Do Central Banks have Precautionary Demands for Expansions and for Price Stability? - A New Keynesian Approach[1]

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Abstract

This paper analyses the impact of asymmetric preferences with respect to inflation and output fluctuations on policymaker's interest-rate reaction functions and tests for their existence. This is done by introducing non quadratic preferences into a New Keynesian framework of the type proposed in Clarida, Gali and Gertler (1999). A methodology designed to identify the dominant type of asymmetry is developed and related to the precautionary demands of policymakers for expansions and for low inflation. Using data for four G7 economies, the paper shows that, nonlinear and asymmetric behaviour is present in many cases. A main finding, for the US, is that after credibility-building and disinflation have been established, the monetary authority develops a greater precautionary demand for output expansions than for low inflation. Conversely, where, as is the case in the UK during the nineties, credibility-building is still a concern for the authorities, managing the business cycle is dominated by concerns of the monetary authorities to keep inflation expectations low.

JEL Codes: E58, E61

1 Introduction

The 1990s have seen the emergence of an apparent consensus in the modeling of monetary policymaking. This is exemplified by the fact that standard linear-quadratic models of central bank (CB) preferences dominate the discussion of monetary policy rules[1]. In parallel, empirical models of central bank behavior focus almost entirely on linear interest rate reaction functions, that are implied by the quadratic specifications of CB preferences[2]. Central banks, on their part, actively debate the extent to which different ways of conducting monetary policy (individual versus collective accountability in monetary policy councils, signalling through public statements, or the degree of openness in publishing forecasts) help or hinder the pursuit of policy objectives[3]. But there is little dissent between CBs when it comes to the choice of primary policy target (the inflation target has become dominant), or on the need to stabilize both inflation and short-run fluctuations in the output gap.

This consensus view suggests that inflation, on the scale of the 1970s and early 1980s, is no longer a threat for those economies whose CBs have adopted, implicitly or explicitly, a system of inflation targeting. 'Flexible inflation targeters' will allow some deviation of inflation from the target pursued, in order to allow for output stabilization, but the weight given to price stability will not allow a marked increase in inflation. As argued by Blinder (1998), Vickers (1998), and McCallum (1997), independent CBs simply do not suffer from the 'inflation bias 'problem identified by Kydland and Prescott (1977) and Barro and Gordon (1983)[4].

However, this view may be excessively optimistic, and to some extent

[1] See for example Svensson (1997), Goodhart (1999), Batini and Haldane (1999), Rudebusch and Svensson (1999).

[2] See Clarida *et al.* (1998, 2000) Muscatelli *et al.* (1999), Muscatelli and Trecroci (2000).

[3] This has led recently to alternative models of monetary policymaking institutions. For instance, the Bank of England has a policy-making body (the Monetary Policy Committee) which is individually accountable and which encourages public scrutiny of individual members. In contrast, the ECB maintains a focus on collective responsibility by its Council. This has led to a debate on the relative merits of the different models (see Buiter (1999), Issing (1999) and Cukierman (2001)).

[4] On this view the main problem faced by CBs is then one of uncertainty surrounding the nature of shocks hitting the economy and 'long and variable lags' in the transmission mechanism (see Goodhart, 1999).

might have been conditioned by the relatively benign inflation conditions of the 1990s. Cukierman (2000, 2002) shows that the inflation bias may reappear even if policymakers target the normal level of employment and output on average. The problem arises whenever the CB is uncertain about the future state of the economy and is more worried about making policy errors that push output below than above its natural level. Jordan (2001) shows that a similar type of bias appears even if the CB has perfect but private information about shocks to the economy. The reason is that inflationary expectations internalize the stronger policy response to recessions leading expectations to be positive on average.

What are the bases for believing that policymakers might have asymmetric employment objectives? First, Blinder (1998) suggests, at least implicitly, that the political pressures faced by the Fed not to raise the interest rate when unemployment falls, are relatively more vigorous than pressures (if any) in the opposite direction when unemployment increases.[5] A second base relies on the psychology of choice, and on the tendency of people to place a greater weight on the prospect of losses than on the prospect of gains in decision making. Kahneman and Tversky (1979, 1982, 1984) and others have highlighted the fact that most individuals are likely to value objective gains of a given magnitude less than losses of the same magnitude and that this will lead to asymmetric behavior in choices under uncertainty.

In terms of the choices facing the CB, even if the probability of positive shocks to employment equals that of negative shocks, if the CB is loss-averse with respect to output and frames decisions in terms of possible employment losses, this will lead to asymmetric behavior with respect to output/employment.

On the other hand asymmetric behavior of this type could also arise with respect to inflation. At times of high inflation a CB charged with achieving price stability is likely to attach greater disutility to rates of inflation above the target than to rates of inflation at a similar distance below it. Nobay and Peel (1998) and Ruge-Murcia (2000) show that in such cases a deflationary bias may arise. Mishkin and Posen (1997) express a similar view in the context of inflation targeting monetary authorities like the Bank of Canada and the Bank of England.

[5] Blinder (1998, pp.19-20) states that: "In most situations the CB will take far more political heat when it tightens pre-emptively to avoid higher inflation than when it eases pre-emptively to avoid higher unemployment".

The burgeonning empirical literature on asymmetric CB objectives is mixed and varied. When asymmetries are present the evidence is sometimes consistent with asymmetric objectives with respect to inflation and in other cases with asymmetric objectives with respect to the output gap. Dolado *et al.* (2000) estimate a variant of the Clarida *et al.* (1998, 2000) interest-rate reaction function for a number of central banks (USA, Germany, Spain, France), allowing for different interest-rate responses for positive and for negative output and inflation movements. They find some evidence of asymmetric CB behavior with respect to the inflation objective, but only for the USA do they find any asymmetry in behavior vis-à-vis output movements. Using a Lucas type transmission mechanism Ruge-Murcia (2001) presents time series evidence that is consistent with the view that monetary policymakers in France and the USA are more averse to negative than to positive output gaps. Ruge-Murcia (2002) and Cukierman and Gerlach (2003) provide cross sectional evidence from developed economies that points in a similar direction. In the case of the second paper both theory and evidence support this view only between 1971 and 1985, when the effective level of CB conservativeness was relatively low. Dolado, Ramon and Ruge-Murcia (2002) present evidence supporting the existence of asymmetric objectives with respect to inflation in the US during the Volcker - Greespan era. Except for Ruge-Murcia (2002) an important impediment to a broader evaluation of the results in the recent literature is that each separate paper features either asymmetries with respect to the output gap or with respect to inflation, but not both.

A main objective of this paper is to provide a framework that is sufficiently flexible to allow for the potential existence of both types of asymmetry. Asymmetric output gap losses lead to the emergence of a precautionary demand for expansions by monetary policymakers. Similarly, asymmetric losses from deviations of inflation from target lead to a precautionary demand for deflation. Using a New Keynesian framework this paper develops a methodology for dealing with both types of precautionary demands as an anchor for empirical work aimed at two main objectives: 1. To test for the possible existence of asymmetries of either kind; 2. When asymmetries are present, to determine empirically, which of the two types of precautionary demands dominates the conduct of monetary policy. The theoretical framework focusses on the implications of asymmetries in objectives for interest rate reaction functions of the type presented in Clarida, Gali and Gertler (1999). The specification of asymmetries in objectives is rather general unlike most recent papers on this topic.[6]

It is shown that both types of precautionary demands may lead to interest rate reaction functions that are non linear in expected inflation and the expected output gap, and that there are systematic relationships between the type of precautionary demand and the curvature of the interest rate reaction function. Stated somewhat loosely, a precautionary demand for price stability leads to reaction functions that are convex in both expected inflation and the expected output gap, and a precautionary demand for expansions leads to concavity in the same two expectations. More precisely, in the absence of a precautionary demand for price stability, a precautionary demand for expansions leads to concave reaction functions while the converse leads to convex reation functions. When both precautionary demands are operative the reaction function is convex or concave or linear depending, *inter alia*, on the relative degrees of asymmetry in losses from the output gap and in losses from deviations of inflation from its target. For a given relative degree of asymmetry in those two objectives the curvature of the reaction function with respect to both expected inflation and the expected output gap also depends on the relative importance attributed by the central bank to the reduction of fluctuations in inflation and output around their respective targets.

To test the theory estimates of interest-rate reaction functions are formulated so as to allow for the possibility of non-linear and asymmetric responses to both expected output and inflation. In addition, the econometric specification allows for a **smooth** transition of the slope of the function between different ranges of the expected values of inflation and of the output gap making it sufficiently flexible to capture a wide range of non-linear and asymmetric reactions.[7] This methodology is applied to estimate interest rate reaction functions in four major industrialized economies (the USA, Japan, Germany and the UK), to test for the existence of non linearities, and to make inferences about the dominant type of precautionary demand in each case. These economies have experienced very different macroeconomic condi-

[6] An exception is Geraats (1999). Except for her paper that focusses on somewhat different issues recent work on asymmetries in monetary policy either assumes a discontinuity at zero for the output gap (Cukierman (2000, 2002)) or specifies losses by means of the Linex function (Nobay and Peel (1998) and Ruge-Murcia (2000, 2001)).

