gap, capacity utilisation and some other exogenous variables as our instruments. These results are close to those presented in table 1.

<sup>12</sup> This is the RBNZ series perc.q.

Model 1 estimates a reaction function with a contemporaneous response to the expected output gap and expected inflation, while Model 2 specifies monetary responses to one quarter-ahead forecasts of inflation and output gap.<sup>13</sup> We refrained from estimating additional reaction functions with longer forecast horizons because of the small sample size available. The following table displays the estimation results;  $p$ -values are bracketed beneath the coefficient estimates.

**Table 1**  
**Linear reaction functions: Australia and New Zealand**

CB	$\rho$	$\alpha$	$\beta$	$\gamma$	J	$\bar{R}^2$
Model 1:						
	$i_t = (1 - \rho)\{\alpha + \beta E_{t-1}\pi_t + \gamma E_{t-1}y_t\} + \rho i_{t-1} + \xi_t$					
AU	0.867 (0.000)	5.707 (0.000)	2.777 (0.023)	2.695 (0.005)	5.658 (0.463)	0.757
NZ	0.550 (0.000)	5.080 (0.000)	1.400 (0.000)	0.671 (0.044)	3.217 (0.781)	0.738
Model 2:						
	$i_t = (1 - \rho)\{\alpha + \beta E_t\pi_{t+1} + \gamma E_t y_{t+1}\} + \rho i_{t-1} + \xi_t$					
AU	0.823 (0.000)	6.457 (0.000)	3.811 (0.005)	0.746 (0.101)	5.479 (0.484)	0.650
NZ	0.671 (0.000)	4.620 (0.000)	1.846 (0.052)	0.610 (0.222)	2.682 (0.848)	0.730

(i) Note that Australia is estimated over the period 1993:1 — 2002:4, New Zealand 1994:1 — 2002:4.

(ii) The bracketed values represent  $p$ -values.

<sup>13</sup> We refrain from using contemporaneous values of the output gap and inflation as instruments under the assumption that these values are not observable to the central bank.

The coefficient estimates for both models suggest substantial interest rate smoothing in New Zealand and even higher interest rate smoothing in Australia. The regressions have good explanatory power. Throughout table 1, the response to expected inflation relative to target is positive, significant and obeys the Taylor principle. The interest rate response to inflation is almost twice as high for Australia as the corresponding coefficients for New Zealand. This is partly driven by the higher degree of interest rate smoothing present in the Australian regressions.

The response to the output gap is significant across all four regressions. The New Zealand coefficient estimates imply a desired interest rate response of approximately 60-70 basis points for a 100 basis point increase in the output gap. For Australia, model 1 implies a high desired response to the output gap of almost 270 basis points for a 100 basis point increase in the output gap. However, in model 2 this falls to a level consistent with the New Zealand regressions. The estimates of the reaction functions displayed in tables 1 and 2 are not unreasonable in the sense that the coefficient estimates are broadly consistent with beliefs about how monetary policy responds to developments in the economy.

Having established plausible linear reaction functions, these models are tested for any omitted non-linearity, using the techniques suggested by Granger and Teräsvirta (1993). Recall that if preferences are not quadratic, there may be nonlinearities in the reaction function. Prior to estimating explicit nonlinear reaction functions, the residuals from the linear reaction functions are tested for linearity.

### 3.2 Residual-based tests

Granger and Teräsvirta (1993) suggest the following test for linearity: (i) take the estimated residuals from the linear reaction function regressions; (ii) regress these residuals on the vector of original regressors used in the reaction function,  $C_t$ , and a “transition variable”, denoted  $z_{dt}$ . Squared and cubed terms of the transition variable are included in the regression to pick up specific nonlinearities. However, because instruments are used within the GMM estimation of the linear reaction function, the appropriate

transition variables are in fact the constructed regressors from the first stage of the GMM procedure. Thus the auxiliary test regression takes the following form:

$$\varepsilon_t = \delta_0' C_t + \delta_1' C_t z_{dt} + \delta_2' C_t (z_{dt})^2 + \delta_3' C_t (z_{dt})^3 + \vartheta_t \quad (13)$$

where  $\varepsilon_t$  represents the estimated residuals from the linear reaction function regressions,  $C_t$  is the vector of constructed regressors in the original reaction function (inflation, output gap and interest rates) and  $z_{dt}$  is the transition variable.

The transition variable can be either a lagged dependent variable, or any other variable used in the reaction function, such as the output gap or inflation. Here, we use contemporaneous and lagged values of the constructed output gap and inflation regressors and lags of the interest rate. Results are presented for two forms of nonlinearity where the null hypotheses are  $\delta_1' = 0$  and  $\delta_2'$  or  $\delta_3' = 0$ . The alternative hypotheses takes the form  $\delta_1' \neq 0$  or  $\delta_2'$  or  $\delta_3' \neq 0$ . The results are presented in the form of  $F$ -tests of the significance of these non-linear terms.

