

ASYMMETRIC POLICY REACTIONS AND INFLATION

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Abstract

Inflation determination is studied in a model in which policy makers care about inflation and the difference between actual and desired output as in Kydland and Prescott (1977) and Barro and Gordon (1983). We extend the analysis by assuming that desired output depends on the realisation of the supply shock, and show that this influences average inflation. Furthermore, we demonstrate that inflation is higher in countries experiencing more volatile output, as implied by the theory, and that the Federal Reserve reacted asymmetrically to output before 1980, which also supports the hypothesis that asymmetric policy responses influence steady-state inflation rates.

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1. Introduction

The sources of the dramatic increase in inflation in many OECD countries in the late 1960s and 1970s remains contentious. Following the influential analysis of Kydland and Prescott (1977) and Barro and Gordon (1983) (KPBG hereafter), it is commonly believed that this inflationary episode resulted from systematic efforts of policy makers to raise output above its steady-state value. While this interpretation of events may be correct, there are theoretical, practical and empirical reasons to doubt the explanatory power of the KPBG hypothesis.

First, McCallum (1997) shows that while the incentive structure studied by KPBG may lead the central bank to attempt to stimulate the economy excessively and can in this way cause inflation to rise, central banks could perfectly well refrain from playing the inflationary game the public expects it to engage in. From a theoretical perspective, there is thus no inherent reason why the inflation bias must arise. Second, Blinder (1998) in reviewing central bank practice argues that central banks do not, in fact, systematically attempt to raise output above potential precisely because they know that doing so is inflationary.¹ Rather, the key problem policy makers face is better described as trying to judge the amount of spare capacity in the economy so as to avoid having policy stoke inflationary pressures. Third and finally, in formal econometric work Ireland (1999) shows that while the long-run behaviour of inflation and unemployment in the US is compatible with the KPBG analysis, the short-run dynamic behaviour is not. Thus, the econometric evidence does not appear to support of the KPBG explanation for the inflationary burst experienced in the 1970s.

In light of these problems with the KPBG hypothesis, recently several authors have demonstrated that an inflation bias could arise as a consequence of asymmetric policy reactions on the part of central banks. Cukierman (1999) considers a version of the KPBG set-up in which policy makers' loss function involves inflation and employment. However, in contrast to the standard case, Cukierman assumes that policy makers care about employment only when it is below its normal level. As in KPBG, there is a single disturbance in the model to the natural rate of employment. Since there is some probability that the shock will be sufficiently large to reduce employment below the natural level, the public attaches a positive probability to the central bank engaging in expansionary monetary policy in order to raise employment to the targeted level. Since the asymmetric loss function implies that the central bank takes no action in the opposite case in which there is a positive shock that pushes employment above the natural level, an inflation bias results. Moreover, since the occurrence of negative employment shocks only elicits responses by the central bank, the inflation bias is positively

¹ See also King (1996).

related to the likely size of the shock as measured by its variance. Jordan (1998) considers a central bank which is unable to control money growth, the policy instrument, perfectly. He shows that since contractionary monetary control errors lead to recessions, the central bank has an incentive not to aim for a too low steady-state inflation rate. Thus, also in this case does a positive inflation bias arise as a consequence of the assumption that policy makers attach greater losses to recessions than to expansions. Similarly, Nobay and Peel (1998) consider the case of a central bank with a loss function which is asymmetric in both real economic activity and inflation. They also demonstrate that the asymmetry of the loss function influences the steady-state inflation rate. Finally, Ruge-Murcia (1999) studies the case in which policy makers' loss function is asymmetric around the optimal inflation rate. While the nature of the asymmetry is not determined in the theoretical analysis, the paper presents empirical estimates using US data for the period 1952-1999 and finds that the Federal Reserve appears to have been more concerned about inflation falling below than rising above the desired level.

In this paper we study the importance of the possible asymmetric responses of policy to economic disturbances. We follow KPBG and assume that policy makers' incentive to inflate is a non-linear function of the underlying supply shocks. Under some parameter restrictions the supply function yields the standard KPBG specification, in which case the central bank aims at raising output above potential. Consequently, the standard inflation bias result arises. In the general case, however, the central bank responds asymmetrically to supply disturbances. Under the assumption that it attaches greater weight to output being below than above its optimal level, an inflation bias proportional to the variance of supply shocks arises. Thus, we obtain an inflation bias for the same reason as Cukierman (1999), Jordan (1998) and Nobay and Peel (1998).