[7] This contrasts with the Dolado *et al.* (2000) specification, which permits only a discontinuous change in slope around some fixed trigger point like an announced inflation target or an output gap value of zero.

tions over the last 20 years, and have had different institutional frameworks governing the conduct of monetary policy.

For the time period between 1980 and 2000 the evidence points to the existence of some asymmetry in the conduct of monetary policy in the US, Germany and the UK, but not in Japan. The reaction function is convex in the expected output gap and inflation in the US and Germany suggesting that the precautionary demand for **low inflation** dominated the conduct of monetary policy in those countries during this period. By contrast it reveals the dominance of a precautionary demand for expansions in the case of the UK. Re-estimation over a latter sub-sample period (1985-2000) reveals interesting differences: It points to a dominant precautionary demand for low inflation in the UK and Japan, and to the the emergence of a dominant precautionary demand for **expansions** in the US whose reaction function becomes concave in the expected output gap and inflation. In contrast, the reaction function for Germany becomes linear in inflation and the output gap.

Those results are consistent with the view that policymakers might become concerned with the most immediate objective at hand. This in turn lends support to the 'framing hypothesis': monetary policymakers are likely to place greater weight on the most imminent risk of loss. At times of disinflation, output loss becomes relatively less important. Conversely during periods that are not characterized by credibility-building and disinflation, asymmetric preferences with respect to output re-emerge. Thus, when the sample includes the early 1980s, both the Fed and the Bundesbank display a dominant precautionary demand for low inflation. In the case of the Fed, after having established its price stability credentials during the early eighties, its policy became dominated, in the latter period, by a precautionary demand for expansions. By contrast monetary policy in the UK was dominated by a precautionary demand for low inflation during the latter period. This is consistent with the fact that the process of inflation stabilization and of reputation building in this country became important from the late 1980s onwards, after a decade of experimentation with different intermediate targets in the early to mid-1980s.

The paper is organized as follows. Section 2 presents the theoretical framework and derives implications for the relationship between the type of precautionary motive that dominates monetary policy and the shape of the reaction function. Section 3 estimates a linear baseline reaction function, tests for the existence of non linearities and then parametrizes them explicitly. Section 4 presents estimates of the model for the 1atter, 1985 - 2000, period and shows that the importance of asymmetric behavior varies between different periods (e.g. at times of disinflation, the output asymmetry becomes relatively less important). Section 5 concludes.

2 Theoretical Framework

2.1 Economic Structure

The behavior of the economy is characterized by means of a New Keynesian, forward looking, sticky prices framework in which inflation and the output gap depend respectively on the expected future values of those variables and in which the policy instrument of the monetary authority is the nominal interest rate. A simple aggregate version of such a framework has recently been summarized compactly by Clarida *et al.* (1999) and is reproduced in what follows;

$$x_t = -\varphi(i_t - E_t\pi_{t+1}) + E_t x_{t+1} + \widehat{g}_t \tag{1}$$

$$\pi_t = \lambda x_t + bE_t\pi_{t+1} + \widehat{u_t} \tag{2}$$

Here x_t and π_t are the output gap and inflation, $E_t x_{t+1}$ and $E_t\pi_{t+1}$ are the expected values of those variables conditioned on the information available in period t, i_t is the nominal rate of interest, $\widehat{g}_t$ is a demand shock, $\widehat{u_t}$ is a cost shock and φ, λ and b are positive coefficients. The expected future output gap appears in the output gap equation to reflect the notion that, since individuals smooth consumption, expectations of higher consumption next period (associated with higher expected output) leads them to demand more current consumption, which raises current output.

As in stylized models of sticky staggered prices pioneered by Calvo (1983), current inflation depends on future expected inflation. In this type of models only a fraction of firms has the opportunity to adjust its price each period and, due to costs of price adjustment, each firm adjusts its price at discrete intervals. Hence when it is given the chance to adjust its price the firm adjusts it by more the higher is expected future inflation. This interpretation implies that b is a discount factor. The positive dependence of inflation on the output gap is based on the view that this gap is a measure of excess demand and is shared by both forward, as well as backward, looking models of the economy in which output is demand determined. The shocks $\widehat{g_t}$ and $\widehat{u_t}$ have two components each. One that is known in period t and another that is not forecastable on the basis of the information available in that period. More precisely

$$\begin{aligned} \widehat{g_t} &= g_t + \widetilde{g_t} \\ \widehat{u_t} &= u_t + \widetilde{u_t} \end{aligned} \tag{3}$$

where g_t, u_t are the known components and $\widetilde{g_t}$, $\widetilde{u_t}$ are the surprise or innovation components of $\widehat{g_t}$ and $\widehat{u_t}$ respectively. The innovations $\widetilde{g_t}$ and $\widetilde{u_t}$ are zero mean mutually and temporally independent white noises.[8]

2.2 General Specification of Asymmetric Objectives

The objective of the monetary authority is to minimize

$$E_0 \sum_{t=0}^{\infty} \delta^t L_t \tag{4}$$

where δ is the discount factor and L_t is given by equation (5).

$$L_t = Af(x_t) + h(\pi_t - \pi^*). \tag{5}$$

Here A is a positive coefficient, π^* is the inflation target and the functions $f(x_t)$ and $h(\pi_t - \pi^*)$ possess the following properties.

$$\begin{aligned} f'(x_t) &< 0 \; for \; x_t < 0, \; f'(x_t) \geq 0 \; for \; x_t \geq 0, \; f(0) = f'(0) = 0, \\ f''(x_t) &> 0, \; f'''(x_t) \leq 0, \\ h'(\pi_t - \pi^*) &\leq 0 \; for \; \pi_t - \pi^* \leq 0, \; h'(\pi_t - \pi^*) > 0 \; for \; \pi_t - \pi^* > 0, \\ h(0) &= h'(0) = 0, \; h''(\pi_t - \pi^*) > 0, \; h'''(\pi_t - \pi^*) \geq 0 \end{aligned} \tag{6}$$

where the tags attached to the functions $f(x_t)$ and $h(\pi_t - \pi^*)$ designate partial derivatives whose order is given by the number of tags. The specification in equation (6) states that losses from both the output gap and the inflation gap

[8]Note that this specification includes the case in which the shocks $\widehat{g_t}$ and $\widehat{u_t}$ are first order Markov processes as a particular case.

(the deviation of inflation from its target) attain their minimal levels when those two gaps are zero and that losses are larger, at least weakly, the larger the absolute value of the gaps. The first order partial derivatives of both $f(x_t)$ and $h(\pi_t - \pi^*)$ are zero when gaps are zero. As with the quadratic, the second partial derivatives are assumed to be positive, but unlike the quadratic $f(x_t)$ and $h(\pi_t - \pi^*)$ need not be symmetric around zero.

Potential asymmetries in objectives are introduced by means of the assumptions on the third partial derivatives. A negative value of $f'''(x_t)$ means that the marginal loss at a given negative output gap is larger than the marginal loss at a positive output gap with the same absolute value. It implies that policymakers have a precautionary demand for expansions. When $f'''(x_t) = 0$ this precautionary demand is zero.[9]

A positive value of $h'''(\pi_t - \pi^*)$ means that, for a given absolute value of the deviation of inflation from its target, the marginal loss of a positive deviation is larger than the marginal loss of a negative deviations. It implies that policymakers are more averse to upward than to downward deviations from the target. Such precautionary demand for price stability may arise in periods of inflation stabilization during which the buildup of credibility is a primary consideration. In the particular case $h'''(\pi_t - \pi^*) = 0$ such precautionary demand is absent.