These residual-based tests are based on test a null hypothesis of linearity against a particular form of non-linearity rather than non-linearity in general. Thus the tests should be viewed as indicative only.

Results of the non-linearity tests are presented in table 2.

**Table 2**  
**Residual-based Indicative tests of non-linearity:**  
**Australia and New Zealand**

Transition Variable	Model 1	Model 2	Model 1	Model 2
	$H_0 : \delta_1' = 0$	$H_0 : \delta_1' = 0$	$H_0 : \delta_2' = \delta_3' = 0$	$H_0 : \delta_2' = \delta_3' = 0$
<b>Australia: 1993:1 — 2002:4</b>				
$\tilde{y}_t$	0.463 (0.710)	0.387 (0.763)	2.458** (0.049)	2.776** (0.031)
$\tilde{y}_{t-1}$	3.196** (0.039)	1.260 (0.308)	0.516 (0.790)	3.362** (0.013)
$\tilde{y}_{t-2}$	1.211 (0.352)	1.127 (0.357)	0.450 (0.838)	1.576 (0.195)
$\pi_t$	2.946* (0.050)	1.195 (0.330)	4.702*** (0.002)	0.742 (0.620)
$\pi_{t-1}$	1.098 (0.366)	3.439** (0.031)	2.314* (0.062)	2.197* (0.075)
$\pi_{t-2}$	0.215 (0.884)	0.359 (0.782)	0.215 (0.968)	0.470 (0.823)
$i_{t-1}$	2.506* (0.080)	0.177 (0.910)	1.425 (0.241)	0.401 (0.871)
$i_{t-2}$	0.271 (0.845)	3.955** (0.019)	0.786 (0.588)	2.671** (0.038)
$i_{t-3}$	0.174 (0.912)	0.752 (0.531)	0.734 (0.626)	1.030 (0.430)
<b>New Zealand: 1994:1 — 2002:4</b>				
$\tilde{y}_t$	0.482 (0.697)	1.080 (0.376)	1.412 (0.250)	1.515 (0.217)
$\tilde{y}_{t-1}$	2.417* (0.092)	1.700 (0.196)	1.519 (0.216)	1.808 (0.143)
$\tilde{y}_{t-2}$	3.767** (0.025)	0.092 (0.963)	3.442** (0.015)	0.878 (0.527)
$\pi_t$	0.103 (0.957)	1.072 (0.380)	0.274 (0.943)	0.566 (0.752)
$\pi_{t-1}$	2.334 (0.100)	0.355 (0.785)	1.350 (0.275)	0.707 (0.646)
$\pi_{t-2}$	0.096 (0.961)	0.248 (0.861)	1.335 (0.283)	0.497 (0.803)
$i_{t-1}$	1.171 (0.342)	0.804 (0.504)	3.121** (0.021)	0.452 (0.835)
$i_{t-2}$	1.301 (0.299)	1.519 (0.238)	0.938 (0.487)	1.127 (0.380)
$i_{t-3}$	1.066 (0.384)	0.124 (0.944)	0.900 (0.512)	0.941 (0.478)

(i) The bracketed values represent  $p$ -values.

(ii) \* Denotes significance at the 10 per cent level, \*\* at the 5 per cent level and \*\*\* denotes significance at the 1 per cent level.

(iii) Under the null hypothesis of  $\delta_0 = 0$ , the test is distributed  $F(3,n-k)$ . For the null hypothesis of  $\delta_1 = \delta_2 = 0$  the test is distributed  $F(6,n-k)$  where  $n$  is the sample size,  $k$  is the number of parameters.

These tests show for Australia some evidence of non-linearity when the lag of the constructed output gap regressor is used as the transition variable. For model 1, the addition of the lag of the constructed output gap regressor has significant explanatory power at the 5 per cent level, suggesting some non-linearity. In addition, the test of the joint significance of higher order terms, ie  $\delta_1 = \delta_2 = 0$ , is significant when the contemporaneous value of the constructed output gap regressor is used as a transition variable. For model 2, both the contemporaneous and immediate lag of the output gap regressor return statistically significant  $F$ -tests for the higher order non-linear terms. Thus there appears to be some non-linearity associated with the output gap for Australia.

The reaction functions also appear to be nonlinear with respect to  $i$  for the case of Australia. For model 1, where the interest rate responds contemporaneously to expected inflation and the expected output gap, both the tests of  $\delta_0 = 0$  and  $\delta_1 = \delta_2 = 0$  are rejected at the 10 per cent level. Furthermore, the lag of the constructed inflation regressor appears to be associated with some non-linearity. There is some evidence of a similar effect when the nominal interest rate is used as the transition variable — four of the twelve tests associated with the nominal interest rate appear to indicate some non-linearity.

The results for New Zealand also show some indication of non-linearity based on the tests above. In particular, the tests of  $\delta_0 = 0$  and  $\delta_1 = \delta_2 = 0$  both return statistically significant  $F$ -tests when the second lag of the constructed output gap is used as the transition variable in model 1.

