

SPURIOUS PHILLIPS CURVES AND THE LONG-RUN RELATIONSHIP BETWEEN INFLATION AND THE MARKUP IN THE UNITED STATES^{*}

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ABSTRACT

Phillips curves have traditionally been estimated without due attention to the underlying time series properties of the data. In particular, the possibility that inflation may have breaks in mean has been ignored. A simulation study and an empirical example based on United States data show that the standard estimates may be seriously flawed by such an omission leading to spuriously upwardly biased estimates of the dynamic inflation terms of the Phillips curve. We suggest a method to account for the breaks in mean and obtain meaningful and unbiased estimates of the short- and long-run Phillips curves in the United States.

Keywords: Phillips curve, inflation, panel data, non-stationary data

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1. INTRODUCTION

The large majority of papers that estimate Phillips curves over the past thirty five years proceeds on the implicit or explicit assumption that inflation is a stationary process. For example, the work of Gordon (1970, 1975, 1977, and 1997), McCallum (1976), Sumner and Ward (1983), Alogoskoufis and Smith (1991), Roberts (1995), Galí and Gertler (1999), Batini, Jackson and Nickell (2000, 2005), Galí, Gertler and López-Salido (2001, 2005), Rudd and Whelan (2005, 2007), and Kiley (2007) use a range of estimators that are unbiased if the data have a constant mean which is implied by the assumption of stationarity.¹

However, if inflation is stationary around a constant mean over the past fifty years in the developed world then there has been only one long-run rate of inflation, one expected rate of inflation and one short-run Phillips curve. It means that all the ‘modern’ Phillips curve theories since Friedman (1968) and Phelps (1967) which argue there can be multiple long-run rates of inflation are empirically irrelevant.² Furthermore, it suggests that the original Phillips curve identified in Phillips (1958) did not ‘breakdown’ in the late 1960s and 1970s as there has been no change to the long-run rate of inflation. Unless we wish to reject our ‘modern’ understanding of the inflationary process we must conclude that assuming inflation has a constant mean is, at best, only an approximation.

There are a growing number of researchers who recognise that assuming inflation is stationary is inconsistent with our theoretical understanding of the inflationary process. For example, King and Watson (1994), Stock and Watson (2007), Cogley and Sbordone (2005, 2006) and Ireland (2007) difference the inflation data to overcome the apparent unit root in the inflation data.³ Russell and Banerjee (2008) and Schreiber and Wolters (2007) also

¹ This is a small selection of the substantial literature on the Phillips curve over the past thirty five years.

² The ‘modern’ theories include the Friedman-Phelps (F-P) expectations augmented Phillips curve, New Keynesian (NK) and hybrid theories. The term Friedman-Phelps Phillips curve acknowledges the intellectual shoulders that the ‘modern’ Phillips curve literature stands on.

³ Cogley and Sbordone (2005, 2006) and Ireland (2007) model the central bank’s target rate of inflation. The dependent variable in these models is $\Delta p_t - \Delta p_t^*$ which is the difference between inflation, Δp_t , and the target rate of inflation, Δp_t^* . In turn, the target rate of inflation is assumed to follow a random walk such that $\Delta p_t^* = \Delta p_{t-1}$ and therefore the dependent variable is $\Delta p_t - \Delta p_{t-1}$ which is the first difference of inflation.

assume that inflation is an integrated process but they estimate long-run cointegrating relationships in the Engle and Granger (1987) sense between inflation and the rate of unemployment. However, it is again the case that inflation can only approximate an integrated process as it appears bounded below at around zero and above at some moderate rate in the developed economies over the past fifty years.⁴

What then is the ‘true’ statistical process of inflation? To answer this question, begin by considering the inflation process as outlined in ‘modern’ Phillips curve theories. If shocks to an economy are mean zero and there is no change in monetary policy then we would expect inflation to vary around the long-run rate of inflation. In these theories, an increase in the long-run rate of inflation requires a loosening in monetary policy and the economy would converge on, and vary around, the new long-run rate of inflation. Consequently, ‘modern’ Phillips curve theories imply inflation is a stationary process around the long-run rate of inflation and that periodically there are discrete changes in the long-run rate in response to discrete changes in monetary policy. Therefore, the ‘true’ statistical process of inflation is a stationary process around shifting means.⁵

Graph 1 shows quarterly United States inflation over the past fifty years where the shifts in the mean rate of inflation are evident.⁶ The low inflation of the 1950s and early 1960s is followed by a slight increase in inflation late in the 1960s. The high inflation of the 1970s and early 1980s following the two oil price increases initiated by the Organisation of Petroleum Exporting Countries (OPEC) is followed by two large reductions in inflation. The first is often referred to as the ‘Volker’ deflation and the second at the start of the 1990s coincides with a severe world-wide recession.

⁴ Russell (2006, 2007) makes the argument that inflation cannot be a stationary or an integrated process in greater detail.

⁵ Two other non-stationary processes are possible for inflation but ignored for simplicity. The first is inflation is trend stationary and the second is inflation is integrated of some order greater than 1. The former is unlikely unless the trend is a proxy for a unidirectional change in the monetary authorities’ target rate of inflation. The later is also unlikely due to the bounded nature of inflation.

⁶ Inflation is measured as the quarterly change in the natural logarithm of the seasonally adjusted gross domestic product implicit price deflator at factor cost multiplied by 400. See Appendix 1 for details of the data used in this paper.

These visual shifts in mean inflation can be identified more formally with the Bai and Perron (1998, 2003a, 2003b) technique to estimate multiple breaks in the mean of the inflation data.⁷ This technique identifies eight breaks in the mean rate of United States inflation and therefore nine ‘inflation regimes’ where the inflation data displays a constant mean. The regimes and their associated mean rates of inflation are shown on the graph as thin horizontal lines. From a purely visual perspective the Bai-Perron technique appears to have captured the major shifts in the mean rate of inflation in the United States.

If inflation is really a stationary process around shifting means then the common assumptions employed in the empirical literature that inflation is either stationary or integrated will lead to biased estimates of Phillips curves. For example, if the shifts in mean are not accounted for then the estimated coefficients on the dynamic inflation terms (i.e. the leads and lags of the independent inflation variables) will be biased upwards.⁸ Importantly, if the shifts in mean are frequent and/or large then the sum of the estimated coefficients on the dynamic inflation terms may equal 1 due to the shifts in mean inflation alone. Similarly, if inflation is assumed to be an integrated process and the data are differenced then the estimates will also be biased. Differencing the inflation data imposes the restriction that the estimated coefficient on the first lag in inflation equals one. Standard tests may imply that this restriction is valid but if the estimated coefficients are biased towards one because of the breaks in the inflation series then the restriction is simply maintaining the bias due to the shifts in mean.⁹

The standard empirical Phillips curve literature provides no evidence that these two common assumptions concerning the statistical process of inflation are valid in the sense that the biases introduced in the estimation of Phillips curves are numerically small and insignificant. This lack of evidence is all the more surprising given that ‘modern’ theories of the Phillips curve would lead us to expect that inflation does not have a constant mean and our empirical understanding suggests inflation is not an integrated process.

⁷ See Appendix 2 for details of the Bai-Perron estimates of the shifts in mean inflation.

⁸ This is a generalisation of the Perron (1989) argument that a trend stationary process with breaks is easily mistaken for an integrated process that contains a unit root.

⁹ This restriction cannot be valid within individual inflation regimes where the data are stationary as the absolute value of the sum of the dynamic inflation terms must be less than one by definition for a stationary process.