In contrast to these authors, however, we also present some empirical evidence which is suggestive of the importance of asymmetric policy responses for explaining inflation rates across countries and over time. We first test whether, as implied by the theory, countries that experience relatively volatile output growth – and therefore face a relatively greater risk of undergoing large recessions – have had above average inflation rates. Using a measure of the variance of output growth and average inflation over the period 1970-96 for a sample of 22 OECD countries, we find that there is indeed a strong positive relationship between these two variables as implied by the theory.² Second, we ask whether there is any evidence that the Federal Reserve reacted asymmetrically to the output gap. Using data for the period 1960-99, we estimate simple reaction functions for the federal funds rate, allowing for a non-linear impact of the output gap, and find no evidence of asymmetric policy reactions. Reestimating the model for the period 1960-79 and 1980-99, however, we do find strong evidence of

² It is notable that countries that have adopted explicit inflation targeting (EIT) appear to be subject to relatively large external shocks, and have experienced above-average inflation rates. This suggests that EIT has been adopted by central banks that in the past tended to accommodate external shocks. See Gerlach (1999).

such asymmetry in the first subsample. While the empirical work is highly preliminary, it suggests that asymmetric policy reactions are relevant for explaining average inflation rates.

The rest of the paper is organised as follows. In Section 2 we present the theoretical model, and solve under several assumptions regarding the central bank's output target. In Section 3 we turn to the empirical evidence and discuss first (Section 3.1) the cross-country evidence on the link between output volatility and average inflation, and then (Section 3.2) assess the time-series evidence for the United States. Section 4 contains the conclusions and suggestions for future research.

2. Theory

2.1 The model

In this section we turn to the formal model. Since there are no dynamics, we suppress time subscripts. Output, y , is given by a traditional Phillips curve:

$$(1) \quad y = \alpha(\pi - E\pi) + u,$$

where π denotes inflation, $E\pi$ the expected rate of inflation, and u is a supply shock which we assume is a normally distributed zero-mean random variable. Thus, $Eu = 0$ and $Eu^2 = \sigma^2$. Note that equation (1) implies that potential output – defined as the level of output when actual and expected inflation coincide – equals u , and that the average output level is zero. We assume that policy makers have a loss function of the form:

$$(2) \quad L = \chi\pi^2 + (y - y^T)^2,$$

where χ measures the relative importance that policy makers attach to stabilising inflation and where y^T is policy makers' target level for output. In the standard KPBG model $y^T > 0$, in which case policy makers try systematically to raise output to the level y^T by producing unexpected inflation. KPBG show that since the public understands policy makers' incentive to inflate, expected inflation also rises. In equilibrium, actual and expected inflation rates are both positive, but the average level of output zero. With a positive level of inflation but an average output level of zero, it is clear from equation (2) that inflation is excessive; that is, there is an inflation bias.

Rather than to think of policy makers as having a constant output target, we think of them as having an output target which is a function of the supply shock. This allows for the possibility that they raise their output target in response to contractionary supply shocks. For reasons that will become clear below, we assume the following general expression for the target level of income:

$$(3) \quad y^T = k_0 + k_1u + k_2(e^{-u} - 1).$$

An attractive feature of this specification is that it nests several plausible loss functions.

- If $k_0 > 0$ and $k_1 = k_2 = 0$, we have the standard KPBG case in which policy makers aim to raise the average level of output above zero, irrespective of the realisation of the supply shock.
- If $k_0 = k_2 = 0$ and $k_1 \neq 0$, policy makers' output target depends linearly on the supply shock. Two subcases are of particular interest. If $k_1 < 0$, policy makers raise their output target in response to contractionary supply shocks in an attempt to stabilise output movements. Moreover, if $k_1 = 1$, policy makers target potential output, that is, $y^T = u$.
- If $k_0 = k_1 = 0$, and $k_2 > 0$, policy makers raise their output target in an asymmetric fashion to supply shocks.

In order to understand the loss function, we substitute (3) into (2). Since the incentives to inflate arise because unexpected inflation raises output, it is critical to understand the output term, which can be written:

$$\left(\alpha(\pi - E\pi) + u - k_0 - k_1 u - k_2 (e^{-u} - 1)\right)^2.$$

To minimise this term, policy makers have an incentive to set the inflation surprise as a function of the supply shock:

$$\alpha(\pi - E\pi) = k_0 + (k_1 - 1)u + k_2 (e^{-u} - 1).$$

Under the standard case considered by KPBG, we have that $k_1 = k_2 = 0$. Policy makers thus have an incentive systematically to generate unexpected inflation, which generates the inflation bias. Consider next the case of non-linear reactions, that is, $k_0 = k_1 = 0$ and $k_2 = 1$. Graph 1 shows the inflation surprise that will minimise the value of the output term, as a function of the realisation of the supply shock.³ Note that for expansionary supply shocks, the loss function implies that policy makers want to generate inflation below the expected rate in order to reduce the shock's impact on activity. Similarly, for contractionary disturbances, policy makers would like to generate unexpected inflation to prevent output from falling excessively. More importantly, however, note that the incentives to generate unexpected inflation are asymmetric: policy makers would like to raise prices by more in response to a contractionary than to expansionary supply shocks. The assumption that policy makers care more about falls than increases in output can be thought of as capturing *recession aversion*.