However, for the New Zealand data there is no evidence of any non-linearity associated with inflation. None of the tests that use inflation as the transition variable return a significant  $F$ -test. With regard to the interest rate, only the test of the higher order terms returns a significant  $F$ -test when the lag of the interest rate is used as a transition variable in model 1.

In summary, the results are indicative of some non-linearity associated with the output gap, inflation and interest rate arguments

in the linear reaction function for Australia. For New Zealand there appears to be some non-linearity associated with the output gap argument and with the lag of the nominal interest rate. The next section estimates non-linear reaction functions to model this apparent non-linearity directly.

## 4 Non-linear reaction functions

To model any non-linearity in the reaction function we explore two non-linear models from the literature: (i) smooth transition regressions based on the hyperbolic tangent function; and (ii) non-linear reaction functions derived from the use of the linex function to model central bank preferences. In the interest of brevity we only present results based on the non-linear equivalent of model 1, ie for reaction functions that allow for an interest rate response to current inflation and the output gap. Results from the other model are very similar and come to the same conclusion.

### 4.1 Smooth transition regressions: the hyperbolic tangent function

Smooth transition models allow for a gradual change from one regime to the other. Since we only focus on the inflation targeting era, we do not expect a sudden regime change and hence think that the smooth transition regressions are appropriate.

An appropriate smooth transition function for modelling the threshold is the hyperbolic tangent function ( $\tanh$ ) that Cukierman and Muscatelli (2003) use to estimate reaction functions for the USA, Germany, Japan and the UK.<sup>14</sup> Over the period 1979:3-2000:1, they find a better fit to gradual regime changes by using the  $\tanh$  function compared to a logistic function.<sup>15</sup> The hyperbolic tangent smooth transition regression (HTSTR) assumes  $F(z_t)$  takes the following form:

$$F(z_t) = \delta_1 \tanh(\varphi(z_t - \delta_2)) \quad (14)$$

<sup>14</sup> The hyperbolic tangent function takes the form  $\tanh(x) = (e^x - e^{-x}) / (e^x + e^{-x})$ .

<sup>15</sup> We also tried the logistic function. The results and conclusions were very similar. However, the fit is marginally improved by the  $\tanh$  function.

where  $\delta_2$  is the point of inflexion in the  $\tanh$  function.

To test whether this specification yields a better fit, and to provide results comparable to Cukierman and Muscatelli (2003), the regressions were repeated using equation (13) to model the nonlinear threshold component. With respect to equation (13),  $\delta_2$  is restricted to zero and in addition,  $\delta_1$  takes the value of 1. The parameter  $\varphi$  is restricted to 0.25. Cukierman and Muscatelli (2003) use a grid search to make inference on the appropriate choice of  $\varphi$ . To allow direct comparison with their paper, we restrict  $\varphi$  to 0.25 but note that our results, in terms of determining the presence of nonlinearity, are not particularly responsive to different values of  $\varphi$  over the range 0.15 to 0.6. Table 6 displays the results of the  $\tanh$  nonlinear estimation.

**Table 3**  
**Hyperbolic tangent smooth transition reaction functions**

Test	CB	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	J	$\bar{R}^2$
	$i_t = c_1 i_{t-1} + (1 - c_1)(c_2 + c_3 \pi_t + c_4 \tilde{y}_t + c_5 \tilde{y}_t \delta_1 \tanh(\varphi \tilde{y}_t - \delta_2) + c_6 \pi_t \delta_1 \tanh(\varphi \pi_t - \delta_2))$								
$\tilde{y}$	AU	0.846 (0.000)	6.469 (0.000)	1.473 (0.024)	2.710 (0.000)	-6.641 (0.054)		3.933 (0.787)	0.729
	NZ	0.433 (0.028)	4.741 (0.000)	1.354 (0.002)	0.553 (0.111)	1.000 (0.399)		2.357 (0.937)	0.642
$\pi$	AU	0.866 (0.000)	5.589 (0.000)	3.775 (0.104)	2.549 (0.006)		3.326 (0.784)	4.967 (0.664)	0.712
	NZ	0.548 (0.000)	5.029 (0.000)	0.879 (0.367)	0.800 (0.045)		1.065 (0.527)	2.468 (0.930)	0.662
$\pi, \tilde{y}$	AU	0.839 (0.000)	7.636 (0.000)	-2.047 (0.336)	3.372 (0.004)	-11.757 (0.091)	-15.497 (0.221)	2.402 (0.934)	0.658
	NZ	0.373 (0.379)	4.610 (0.000)	1.693 (0.262)	0.431 (0.509)	1.417 (0.578)	-0.721 (0.817)	2.333 (0.801)	0.623

The reaction function in row 1 tests for the significance of a nonlinear response to the output gap, modelled with the tanh function, for Australia. The coefficient on the nonlinear response is negative, and statistically significant at the 10 per cent level. The regression appears well specified with the linear responses correctly signed and significant at the 5 per cent level. In fact, the linear components of the regression are remarkably stable when compared with their counterparts from the linear regression in table 1. Again, the nonlinear response to the output gap is positive but insignificant for New Zealand.