This paper sets out to measure the biases introduced into the estimation of ‘modern’ United States Phillips curves that stem from the two common assumptions in the empirical Phillip curve literature. In the next section we use a Monte Carlo analysis to examine the biases due to the unaccounted shifts in the mean rate of inflation when estimating Friedman-Phelps (F-P), New Keynesian (NK) and hybrid Phillips curves. The analysis demonstrates that the size and significance of expected inflation (i.e. the lead in inflation) as commonly measured in the standard NK and hybrid literatures can be generated by the shifts in mean alone. Importantly, the shifts in mean also generate the result that the sum of the dynamic inflation terms equals one in the NK and hybrid models and is large, positive, significant and only marginally less than one in the F-P model.

The Monte Carlo analysis then considers the methods employed in the literature to overcome the apparent non-stationarity in the inflation data. There are two ways to proceed. The first is to assume the data are integrated and the second is that inflation is a stationary process around shifting means.

If we assume that inflation is an integrated process and difference the data to remove the unit root we demonstrate that this does not alleviate the biases in the estimation process. Instead, this re-parameterisation of the data only serves to maintain or increase the bias in the estimated Phillips curves. In contrast, if we model the Phillips curve within an integrated system we find that the unaccounted shifts in mean inflation do not lead to the erroneous acceptance of long-run relationships in the data in the sense of Engle and Granger (1987).

The second way to proceed is provided by Russell (2007) who explicitly models inflation as a stationary process around shifting means. Russell (2007) begins by identifying the ‘inflation regimes’ via applying the Bai-Perron technique to the inflation data as described above. Each inflation regime can then be modelled as an individual time series of data and this allows us to estimate Phillips curve models using standard, and well understood, fixed effects time series panel techniques to account for the different mean rates of inflation across inflation regimes. The Monte Carlo analysis demonstrates that even though the Bai-Perron technique fails to identify exactly the inflation regimes in the data the methodology followed in Russell (2007) reduces the biases to insignificant levels.

Section 3 estimates F-P, NK and hybrid Phillips curves with nearly fifty years of quarterly United States inflation data using the panel approach of Russell (2007). In keeping with the recent NK and hybrid literatures we estimate Phillips curves with the ‘forcing’ variable measured as the markup of price on unit labour costs.

Once the biases associated with the shifts in the mean rate of inflation have been accounted for in the estimation of the United States Phillips curves we find that; (i) there is no significant role for expected inflation in the NK and hybrid models of inflation; (ii) there is very weak evidence that any of the lags in inflation are significant in the inflation-markup Phillips curve; and (iii) there is a negative non-linear ‘implicit’ long-run relationship between inflation and the markup.

Therefore, understanding the statistical process of inflation is important. If our theoretical understanding of inflation is correct and inflation is stationary around shifting means then all empirical work that does not adequately allow for the non-stationary properties of the data will provide badly biased and imprecise estimates. In short, the estimated short and long-run Phillips curves will be spurious.¹⁰ Consequently, further development of theories to explain the dynamics of inflation and policy will be badly misinformed by these biased estimates. In a real sense scientific progress in explaining inflation will be curtailed by the lack of valid estimation of the existing theories and a valid understanding of the ‘true’ statistical process of inflation.

¹⁰ See the work of Yule (1926), Granger and Newbold (1974, 1977), Plosser and Schewert (1978), Hendry (1980), Box and Jenkins (1976) and Phillips (1986) on ‘spurious’ regressions.

2. A MONTE CARLO ANALYSIS OF THE BIASES

2.1 'Modern' Phillips Curves

The 'modern' Phillips curve literature can be thought of in terms of restrictions to the reduced form of the hybrid Phillips curve:¹¹

$$\Delta p_t = \delta_f E_t(\Delta p_{t+1}) + \delta_b \Delta p_{t-1} + \delta_z z_t + \varepsilon_t \quad (1)$$

where inflation, Δp_t , depends on expected inflation, $E_t(\Delta p_{t+1})$, conditioned on information available at time t , lagged inflation, Δp_{t-1} , a 'forcing' variable, z_t , and an error term, ε_t , due to the random errors of agents and the shocks to inflation. Inflation is defined as the first difference of the price level such that: $\Delta p_t = p_t - p_{t-1}$ and lower case variables are in natural logarithms. There are numerous measures of the 'forcing' variable in the Phillips curve literature including the gap between the unemployment rate and its long-run level, the gap between real and potential output, real marginal costs, the markup of price on unit labour costs and labour's income share.

In the purely backward looking adaptive expectations Phillips curve model of Friedman (1968) and Phelps (1967) $\delta_f = 0$ and $\delta_b = 1$. In contrast, the New Keynesian (NK) Phillips Curve models of Clarida, Gali and Gertler (1999) and Svensson (2000) agents employ rational expectations and are purely forward-looking resulting in $\delta_f = 1-d$ and $\delta_b = 0$ where d is the rate of time discount. Finally, the hybrid models of Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001) incorporate agents that are both backward and forward looking and $\delta_f + \delta_b = 1-d$.

To make the NK and hybrid theories 'scientific' in the sense of Popper (1959) the magnitude of the discount rate, d , needs to be identified explicitly in the theory.¹² That $1-d < 1$

¹¹ For a general overview see Henry and Pagan (2004).

¹² Popper (1959) argues a theory is 'scientific' if it provides predictions that can be tested empirically. In the NK model, if the magnitude of d is not defined it can only be estimated *assuming* the underlying theory is

introduces a conundrum for the NK and hybrid theories. The NK theory is derived by optimising around the steady state. If one interprets the ‘steady state’ as the long run in the NK and hybrid theories then the theoretical model is solved for a given long-run rate of inflation. The model, therefore, is identifying the short-run Phillips curve associated with a particular long-run rate of inflation. The conundrum is this. If we assume risk neutral agents and the real rate of interest is in the order of 0.04 then $1-d = 0.96$. This implies the NK and hybrid models describe the dynamics of a stationary inflation process as the absolute value of $1-d$ is less than 1. However, persistence in this short-run model (i.e. where the mean rate of inflation is constant in the steady state) is extremely high suggesting very persistent deviations in inflation from its long-run level in the short run.

It also means the NK and hybrid theories make no explicit predictions concerning the slope of the long-run Phillips curve as it only identifies the short-run Phillips curve for each long-run rate of inflation.¹³ To identify the long-run NK and hybrid Phillips curves one needs to first estimate equation (1) for each inflation regime, i , and then calculate:

$$\bar{z}^i \Big|_{\Delta p^i} = \frac{\hat{d}^i}{\hat{\delta}_z^i} \overline{\Delta p}^i \quad (2)$$

where $\bar{z}^i \Big|_{\Delta p^i}$ is the long run value of the forcing variable in inflation regime i , the long-run rate of inflation in regime i is $\overline{\Delta p}^i$ and \hat{d}^i and $\hat{\delta}_z^i$ are the estimated parameters from equation (1) for each of the inflation regimes. One can then examine combinations of \bar{z}^i and $\overline{\Delta p}^i$ to observe the slope of the long-run Phillips curve.

However, as acknowledged in Rudd and Whelan (2006) the empirical work on the NK and hybrid models ignore this conundrum and proceed assuming $d = 0$ in both models.

true. Any estimated value of $1-d$ is therefore consistent with the theory and can be explained by risk averse agents and the rate of time discount. Consequently, empirical work cannot ‘test’ the NK theory and is only estimating d assuming the NK theory is ‘true’.

¹³ The technique of optimising around the steady state changes the nature of the solution to one of deviations from particular steady state values. It cannot, therefore, identify the relationship between a range of steady state values.

Consequently, on an empirical level all three models predict that $\delta_f + \delta_b = 1$ in equation (1) and the standard interpretation of this is that the long-run Phillips curve is ‘vertical’.

This standard interpretation introduces its own difficulties in the estimation of Phillips curves in that if $\delta_f + \delta_b = 1$ then the inflation data are non-stationary. In this case, estimating equation (1) without accounting for the non-stationary data using techniques such as ordinary least squares, two stage least squares or generalised method of moments is invalid. If however the absolute values of the estimates of $\delta_f + \delta_b$ are less than one these estimation techniques are valid but the statistical process of the data is inconsistent with all three theories.