We show below that the asymmetric policy responses arising from the assumed loss function imply that countries which experience large supply shocks will have higher average inflation rates. To understand intuitively why this is the case, note that in forming expectations about inflation the public

³ The curve is drawn under the assumption that $\alpha = 1$.

takes into consideration how policy makers' incentive to stimulate the economy depend on the realisation of the supply shock. It is clear from Graph 1 that policy makers in countries in which supply shock have a relatively high variance on average have incentives to generate larger inflation surprises.

Having specified the model we next solve it.

2.2 Solving the model

The first-order condition associated with (2) is given by:

$$(4) \quad \frac{\partial L}{\partial \pi} = 2\chi\pi + 2\alpha\{\alpha(\pi - E\pi) + u - (k_0 + k_1u + k_2(e^{-u} - 1))\} = 0.$$

Solving for the rate of inflation we obtain:

$$(5) \quad \pi = \left(\frac{1}{\chi + \alpha^2} \right) \times \left\{ \alpha^2 E\pi + \alpha(k_0 + (k_1 - 1)u + k_2(e^{-u} - 1)) \right\}.$$

To proceed, we use a Taylor-series approximation to arrive at $e^{-u} - 1 \approx u^2 / 2 - u$. We then have that:

$$(6) \quad \pi = \left(\frac{1}{\chi + \alpha^2} \right) \times \left\{ \alpha^2 E\pi + \alpha \left(k_0 + (k_1 - 1)u + k_2 \left(\frac{u^2}{2} - u \right) \right) \right\}.$$

To solve for the rate of inflation, we first compute the expected rate of inflation. Taking expectations of both sides of (6) yields:

$$(6') \quad E\pi = \left(\frac{1}{\chi + \alpha^2} \right) \times \left\{ \alpha^2 E\pi + \alpha \left(k_0 + k_2 \frac{\sigma^2}{2} \right) \right\}.$$

which in turn implies that:

$$(6'') \quad E\pi = \frac{\alpha}{\chi} \left\{ k_0 + k_2 \frac{\sigma^2}{2} \right\}.$$

Equation (6) states that the expected rate of inflation depends positively on k_0 , the difference between the mean level of potential output and the policy makers' target and, as already noted, on the variance of supply shocks. Using (6) and (6''), we can then solve for the decision rule for inflation:

$$(7) \quad \pi = \frac{\alpha}{\chi + \alpha^2} \left\{ \left(\frac{\chi + \alpha^2}{\chi} \right) k_0 + \frac{\alpha^2}{\chi} k_2 \frac{\sigma^2}{2} + (k_1 - k_2 - 1)u + k_2 \frac{u^2}{2} \right\}.$$

Using (6'') and (7), we obtain the following solution for the expectational error of inflation:

$$(8) \quad \pi - E\pi = \frac{\alpha}{\chi + \alpha^2} \left\{ k_2 \left(\frac{u^2}{2} - \frac{\sigma^2}{2} \right) + (k_1 - k_2 - 1)u \right\},$$

which implies that output is given by:

$$(9) \quad y = \frac{\alpha^2 k_2}{\chi + \alpha^2} \left\{ \left(\frac{u^2}{2} - \frac{\sigma^2}{2} \right) \right\} + \frac{\alpha^2 (k_1 - k_2) + \chi}{\chi + \alpha^2} u.$$

The solutions to the model are given by (7) and (9). To interpret these expressions, it is instructive to consider the different sub-cases discussed above.

2.2.1 Targeting potential output

As a starting point we study the case in which policy makers target potential output, that is, $y^T = u$. In this case the solutions for inflation and output are:

$$(10a) \quad \pi = 0$$

$$(10b) \quad y = u.$$

Thus, policy makers hold inflation constant over time and let output fluctuate in response to the supply shocks.