A similar picture emerges for the remaining reaction functions — the nonlinear response to the output gap for Australia is negative and significant, there is no evidence of a nonlinear response for the New Zealand reaction functions. We conclude on the basis of the results presented in table 3, that that we cannot reject linearity of the reaction function and hence cannot reject the quadratic approximation to New Zealand central bank preferences. However, based on the concavity of the interest rate response to the output gap, the preferences of the Reserve Bank of Australia appear to be asymmetric with respect to the output gap. In other words, the RBA appears to dislike negative output gaps more than they dislike positive output gaps.

#### 4.2 The Linex function: an alternative nonlinear preference approximation

The strength of the approach detailed in Cukierman and Muscatelli (2003) is the generality of the range of preferences allowed by the central bank. This can also be a weakness because a general non-linear specification gives no direction on the type of non-linear preferences that should serve as the metric to evaluate alternative monetary policies.

One common loss function specification within the literature on central bank preferences is the linex loss function. Surico (2003) uses this specification to evaluate the preferences for the European Central Bank and finds evidence for some asymmetric behaviour. The specification is useful because it ascribes a specific functional

form and this function nests quadratic preferences. With respect to inflation and output gap nonlinearities, the linex function takes the following form:

$$L_t = \left[ \frac{\exp(\alpha(\pi_t - \pi^*)) - \alpha(\pi_t - \pi^*) - 1}{\alpha^2} \right] + \lambda \left[ \frac{\exp(\gamma \tilde{y}_t) - \gamma \tilde{y}_t - 1}{\gamma^2} \right] + \frac{\mu}{2} (i_t - i^*)^2 \quad (15)$$

The parameters  $\alpha$  and  $\gamma$  represent the degree of asymmetry with respect to inflation deviations and the output gap respectively. Quadratic preferences are recovered for  $\alpha = \gamma = 0$ .<sup>16</sup> The model expressed in equations (3) and (4) can be rewritten as follows:

$$\tilde{y}_t = -\phi i_t + \hat{\epsilon}_t \quad (16)$$

$$\pi_t = \xi \tilde{y}_t + \hat{\epsilon}_t \quad (17)$$

where  $\hat{\epsilon}_t = E_t \tilde{y}_{t+1} + \phi E_t \pi_{t+1} + \hat{g}_t$  and  $\hat{\epsilon}_t = \theta E_t \pi_{t+1} + \hat{u}_t$  such that  $\hat{\epsilon}_t$  and  $\hat{\epsilon}_t$  represent the components of the model the central bank cannot control. Furthermore, because the model contains no lag structure, intertemporal optimisation reduces to solving an infinite sequence of static problems, that is, minimising the period loss function.

Surico (2003) shows that the first order condition for this problem is:

$$-E_{t-1} \left( \frac{e^{[\alpha(\pi - \pi^*)]} - 1}{\alpha} \right) \xi \phi - E_{t-1} \left( \frac{e^{\gamma \tilde{y}_t} - 1}{\gamma} \right) \theta \phi + \mu (i_t - i^*) = 0 \quad (18)$$

and taking a first order Taylor approximation to the first-order condition at  $\alpha = \gamma = 0$  yields:

<sup>16</sup> Use L'Hopital's rule, differentiating twice with respect to  $\alpha$  and  $\gamma$ .

$$\begin{aligned}
& -\xi\phi E_{t-1}(\pi_t - \pi^*) - \lambda\phi E_{t-1}(\tilde{y}_t) - \frac{\alpha\xi\phi}{2} E_{t-1}[(\pi_t - \pi^*)^2] \\
& - \frac{\lambda\phi\gamma}{2} E_{t-1}(y_t^2) + \mu(i_t - i^*) + e_t = 0
\end{aligned} \tag{19}$$

where  $e_t$  are the higher order terms from the Taylor expansion.<sup>17</sup> Finally, solving for  $i_t$ , the reaction function reduces to:

$$\begin{aligned}
i_t = & (1 - c_1)(c_2 + c_3(\pi_t - \pi^*) + c_4\tilde{y}_t + c_5(\tilde{y}_t^2) \\
& + c_6(\pi_t - \pi^*)^2) + c_1i_{t-1} + v_t
\end{aligned} \tag{20}$$

where the reaction function coefficients are direct function of the parameters in the Clarida, Gali and Gertler (1999) model and the central bank preferences, ie:

$$c_2 \equiv i^*, \quad c_3 \equiv \frac{\xi\phi}{\mu}, \quad c_4 \equiv \frac{\lambda\phi}{\mu}, \quad c_5 \equiv \frac{\alpha\xi\phi}{2\mu}, \quad c_6 \equiv \frac{\lambda\phi\gamma}{2\mu}.$$

Table 4 below depicts the results of estimating equation (20), and restricted forms of equation (17) that allow for only a nonlinear response to inflation or the output gap. Recall that the logistic and tanh smooth transition regression functions found evidence of a nonlinear response to the output gap for Australia. This result is confirmed in the linex model — the coefficient on the output gap squared is negative and statistically significant. The corresponding coefficient for New Zealand is positive and insignificant at the 10 per cent level.