The NK and hybrid models are usually estimated using generalised method of moments (GMM) estimator with instrumental variables to overcome the problem of the correlation between expected inflation and the forcing variable with the error term. This estimation technique has received considerable attention in the econometrics literature in terms of the problems of weak instruments and whether or not the models are identified.¹⁴ However, if inflation is stationary around shifting means and these shifts are accounted for appropriately then the inflation data are far from integrated and so these criticisms of GMM estimation are less relevant.

The empirical Phillips curve literature over the past thirty five years produces remarkably similar results. In the Friedman-Phelps and the New Keynesian models the estimates of δ_b and δ_f are insignificantly different from the predicted values in their respective models. In the more general hybrid model that allows the inflation dynamics to include both leads and lags in inflation the sum of δ_b and δ_f is found to be insignificantly different from one with usually a larger coefficient on expected inflation which is interpreted as evidence that forward looking agents dominate backward looking agents in the price setting process. This

¹⁴ Pesaran (1981, 1987), Staiger and Stock (1997), Stock, Wright, and Yogo (2002), Mavroeidis (2004, 2005), Dufour (2003) and Dufour, Khalaf and Kichian (2006a, 2006b) focus on the poor performance of the estimator when the data are integrated or near integrated.

repeated finding that $\delta_f + \delta_b = 1$ in all three models leads to one of the central ‘tenants’ of Phillips curve theories which is that the vertical long-run Phillips curve is empirically valid.

However, this consensus is built on empirical methods which do not adequately account for the non-stationary properties in the data. If inflation is stationary around shifting means as argued above then there will be an upward bias in the estimates of δ_b and δ_f . Furthermore, if the shifts are large and/or frequent then $\delta_f + \delta_b$ will be insignificantly different from 1 in all three estimated Phillips curve models. The following Monte Carlo analysis demonstrates the proposition that the estimates of δ_b and δ_f in equation (1) are severely biased due to the presence of unaccounted shifts in the mean rate of inflation in the data. The analysis considers in turn the biases associated with three assumptions employed in the empirical literature when estimating Phillips curves, namely, inflation is stationary, an integrated process of order one, and stationary around shifting means.

2.2 *Generating inflation as a stationary process*

We begin by generating 190 observations of a stationary forcing variable, x_t , and then use this variable to generate an ‘inflation’ series, y_t , that contains no dynamic inflation terms. The statistical characteristics of the generated variables are similar to that of the markup and inflation used in the next section to estimate Phillips curves for the United States. The forcing variable, x_t , is generated as:

$$x_t = 0.937967 x_{t-1} + \omega_t \quad (3)$$

where the first observation, x_0 , is zero and ω_t is a random draw from a normal distribution with mean zero and a standard error of 0.006388. The coefficient on the lagged forcing variable and the standard error are equivalent to those from an estimated AR(1) model of the markup.

The second generated series is the inflation series, y_t , such that

$$y_t = -0.205406x_t + v_t \quad (4)$$

where v_t is a random draw from a normal distribution with a mean of zero and a standard error of 0.004753. The coefficient on the forcing variable, x_t , is equivalent to the estimated coefficient from estimating equation (1) using United States inflation and markup data with the dynamic inflation terms restricted to zero. By construction the forcing variable, x_t , and the inflation series, y_t , are stationary variables with constant means.

Using the generated inflation variable, y_t , and forcing variable, x_t , we estimate three versions of the Phillips curve as set out in equation (1) where we know by construction that $\delta_b = 0$, $\delta_f = 0$ and $\delta_z = -0.205406$ in the ‘true’ underlying Phillips curve model that generated the data. In keeping with the NK and hybrid Phillips curve literatures the models are estimated using GMM with three lags of both the generated inflation and forcing variables as instruments for the lead in inflation and the contemporaneous forcing variable. The models are estimated 10,000 times using Monte Carlo techniques to obtain the average values of the statistics and estimated coefficients from the models.¹⁵

Single equation estimates of the three models are reported in the first three columns of Table 1 under the headings F-P (Friedman-Phelps), NK (New Keynesian) and hybrid. In all three models the estimated coefficients on the dynamic inflation terms are very similar in magnitude to their ‘true’ values (i.e. zero) and insignificantly different from zero. The models also provide estimates of the forcing variable coefficient which are close numerically to its true value of -0.205406 and significantly different from zero. The fourth column headed ‘ND’ demonstrates that removing the inflation dynamics also leads to an estimated model that is very similar to the ‘true’ model. In all four models we can accept the restriction that the estimated coefficients equal their ‘true’ values in the data generating process. We can conclude, therefore, that we can retrieve fairly accurately the ‘true’ model that generated

¹⁵ Inference is unaffected if the median instead of the mean values of the estimated parameters are considered. The distributions of the estimated coefficients and statistics are uni-modal and largely symmetrical with relatively low levels of skewness and kurtosis.

the inflation data by estimating any of the three modern Phillips curve models based on equation (1).

2.2 *Generating inflation as a stationary process around shifting means*

We now generate a ‘mean-shift inflation’ variable, y_t^{MS} , which adds to y_t the mean rate of inflation associated with each of the nine inflation regimes reported in Graph 1 and constructed as:

$$y_t^{MS} = y_t + \mu_t^i \quad (5)$$

where μ_t^i is the mean rate of inflation in regime i as reported in Table A2 of Appendix 2. Consequently, the only difference between y_t^{MS} and y_t is the mean rate of inflation associated with each of the inflation regimes.

The three right hand columns of Table 1 report the mean values of the Monte Carlo estimates from the three versions of the Phillips curve model but this time estimated with the mean-shift inflation data, y_t^{MS} , and the forcing variable, x_t . In the New Keynesian and hybrid models the lead in inflation is significantly greater than zero and insignificantly different from 1. In the Friedman-Phelps model the sum of the lags in inflation is 0.7108 which is significantly greater than zero and significantly less than 1 at the five percent level. In all three models we strongly reject the restriction that the estimates equal their true values (see F in Table 1). Finally, note that the Monte Carlo analysis demonstrates that the shifts in the mean rates of inflation alone can generate the New Keynesian and hybrid Phillips curve result that the sum of the coefficients on the dynamic inflation terms is insignificantly different from 1. For the Friedman-Phelps model the shifts in mean introduces a bias to the estimates which is only slightly less than 1.

Table 1 also demonstrates the bias is not confined to the estimates of the dynamic inflation terms but also affects the estimated coefficient on the forcing variable. In all three models estimated with the generated mean shift inflation variable the forcing variable is now insignificant at the 5 per cent level and numerically very small. As should be expected, the forcing variable which is stationary is unable to explain the generated inflation variable which has a changing mean. The finding that the stationary forcing variable is insignificant

is common in the empirical Phillips curve literature and motivates Gali and Gertler (1999) to use labour's income share which they find significant in their estimated Phillips curve model.¹⁶

An interesting result from the analysis is that it identifies the role that the lead in inflation plays in the estimation process. It appears that the interaction of the shifts in mean and the lead in inflation introduces severe serial correlation in the residuals. Furthermore, in the hybrid model that incorporates both a lead and lag in inflation it is the lead that is biased upwards and the lag in inflation remains numerically close and insignificantly different from its 'true' value of zero. This may well explain the standard finding in the hybrid Phillips curve literature that $\delta_f > \delta_b$ which is interpreted as forward looking agents dominate backward looking agents in the economy.

2.3 Assuming inflation is integrated

Testing the 10,000 generated mean-shift inflation series, y_t^{MS} , for the presence of a unit root using the augmented Dickey-Fuller test provides a mean value of the test statistics of -2.615 which can be compared with the 5 per cent critical value of -2.877 assuming a constant and no trend. Based on these results we might conclude erroneously that the generated mean shift inflation series is an integrated process of order one.