2.2.2 Targeting a positive output level

We next consider the KPBG case in which the target level for output is positive and constant over time. More formally, $y^T = k_0 > 0$. The solutions for inflation and output in this case are given by:

$$(11a) \quad \pi = \frac{\alpha}{\chi + \alpha^2} \left\{ \left(\frac{\chi + \alpha^2}{\chi} \right) k_0 - u \right\}$$

$$(11b) \quad y = \frac{\chi}{\chi + \alpha^2} u.$$

Two aspects of this solution are notable. First, supply shocks elicit smaller output responses than when policy makers target potential output. Thus, there is some stabilisation bias. The corollary of this is that inflation responds by more than when the central bank targets potential output. Second, policy makers' desire to raise output leads to an inflation bias which is proportional to k_0 . However, and as evidenced by the fact that k_0 does not enter the expression for output, policy makers' attempt to expand economic activity does not influence the mean level of output. Policy makers' attempts to expand economic activity thus lead to an increased average rate of inflation, which is welfare reducing, without influencing output. In light of the fact that this policy thus is suboptimal, it is

difficult to understand why policy makers would pursue it. Below we demonstrate that excess inflation can arise if policy makers' respond asymmetrically to output, and argue that this is a more plausible explanation for the inflation bias.

2.2.3 *Linear output target*

Next we consider the case in which the output target is linear in u , that is, $y^T = k_1 u$. The solutions for inflation and output are in this case given by:

$$(12a) \quad \pi = \frac{\alpha u}{\chi + \alpha^2} (k_1 - 1)$$

$$(12b) \quad y = \frac{u}{\chi + \alpha^2} (\alpha^2 k_1 + \chi)$$

Comparing these solutions with those in which policy markers target potential output, we note that inflation responds by more, and output by less, to the supply shock. The average level of inflation is, however, zero. In this case there is thus no inflation bias.

2.2.4 *Asymmetric output target*

Next we turn to the case in which policy makers' output target is a non-linear function of the supply shock. More particularly, we assume that $y^T = k_2 (e^{-u} - 1)$ which implies that the authorities respond more to contractionary than to expansionary disturbances. The solutions for inflation and output are given by:

$$(13a) \quad \pi = \frac{\alpha}{\chi + \alpha^2} \left\{ \frac{\alpha^2}{\chi} k_2 \frac{\sigma^2}{2} - (1 + k_2)u + k_2 \frac{u^2}{2} \right\}.$$

$$(13b) \quad y = \frac{\alpha^2 k_2}{\chi + \alpha^2} \left\{ \left(\frac{u^2}{2} - \frac{\sigma^2}{2} \right) \right\} + \frac{u}{\chi + \alpha^2} (\chi - \alpha^2 k_2).$$

As can be seen, in this case there is an inflation bias proportional to the variance of the supply shocks.

Before turning to the econometric analysis, we note that the central finding in the analysis above is that an inflation bias arises either if policy makers target a positive output level ($k_0 > 0$) or if they are more concerned by contractionary than expansionary supply shocks ($k_2 > 0$).

We conclude this section by emphasising that the hypothesis of asymmetric policy reactions yields a positive relationship between inflation and the variance of supply shocks, as evidenced by equations (13a-b). By contrast, the standard KPBG hypothesis yields no such relationship, as evidenced by

equations (11a-b). This suggests that it is possible to assess the empirical validity of the hypothesis that asymmetric policy reactions account for differences in inflation across countries and over time.

3. Empirical evidence

In this section we present some preliminary empirical evidence that is compatible with the notion that asymmetric policy reactions are important for explaining variation in inflation across countries and over time. We stress that the evidence is meant to be illustrative. Clearly, more econometric work is necessary to determine whether the factors emphasised in this paper are in fact relevant for understanding the determination of steady-state inflation rates.

3.1 Cross-country evidence

Turning first to the cross-country evidence, note from the analysis above that it is possible to discriminate between the KPBG and the asymmetric policy reaction hypotheses by studying whether average inflation rates and the variance of supply shocks are correlated across countries. Rather than studying the variance of supply shocks, however, we focus on the variance of output. To understand why, recall first that $\sigma_y^2 = E(y - Ey)^2 = Ey^2$ since the expected value of output is zero. Furthermore, define $\vartheta = \alpha^2 k_2 / 2(\chi + \alpha^2)$ and $\psi = (\chi - \alpha^2 k_2) / (\chi + \alpha^2)$. We can then write the variance of y as:

$$(14) \quad \sigma_y^2 = E \left\{ \psi^2 (u^2 - \sigma^2)^2 + \vartheta^2 u^2 + 2\vartheta\psi(u^2 - \sigma^2)u \right\}$$