2.3 The policy process and the policy rule

An important aspect of monetary policymaking is that the interest rate has to be chosen before the realization of economic shocks is known with certainty by policymakers. This fact is captured here through the assumption that the innovations $\widetilde{g}_t$ and $\widetilde{u}_t$ are unknown at the time policymakers pick the nominal interest rate i_t. The policy rule can be found by minimizing the expected value from equation (4) subject to the behavior of the economy as given by equations (1) and (2). Inserting those equations into equation (5), substituting the resulting expression into equation (4) and taking the

[9] There is a strong analogy between the precautionary demand of policymakers for expansions and the precautionary demand for savings by consumers. Kimball (1990) shows that a necessary and sufficient condition for the existence of the latter is that the marginal utility of consumption or income be a convex function of income (a positive third partial derivative). Similarly, the condition $-f'''(x_t) > 0$, which is necessary and sufficient for the existence of a precautionary demand for expansions, means that the marginal utility, to policymakers, of an increase in output is a convex function of output.

expected value conditional on period's 0 information, the problem of the central bank is to choose the current interest rate i_0 and the sequence of future interest rates i_t, $t > 0$ so as to minimize the following expression

$$E_0 \sum_{t=0}^{\infty} \delta^t \left\{ \begin{array}{c} Af\left[-\varphi(i_t - E_t\pi_{t+1}) + E_t x_{t+1} + g_t + \widetilde{g_t}\right] + \\ h\left[\lambda(-\varphi(i_t - E_t\pi_{t+1}) + E_t x_{t+1} + g_t + \widetilde{g_t}) + bE_t\pi_{t+1} + u_t + \widetilde{u_t}\right] \end{array} \right\}. \tag{7}$$

Under discretion policymakers take expectations of future variables as given and reoptimize each period. Since there are no lags this problem can be decomposed into a series of separate one period problems. The typical first order condition for an internal maximum is therefore

$$AE_t f'[.] + \lambda E_t h'[.] = 0, \quad t = 0, 1, 2, .. \;. \tag{8}$$

Since g_t and u_t are known in period t the expectation E_t is taken over the distributions of the (unknown in period t) innovations $\widetilde{g_t}$ and $\widetilde{u_t}$. The period t condition determines the interest rate chosen in that period as a function of the known parts of the shocks, and the inflation and output gap expected for period $t+1$. Note that, since policy is discretionary and neither the economic structure nor the objective function contain lagged terms, the current choice of interest rate does not affect current expectations of future periods' inflation and the output gap. Those expectations depend only on period's t perceptions of period's $t+1$ shocks: $E_t g_{t+1}$, $E_t u_{t+1}$, on $E_t i_{t+1}$ and on more distant expectations. This can be seen by taking expected values, as of t, of the economic structure in equations (1) and (2) which yields

$$E_t x_{t+1} = -\varphi(E_t i_{t+1} - E_t\pi_{t+2}) + E_t x_{t+2} + E_t g_{t+1} \tag{9}$$

$$E_t\pi_{t+1} = \lambda E_t x_{t+1} + bE_t\pi_{t+2} + E_t u_{t+1} \tag{10}$$

2.4 Comparative statics with respect to $E_0\pi_1$ and the effect of asymmetric objectives

The choice of current interest rate depends, via the first order condition in equation (8), on the rate of inflation and on the output gap expected for next period. Totally differentiating the first order condition for $t = 0$ in (8) with respect to $E_0\pi_1$ and rearranging

$$\frac{di_0}{dE_0\pi_1} = \frac{1}{\varphi}\frac{\varphi A E_0 f_0^{''}[.] + \lambda(\varphi\lambda + b)E_0 h_0^{''}[.]}{A E_0 f_0^{''}[.] + \lambda^2 E_0 h_0^{''}[.]} \equiv \frac{\varphi A E_0 f_0^{''}[.] + \lambda(\varphi\lambda + b)E_0 h_0^{''}[.]}{\varphi D}. \tag{11}$$

where

$$\begin{aligned} f_0^{''}[.] &\equiv f^{''}[-\varphi(i_0 - E_0\pi_1) + E_0 x_1 + g_0 + \widetilde{g_0}], \\ h_0^{''}[.] &\equiv h^{''}[\lambda(-\varphi(i_0 - E_0\pi_1) + E_0 x_1 + g_0 + \widetilde{g_0}) + bE_0\pi_1 + u_0 + \widetilde{u_0}]. \end{aligned} \tag{12}$$

Since, as stated in equation (6), all the second partial derivatives are positive the expression in equation (11) is positive, implying that policymakers react to an increase in expected inflation by raising the nominal interest rate. Furthermore, since the numerator is larger than the denominator, the nominal rate increases by more than the increase in inflationary expectations implying that policymakers raise the exante real rate in response to an increase in inflationary expectations.

To evaluate the impact of asymmetric objectives on the extent to which the response of the interest rate to a change in expected inflation is non linear we now differentiate the expression in equation (11) with respect to $E_0\pi_1$ again. After some algebra the resulting expression is

$$\frac{d^2 i_0}{d(E_0\pi_1)^2} = \frac{A\lambda b^2}{\varphi D^3}\left\{A(E_0 f_0^{''})^2 E_0 h_0^{'''} + \lambda(E_0 h_0^{''})^2 E_0 f_0^{'''}\right\} \tag{13}$$

where the functions' brackets have been deleted to simplify notation.[10] Provided asymmetries in objectives operate with respect to both inflation and the output gap $E_0 f_0^{'''} < 0$ and $E_0 h_0^{'''} > 0$ implying that the model is sufficiently general to accommodate precautionary demands for both expansions, as well as for inflation rates below the (inflation) target. Since the coefficients of $E_0 h_0^{'''}$ and of $E_0 f_0^{'''}$ are both positive this expression may be of either sign. implying that the reaction function of the central bank may, in general, be convex or concave. If there is **only** a precautionary demand for price stability, $E_0 f_0^{'''} = 0$, and the reaction function is convex. If there is **only** a

[10] The second derivative of the reaction function of the central bank with respect to $E_0\pi_1$ invloves, *inter alia*, the term $\frac{di_0}{dE_0\pi_1}$. The expression in equation (13) is obtained by differentiating (11) with respect to $E_0\pi_1$, by using the expression for $\frac{di_0}{dE_0\pi_1}$ from equation (11) in the resulting expression, and by rearranging.

precautionary demand for expansions, $E_0 h_0^{'''} = 0$, and the reaction function is concave. If both asymmetries are absent, $E_0 f_0^{'''} = E_0 h_0^{'''} = 0$ and the response of the interest rate to expected inflation is predicted to be linear.

More generally, the curvature of the reaction function depends on the relative magnitudes of the precautionary demands for price stability and for expansions as characterized by $E_0 h_0^{'''}$ and $E_0 f_0^{'''}$, as well as on the relative magnitudes of the coefficients of those two terms. Equation (13) suggests that, although a relatively larger precautionary demand for expansions than for price stability is likely to induce a concave reaction function, this does not follow automatically since the curvature properties of the reaction function also depend on the weights of $E_0 h_0^{'''}$ and of $E_0 f_0^{'''}$. In particular equation (13) suggests that, even if $E_0 h_0^{'''}$ and $E_0 f_0^{'''}$ are equal, the reaction function will be convex if the central bank is sufficiently more concerned with stabilization of output relatively to stabilization of inflation (A is relatively large).

2.5 Comparative statics with respect to $E_0 x_1$ and the differential effects of different types of asymmetries

Totally differentiating the first order condition for $t = 0$ in (8) with respect to $E_0 x_1$

$$AE_0 f_0^{''}[.]\left(\varphi(\frac{di_0}{dE_0 x_1} - \lambda) + 1\right) + \lambda E_0 h_0^{''}[.]\left(\left(\lambda(\varphi(\frac{di_0}{dE_0 x_1} - \lambda) + 1\right) + b\lambda\right) = 0 \tag{14}$$

Note that this expression takes into consideration that a unit increase in $E_0 x_1$ induces, via equation (10), an increase of size λ in $E_0 \pi_1$. Solving for $\frac{di_0}{dE_0 x_1}$ we obtain

$$\frac{di_0}{dE_0 x_1} = \frac{1}{\varphi}\frac{A(1+\varphi\lambda)E_0 f_0^{''}[.] + \lambda^2(1+\varphi\lambda+b)E_0 h_0^{''}[.]}{D}. \tag{15}$$

The specification of the segments $h(.)$ and $f(.)$ of the losses from deviations of inflation and output from their respective targets in equation (6) implies that the response of the interest rate to an increase in the expected output gap is positive. To evaluate the effects of the precautionary demands for expansion and for price stability on the form of the functional relationship between those two variables we differentiate the expression in equation (15) again with respect to $E_0 x_1$. After some algebra the resulting expression is

$$\frac{d^2 i_0}{d(E_0 x_1)^2} = \lambda^2 \frac{A\lambda b^2}{\varphi D^3}\left\{A(E_0 f_0^{''})^2 E_0 h_0^{'''} + \lambda(E_0 h_0^{''})^2 E_0 f_0^{'''}\right\} \qquad (16)$$

The coefficients of both $E_0 f_0^{'''}$ and of $E_0 h_0^{'''}$ are positive. Since $E_0 f_0^{'''} < 0$ and $E_0 h_0^{'''} > 0$ the sign of this expression is determined by the relative importance of the precautionary demand for expansions, as measured by the absolute value of $E_0 f_0^{'''}$, and of the precautionary demand for low inflation as measured by $E_0 h_0^{'''}$. If the first asymmetry dominates, the interest rate reaction function should be a concave function of the expected output gap, whereas, if the second dominates, it should be a convex function of the expected output gap. In the absence of either type of asymmetry the reaction should be linear in the expected output gap.[11]

Comparison of equations (16) and (13) suggests that the second derivative of the reaction function with respect to $E_0 x_1$ is equal to the second derivative of the reaction function with respect to $E_0 \pi_1$ multiplied by a positive constant, λ^2. It follows that the reaction function is convex (concave) in the expected output gap if and only if it is convex (concave) in expected inflation. Hence a dominant precautionary demand for low inflation induces a reaction function that is convex in **both** expected inflation and the expected output gap, while a dominant precautionary demand for expansions induces a reaction function that is concave in **both** of those expectations. In the absence of both precautionary demands, or if they happen to neutralize each other, the reaction function is linear. Note that, other things the same a higher level of CB conservativeness (a lower A), increases the likelihood that the precautionary demand for expansions dominates the curvature of the reaction function.