There are two streams in the literature that proceed assuming inflation is an integrated variable. The first argues explicitly that inflation is integrated and then proceeds to difference the inflation data so as to remove the unit root.¹⁷ Equation (1) is therefore re-parameterised as:

$$\Delta^2 p_t = \psi_f E_t(\Delta^2 p_{t+1}) + \psi_b \Delta^2 p_{t-1} + \psi_z \Delta z_t + \omega_t \quad (6)$$

¹⁶ Gali and Gertler (1999) argue that potential output and long-run unemployment are difficult to measure and therefore deviations from these measures are poor predictors of inflation. The analysis here suggests insignificance of these variables in the inflation process is less to do with measurement difficulties and more to do with misunderstanding the statistical process of inflation.

¹⁷ This stream includes the work of King and Watson (1994) and Stock and Watson (2007) who explicitly difference the data to remove the unit root in the data and Cogley and Sbordone (2005, 2006) and Ireland (2007) who's approach is equivalent to differencing the data as explained in footnote 3.

where $\Delta^2 p_t = \Delta p_t - \Delta p_{t-1}$ is the second difference of the price level and the first difference in inflation. The F-P, NK and hybrid versions of equation (6) are estimated with the GMM estimator using the differenced generated mean shift inflation data, Δy_t^{MS} and the differenced forcing variable, Δx_t . The Monte Carlo results are reported in Table 2 show that estimating the F-P, NK and hybrid forms of the Phillips curve using differenced data does not recover the ‘true’ underlying model that generates the inflation data.

For the F-P model we can reject the restriction that the estimated coefficients are equal to their ‘true’ values (see ‘ F ’ in Table 2). For the NK and hybrid models the imprecision of the estimates lead us to accept the restriction that the estimates are equal to their true values even though the lags in inflation are significant and the point estimate of the sum of the dynamic inflation terms are -0.3772 and -1.3475 for the NK and hybrid models respectively. The imprecision of the estimated models is further demonstrated by being able to accept the restriction that the sum of the dynamic inflation terms is equal to zero at the five per cent level of significance (reported as ‘ Σ ’ in Table 2) even though the lags in inflation are highly significant in the hybrid model. Consequently, if we incorrectly assume that the data are integrated and difference the data we will not retrieve the ‘true’ underlying model as we identify significant dynamic inflation terms in the F-P and hybrid models and the forcing variable is insignificant in all three models. Furthermore, an ‘overzealous’ researcher who differences the inflation data in response to the unit root tests and the knowledge that these tests are in line with the predictions of the F-P, NK and hybrid models will be severely misled by the results even though their actions are supported by standard empirical tests.

The differencing of the mean shift inflation data, y_t^{MS} , only serves to maintain or increase the bias in the estimated dynamic inflation terms to now equal 1 in all three models (F-P, NK and hybrid). If one unravels the estimates of the dynamic inflation terms from Table 2 then the sum of the dynamic inflation terms is one in all three models due to the restriction imposed when differencing the data. The differencing re-parameterisation does not overcome the problem of the shifting means in the inflation data but incorporates rigidly the modelling deficiencies of not recognising the shifts in mean inflation when estimating Phillips curves.

The second stream that assumes inflation is an integrated process proceeds by estimating an integrated system that assumes that inflation and the forcing variable are both integrated of

order one.¹⁸ To examine if the shifts in mean inflation lead to the incorrect inference concerning the presence of a long-run cointegrating relationship between inflation and the forcing variable we estimate using Monte Carlo techniques a VAR-ECM system using the generated mean shift inflation data y_t^{MS} and the generated forcing variable, x_t . In this case we correctly conclude that there is no long-run relationship between inflation and the forcing variable.¹⁹

2.4 Assuming inflation is a stationary process around shifting means

How then can we retrieve the estimates of the ‘true’ model based on the generated data in equation (5)? The solution suggested in Russell (2007) is as follows. First, apply the Bai-Perron technique to identify the inflation regimes in the generated mean-shift inflation series, y_t^{MS} . Second, partition the generated mean shift inflation data into n cross sections of data where each cross section is an individual inflation regime identified in the first stage. Finally, estimate the Phillips curve models using a two stage least squares fixed effects panel estimator to account for different mean rates of inflation in the inflation regimes.

The panel fixed effects specification of the hybrid Phillips curve model of equation (1) is:

$$\Delta p_t^n = \phi^n + \phi_f E_t^n (\Delta p_{t+1}^n) + \phi_b \Delta p_{t-1}^n + \phi_z z_t^n + \eta_t^n \quad (7)$$

where the ‘ n ’ superscript indicates the inflation regime from which the data are drawn from. The unobserved regime-specific time invariant fixed effects, ϕ^n , allow for shifts in the mean rate of inflation across regimes and η_t^n is a disturbance term which is independent across inflation regimes.

Table 3 reports the number of breaks in the mean rate of inflation identified in the 10,000 generated mean-shift inflation series, y_t^{MS} , by the Bai-Perron technique. The structural

¹⁸ As well as the I(1) systems Phillips curve papers mentioned in the introduction one could include the work that estimates I(1) systems to identify a negative long-run cointegrating relationship between inflation and the markup of Banerjee, Cockerell and Russell (2001), and Banerjee and Russell (2001a, 2001b, 2004, 2005), Russell and Banerjee (2006, 2008), and Banerjee, Mizen and Russell (2007).

¹⁹ The mean value of the Engle Granger cointegration test statistic from the Monte Carlo simulations is -2.043 . The 1, 5 and 10 per cent critical values are -3.956 , -3.369 and -3.068 respectively. [replace with Johansen Trace test]

breaks model estimated is the same as that used to estimate the breaks in mean inflation reported in Appendix 2. The mean and median numbers of regimes are 4.99 and 5 respectively. This can be compared with the ‘true’ number of 8 breaks in mean inflation in the generated data. Therefore, it appears that the Bai-Perron technique consistently underestimates the number of breaks and inflation regimes in the data. Consequently, once the data are partitioned in line with the estimated breaks in mean inflation using the Bai-Perron technique we can expect some residual non-stationarity somewhere in the estimated inflation regimes.

Using the inflation regimes identified by the Bai-Perron technique in each of the 10,000 generated mean shift inflation series to partition the generated data, the mean values of the panel estimates of the Phillips curve models are reported in Table 4. Re-organising the data into an unbalanced time series panel format does not in itself affect the estimates. This is easily demonstrated by restricting the constant, ϕ^n , to be the same across all the inflation regimes when applying the fixed effects panel estimator to the generated data. This restriction is equivalent to assuming the mean rate of inflation is the same in each inflation regime. The mean results for the F-P, NK and hybrid models are reported in the first three columns of Table 4. Note the results are very similar to those reported in columns 4 to 6 in Table 1 in terms of the estimates of the dynamic inflation terms and the forcing variable.

Two stage least squares estimates of the fixed effects panel estimates of the three ‘modern’ Phillips curve models are reported in columns 4 to 6 of Table 4. We see that after allowing for the shifts in mean across regimes by using the fixed effects estimator all three estimated models are now insignificantly different from the ‘true’ underlying model that generates the data (see F in Table 4.). The dynamic inflation terms are all insignificant and the size of the forcing variable is around half its ‘true’ value of -0.2054 . The final column headed ND excludes the insignificant dynamic inflation terms from the estimated model and we find that the forcing variable is significant but remains half its ‘true’ size.