Since u is normally distributed, we have that $Eu^3 = 0$ and $Eu^4 = 3\sigma^4$ (see Mood, Graybill and Boes (1974), p. 541). It thus follows that the variance of output is given by:

$$(15) \quad \sigma_y^2 = 2\psi^2\sigma^4 + \vartheta^2\sigma^2,$$

which implies that there is a monotonic relationship between σ^2 and σ_y^2 . We can therefore study the relationship between σ_y^2 and inflation (instead of the relationship between σ^2 and inflation). To do so, we calculate the average annual percentage change of the GDP deflator and the variance of the growth rate of real GDP for 22 countries over the period 1970-96.⁴ Two aspects of the scatter plot of the data in Graph 2 are of interest. First, there is a positive relationship between the two variables, with no obvious outliers. Thus, the cross-country evidence does suggest that countries in which output is

⁴ The countries are Australia, Austria, Belgium, Canada, Denmark, Germany, Finland, France, Greece, Ireland, Italy, Japan, the Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States.

relatively volatile have experienced higher average inflation rates, as suggested by the hypothesis of asymmetric policy reactions. Second, there is evidence of heteroscedasticity in that the absolute value of the regression errors appear positively correlated with the variance of output growth.

To explore the theory more formally, we next regress average annual inflation on a constant and the variance of output growth.⁵ The OLS estimates in Table 1 indicate that the slope parameter is highly significant. Since the scatter diagram reveals evidence of heteroscedasticity, we recompute the t-statistics using White standard errors (in brackets, []).⁶ However, the slope parameter remains highly significant. Since it appears that the variance of the residual is proportional to the variance of output growth, we reestimated the equation using weighted least squares (WLS) using the variance of output growth as weights. Also in this case is the slope parameter significant. Thus, the regression analysis confirms that there is a positive relationship between the average level of inflation and the variance of output growth, as hypothesised.

3.2 Evidence on asymmetric policy reactions in the US

While the cross-sectional evidence is consistent with the notion that policy makers are more concerned by output falling below potential than rising above it, more direct evidence of such asymmetric policy reactions is desirable. Below we provide some simple but illustrative evidence suggesting that the Federal Reserve may have responded in this fashion to output gaps in the pre-1980 period.

The starting point for the analysis is a standard reaction function according to which the central bank sets short-term interest rates in response to current inflation rates and output gaps, and the past level of interest rates:

$$(16) \quad r_t = \omega_0 + \omega_1 r_{t-1} + \omega_2 \pi_t + \omega_3 \tilde{y}_t + \varepsilon_t,$$

where \tilde{y}_t denotes the output gap and r_t a short-term interest rate controlled by policy makers.⁷ To incorporate the possibility of asymmetric policy reactions to the output gap, we expand equation (16) by adding a non-linear function of the output gap, $f(\tilde{y}_t)$. Our testing strategy is simple: if the coefficient attached to $f(\tilde{y}_t)$ is significantly different from zero, we reject the hypothesis that policy makers' respond linearly to output gaps.

⁵ Since the independent variable is estimated, this equation is subject to generated regressors bias (Pagan (1984)). It seems implausible that this could be sufficiently large to materially influence the results.

⁶ The p-value for a White test for heteroscedasticity (which is given by the p-value for the F-test for a regression of the square of the residuals on a constant, and the level and square of the variance of output growth) is 0.0%.

⁷ Amato and Laubach (1999) estimate reaction functions of this form for the United States and discuss their interpretation. Clarida, Galí and Gertler (1998) estimate a forward-looking version of (17) for a range of countries. Gerlach and Schnabel (2000) estimate similar reaction functions on synthetic data for the Euro area.

This testing strategy requires us to select a suitable functional form for $f(\tilde{y}_t)$. To do so, we must consider what properties of would be desirable. First, a zero output gap should not play a role in interest setting so that $f(0) = 0$. Second, as output rises relative to potential, the desired short-term rate presumably also rises as the central bank attempts to reduce inflationary pressures, that is, $f'(0) > 0$. Furthermore, the central bank should change interest rates by less in response to any given move in the output gap the higher output is relative to potential. Thus, $f''(0) < 0$. Given the theoretical model, it seems natural to select an exponential function of the form:

$$(17) \quad f(\tilde{y}_t) = 1 - e^{-\tilde{y}_t}.$$

In what follows we use this specification and estimate reaction functions of the form

$$(18) \quad r_t = \omega_0 + \omega_1 r_{t-1} + \omega_2 \pi_t + \omega_3 \tilde{y}_t + \omega_4 \left\{ 1 - e^{-\tilde{y}_t} \right\} + \varepsilon_t,$$

on US data spanning the period 1960:1-99:3. Since the independent variables are all predetermined, the equation can be estimated using ordinary least squares. To test for asymmetric policy reactions, we simply perform a t-test on the hypothesis that $\omega_4 = 0$. Under the recession-aversion hypothesis, we expect instead to find that $\omega_4 > 0$.