<sup>17</sup> Surico (2003) model includes a non-linear Phillips equation. For simplicity, this specification removes the non-linearity in the Phillips equation.

**Table 4:**  
**Linex nonlinear reaction functions**

Test	CB	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	J	$\bar{R}^2$
		$i_t = c_1i_{t-1} + (1 - c_1)(c_2 + c_3\pi_t + c_4\tilde{y}_t + c_5\tilde{y}_t^2 + c_6\pi_t^2)$							
$\tilde{y}$	AU	0.847 (0.000)	6.477 (0.000)	1.429 (0.028)	2.715 (0.000)	-1.600 (0.057)		3.878 (0.567)	0.729
	NZ	0.429 (0.033)	4.745 (0.000)	1.358 (0.002)	0.547 (0.117)	0.231 (0.392)		2.319 (0.940)	0.636
$\pi$	AU	0.867 (0.000)	5.588 (0.000)	3.752 (0.109)	2.571 (0.006)		0.746 (0.803)	4.987 (0.662)	0.712
	NZ	0.550 (0.000)	5.105 (0.000)	1.125 (0.244)	0.741 (0.062)		0.131 (0.721)	2.554 (0.923)	0.683
$\pi, \tilde{y}$	AU	0.832 (0.000)	6.968 (0.000)	1.268 (0.125)	2.851 (0.000)	-2.114 (0.044)	-10.812 (0.429)	3.366 (0.849)	0.680
	NZ	0.365 (0.391)	4.600 (0.000)	1.706 (0.236)	0.418 (0.516)	-0.161 (0.801)	0.328 (0.563)	2.163 (0.826)	0.614

Rows 3 and 4 depict tests for a nonlinear response to deviations of inflation from target. The square of deviations of inflation from target is positive and insignificant within both regressions.

The joint tests of nonlinear response, in rows 5 and 6, confirm the working hypothesis: Australia shows some evidence of a nonlinear response to the output gap but not inflation, New Zealand shows no evidence of nonlinear response to inflation or the output gap.

The benefit of approximating asymmetric preferences with the linex representation is that an approximation of the asymmetry can be obtained to compare directly with standard, quadratic preference representations.

Consider row 1, the regression that tests the Australian reaction function for a nonlinear response to the output gap. For this

regression, there is no response to the square of inflation, effectively restricting  $c_6$ , and the asymmetry with respect to inflation, to zero. For the remaining coefficients:

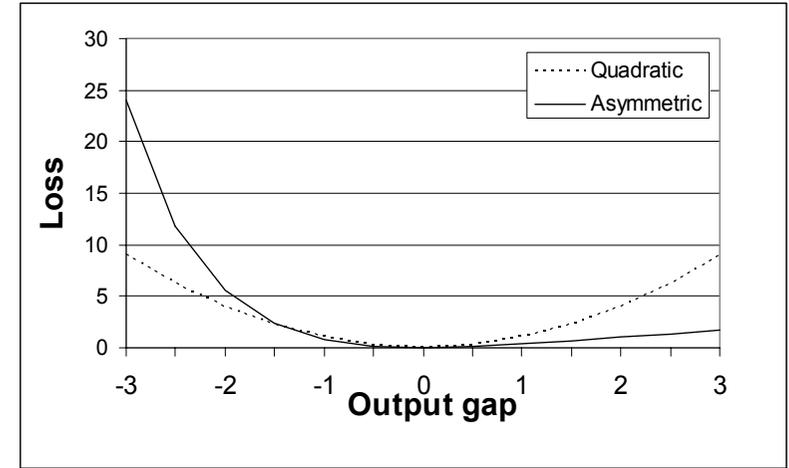
$$c_2 = 6.477 \equiv i^*, \quad c_3 = 1.429 \equiv \frac{\xi\phi}{\mu},$$

$$c_4 = 2.715 \equiv \frac{\lambda\phi}{\mu}, \quad c_5 = -1.600 \equiv \frac{\alpha\phi\gamma}{2\mu}$$

using these results, we can infer some of the preference parameters. Note that the preference parameter on the output gap,  $\gamma$ , is equal to  $\frac{2c_5}{c_4}$ , which reveals a parameter estimate of -1.246, with an associated  $p$ -value of (0.011), when we allow for the joint distribution of the two parameter estimates. Thus the RBA appears to possess asymmetric preferences with regard to the output gap at the 5 per cent level of significance. Figure 1 below graphs the estimated asymmetric preference over the output gap compared to the standard quadratic representation. Note that negative output gaps carry a higher loss than the quadratic representation while positive output gaps Australia's central bank are overweighted within the loss function according to the standard quadratic representation.

Turning to the New Zealand version of this reaction function, the parameter  $c_5$ , is insignificant; there is no evidence of output gap asymmetry for New Zealand. Thus, we conclude that Australia targets inflation in conjunction with an asymmetric preference that leans more heavily against negative output gaps, while New Zealand targets inflation with symmetric preference for both inflation and the output gap. These preferences are shown in figure 1.