3 Estimating an Interest Rate Reaction Function Model with Non-linear Responses

The major empirically testable implications of the model are:

1. In the absence of asymmetries in objectives, the reaction function should be linear in both expected inflation and the expected output gap.

[11] Note that the reaction to $E_0 x_1$ may be linear even if both precautionary demands are present, provided those two effects offset each other.

However detection of such linearity does not necessarily imply that precautionary motives are absent since both may operate but roughly offset each other in a manner that produces a linear reaction function (see equations (13) and (16)).

2. Depending on whether $A(E_0 f_0^{''})^2 E_0 h_0^{'''}$ is larger or smaller than $\lambda(E_0 h_0^{''})^2 \mid E_0 f_0^{'''} \mid$ the reaction function will be a convex or a concave function of **both** expected inflation and of the expected output gap. Hence detection of convexity in both of those expectations implies that there is a precautionary demand for price stability while detection of concavity in both of them implies that there is a precautionary demand for expansions. However, detection of convexity does not necessarily imply that a precautionary demand for expansions is non existent, and detection of concavity does not necessarily imply that a precautionary demand for price stability is non existent.

3. When the precautionary demands for expansions and for price stability are of similar magnitudes, in the sense that $E_0 h_0^{'''} = E_0 f_0^{'''}$, the reaction function will be convex in both expected inflation and the expected output gap if the central bank is relatively more concerned with deviations of output from potential in comparison to deviations of inflation from its target ($A(E_0 f_0^{''})^2 > \lambda(E_0 h_0^{''})^2$). In the opposite case the reaction function will be a concave function of expected inflation and the expected output gap.

To test those implications we estimate reaction functions for short-term interest rates (the federal funds rate for the US and call money rates for other countries) for the period[12] 1980-2000, using quarterly data (the data series employed are detailed in the Data Appendix). We begin by presenting results from the estimation of a standard linear interest reaction function as a baseline against which to evaluate non-linear/asymmetric interest rate reaction functions.

3.1 A Standard Linear Reaction Function

The first order condition in equation (8) specialized to period 0 implies that the current interest rate is determined by the expected future values of infla-

[12]In the case of Germany, the ECB took over control of monetary policy at the beginning of EMU. Nevertheless, there is substantial casual evidence to suggest that until the beginning of EMU in 1999, the Bundesbank continued to pursue its domestic objectives in setting interest rates.

tion and of the output gap[13]. In practice, it is well known that there will be some interest-rate smoothing, so that equation (8) is best seen as a desired interest rate, i^* , to which the authorities are assumed to converge through a partial adjustment mechanism (see Clarida *et al.*, 1998, 2000)[14]:

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

In the absence of asymmetries ($E_0 h_0^{'''} = E_0 f_0^{'''} = 0$) the non linear terms in equations (13) and (16) are both zero and, for estimation purposes, the reaction function can be approximated by the following linear relation

$$i_t = (1-\rho)\{\alpha + \beta(E[\pi_{t,k}|\Omega_t] - \pi^*) + \gamma E[x_{t,q}|\Omega_t]\} + \rho i_{t-1} + \upsilon_t \qquad (17)$$

where υ_t is an exogenous interest rate control error. Adding and subtracting $\beta E[\pi_{t,k}|\Omega_t]$ and $\gamma E[x_{t,q}|\Omega_t]$ to equation (17) and rearranging

$$i_t = (1-\rho)\{\widetilde{\alpha} + \beta\pi_{t,k} + \gamma x_{t,q}\} + \rho i_{t-1} + \varepsilon_t \qquad (18)$$

where $\widetilde{\alpha} = \alpha - \beta\pi^*$ and the error term ε_t contains the forecast errors and the interest rate control error: $\varepsilon_t = -\left[\beta(\pi_{t,k} - E[\pi_{t,k}|\Omega_t]) + \gamma(x_{t,q} - E[x_{t,q}|\Omega_t])\right] + \upsilon_t$.

To estimate equation (18) we employ Hansen's (1982) Generalized Method of Moments (GMM), using as instruments four lags of the policy instrument and of the policy targets (output and inflation). Clarida *et al.* experiment with various leads for the output gap and expected inflation, but in fact q=k=1 seems to fit the data reasonably well, and the estimates of the parameters are not too sensitive to changes in q and k over the range of 1 to 4 quarters[15].

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[13] As can be seen from the data Appendix, we use official estimates of potential output (OECD, CBO) to construct series for the output gap. In contrast, Muscatelli *et al.* (1999) use a Kalman Filter based estimation to allow for gradual learning by the authorities of changes in the processes generating inflation and the output gap. Using official data on the output gap makes our results more directly comparable to most of the existing empirical literature on interest rate reaction functions.

[14] For a justification of interest-smoothing behaviour, see Cukierman (1990, 1992). Svensson (2000) and Muscatelli *et. al.* (1999) develop models that include the costs of interest rate adjustment in the optimization exercise.

[15] The lack of sensitivity of the result to the choice of lead period is probably due to the high degree of serial correlation in these series.

The estimates obtained for equation (18) for all four countries, using GMM are shown in Table 1. Four lags of the explanatory variables are used as instruments in the estimation.

Table 1: GMM Estimates of Linear Interest Rate Reaction Functions

Country	$\widehat{\widehat{\alpha}}$	$\widehat{\beta}$	$\widehat{\gamma}$	$\widehat{\rho}$	Statistics	Sample Period
USA	1.32 (1.60)	1.88 (0.61)	0.69 (0.31)	0.80 (0.06)	$\sigma = 1.04$, $J(11) = 0.29$	1979:3-1999:4
Germany	-5.90 (7.72)	3.38 (1.98)	3.74 (3.71)	0.92 (0.07)	$\sigma = 0.70$, $J(11) = 0.09$	1979:3-2000:1
Japan	1.36 (1.05)	1.72 (0.62)	0.17 (0.08)	0.88 (0.03)	$\sigma = 0.60$, $J(11) = 0.16$	1979:3-2000:1
UK	4.32 (0.83)	1.03 (0.17)	0.69 (0.26)	0.79 (0.05)	$\sigma = 1.08$, $J(11) = 0.10$	1979:3-1999:3

Notes: Numbers in brackets indicate standard errors (using a consistent covariance matrix for heteroscedasticity and serial correlation); σ indicates the standard error of the estimate; J(n) is Hansen's test of the model's overidentifying restrictions. It is distributed as a $\chi^2(n)$ variate under the null hypothesis of valid overidentifying restrictions. None of the J tests are significant at the 5% level.

The estimates in Table 1 are consistent with those reported in Clarida *et al*, allowing for the slightly different sample period used here. Excluding the UK, all the countries have been characterized during the last two decades by a long-run response of interest rates to expected inflation that is larger than unity. In the case of the UK the point estimate for $\widehat{\beta}$ is close to one, which is consistent with the fact that inflation was brought under control much later. The interest rate response to the expected output gap is not significant in the case of Germany, but is significant in the case of all remaining countries. Note also that the UK has a higher equilibrium real interest rate under this model than Japan, Germany and the US where it is not significantly different from zero. Clarida *et al* have used similar estimates to support the conclusion that a number of major industrialized economies have, *de facto*, followed an implicit forward-looking inflation targeting policy.

3.2 Evidence of non-linear or asymmetric behavior

What evidence is there that linear models of the type estimated by Clarida *et al.* (1998, 2000) and reported above do not capture the full story as far as interest rate decision-making is concerned? To provide a preliminary answer this question we use a number of diagnostic tests. In particular we focus on a class of residual-based tests designed to verify whether non-linear effects are present (see Granger and Terasvirta, 1993)[16].

Using the fitted residuals from (18), one fits the auxiliary model:

$$\widehat{\varepsilon}_t = \boldsymbol{\delta}_0'\mathbf{x}_t + \boldsymbol{\delta}_1'\mathbf{x}_t z_{td} + \boldsymbol{\delta}_2'\mathbf{x}_t(z_{td})^2 + \boldsymbol{\delta}_3'\mathbf{x}_t(z_{td})^3 \tag{19}$$

where $\mathbf{x}_t$ is the vector of regressors in the original model, and z_{td} is a 'transition variable' which may be either a lagged dependent variable (the interest rate) or any of the variables in the model (inflation, output gap), or indeed any other variable which might explain non-linear behavior in the model. The results from applying these tests are shown in Table 2. The tests show that in all four countries there is evidence supporting some non-linearity in the response of the interest rate. The only exception is Germany, for which the tests are only marginally significant, and are not significant when output or inflation is used as the transition variable.