Having accounted for the shifts in mean in the estimation procedure we now conclude correctly that expected inflation and lagged inflation are insignificant in all three models. Furthermore, we can now easily accept the restriction that the estimated coefficients equal their ‘true’ values. However, note the imprecision in the NK and hybrid models is so large that we can simultaneously accept at the 5 per cent level that the sum of the dynamic terms

equals zero and 1 (see Table 4). In contrast, the F-P model at the 5 per cent level accepts the restriction that the lag in inflation is zero and rejects the term is equal to 1. It appears that including the lead in inflation increases the imprecision of the estimates markedly both here and in the earlier analysis irrespective of whether it is significant.

Note also that the estimated value of the forcing variable is around half its ‘true’ value in all four models reported in columns 4 to 7 in Table 4. It appears that the residual non-stationarity in the data following the Bai-Perron stage of the analysis is not enough to bias the dynamic terms to significant levels. However, the non-stationarity does bias towards zero the coefficient on the forcing variable. This is a consistent finding of the Monte Carlo analysis reported here that any non-stationarity in the inflation data biases the stationary forcing variable towards zero.

The panel estimation procedure provides estimates that are insignificantly different from their ‘true’ values even though the Bai-Perron technique underestimates on average the ‘true’ number of the inflation regimes and by implication does not correctly identify the ‘true’ dates of the inflation regimes. However, even given the inaccuracies in the Bai-Perron technique we find that the Phillips curve models subsequently estimated using fixed effects panel techniques provide estimates that are insignificantly different from the ‘true’ model that generates the inflation data. At the very least this procedure leads to the correct inferences concerning the significance and size of ϕ_b and ϕ_f and a value for ϕ_z which is significantly different from zero, has the correct sign and marginally different from its ‘true’ value. Of course this analysis suggests that there are gains in terms of reducing the bias in the estimation process from more accurately identifying the breaks in mean inflation.

In summary it appears that the standard estimates in the empirical literature that approximates the inflation process by assuming that inflation is either a stationary process with a constant mean or an integrated process which is differenced result in biased estimates of the underlying behaviour of agents. This is due to the unaccounted shifts in the mean rate of inflation. We might conclude therefore that the overwhelming consensus within the empirical Phillips curve literature that (i) the dynamic inflation variables in the F-P, NK and hybrid Phillips curves sum to 1; (ii) expected inflation as measured in the NK and hybrid Phillips curve literature plays a significant and dominant role in the dynamics of inflation; and (iii) measures of the forcing variable that are stationary are insignificant indicate the

repeated application of inappropriate estimation techniques on inflation data which is stationary around shifting means. These conclusions are simply a demonstration of the Perron (1989) result that stationary processes with breaks are easily mistaken for unit root processes. Furthermore, given the large biases in the estimates the standard empirical results should not be used to validate any of the competing ‘modern’ Phillips curve theories. In short, the standard estimation of Phillips curves that assumes that inflation is stationary, or integrated and differenced, are so badly biased that the results are invalid.

These results are particularly relevant for three related literatures that are in part based on the Phillips curve literature. The first is the literature on autoregressive (AR) measures of inflation persistence that includes papers by Benati (2008), Cecchetti and Debelle (2006), and Altissimo, Bilke, Levin, Matha, and Mojon (2006). This literature looks for breaks in the autoregressive process of inflation and not shifts in mean inflation. As demonstrated above, the estimates of AR models of inflation are badly biased due to the un-modelled shifts in mean inflation. Consequently, this literature is identifying periods when the bias in the estimated AR process changes. In other words a break is identified because the frequency and size of the breaks in mean inflation are different between two periods. Furthermore, once the breaks are large and frequent then the estimates in the autoregressive process are biased to 1 and so no break will be identified.

The second literature considers how the order of integration in inflation data has varied over time and includes papers by Halunga, Osborn and Sensier (2009), Beechey and Osterholm (2007), Cogley, and Sargent (2001) and Kumar and Okimoto (2007). This literature recognises there have been ‘breaks’ in the statistical process of inflation but do ask the obvious question of where the unit root is coming from in data that cannot be ‘truly’ integrated due to its bounded nature. Consequently, the literature does not model inflation as a stationary process around shifting means and therefore the empirical analysis within this literature is also badly biased.

The third literature estimates the structural parameters of the NK and hybrid Phillips curve theories.²⁰ This literature aims to bypass the difficulties of estimating Phillips curves directly

²⁰ For example see, Galí and Gertler (1999) and Galí, Gertler and López-Salido (2001, 2005).

by estimating the underlying behavioural, or structural, parameters of the model. The problem is that the structural parameters are conditioned on inflation and as the shifts in mean are not accounted for in the analysis the structural parameters are biased in the same way as the standard Phillips curve analysis.

3. PANEL ESTIMATES OF THE UNITED STATES PHILLIPS CURVES

We now turn to estimating Phillips curves with quarterly United States data for the period March 1960 to June 2007 using the process proposed by Russell (2007). In line with much of the recent NK and hybrid Phillips curve literatures the models are estimated using the markup of price on unit labour costs as the forcing variable.

Before proceeding with the estimation of (7) there are a number of issues that need to be addressed.²¹ First, the models are estimated using two stage least squares due to the lead in inflation, Δp_{t+1}^n , and contemporaneous forcing variable, z_t^n , being correlated with the error term. Two lags of inflation and the forcing variable are used as instruments. Second, the cross-section panels are unbalanced with a large variation in the number of observations between the smallest regime (9 observations) and the largest regime (51 observations). The problem is that when the individual cross sections are small it is well documented that the estimates are biased.²² Therefore, a relevant question is, ‘when are panels small?’ One rule-of-thumb is that the cross section panels are considered ‘small’ if estimation is invalid due to too few degrees of freedom using an individual cross section of data. In our case the shorter inflation regimes are arguably invalid while the longer regimes are easily long enough to be valid. In any case, it is demonstrated below that the estimated Phillips curves are not affected in any meaningful way if we exclude the shortest inflation regimes.

²¹ For a very clear and straightforward explanation of the problems surrounding the estimation of dynamic time series models using panel techniques see Bond (2002). For a more detailed treatment of these issues see Hsiao (2003).

²² For example, see Arellano and Bond (1991), Arellano and Bover (1995), Blundell and Bond (1998) and Bond (2002) who overcomes the problem of ‘dynamic panel bias’ when t is very small by estimating the models with the Arellano-Bond estimator. Estimating the panel model via a forward orthogonal deviation Arellano-Bond estimator the results are not affected in an economic or quantitative sense.

Third, two panel estimators present themselves. The random effects model is strongly rejected by the data in favour of the fixed effects estimator. As the latter also has a ready interpretation as accounting for the different mean rates of inflation across inflation regimes, only the fixed effects set of models are reported below.

Fourth, the panel fixed effects Phillips curve models of equation (7) restricts the coefficients on the dynamic inflation terms and the forcing variable to be the same across inflation regimes. This restriction is accepted by the data and reported in the notes to the relevant tables.

Using this approach to estimating Phillips curves has a number of advantages. First, the Monte Carlo analysis above demonstrates that even when the Bai-Perron technique fails to identify the inflation regimes exactly the biases due to any remaining non-stationarity in the data are insignificantly small. Second, the estimated fixed effects have a ready interpretation as the mean rate of inflation in each inflation regime. Third, the panel approach provides unbiased estimates of the coefficients on expected inflation, ϕ_f , and lagged inflation in equation (7). This allows us to enquire into the veracity of the three competing ‘modern’ Phillips curve theories. Fourth, the estimates allow us to examine with unbiased estimates the proposition that the long-run Phillips curve is vertical.