**Figure 1: Australian output gap preferences**



In addition, the parameter estimates from the linex reaction functions reveal something about the parameter  $\lambda$ , that measures the relative concern for output gap deviations relative to inflation deviations.

Note that  $\lambda$  can be expressed as  $\frac{\xi c_4}{c_3}$ . If we assume that  $\xi$  is the

same for both Australia and New Zealand (so that the effect of the output gap on inflation is identical), we can infer the relative output gap concern. For the Australian regression,  $\frac{c_4}{c_3} = 1.900$ ; for New

Zealand  $\frac{c_4}{c_3} = 0.403$ . Thus unless the effect of the output gap on

inflation is approximately five times larger in Australia than New Zealand, we can attribute a higher concern for output gap deviations to Australia.<sup>18</sup>

<sup>18</sup> The exercise of estimating the full Clarida, Gali and Gertler (1999) model is beyond the scope of this paper. However, preliminary estimation by GMM, with a similar instrument set (four lags of inflation and for lags of the output gap) places statistically significant coefficients of 0.157 and 0.140 for Australia and New Zealand respectively.

### 4.3 Instrument robustness check

All three models use instruments to proxy for endogenous expectational variables. A growing literature on weak instruments — where the instruments are not strongly correlated with the endogenous variables — notes that if instruments are indeed weak, the sampling distribution of instrumental variable estimates are non-normal and the hypothesis tests associated with these estimates are unreliable.<sup>19</sup> If the instruments used in this paper are weak, this undermines the key result suggestive of a more aggressive policy response to positive output gaps relative to negative output gaps on the part of the RBA.

One rule of thumb suggested by Staiger and Stock (1997) is that the F-statistic on the first-stage IV regression of the instruments on the endogenous variables should be larger than 10. For multiple regressors, the Cragg-Donald statistic (a matrix equivalent to the F-statistic) is appropriate. Stock and Yogo (2003) provide critical values for testing the null of weak instruments. Generally, within our specifications, the addition of non-linear terms results in test-statistics that fail to reject the null of weak instruments.

As Stock, Wright and Yogo (2002) note, these tests are conservative in the sense that the null of the presence of weak instruments is based on any linear combination of the coefficients. The concern of this paper is almost solely focussed on a single coefficient — the coefficient on the nonlinear output gap term. Thus the testing procedure of Stock and Yogo (2003) appears particularly conservative for the question this paper addresses.

However, we take the possibility of weak instruments seriously and undertake two alternative methods that seek to partially test the robustness of the key result of a significant nonlinear response to the output gap on behalf of the RBA. Firstly, an alternative instrument set, that includes two lags of inflation, the output gap, the nonlinear terms and lags two and three of the interest rate was used as an instruments set. Secondly, the method of continuously updated-

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<sup>19</sup> Stock, Wright and Yogo (2002) provide a useful survey of the weak instrument literature.

GMM was used with in conjunction with the alternative instrument set.<sup>20</sup> This estimation method allows the variance-covariance matrix to update, altering the weighting matrix and hence the criterion function for each parameter update. Stock, Wright and Yogo (2002) note that this method appears “partially robust to weak instruments” while Hansen, Heaton and Yaron (1996) detail the finite sample properties of this estimation method. Table 5 below shows the results of the alternative estimation procedures for Australia only. The standard results from previous tables are re-presented for comparison.

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<sup>20</sup> We are grateful to Bruce Hansen for Gauss code for continuously updated GMM.