The results are presented in Table 2. Inflation is measured by the change over four quarters of headline CPI, short-term interest rates by the federal funds rate, and the output gap is constructed using the Hodrick-Prescott filter. Consider first the estimates for the full sample period, 1960:1-99:3. Estimating the model without the non-linear term, we find that all parameters are highly significant. The long-run effect of a one percentage point increase in inflation is somewhat below unity or $0.11/(1-0.86) = 0.79$. The long-run effect of a unit increase of the output gap is about 2.14. The mean lag, given by $0.86/(1-0.86)$, indicates that half the adjustment of interest rates occurs about 6 quarters after the change in inflation or the output gap. Thus, these estimates suggest that the Federal Reserve reacted only very slowly to changes in economic conditions. Next, we reestimate the model including the non-linear output gap term. The results indicate that ω_4 is insignificantly different from zero, and that the estimates of the other parameters are similar to those obtained for the restricted regression. While these results are not supportive of the hypothesis that policy makers responded asymmetrically to movements in the output gap, estimates of reaction functions such as these are sensitive to the policy regime in operation. In particular, since inflation started to decline sharply following the appointment of Paul Volcker as Chairman of the Board of Governors in 1979, it is plausible that the parameters in equations (17) and (18) shifted at that time.⁸ We therefore reestimate the equations for the subsamples

⁸ This hypothesis is supported by a formal Chow test for stability of the parameters in equation (18), which yields $p = 0.031$ for a break at 1979:3.

1960:1-79:3 and 1979:4-99:3. Turning first to the estimates for the second subsample, we note that the parameters are quite similar to those for the full sample. In particular, the non-linear output-gap term is highly insignificant. In the interest of brevity we therefore turn to the results for the pre-Volcker period.

Note first that the non-linear output-gap term is highly significant together with the other parameters. There are also other interesting changes in the parameter estimates. The coefficient on the lagged funds rate is smaller than for the full sample, and implies a mean lag of just about 2 quarters. Thus, the Federal Reserve responded relatively fast to changes in economic conditions in the 1960s and 70s. However, since the inflation parameters also changes, the long-run impact of inflation on the federal funds rate is similar to before, or about 0.71.

Since ω_4 is significant in the first sub-sample, it is of interest to calculate the implied sensitivity of the federal funds rate to the output gap, which in this case depends also on the level of the output gap. To see this, note that the relevant effect can be written as:

$$(19) \quad \left. \frac{\partial r_t}{\partial \tilde{y}_t} \right|_{\tilde{y}_0} = \hat{\omega}_3 + \hat{\omega}_4 e^{-\tilde{y}_0},$$

where \tilde{y}_0 denotes the level of the output gap at which we compute the derivative. Using the estimates for ω_3 and ω_4 obtained for the first subsample, we can construct estimates of the responses of the federal funds rate to the output as a function of the size of the output gap. Graph 3 shows the resulting estimates together with a 95% confidence band.⁹ The figure illustrates the non-linearity of the response: while the derivative is about 0.29 when the output gap is zero, it is about 0.50 when that gap is -2% and about 0.26 when the gap is 2%. By comparison, the estimated sensitivity of the interest rates to the output gap is 0.35 when a linear model is fitted to the data.

In interpreting Graph 3 it should be noted that we view the test of the hypothesis that $\omega_4 = 0$ as a simple specification test, and the rejection of this hypothesis as indicating that a non-linear reaction function which allows for asymmetric policy responses fits the data better. However, the functional form assumed for $f(\tilde{y}_t)$ restricts the types of non-linearities that are possible in the Graph. Thus the results are best seen as suggesting that the Federal Reserve reacted more strongly to output below than above potential, but not as providing sharp estimates of the exact nature and degree of asymmetry.¹⁰

Overall, these results are compatible with the notion that asymmetric policy adjustments to the output gap characterised the behaviour of the Federal Reserve in the 1960s and 70s. The surge in inflation in

⁹ The standard errors were computed as in Greene (1997, p. 369).

¹⁰ It is notable that Dolado et al. (2000) also find evidence that the Federal Reserve reacted asymmetrically to the output gap in policy responses.

the 1970s might thus have been due to the Federal Reserve responding aggressively to the output gap that developed following the first oil shock in 1973, and anticipations of such asymmetric behaviour got embedded in inflationary expectations.¹¹

4. Conclusions

This paper has explored whether asymmetric policy reactions by central banks to movements in real economic activity can explain why average inflation rates differ between countries and over time. We show that by responding more strongly to recessions than to expansions, an inflation bias arises even if central banks' loss functions are minimised at zero inflation and output at potential. Furthermore, we demonstrate that countries in which output is relatively volatile – in which thus large recessions are relatively likely – have experienced above-average inflation rates, as predicted by the theoretical analysis. Finally, we provide some evidence that the Federal Reserve responded in an asymmetric fashion to output gaps in the period 1960:1-79:4.