The last advantage is particularly important on empirical and policy levels. The panel approach provides estimates of the individual short-run Phillips curves for each inflation regime. The panel estimates must be of the short-run Phillips curve as the mean rate of inflation, and therefore the long-run rate of inflation, is constant in each cross section inflation regime. As the data in each inflation regime is stationary by construction the estimated absolute value of $\phi_f + \phi_b$ must be less than 1. This does not mean that the long-run Phillips curve is not vertical. Instead, it means that the data in any one inflation regime cannot reveal the slope of the long-run Phillips curve as it only has one mean, or long-run, rate of inflation. One short-run Phillips curve can only identify one long-run combination of inflation and the forcing variable. However, we can calculate from the panel estimates the long-run value of the forcing variable associated with the mean rate of inflation in each inflation regime. This provides multiple combinations of the long-run inflation rate and forcing variable so that we can then examine if the combinations lie along a linear vertical

line. This issue is returned to in section 4 following the reporting of the estimates.

3.1 *Estimates of the United States Phillips Curves*

Table 5 reports 2SLS estimates of the F-P, NK and hybrid Phillips curves from equation (7) using the markup of price on unit labour costs as the measure of the forcing variable. Columns 1 to 3 of Table 5 report the panel estimates with the restriction that the estimated constant from each regimes is the same such that, $\phi^1 = \phi^2 = \dots = \phi^9$. We see that many of the standard results in the literature discussed above are retrieved. In the NK and hybrid models the sum of the dynamic inflation terms sum to one and in the hybrid model forward looking behaviour dominates the backward looking behaviour of agents.

Reported in columns 5 to 8 in Table 5 are the fixed effects estimates of the Phillips curves. Having now accounted for the changing mean rates of inflation across inflation regimes we find that the sum of the estimated dynamic inflation terms in the F-P and NK models is significantly less than 1. In the hybrid model we can accept the sum of the dynamic inflation terms equals 1 but each dynamic term is individually insignificant at the 5 per cent level and the estimated coefficients sum to 0.5567. Importantly in the NK and hybrid models, expected inflation, Δp_{t+1}^n , as commonly measured in the literature plays no significant role in the dynamics of inflation. Of some interest is the finding that in all three models the dynamic inflation terms are jointly insignificant. In the F-P model the dynamic inflation term is insignificantly different from zero and significantly less than 1 and equal to 0.1263. Finally, except for the hybrid model where the variable is insignificant, the markup has a significant and negative impact on inflation.

3.2 *The impact of the Bai-Perron estimates on the panel estimates*

The Bai-Perron technique estimates nine inflation regimes. However, two inflation regimes (numbers 4 and 5) that coincide with the first OPEC oil price shock in the early to mid 1970s are identified having met the constraint of the minimum number of quarters in an inflation regime. Consequently, these two regimes are likely not to have a constant mean rate of inflation and are non-stationary.

We therefore re-estimate the models using the panel technique after separating the data into ‘stationary’ inflation regimes (regime numbers 1, 2, 3, 6, 7, 8, and 9) and ‘non-stationary’ regimes (numbers 4 and 5). The results are reported in table 6 and further demonstrate the need for the data to be stationary. With the stationary regimes, all three models demonstrate that the dynamic inflation terms are highly insignificant and that the ‘best’ model is simply inflation regressed on the markup. In the last four columns the panel technique is applied to the non-stationary inflation regimes where the dynamic inflation terms are individually significantly different from zero and jointly insignificantly less than one as in the standard Phillips curve literature.

Given that non-stationary regimes are small relative to the data in the stationary regimes the impact on the estimates reported in Table 5 using all the data from the stationary and non-stationary regimes is small. However, the results in the first four columns in Table 6 reinforce the conclusion that the dynamic inflation terms in the F-P, NK and hybrid models have no significant role in determining the dynamics of the inflation-markup Phillips curve model and are significant in the standard empirical literature only because the estimation process ignores the shifting mean rates of inflation.

It is important to note that the use of the Bai-Perron technique to identify the breaks in mean inflation is not driving the results. The Monte Carlo analysis in Section 2 demonstrates that even though the Bai-Perron technique does not identify the breaks exactly the fixed effects panel techniques used here provides estimates that are insignificantly different from the ‘true’ model. Furthermore, Perron (1989) and the analysis in Section 2 tells us the direction of the bias on the dynamic inflation terms due to incorrectly identifying the breaks and any residual non-stationarity in the data is upwards. Therefore, given the Bai-Perron technique has almost certainly not identified the breaks in mean inflation exactly this means that overturning the standard findings in the literature that the lead in inflation is significant and the dynamic inflation terms sum to 1 is made more difficult. This suggests these findings are robust to the choice of technique for identifying multiple structural breaks in the data.

4. ESTIMATES OF THE IMPLICIT LONG-RUN INFLATION-MARKUP RELATIONSHIP

In our Phillips curve models estimated with panel techniques we are simultaneously estimating nine short-run Phillips curves associated with the nine mean, or long-run, rates of inflation identified earlier by the Bai-Perron technique. As the data are stationary by construction it should be of no surprise that the sum of the estimated coefficients on the dynamic inflation terms is significantly less than one.

To identify the long-run Phillips curve, therefore, we need to first identify the long-run value of the forcing variable associated with the long-run rate of inflation in each inflation regime. The latter is defined as the mean rate of inflation in each regime. The former is defined as the value of the forcing variable that will be attained when inflation is at its long-run rate and all inflation dynamics have been exhausted.

We can, therefore, write the implicit long-run value of the forcing variable, \bar{z}^n , in inflation regime, n , implied in equation (7) as:

$$\bar{z}^n = \frac{1}{\phi_z} \left[\overline{\Delta p}^n (1 - \phi_f - \phi_b) - \phi^n \right] \quad (8)$$

where $\overline{\Delta p}^n$, is the mean rate of inflation in inflation regime, n . The parameters ϕ_f , ϕ_b , ϕ_z and ϕ^n are the estimated coefficients from the panel estimates of equation (7).

If we further assume that the n combinations of the long-run rates of inflation and the implicit long-run values of the forcing variable loosely lie along the implicit long-run Phillips curve then we can examine if the curve is vertical or has a significant positive or negative slope without the bias associated with the standard methods of estimating the Phillips curve.

The linear representation of the implicit long-run Phillips curve can therefore be represented as:

$$\overline{\Delta p}^n = \alpha_0 + \alpha_1 \bar{z}^n \quad (9)$$

and, one general non-linear representation may be written as:

$$\overline{\Delta p}^n = \beta_0 \exp(\beta_1 \bar{z}^n) \quad (10)$$

Table 7 provides ordinary least squares estimates of the linear and non-linear implicit long-run Phillips curves. The implicit long-run values are calculated using the markup only model estimated with the stationary data only (see column 4 of Table 6).²³ We see that there is a significant negative slope to the implicit long-run Phillip curve of -0.1113. Given the long-run Phillips curve cannot be linear if it is not vertical then the non-linear long-run Phillips curve is a better representation of the long-run inflation-markup relationship in the data.²⁴

For comparison, Table 7 also provides estimates of the long-run cointegrating relationship between inflation and the markup in the Engle and Granger (1987) sense assuming that inflation and the markup are integrated processes. Using all the data from March 1960 to June 2007 we find that we can accept the hypothesis of one cointegrating vector. This approach to identifying the long-run inflation-markup relationship is that followed in a series of papers beginning with Banerjee, Cockerell and Russell (2001).²⁵ Their approach acknowledges that the ‘true’ statistical process of inflation is most likely stationary around frequent shifts in mean and that this process can be approximated as an integrated process for the purpose of estimating the long-run inflation-markup relationship. The estimated cointegrating long-run inflation-markup relationship reported in Table 7 (- 0.3503) is similar in size to the implicit long-run relationship of -0.1113 suggesting that approximating inflation as an integrated process and estimating cointegrating relationships between inflation and the markup is valid.²⁶

²³ These estimates are chosen when calculating the implicit long-run Phillips curve as it avoids the biases introduced by the non-stationary data in regimes 4 and 5.