**Table 5:**  
**Instrument robustness: Australia 1993:1 — 2002:4**

	CB	C(1)	C(2)	C(3)	C(4)	C(5)	C(6)	J	$\bar{R}^2$
		$i_t = c_1 i_{t-1} + (1 - c_1)(c_2 + c_3 \pi_t + c_4 \tilde{y}_t + c_5 \tilde{y}_t \delta_1 \tanh(\phi \tilde{y}_t - \delta_2) + c_6 \pi_t \delta_1 \tanh(\phi \pi_t - \delta_2))$							
(i)	$\tilde{y}$	0.846 (0.000)	6.469 (0.000)	1.473 (0.024)	2.710 (0.000)	-6.641 (0.054)		3.933 (0.787)	0.729
(ii)	$\tilde{y}$	0.825 (0.000)	6.155 (0.000)	0.768 (0.319)	5.468 (0.050)	-6.351 (0.099)		2.724 (0.909)	0.742
(iii)	$\tilde{y}$	0.842 (0.000)	7.516 (0.003)	-1.211 (0.871)	3.163 (0.000)	-14.334 (0.015)		6.718 (0.459)	0.705
(i)	$\pi, \tilde{y}$	0.839 (0.000)	7.636 (0.000)	-2.047 (0.336)	3.372 (0.004)	-11.757 (0.091)	-15.497 (0.221)	2.402 (0.934)	0.658
(ii)	$\pi, \tilde{y}$	0.810 (0.000)	6.488 (0.000)	2.948 (0.479)	7.193 (0.038)	-9.429 (0.078)	-7.620 (0.494)	2.565 (0.767)	0.699
(iii)	$\pi, \tilde{y}$	0.808 (0.000)	6.793 (0.012)	-1.983 (0.270)	2.901 (0.004)	-9.292 (0.153)	-6.601 (0.633)	3.314 (0.652)	0.664
		$i_t = c_1 i_{t-1} + (1 - c_1)(c_2 + c_3 \pi_t + c_4 \tilde{y}_t + c_5 \tilde{y}_t^2 + c_6 \pi_t^2)$							
(i)	$\tilde{y}$	0.847 (0.000)	6.477 (0.000)	1.429 (0.000)	2.715 (0.000)	-1.600 (0.057)		3.878 (0.567)	0.729
(ii)	$\tilde{y}$	0.825 (0.000)	6.155 (0.000)	0.768 (0.319)	5.468 (0.050)	-6.351 (0.099)		2.840 (0.899)	0.728
(iii)	$\tilde{y}$	0.845 (0.000)	7.556 (0.001)	-1.284 (0.243)	3.284 (0.001)	-3.595 (0.015)		6.716 (0.459)	0.701
(i)	$\pi, \tilde{y}$	0.832 (0.000)	6.968 (0.000)	1.268 (0.125)	2.851 (0.000)	-2.114 (0.044)	-10.812 (0.429)	3.366 (0.849)	0.680
(ii)	$\pi, \tilde{y}$	0.810 (0.000)	6.488 (0.000)	2.948 (0.479)	7.193 (0.038)	-9.429 (0.078)	-7.620 (0.494)	2.561 (0.767)	0.699
(iii)	$\pi, \tilde{y}$	0.814 (0.000)	6.719 (0.013)	-1.921 (0.273)	2.918 (0.004)	-2.207 (0.157)	-1.432 (0.669)	3.916 (0.561)	0.666

NB: (i) Denotes GMM estimation on the standard instruments; (ii) denotes GMM estimation on the alternative instruments; and (iii) denotes CU-GMM on the alternative instruments.

Results for the hyperbolic tangent function are presented in the first half of the table where the coefficient on the nonlinear output gap term is negative and statistically significant. For the hyperbolic tangent function, the nonlinear output gap coefficient is statistically significant at the 10 per cent level (returning a  $p$ -value of 0.099) for the alternative instrument set and statistically significant under continuously-updated GMM. This result holds when the nonlinear inflation term is added to the alternative instrument set estimation

but the significance of the nonlinear output gap is again overturned when the nonlinear inflation term is included in the continuously-updated GMM regression.

Secondly, results for the reaction function implied by the lineax preference function are displayed in the final half of the table. The negative coefficient on the nonlinear output gap terms is significant at the 10 per cent level under continuously-updated GMM but not under the alternative instrument set (a  $p$ -value of 0.102 is returned). Furthermore, the significance of the nonlinear output gap term is overturned when the nonlinear inflation term is included in the regressions based on the alternative instrument set and continuously updated GMM.

In summary these regressions do not appear to resolve the issue of weak instruments. However, by the same token, there is no strong evidence to suggest the results are largely dependent on the choice of instrument set and the results of the continuously-updated GMM suggest the nonlinear response to the output gap is generally statistically significant.

## 5 Conclusion

Australia and New Zealand were two of the first countries to adopt explicit inflation targets. Consequently, these countries provide an interesting context to see whether the revealed preferences of their central banks conform to the quadratic preference assumption that is standard within the monetary policy literature. The banks' preferences are revealed through the history of their policy actions.

Residual-based tests from linear reaction functions indicate some limited non-linearity for both Australia and New Zealand.

Hyperbolic tangent smooth transition regression models suggest that Australia has a statistically significant asymmetric response to the output gap but not to inflation. In particular, a negative output gap elicits a larger movement in interest rates than a positive output gap of the same magnitude. From this asymmetric response, we infer that the Reserve Bank of Australia has an asymmetric preference that weights positive output gaps less strongly within the loss function

than it does negative output gaps. No such asymmetric response is found with respect to inflation deviations from target and accordingly we find no evidence that the Reserve Bank of Australia has had asymmetric preferences over inflation outcomes. For New Zealand, there is no evidence of asymmetry in the reaction function and we infer that over the time period in question, policymakers in New Zealand have behaved symmetrically with respect to the output gap and inflation deviations from target.

Finally, relative to the set of preferences encompassed by the hyperbolic tangent smooth transition reaction functions, a more restrictive set of preferences, based on the linex function, suggests that the reaction functions include the square of the output gap and the square of inflation deviations from target. Again, the only strong evidence of asymmetry is with respect to the Reserve Bank of Australia's response to the output gap. Australia appears to respond less aggressively to positive output gaps as compared to negative output gaps. The relative strength of response of inflation to the output gap allows us to infer central bank concern about the output gap relative to inflation. The Reserve Bank of New Zealand appears to have focused more on inflation deviations from target than on the output gap over the period in question. For the Reserve Bank of Australia, the output gap is given relatively greater importance, especially when it is negative.