There are several points to note about these tests. First, we are performing these tests against a variety of possible transition variables. We will focus, in what follows, primarily on using either the output gap or the level of inflation as transition variables. The reason is that the theoretical framework implies that whether the interest rate reaction function is a convex or concave function of the output gap and inflation carries implications for the dominant type of asymmetry. Second, because we do not know the true nature of the non-linear model under the alternative hypothesis (and the appropriate transition variable(s)), the true significance level (size) of these multiple non-linearity tests cannot be known with precision. Hence they should be treated as indicative tests[17]. In other words, the statistical

[16] Granger and Terasvirta stress that this form of test has power against a variety of non-linear effects, such as a logistic-smooth-transition or an exponential-smooth-transition model.

[17] In general these tests are only valid when the residuals are obtained from least-squares estimation procedures. As an alternative, we tested whether the non-linear terms were significant when added directly to the GMM model. They were still significant. In order to verify that the non-linearity tests are not picking up any omitted variables in the reaction

test described here is a generic test which has power against different types of non-linear behavior.

Table 2: Tests of Non-linear Interest Rate Responses

USA	$H_0 : \boldsymbol{\delta}_1 = \mathbf{0}$	$H_0 : \boldsymbol{\delta}_2 = \boldsymbol{\delta}_3 = \mathbf{0}$
$z_{td} = y$	0.43	3.02***
$z_{td} = \pi$	3.52**	6.14***
$z_{td} = i_{t-1}$	3.58**	4.47***
Germany	$H_0 : \boldsymbol{\delta}_1 = \mathbf{0}$	$H_0 : \boldsymbol{\delta}_2 = \boldsymbol{\delta}_3 = \mathbf{0}$
$z_{td} = y$	1.08	1.77
$z_{td} = \pi$	0.98	2.08
$z_{td} = i_{t-1}$	2.37*	13.15***
Japan	$H_0 : \boldsymbol{\delta}_1 = \mathbf{0}$	$H_0 : \boldsymbol{\delta}_2 = \boldsymbol{\delta}_3 = \mathbf{0}$
$z_{td} = y$	0.28	1.05
$z_{td} = \pi$	17.39***	11.19***
$z_{td} = i_{t-1}$	19.17***	12.93***
UK	$H_0 : \boldsymbol{\delta}_1 = \mathbf{0}$	$H_0 : \boldsymbol{\delta}_2 = \boldsymbol{\delta}_3 = \mathbf{0}$
$z_{td} = y$	0.65	2.51**
$z_{td} = \pi$	1.20	3.30***
$z_{td} = i_{t-1}$	1.27	3.04***

Note: The $\delta_1 = 0$ test is distributed as an F(3,69) variate under the null, whilst the $\delta_2 = \delta_3 = 0$ test is distributed as a F(6,69) variate under the null. A (*), (**), (***) indicates that the null hypothesis of a zero restriction is rejected at respectively the 10%, 5% or 1% level.

3.3 A model of Asymmetry with Non-linear Responses

The tests in section 3.2 suggest that an alternative interest rate reaction function to the linear one might be appropriate. A variety of different types of models can be constructed to capture asymmetric/non-linear interest rate responses. In experimenting with these models, we concentrated our attention on smooth-transition models, i.e. models which predict a gradual switch from one regime to the other. In contrast to threshold models, which predict

function, we also tried to add the nonlinear terms when the reaction functions also included a lagged value of inflation and output. Again, the nonlinear terms were still found to be significant. We are grateful to Adrian Pagan for suggesting these additional tests.

a sudden switch between regimes, smooth-transition regressions (STR) use particular functional forms to specify the way in which an economy moves from one regime to another. In our case STR appear to be preferable to threshold models since it is unlikely that over the 20 years sample period the switch point, or threshold, for the reaction of monetary policy has remained unchanged as both the individuals involved in decision-making and the objectives of policy have changed[18] In addition, the notion of 'framing' discussed in the introduction suggests that policymakers are likely to develop subjective notions of risk vis-a-vis the inflation and output targets, and that these notions of riskiness are likely to evolve gradually over time. It is unlikely that, after passing a particular threshold for inflation or the output gap, CB behavior will change in a discontinuous manner. Hence, STR models seem as more appropriate for the analysis of non-linear and asymmetric behavior.

A smooth-transition regression (STR) model can be built following the modelling strategy proposed in Granger and Terasvirta (1993). A version of the reaction function in equation (18) that allows for a smooth transition specification of non linearities is given by

$$i_t = (1-\rho)\{\widetilde{\alpha} + \beta_1 \pi_{t,1} + \gamma_1 x_{t,1} + \{\beta_2 \pi_{t,1} + \gamma_2 x_{t,1}\} F(z_t)\} + \rho i_{t-1} + \varepsilon_t \quad (20)$$

where z_t is the variable which determines the transition and $F(z_t)$ is an appropriate non linear and continuous function of z_t. Granger and Terasvirta (1993) propose either the logistic or exponential functions to model the smooth transition (the so-called LSTR models). However, we obtained a better fit for our data using a hyperbolic tangent (tanh) function to capture the gradual transition between regimes (such a parametrization has been proposed by Bacon and Watts (1971), and Seber and Wild (1989)). The hyperbolic tangent smooth transition regression (HTSTR) assumes the following form[19] for $F(z_t)$:

$$F(z_t) = \tanh(\psi(z_t - \vartheta)). \quad (21)$$

The theory, as well as the tests in Table 2 suggest that the expected values of both the output gap and inflation might be appropriate transition variables. In fact, equation (20) involves a more restrictive specification than necessary

[18] Dolado *et al.* (2000) partly recognize this by allowing the (unknown) switch point for inflation to be determined by official inflation targets.

[19] Where ϑ represents the point of inflexion in the tanh function.

since it suggests that a single transition variable (*either the* output gap *or* inflation) govern the non-linear responses with respect to both output and inflation. In practice, it might be the case that both large deviations from the inflation target or from the desired level of output will generate changes in the slope of the reaction function. In order to allow for asymmetries in both output and inflation to be triggered independently by transitions in *both* output *and* inflation, we respecify equation (20) as follows:

$$i_t = (1-\rho)\{\widehat{\alpha}+\beta_1\pi_{t,1}+\gamma_1 x_{t,1}+\beta_2\pi_{t,1}F_\pi(\pi_{t,1})+\gamma_2 x_{t,1}F_x(x_{t,1})\}+\rho i_{t-1}+\varepsilon_t \quad (22)$$

where $F(.)$ is defined in equation (21) and the subscripts π and x that are attached to $F(.)$ allow for the possibility that the parameters ψ and ϑ vary depending on whether the variable which determines the transition is the output gap or inflation, i.e. $F_\pi(\pi_{t,1}) = \tanh(\psi_\pi(\pi_{t,1} - \vartheta_\pi))$ and $F_x(x_{t,1}) = \tanh(\psi_x(x_{t,1} - \vartheta_x))$

Equation (22) has the following properties: As inflation varies around the threshold ϑ_π, the value of the hyperbolic tangent function varies between -1 and 1. Suppose for instance that for inflation $\vartheta_\pi = 4\%$, and that $\psi_\pi = 1$. At low inflation rates (approximately 2% below the threshold the tanh function is close to its lower asymptote of -1), the long-run response of the nominal interest rate to inflation is given by $(\beta_1 - \beta_2)$. In contrast, at high inflation rates (approximately 2% above the threshold, i.e. at 6% inflation, the tanh function is close to its upper asymptote of 1), the nominal interest rate response to expected inflation is given by $(\beta_1 + \beta_2)$. In the interval between these two asymptotes, the response lies somewhere in between these two values. In Section 3.5, having estimated the model, we shall illustrate how the response function varies over different values of output and inflation using graph plots.