²⁴ If the long-run Phillips curve is not vertical then as inflation tends to an infinite rate the markup will exceed its defined boundaries. Therefore, if the long-run Phillips curve displays a negative slope then it must be non-linear and approach the vertical as the mean rate of inflation increases.

²⁵ See also the references cited in footnote 18.

²⁶ The estimated long-run cointegrating relationships reported in Banerjee and Russell (2001a, 2001b, 2005) for the United States are - 0.4065, - 0.5402 and - 0.3959 respectively. These estimates are remarkably stable given the different data samples, frequencies, and levels of aggregation employed in these papers.

The smaller negative slope of the implicit long-run inflation-markup relationship estimated using the panel approach compared with the slope of the cointegrating relationship from the VAR-ECM may be due to the exclusion of the relatively high inflation non-stationary inflation regimes from the panel analysis. If the long-run inflation-markup relationship is non-linear with a negative slope then the linear implicit long-run inflation-markup relationship coincides with the lower portion of the non-linear curve that has a smaller slope.

3.4 *A graphical representation of the results*

Graph 2 provides a graphical representation of the estimated ‘markup only’ model reported in the fourth column of Table 6. The graph shows quarterly combinations of the inflation rate and the markup between March 1960 and June 2007. The data from each inflation regime are represented by different symbols on the graphs. Shown as thin lines and denoted SRPC are the estimated short-run Phillips curves assuming the dynamics of inflation are exhausted. Shown as large crosses on the graph are the long-run combinations of inflation and the markup. As the non-stationary regimes are excluded and only the stationary inflation regimes are used in the estimation there are seven short run Phillips curves and seven long-run combinations of inflation and the markup shown on the graph. Finally, the two thick lines denoted LRPC and LRPC (VAR) are the non-linear estimate of the implicit long-run Phillips curve and the cointegrating long-run inflation-markup relationship reported in Table 7.²⁷

The graph shows that the short-run Phillips curves for each inflation regime have a smaller negative slope than the long-run curve. While not explicitly modelled in the panel estimation process, the technique is able to identify the long-run markup associated with each mean rate of inflation. In the short run an increase in the rate of inflation is associated with a relatively large fall in the markup. However, in the long run when all adjustment has been completed the markup recovers slightly to its new long-run level but still remains lower with a higher mean rate of inflation.

²⁷ The short and long-run Phillips curves are drawn in Graph 2 over the range of the actual markup in each case. Note that the SRPCs for regimes 2, 7 and 9 overlap on the graph.

5. EXPLAINING THE SLOPE OF THE LONG-RUN INFLATION MARKUP RELATIONSHIP

There are a number of theories that predict a negative relationship between inflation and the markup.²⁸ Explanations in the Mankiw (1985) and Parkin (1986) menu costs tradition can be separated into two groups. The first is a series of papers by Rotemberg (1983), Kuran (1986), Naish (1986), Danziger (1988), Konieczny (1990) and Bénabou and Konieczny (1994) who focus on the direct effect of the menu costs on the markup and argue that higher rates of inflation lead to a lower average markup. The second group are the papers by Bénabou (1988, 1992) and Diamond (1993) who argue that higher inflation increases the returns to search leading to a more competitive goods market and a lower markup. In these models the higher returns to search are because of higher relative price variability with higher inflation in a menu cost model.

For the inflation markup relationship to be 'long-run' in nature requires the menu cost price adjustment rule to be invariant to changes in the mean rate of inflation. This is unlikely to be the case as firms would respond to the lower average markup relative to its profit maximising level by changing the price rule. Consequently these standard theories can at best only explain the short-run relationship between inflation and the markup for each given inflation regimes where the mean rate of inflation is constant.

In contrast Russell (1998), Russell, Evans and Preston (2001) and Chen and Russell (2001) argue explicitly that the markup and inflation are related in the steady state²⁹. These papers model how non-colluding price-setting firms adjust prices in an uncertain economic environment. In particular the papers focus on the difficulties that firms face when trying to coordinate price rises in an inflationary environment so as to avoid the repercussions of inadvertent changes in relative prices. Importantly, it is argued that the information that is missing to firms is not of a type that is revealed when inflation is stable. As a result the negative relationship proposed by these theories is between mean rates of inflation and the markup. Specifically, higher mean rates of inflation serve to lower the markup but it does so at a declining rate. The markup is at a maximum at zero inflation and then converges on

²⁸ Explanations of the inflation-markup relationship are discussed briefly in Russell and Banerjee (2008) and in more detail in Russell (2006).

²⁹ The steady state is defined as all nominal variables growing at the same constant rate.

some minimum value with increasing mean rates of inflation. The relationship is explicitly non-linear as we would expect and consistent with the empirical findings of this paper.³⁰

6. IMPLICATIONS FOR THE ‘MODERN’ THEORIES OF THE PHILLIPS CURVE

What does this paper imply for the ‘modern’ Phillips curve theories? First, if inflation is stationary around shifting means as argued here there cannot be any empirical support for the behavioural underpinnings of any of the ‘modern’ Phillips curve theories. Within a single inflation regime with a constant mean the sum of the inflation terms must be less than one by definition. Given the possibility that inflation can have a constant mean for an extended period then this period must be inconsistent with all three ‘modern’ Phillips curve theories.

Second, there is no evidence that the lead in inflation as argued and measured in the New Keynesian and hybrid Phillips curve literatures is significant after allowing for the shifts in mean inflation. This term in the standard empirical analysis appears to only indicate there are unaccounted breaks in the mean rate of inflation and has no behavioural relevance.

Third, there is only marginal evidence that any lags in inflation are significant in the inflation-markup Phillips curve. Given unidentified breaks serve to increase the estimated coefficients on the dynamic inflation terms the marginal significance may simply be due to residual non-stationarity in the inflation data due to unidentified or miss-identified shifts in means. Indeed, the panel models estimated with the data from the inflation regimes where we are more confident that the data are stationary suggest a clear rejection of the hypothesis of significant dynamic terms.

Fourth, given the New Keynesian model is not supported empirically the markup should be interpreted on an empirical level as an error correction mechanism.³¹ On a behavioural level

³⁰ Friedman (1977) and Akerlof, Dickens and Perry (1996, 2000) argue that the long-run Phillips curve as defined between inflation and the unemployment rate has a positive slope. In these cases high unemployment rate is associated with higher real wages relative to productivity (i.e. a low markup). Therefore these papers imply that higher mean rates of inflation are associated with a lower markup. For further discussion on this issue see Russell and Banerjee (2008).

³¹ In natural logarithms, the markup, mu , of price, p , on unit labour costs, $w+l-y$, is: $mu = p - (w+l-y)$ which is the inverse of labour’s share of income or the ratio of prices over unit labour costs.

the markup may well proxy the average profit margin of firms as argued in the price-setting theories of Russell (1998), Russell, Evans and Preston (2001) and Chen and Russell (2001). Furthermore, in the developed world agents sequentially experience extended periods of mean reverting inflation where each of these periods have different mean rates of inflation. It would be rational, therefore, for agents (whether forward or backward looking) to recognise this statistical process. It is also rational, therefore, for agents to expect deviations in inflation and the markup from their long-run values to eventually be extinguished within a particular inflation regime and that these variables will return to their long-run levels over time. While most rational agents do not know what an error correction mechanism is we should not be surprised to find that the behaviour of agents in the inflation process can be approximated by an error correction mechanism such as that estimated in the panel models above and that leads and lags in inflation do not enter directly into the dynamics of inflation.

Finally, in the 1960s macroeconomic policy was conceived on the implicit assumption that a permanent loosening in monetary policy would permanently increase output. The analysis above does not support the behaviour underpinning the Friedman-Phelps model but reveals the remarkable insight of Friedman and Phelps that 'real' economic variables are independent of the mean rate of inflation in the long run is empirically correct. But the insight is only true to a first approximation. The analysis in this paper demonstrates that at low to moderate mean rates of inflation it looks as though there is a significant negative long-run relationship between inflation and the markup.