However, while the empirical analysis suggests that asymmetric policy responses may play a role in determining steady-state inflation rates, more empirical work is clearly necessary. Three sets of issues deserve attention. First, it would be important to determine whether our results for the Federal Reserve are robust to different specifications of the reaction function and, in particular, the assumed form of the non-linearity of $f(\tilde{y}_t)$. Second, it is desirable to extend the empirical work to other countries and time periods to see whether, in fact, steady-state inflation rates are related to the degree of asymmetry in central banks' reactions to the output gap. Third, if such a link is firmly established, it would be important to know why the correlation arises. One plausible hypothesis is that institutional factors, in particular the degree of independence of the central bank, may explain the degree of asymmetry in the policy reactions and therefore the average inflation rate.

¹¹ By contrast, Orphanides (1999) argues that the increase in inflation in this period was due to the Federal Reserve overestimating the size of the output gap, and thus kept rates low to speed up the return of output to potential. Under this interpretation of events, however, one would have expected the Federal Reserve to view the increasing inflation rate as an indication that the output gap was smaller than it thought at the time, and to tighten monetary policy.

Table 1
Regression of average inflation on the variance of output growth

22 observations

	OLS	WLS
Constant	1.03 (0.61) [0.52]	-2.94 (-0.94)
Variance of output growth	1.29 (4.70) [2.94]	1.80 (5.21)
R-squared	0.52	0.81 weighted 0.39 unweighted

Notes: t-statistics in parenthesis; t-statistics computed using White standard errors in brackets. The variance of output growth is used as the weighting series for the WLS estimates.

Table 2
Estimates of

$$r_t = \omega_0 + \omega_1 r_{t-1} + \omega_2 \pi_t + \omega_3 \tilde{y}_t + \omega_4 \{1 - e^{-\tilde{y}_t}\} + \varepsilon_t$$

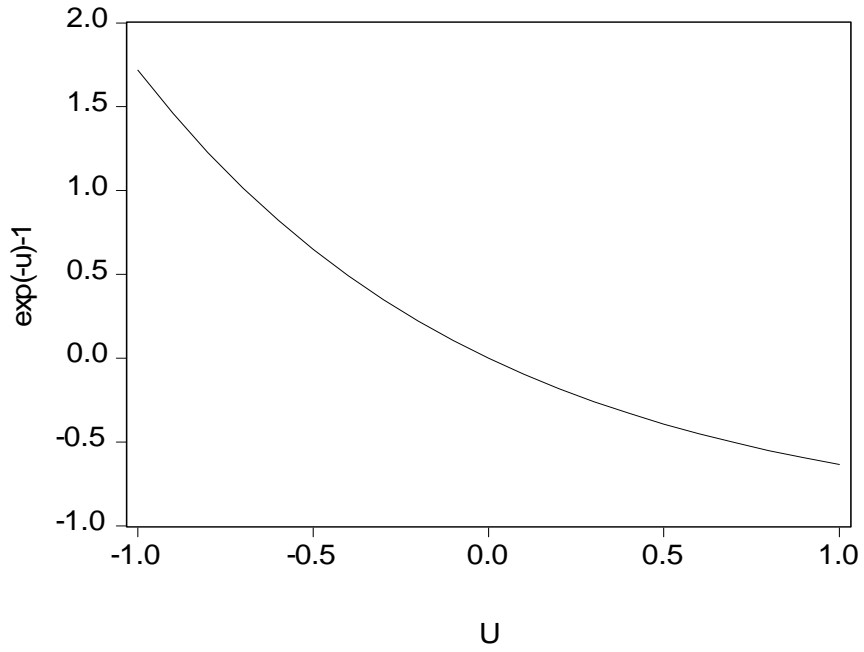
Sample period	ω_0	ω_1	ω_2	ω_3	ω_4	\bar{R}^2/DW
1960:1–99:3	0.43*** (2.69)	0.86*** (26.27)	0.11*** (3.01)	0.30*** (6.50)		0.92 1.87
	0.44*** (2.66)	0.86*** (25.47)	0.11*** (3.00)	0.30*** (4.94)	-0.00 (0.94)	0.92 1.87
1960:1–79:3	0.87*** (4.09)	0.70** (9.59)	0.19*** (3.20)	0.35*** (7.81)		0.93 1.63
	0.88*** (4.29)	0.68*** (9.49)	0.23*** (3.82)	0.26** (4.22)	0.03** (2.27)	0.94 1.78
1979:4–99:3	0.49* (1.70)	0.82*** (15.25)	0.20** (2.93)	0.25** (2.82)		0.91 1.92
	0.52* (1.79)	0.81*** (14.41)	0.20** (2.98)	0.32** (2.53)	-0.01 (0.69)	0.91 1.91

Notes: t-statistics in parenthesis. \bar{R}^2/DW denotes the adjusted R-squared and the Durbin-Watson statistic.