In fact our theoretical model suggests a more restricted version of this model, as the convexity of the interest rate reaction vis-a-vis inflation should be closely related to the convexity vis-a-vis output. In particular, the theory suggests that:

$$\frac{\partial^2 i_t}{\partial x_{t,1}^2} = \lambda^2 \frac{\partial^2 i_t}{\partial \pi_{t,1}^2} \quad (23)$$

Differentiating equation (22) with respect to $x_{t,1}$ and $\pi_{t,1}$ we see that:

$$\frac{\partial^2 i_t}{\partial x_{t,1}^2} = \gamma_2 \left[2\psi_x F_x^{'}(x_{t,1}) + x_{t,1}\psi_x^2 F_x^{''}(x_{t,1}) \right]$$

$$\frac{\partial^2 i_t}{\partial \pi_{t,1}^2} = \beta_2 \left[2\psi_\pi F_\pi^{'}(\pi_{t,1}) + \pi_{t,1}\psi_\pi^2 F_\pi^{''}(\pi_{t,1}) \right]$$

Note that, if $\psi_x = \psi_\pi \equiv \psi$, then $F_\pi = F_x \equiv F$ for $(\pi_{t,1} - \vartheta_\pi) = (x_{t,1} - \vartheta_x)$, and by setting $\gamma_2 = \lambda^2\beta_2$ we have $(\partial^2 i_t/\partial x_{t,1}^2) = \lambda^2(\partial^2 i_t/\partial \pi_{t,1}^2)$ which implies the restriction suggested by theory that the convexity (concavity) of the reaction function with respect to inflation should be related to that with respect to output. As we shall see below, we generally find that our models fit the data well with the restrictions that $\psi_x = \psi_\pi \equiv \psi$, and $\gamma_2 = \lambda^2\beta_2$, which simplifies equation (22) to:

$$i_t = (1-\rho)\{\widetilde{\alpha} + \beta_1\pi_{t,1} + \gamma_1 x_{t,1} + \beta_2\pi_{t,1}F(\pi_{t,1} - \vartheta_\pi) + \lambda^2\beta_2 x_{t,1}F(x_{t,1} - \vartheta_x)\} + \rho i_{t-1} + \varepsilon_t \quad (24)$$

3.4 Estimating a HTSTR Model

Equation (24) is estimated by GMM. As before, we use four lags of all the explanatory variables in the estimation. Table 3 reports the estimated parameters. Estimation of (24) subject to the restriction that $\lambda^2\beta_2$ and β_2 have the same sign, allows us to make some inference about the size of λ^2. As far as the values of $\vartheta_x, \vartheta_\pi$ and ψ are concerned, we conducted a grid search, as free estimation of these parameters led to convergence problems with the non-linear optimisation algorithm. We selected the value of $\vartheta_x, \vartheta_\pi$ and ψ that provided the best fit. In the case of ψ, as we shall see below, a value which is less than unity ensures that the functions $x_{t,1}F(x_{t,1})$ and $\pi_{t,1}F(\pi_{t,1})$ are convex for the range of most of our observations. In general, we found that estimating our models setting $\psi = 0.25$ provided the best fit[20]. This implies that these functions are convex for the ranges $(\vartheta_\pi - 4\%, \vartheta_\pi + 4\%)$ and $(\vartheta_x - 4\%, \vartheta_x + 4\%)$, which cover 95-100% of all our observations for inflation and output.

[20] We tried a grid search between $\psi = 0.4$ and $\psi = 0.15$.

Table 3: GMM Estimates of Smooth-Transition non-Linear Reaction Functions

Country	Estimated Coefficients						Statistics	Sample Period
	$\widehat{\widetilde{\alpha}}$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\gamma}_1$	$\widehat{\gamma}_2$	$\widehat{\rho}$		
USA	4.45 (0.82)	0.94 (0.30)	0.94 (0.30)	1.04 (0.59)	0.33 (0.10)	0.85 (0.08)	$\sigma = 1.04$, $J(11) = 18.1$	1979:3-1999:4
Germany	2.16 (0.90)	1.21 (0.33)	0.94 (0.47)	0.58 (0.25)	0.21 (0.10)	0.82 (0.06)	$\sigma = 0.61$, $J(11) = 3.46$	1979:3-2000:1
Japan	1.19 (0.42)	1.68 (0.28)	0.15 (0.77)	0.66 (0.30)	0.03 (0.15)	0.84 (0.04)	$\sigma = 0.59$, $J(11) = 7.48$	1979:3-2000:1
UK	−0.03 (1.94)	2.43 (0.67)	−1.19 (0.59)	0.46 (0.18)	−0.05 (0.02)	0.71 (0.06)	$\sigma = 1.06$, $J(11) = 10.7$	1979:3-1999:3

Notes: Numbers in parenthesis indicate standard errors (using a consistent covariance matrix for heteroscedasticity and serial correlation); σ indicates the standard error of the estimate; J(n) is Hansen's test of the model's overidentifying restrictions, which is distributed as a $\chi^2(n)$ variate under the null hypothesis of valid overidentifying restrictions. None of the J tests are significant at the 5% level.

Except for Japan the best fit was obtained with a value of $\vartheta_\pi = 4\%$ for the inflation asymmetry, and $\vartheta_x = 0$ in the case of the output gap asymmetry. To be precise, the monetary authorities appear to be asymmetric as between positive and negative values of the output gap, and between situations of high inflation (inflation above 4%) and situations of low inflation (below 4%). In the case of Japan during the post-1985 period the best fit was obtained for a value of ϑ_π of 2% [21]. In the case of λ, this is estimated[22] subject to the restriction that $\gamma_2 = \lambda^2\beta_2$. In all cases we tested whether a more parsimonious model could be fitted in order to raise the precision of the estimates. Since it was not rejected[23], the restriction $\widehat{\beta_1} = \widehat{\beta_2}$ was imposed in the case of the US.

There are several important points to note about these estimates. First, in the case of the US, the UK, and Germany there are clear signs of non-linearities as the non-linear effects on inflation and output (β_2 and γ_2) are significant for those countries. In the case of Japan the non-linear effect is not significant over the full sample. As we shall see in the next section, the Japanese estimates show a more marked non-linearity if only the latter part of the sample is used (post-1985), indicating that non-linear/asymmetric effects have become more important since the mid-1980s. In the case of Germany and the USA there appears to have been a dominance of the precautionary demand for low inflation, as the reaction function is convex in the expected inflation and output terms. In the case of the UK monetary authorities[24] the reaction function is concave, indicating a dominance of the precautionary demand for expansions. As we shall see later The Bundesbank's behavior

[21]This is probably because during this period inflation in Japan rarely exceeded 2-3%.

[22]As can be calculated from Table 3, the values of λ range from 0.2 in the case of the UK to 0.45 for Japan, 0.47 for Germany, and 0.59 in the case of the US. These estimates seem broadly consistent with the estimates for λ cited in footnote 32 of Clarida *et al.* (2000), and with the estimates reported in Gali *et al.* (2001). The nonlinear restriction $\gamma_2 = \lambda^2\beta_2$ can be tested using the GMM counterpart to the likelihood ratio test suggested by Newey and West (1987), known as the D-test. This test computes the difference in the GMM criterion function between the unrestricted and restricted estimates. The null hypothesis of a valid restriction was always accepted at the 5% significance level. For the full-sample estimates the D-test values (which are distributed as a chi-squared (1) under the null hypothesis) were as follows: 2.710 for the USA, 3.030 for the UK, 0.202 for Japan, and 0.001 for Germany.

[23]This was tested using an LM test: the test statistic is 1.52, which is distributed as a $\chi(1)$ variate under the null of a valid restriction, and is insignificant at the 5% level.

[24]The UK Treasury till 1997, then the independent Bank of England.

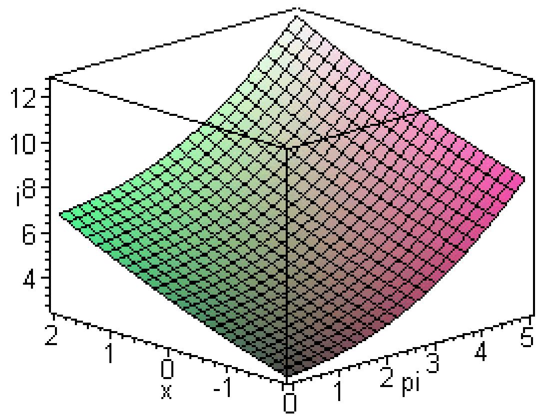

Figure 1: Non-Linear Reaction Function, USA 1979-2000

appears to have been less subject to asymmetries if we focus on the post-1985 sample. The dominance of the precautionary demand for inflation appears to have been a phenomenon of the early part of the 1980s.

To illustrate the nature of the asymmetric behavior implied by these estimates, we can plot the reaction function in three-dimensional space (x, π, i) for the USA and Germany. This is shown in Figures 1 and 2, where the vertical axis shows the long-run value of the interest rate for given combinations of the output gap and inflation. Hence the asymmetric/non-linear reaction function of Table 3, which is shown as a curved plane, convex to both output and inflation.

Figure 1 shows that the convexity with respect to output is greater for the USA than for Germany (Figure 2), where the response is greater with respect to inflation, for any given level of the output gap. For the USA, interest rates only begin to increase more sharply as inflation rises towards 3%, and below 2% the response flattens out, suggesting that interest rates tend to reach a floor. Figure 1 also shows that the concavity with respect to inflation is more salient than the concavity with respect to the output gap. This is a consequence of the fact that the estimate of λ^2 for the US is about a third implying, via equation (23), that the convexity with respect to the output gap is smaller.