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## Appendix A

Cukierman and Muscatelli (2003) proceed by substituting the aggregate demand (equation (3)) and aggregate supply (equation (4)) equations into the period loss function for the policymaker. This yields:

$$E_0 \sum_{t=0}^{\infty} \delta^t \left\{ \begin{array}{l} Af[-\phi(i_t - E_t \pi_{t+1}) + E_t \tilde{y}_{t+1} + g_t + \tilde{g}_t] + \\ h[\xi(-\phi(i_t - E_t \pi_{t+1}) + E_t \tilde{y}_{t+1} + g_t + \tilde{g}_t) + \theta E_t \pi_{t+1} + u_t + \tilde{u}_t] \end{array} \right\} \quad (\text{A.1})$$

Cukierman and Muscatelli (2003) limit the policymaker to policy under discretion. Because the structural Clarida, Galí and Gertler (1999) model has no lags, the policymaker’s problem reduces to a repeated one period problem. As Cukierman and Muscatelli (2003) show, the minimising problem results in a first order condition of the form:

$$\lambda E_t f'[\cdot] + \xi E_t h'[\cdot] = 0, \quad t = 0, 1, 2, \dots \quad (\text{A.2})$$

Because the policymaker’s problem reduces to a period by period problem, comparative statics are revealing about the optimal interest rate reaction. The interest rate responds to next period’s expected realisation of inflation and the output gap. Cukierman and Muscatelli (2003) show that totally differentiating the first order condition at  $t=0$ , with respect to inflation, yields:

$$\frac{di_0}{dE_0 \pi_1} = \frac{1}{\phi} \frac{\phi \lambda E_0 f_0''[\cdot] + \xi(\phi \xi + b) E_0 h_0''[\cdot]}{\lambda E_0 f_0''[\cdot] + \xi^2 E_0 h_0''[\cdot]} \equiv \frac{\phi \lambda E_0 f_0''[\cdot] + \xi(\phi \xi + b) E_0 h_0''[\cdot]}{\phi D} \quad (\text{A.3})$$

where  $D = \lambda E_0 f_0''[\cdot] + \xi^2 E_0 h_0''[\cdot]$  and:

$$f_0''[\cdot] \equiv f''[-\phi(i_0 - E_0 \pi_1) + E_0 \tilde{y}_1 + g_0 + \tilde{g}_0] \quad (\text{A.4})$$

$$h_0''[\cdot] \equiv h''[\xi \lambda (-\phi(i_0 - E_0 \pi_1) + E_0 \tilde{y}_1 + g_0 + \tilde{g}_0) + \theta E_0 \pi_1 + u_0 + \tilde{u}_0] \quad (\text{A.5})$$

Similarly, the differentiating the first order condition with respect to the output gap results in the following:

$$\frac{di_0}{dE_0\tilde{y}_1} = \frac{1}{\phi} \frac{\lambda(1+\phi\xi)E_0f_0''[\cdot] + \xi^2(1+\phi\xi+b)E_0h_0''[\cdot]}{D} \quad (\text{A.6})$$

To evaluate the effect of asymmetric preferences on non-linearities in the reaction function, Cukierman and Muscatelli (2003) examine the second order derivatives. The second order derivative with respect to inflation is:

$$\frac{d^2i_0}{d(E_0\pi_1)^2} = \frac{\lambda\xi b^2}{\phi D^3} \left\{ \lambda(E_0f_0'')^2 E_0h_0''' + \xi(E_0h_0'')^2 E_0f_0''' \right\}. \quad (\text{A.7})$$

Assuming that there exists asymmetric preferences over inflation and the output gap,  $E_0f_0''' < 0$  and  $E_0h_0'''(\cdot) > 0$ . Furthermore, the parameters  $\lambda, \xi, \phi$  and  $\theta$  are all positive. This implies that the sign of the second derivative of the interest rate with respect to inflation may either be positive or negative. As Cukierman and Muscatelli (2003) state:

“If there is only a precautionary demand for price stability,  $E_0f_0''' = 0$  and the reaction function is convex. If there is only precautionary demand for expansions,  $E_0h_0''' = 0$  and the reaction function is concave. If both asymmetries are present,  $E_0f_0''' = E_0h_0''' = 0$  and the response of the interest rate to expected inflation is predicted to be linear.”

Cukierman and Muscatelli (2003) show that the second order derivative with respect to the output gap is:

$$\frac{d^2i_0}{d(E_0\tilde{y}_1)^2} = \xi^2 \frac{\lambda\xi\theta^2}{\phi D^3} \left\{ \lambda(E_0f_0'')^2 E_0h_0''' + \xi(E_0h_0'')^2 E_0f_0''' \right\}. \quad (\text{A.8})$$

Thus the second order derivatives are linearly related to each other via the term  $\xi^2$ .