Graph 1

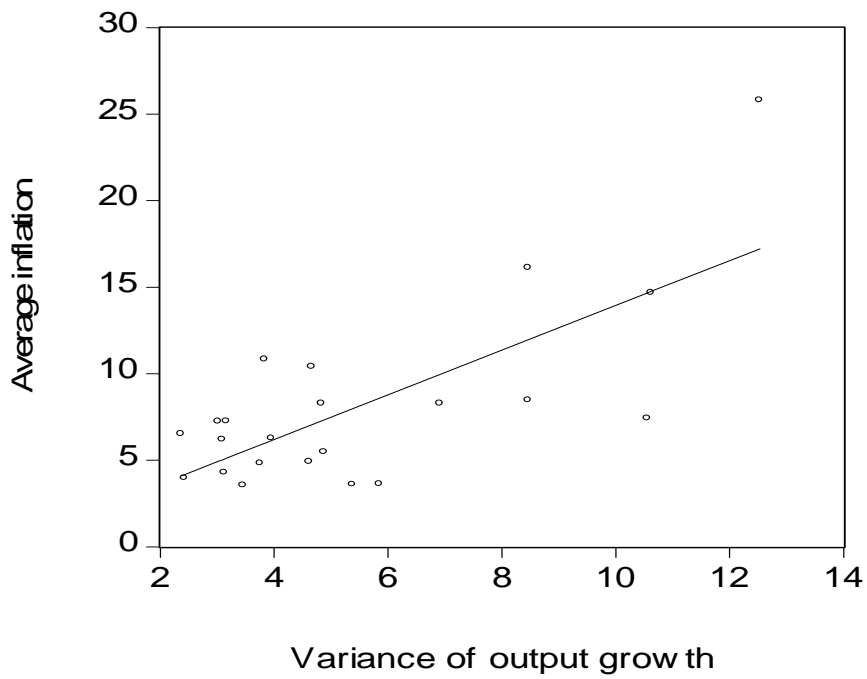
Plots of unexpected inflation as a function of u.

$$\pi - E\pi = e^{-u} - 1$$



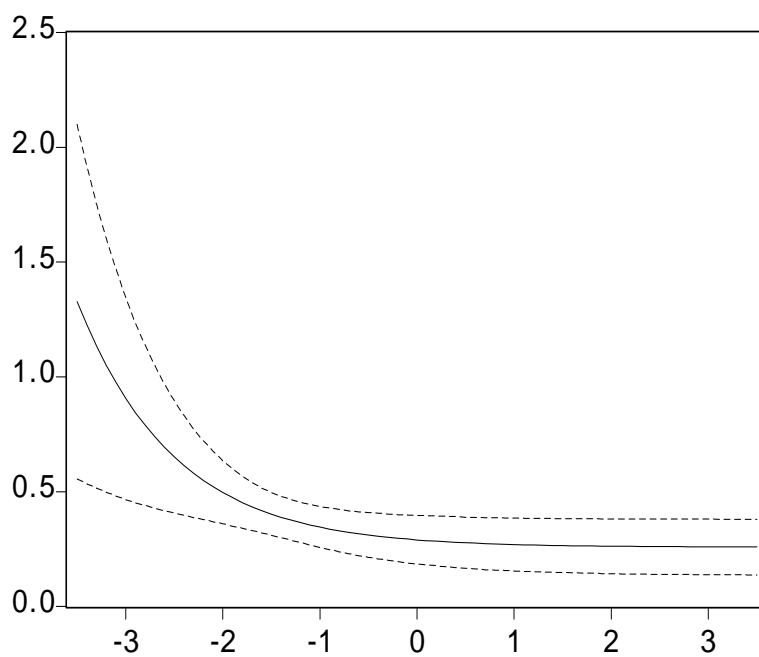
Graph 2

Average inflation versus variance of output growth



Graph 3

**Estimated sensitivity of the federal funds rate (on the vertical axis),
as a function of the output gap (on the horizontal axis).**



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