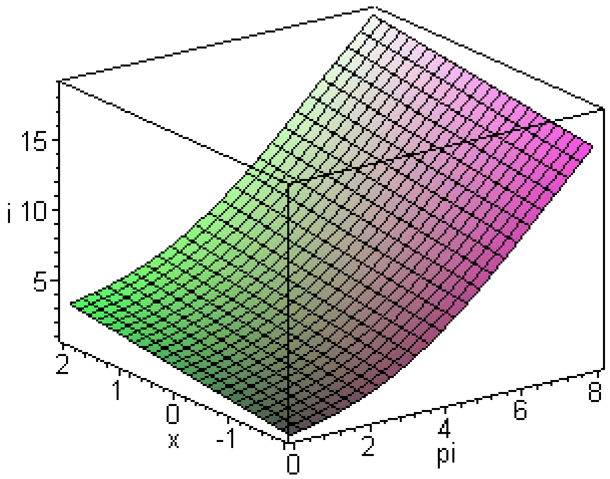

Figure 2: Non-Linear Reaction Function, Germany 1979-2000

As explained above, the convexity of the reaction function implies a dominance of the precautionary demand for low inflation on the part of the Bundesbank and the Fed, but this does not in itself imply the absence of a precautionary demand for expansions.

In the case of the UK, however, the interest rate reaction function is concave in **both** inflation and the output gap for the full sample (both β_2 and γ_2 are significantly negative). This is shown in Figure 3. Whilst this may at first sight seem surprising, given that interest rates in the UK rose quite sharply in the 1980s, Figure 3 shows that the concavity in interest rates with respect to inflation is such as to imply a peak for interest rates a bit above 12%. Essentially the concavity seems to be capturing a reluctance for the UK monetary authorities to raise interest rates sharply during expansions, which is consistent with a dominant precautionary demand for expansions. This was probably at the root of the inflationary bias in the UK. Despite the persistence of inflation and the existence of different institutional regimes in the UK since 1979, these findings suggest that the majority of the period (1979-97) involved the political authorities in the UK struggling to build up an anti-inflationary reputation because the institutional framework was

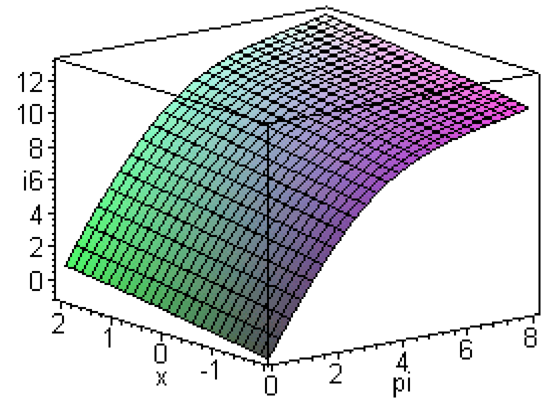

Figure 3: Non-Linear Reaction Function, UK 1979-2000

not designed to address macroeconomic stability. As we shall see below, the results for the UK change markedly when we focus only on the latter part of the sample.

4 Estimates for a latter Sub-Sample

We examine next whether our results vary when we delete the first half of the eighties from the sample. There is considerable evidence from empirical work on linear interest rate reaction functions, that CB behavior has varied over time (Muscatelli *et. al.*, 1999, Muscatelli and Trecroci, 2000, Clarida *et. al.*, 2000). Interestingly we find that, once we look at sub-sample estimates, the nature of the asymmetries seem to change.

Estimates of the HTSTR model for the sub-sample 1985-1999 are reported in Table 4. All the non-linear output and inflation terms are now significant[25]. As before we estimate the model subject to the restriction

[25] Again where possible we test for a more parsimonious model by imposing equality restrictions between $\widehat{\beta}_1$ and $\widehat{\beta}_2$ when this is supported by the data. In the case of the US, the restriction that $\widehat{\beta}_1 = -\widehat{\beta}_2$ yielded an LM test statistic of 0.76. In the case of the UK the restriction that $\widehat{\beta}_1 = \widehat{\beta}_2$ gave an LM test statistic of 1.02. Both are distributed as a $\chi(1)$ variate under the null of a valid restriction, and are insignificant at the 5% level.

$\gamma_2 = \lambda^2 \beta_2$, suggested by theory.

Table 4: Sub-Sample GMM Estimates of Smooth-Transition non-Linear Reaction Functions

Country	Estimated Coefficients						Statistics	Sample Period
	$\widehat{\bar{\alpha}}$	$\widehat{\beta}_1$	$\widehat{\beta}_2$	$\widehat{\gamma}_1$	$\widehat{\gamma}_2$	$\widehat{\rho}$		
USA	1.34 (1.19)	1.50 (0.43)	−1.50 (0.43)	1.07 (0.29)	−0.53 (0.15)	0.87 (0.03)	$\sigma = 0.39$, $J(11) = 1.36$	1985:1-1999:4
Germany	−1.14 (3.69)	2.12 (1.10)	1.26 (1.84)	1.88 (1.73)	0.28 (0.40)	0.95 (0.04)	$\sigma = 0.42$, $J(11) = 1.93$	1985:1-1999:4
Japan	0.30 (0.60)	1.76 (0.49)	3.20 (1.12)	1.13 (0.48)	0.64 (0.22)	0.90 (0.03)	$\sigma = 0.39$, $J(11) = 1.43$	1985:1-2000:1
UK	5.00 (0.57)	0.68 (0.11)	0.68 (0.11)	0.69 (0.27)	0.03 (0.004)	0.77 (0.09)	$\sigma = 0.80$, $J(11) = 8.97$	1985:1-1999:3

Notes: Numbers in parenthesis indicate standard errors (using a consistent covariance matrix for heteroscedasticity and serial correlation); σ indicates the standard error of the estimate; J(n) is Hansen's test of the model's overidentifying restrictions, which is distributed as a $\chi^2(n)$ variate under the null hypothesis of valid overidentifying restrictions. None of the J tests are significant at the 5% level.

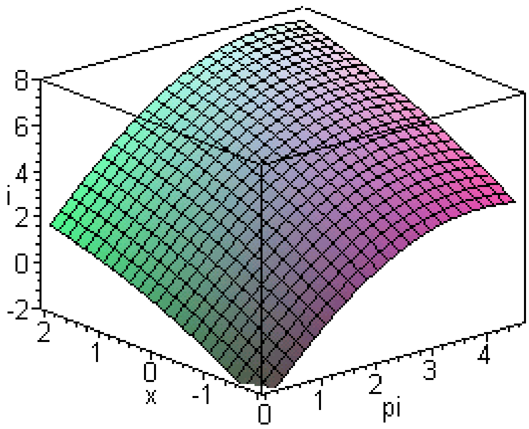

Figure 4: Non-Linear Reaction Function USA 1985-2000

Figure 4 plots the resulting long run non linear reaction function for the US. This shows a concavity with respect to both inflation and the output gap. The estimates of β_2 and γ_2 are now negative and significant, implying that the reaction function is a concave function of the expected output gap and expected inflation. In terms of our theoretical model (see equation (16)) this concave shape is consistent with the view that, after having brought inflation under control, the US Fed developed a precautionary demand for expansions which was dominant relative to the precautionary demand for low inflation. It seems that, following the credibility-building period of the early 1980s, the Fed became relatively more sensitive to recessions. An interesting point to note about Figure 4 is that the concavity is more marked than that of the UK (Figure 3) for relatively low inflation rates[26], with nominal interest rates peaking at inflation rates of 4-5%. The concavity with respect to the output gap in the USA (Figure 4) is also more marked than that for the UK (Figure 3). This suggests perhaps a different interpretation for the US post-1985 estimates than for the UK full-sample estimates. In the latter case it seems to be linked to an unwillingness to raise interest rates sufficiently to match very high inflation and a lack of credibility in lowering inflation expectations

[26] Note that US inflation rates post-1985 always remained below 4.7%, so that the reaction function was always on the upward-sloping part of the concave function.

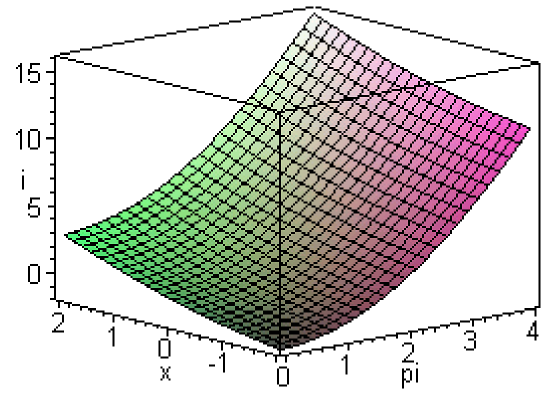

Figure 5: Non-Linear Reaction Function, Japan 1985-2000

given the authorities precautionary preferences for expansions. In the case of the USA there seems to have been a more active response to the output gap for any given inflation rate.

We plot the reaction function for Japan for the post-1985 period in Figure 5, which shows convexity with respect to the two explanatory variables, and hence a dominance of the precautionary demand for low inflation. The fact that the reaction function is now significantly convex in the output gap (γ_2 and β_2 positive and significant) supports the view that the dominant asymmetry in Japanese monetary policy, in the post 1985 period, is the precautionary demand for low inflation.

Unlike the US, the period since 1985 in the UK has been dominated by further reputation building (and since 1992 the adoption of inflation targeting, leading to CB independence in 1997). As is apparent from the short run coefficients in Table 4 and from Figure 6, the reaction of the interest rate to the output gap and inflation in the UK has a convex shape which is consistent (see equations (13) and (16)) with the existence of a dominant precautionary demand for low inflation.[27]

Unfortunately it is not possible to establish, given the few data points

[27] This is consistent with evidence in Ruge-Murcia (Forthcoming) that supports the existence of a precautionary demand for low inflation in the UK during the nineties.

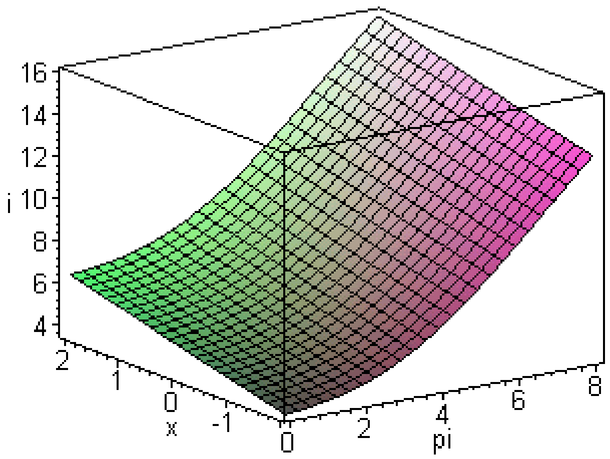

Figure 6: Non-Linear Reaction Function, UK: 1985-2000

at our disposal, whether UK behavior has changed further since 1997. Estimating the model from 1992 as opposed to 1985 yields very similar results, with an interest rate reaction function which is convex. This re-enforces the view that during periods of reputation building (or credible disinflation), the precautionary demand for expansions becomes relatively less important, whilst once inflation has been under control for some time (the US since the mid-1980s), the precautionary demand for expansions dominates the precautionary demand for low inflation.

To sum up, the evidence in Table 4 suggests that, post-1985, non-linear responses are no longer important for Germany ($\widehat{\beta}_2$ and $\widehat{\gamma}_2$ become insignificant), whilst non-linear effects remain important for the UK and the US, and become significant for Japan. Interestingly, the US reaction function becomes concave with respect to inflation and output post-1985, whilst the UK and Japanese reaction functions become convex with respect to expected inflation and output.

Except for Japan, these findings lend support to the notion that policymakers try harder to avoid the retrospective policy mistakes which were most in evidence during the immediately preceding periods. Monetary policymakers seem to change their behavior over time in response to changing prevailing circumstances. They are likely to place greater weight on the most imminent risk of loss. At times of reputation building (like the UK in the nineties and the US in the early 1980s) inflation appears to be the number one priority, and output loss becomes relatively less important. The UK's behaviour when the sample includes the early to mid-1980s seems to have been characterised by a greater preoccupation with output loss, although this may in part be explained by experimentation with different intermediate objectives, including the exchange rate. Conversely during periods that are not characterized by credibility-building and disinflation (e.g. the USA in the post-1985 period), asymmetric preferences with respect to the output gap re-emerge, creating the potential for an inflation bias.[28]. In the case of Japan, the finding that a precautionary demand for low inflation becomes more important may be symptomatic of other factors: for instance a preoccupation with avoiding a depreciating Yen/Dollar exchange rate even when it would have been wiser to target domestic inflation and output[29]. In the case of Germany, it appears that once the high-inflation years of the 1980s had passed, a predominant precautionary demand for low inflation seems to have given way to either an equal concern for both (offsetting precautionary demands for low inflation and output), or simply an abandonment of this precautionary demand.

5 Concluding Remarks

At the theoretical level this paper shows how asymmetries in the monetary authority's objective function translate into non-linearities in interest rate reaction functions when the structure of the economy is characterized by a

[28] As shown in the theory section larger losses from negative, than from positive, output gaps are consistent with the existence of a precautionary demand for expansions on the part of monetary authorities. Cukierman (2000) and Ruge-Murcia (2001) show, for a Lucas type supply function, that the existence of such a demand creates an inflation bias even if policymakers target the natural level of output on average. Section 5 in Cukierman (2002) shows that a similar result carries over to economies characterized by New - Keynesian transmission mechanisms as well.

[29] Muscatelli *et al.* (1999) present evidence in this regard. McKinnon has suggested in private conversation that Japan's restrictive policy during the nineties is, to a large extent, induced by fear of a protectionist reaction to a depreciating Yen on the part of the US Congress.

New - Keynesian transmission mechanism. At the empirical level the paper shows that there is empirical support for such non-linearities and asymmetries. This is done by estimating interest rate reaction functions, that allow for non linearities, for a number of G7 economies (the USA, Japan, Germany, and the UK). For all countries there is some evidence of asymmetric behavior, although in the case of one country, Germany, it seems to be confined to the early part of the 1980s.

Of course, parameters of interest rate reaction functions are convolutions of preference parameters and of structural parameters of the economy. The theoretical framework implies that the existence of precautionary demands for expansions and low inflation lead to reaction functions that are either concave or convex in expected inflation and output, depending on which precautionary demand dominates. When the precautionary demand for expansions dominates the conduct of monetary policy the reaction function is concave in both expected inflation and the expected output gap. When the precautionary demand for low inflation dominates, the reaction function is convex in expected inflation and the expected output gap. Thus the nature of non linearity in the reaction function is informative about the dominant type of asymmetry in objectives.

Using estimates for both the full sample period (1980 - 2000) and a latter sub - period (1985 - 2000), we find that the output asymmetries in the interest rate reaction functions vary between countries and even within countries between different periods. For instance, it appears that where credibility-building and disinflation has already been achieved (e.g. the USA after 1985), the monetary authorities develop a greater precautionary demand for output expansions than for low inflation, or (as in the case of Germany), convexity disappears suggesting a weakening of the precautionary demand for low inflation, or a strenghening of the precautionary demand for expansions. Such changes might have been induced by the problems that had to be faced following German reunification. Conversely, where credibility-building is still a concern for the authorities (e.g. the UK over the late eighties and part of the nineties), managing the business cycle is dominated by the concern of monetary authorities to keep inflation expectations low.[30]

[30]An alternative explanation for convexity of the reaction function is a convex (to the origin) Phillips curve. Dolado, Ramon and Naveira (2002) investigate this reason for convexity and find suport for it in Germany, France and Spain but not in the US. Discrimination between their explanation for convexity and the existence of a precautionary demand for low inflation must await further work.

A broader implication of asymmetries, when the precautionary demand for expansions dominates, is that a new source of inflationary bias may emerge. Unlike the traditional Kydland-Prescott-Barro-Gordon inflation bias, the monetary authorities end up generating an inflation bias not because they are targeting a level of output which is too high, but because they are (correctly) perceived by the private sector to react less aggressively to output expansions than to output contractions. Hence this precautionary demand for expansions may generate a self fulfilling resurgence of inflation expectations.[31]

Variation over time in the behavior of monetary authorities of the kind detected in this paper is sometimes attributed to institutional change. But, as shifts in the behavior of the monetary authorities can also be detected in countries like the USA and Germany where the institutional structure has remained relatively stable, one could interpret shifts in behavior to the notion of 'framing', i.e. that the monetary authorities attach greater weight to the most evident prospect of loss of the time. In particular, the empirical findings are consistent with the view that monetary authorities develop a stronger aversion to the losses that were mostly in evidence during the preceding several years. Those findings are consistent with the view that, following changes in the economic environment, non negligible changes also occur in the relative potencies of the precautionary demands for expansions and for price stability even in he absence of formal institutional changes like reform of CB legislation.

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On the other hand, the potential existence of a convex Phillips curve reenforces our conclusion that, when reaction functions are found to be concave, this indicates that the precautionary demand for expansions is dominant and pretty strong.

[31]The theory underlying this process is spelled out in Cukierman (2002) for both New Keynesian and 'natural rate' transmission mechanisms. Supporting cross sectional evidence, utilizing a natural rate transmission mechanism, appears in Ruge Murcia (2002) and in Cukierman and Gerlach (2003). Supporting time series evidence for the USA and France with a natural rate transmission mechanism is provided in Ruge Murcia (2001).

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7 Data Appendix

Time Series	GDP for x	(Potential GDP) for x	π	i
USA	BEA/CBO	BEA/CBO	Retail Price Index (OECD)	Federal Funds Rate (IFS)
Germany	OECD	OECD	Retail Price Index (OECD)	Call Money Rate (IFS)
Japan	OECD	OECD	Retail Price Index (OECD)	Call Money Rate (IFS)
UK	OECD	OECD	CPIX up to 1987Q1 (OECD), RPIX thereafter (ONS)	London Clearing Banks Overnight Rate (IFS)

Note: x is defined as the output gap as a percentage of potential output; potential output data is 6-monthly and interpolated to obtain quarterly data.