7. CONCLUSION

Applied econometricians since Granger and Newbold (1974) have been careful to account for non-stationarity in the data. However, applied econometricians often think in terms of two 'popular' statistical processes; namely, stationary and integrated. In part this is because of the importance and the success of Granger and Newbold (1974) followed quickly by the widespread acceptance of the Dickey and Fuller (1979) univariate unit root test based on the null hypothesis of a unit root in the data. With the difficulties of estimating models with integrated data understood and the test for a unit root firmly established, the emergence of cointegration analysis with Engle and Granger (1987) provided a theoretically elegant solution to the difficulties of modelling integrated variables. These three important advances

in econometrics are interlinked and may have led applied econometricians to overly focus on the two popular statistical processes. The strength of this focus is demonstrated by how the warnings of Perron (1989) concerning the biases due to breaks in series have been largely overlooked even after twenty years. These warnings are routinely ignored by applied econometricians in general and by nearly all applied Phillips curve researchers in particular.

In contrast, the addition of shifts in mean to a stationary process is often thought of as ‘nuisance’ parameters and not very interesting. This paper argues that in many cases the ‘true’ statistical process is stationary around shifting means and that the two ‘popular’ assumptions when analysing data can only be approximations of the ‘true’ process at best. As such, the approximations bring with them biases which are large and non-trivial in the case of inflation and the estimation of Phillips curves. So large that all the standard results in the empirical Phillips curve literature over the past thirty five years are due to the biases introduced by the ‘popular’ assumptions alone and the estimates are ‘spurious’ with little or no behavioural relevance.

Furthermore, the consistency in the findings reported in the empirical Phillips curve literature over the past thirty five years does not validate any of the underlying ‘modern’ theories of inflation. Instead the consistency simply reflects the repeated use of the same incorrect assumptions concerning the data and the same inappropriate estimation techniques by researchers. The combination of the incorrect assumptions and the incorrect estimation techniques lead to badly biased estimates that are fortuitously congruent with the predictions of modern theories of the Phillips curve.

What then are the ‘stylised facts’ from these results that future Phillips curve theories need to explain? First, the long-run relationship between inflation and the markup is non-linear and negative at low to moderate rates of inflation. Second, the lead in inflation as commonly estimated in the literature has no significant role in the dynamics of inflation. Third, given inflation is stationary within an inflation regime then the sum of the dynamic inflation terms must be less than one and may be close to or equal to zero. And fourth, the markup should be seen as an error correction term which is possibly a proxy for the profitability of firms.

Finally, this paper argues that assuming data is stationary or integrated when the ‘true’ statistical process is stationary around shifting means leads to non-trivial and large biases

in the estimation of models. This argument is relevant to any empirical work where careful consideration of the data should alert the researcher that assuming the data is stationary or integrated is only an approximation of the 'true' statistical processes. Before proceeding with the estimation under these assumptions it would be prudent to examine the size of the biases due to the approximation using a Monte Carlo simulations before proceeding. If the biases are large as we know may be the case from Perron (1989) and demonstrated here then the approximation is poor and should be avoided.

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APPENDIX 1 DATA APPENDIX

The data are seasonally adjusted and quarterly for the period March 1960 to June 2007 for the United States. The United States national accounts data are from the National Income and Product Account tables from the United States of America, Bureau of Economic Analysis. The data were downloaded from via the internet on the 9th October 2007.

United States Data	
<i>Variable</i>	<i>Details</i>
GDP implicit price deflator at factor cost	Nominal GDP at factor cost is nominal GDP (Table 1.1.5, line 2) plus subsidies (Table 1.10, line 10) less taxes (Table 1.10, line 9). GDP implicit price deflator is nominal GDP at factor cost divided by constant price GDP at 2000 prices, Table 1.1.6, line 1. Inflation is the first difference of the natural logarithm of the GDP implicit price deflator at factor cost. Note that Graph 1 shows the estimated inflation regimes multiplied by 400 to be consistent with annualised inflation data.
The Markup	Calculated as the natural logarithm of nominal GDP at factor cost divided by wages, salaries and supplements, Table 1.10, line 2.

The Data Generated for the Monte Carlo Analysis

The data are generated using WinRATS pro 6.2. The forcing variable, x_t , is generated as: $x_t = 0.937967 x_{t-1} + \omega_t$ where the first observation, x_0 , is zero and ω_t is a random draw from a normal distribution with mean zero and a standard error of 0.006388. The ‘seed’ value is: 250305.

The ‘inflation’ series, y_t , such that $y_t = -0.205406 x_t + v_t$ where v_t is a random draw from a normal distribution with a mean of zero and a standard error of 0.004753. The ‘seed’ value is: 171193

The mean-shift ‘inflation’ variable, y_t^{MS} , is: $y_t^{MS} = y_t + \mu_t^i$ where μ_t^i is the mean rate of inflation in regime i as reported in Table A2 of Appendix 2.

The actual data and the generated data are available at www.BillRussell.info.

APPENDIX 2 IDENTIFYING THE INFLATION REGIMES

The Bai and Perron (1998, 2003a, 2003b) approach minimises the sum of the squared residuals to identify the dates of k breaks in the inflation series and, thereby, identify $k + 1$ ‘inflation regimes’. The estimated model is:

$$\Delta p_t = \gamma_{k+1} + \tau_t \quad (\text{A2.1})$$

where Δp_t is inflation and γ_{k+1} is a series of $k + 1$ constants that estimate the mean rate of inflation in each of $k + 1$ inflation regimes and τ_t is a random error. The model is corrected for serial correlation with a minimum regimes size of 5 per cent of the total sample (nine quarters) and chosen using the Bayesian Information Criterion. If the model is not corrected for serial correlation the break dates are unaffected. The model is estimated using quarterly data for the period March 1960 to June 2007 for the United States. The results of the estimated models are reported in the table below. Note that Graph 1 shows the estimated inflation regimes multiplied by 400 to be consistent with annualised inflation data. The Bai-Perron programme was estimated using Gauss 5.0 and was kindly made available by Pierre Perron on his personal internet site.

<i>Regime</i>	<i>Dates of the ‘Inflation Regimes’</i>	<i>Mean Rate of Inflation</i>
1	March 1960 to September 1964	0.003133
2	December 1964 to June 1967	0.006844
3	September 1967 to December 1972	0.011385
4	March 1973 to March 1975	0.021266
5	June 1975 to June 1977	0.015419
6	September 1977 to September 1981	0.020361
7	December 1981 to December 1990	0.008863
8	March 1991 to September 2003	0.005005
9	December 2003 to June 2007	0.007613

Table 1: Phillips Curve estimates from the generated data

Constant Mean Rate of Inflation dependent variable y_t					Shifting Mean Rates of Inflation dependent variable y_t^{MS}			
	F-P	NK	Hybrid	ND		F-P	NK	Hybrid
y_{t+1}		0.0191 (0.0)	0.0186 (0.0)		y_{t+1}^{MS}		1.0315 (14.1)	0.9785 (5.2)
y_{t-1}	- 0.0104 (- 0.2)		- 0.0078 (- 0.1)		y_{t-1}^{MS}	0.2984 (4.4)		0.0377 (0.6)
y_{t-2}					y_{t-2}^{MS}	0.2201 (3.1)		
y_{t-3}					y_{t-3}^{MS}	0.1923 (3.1)		
x_t	- 0.2076 (- 8.1)	- 0.2017 (- 2.5)	- 0.2034 (- 2.1)	- 0.2052 (- 10.1)	x_t	- 0.0563 (- 1.8)	- 0.0146 (- 0.6)	- 0.0158 (- 0.6)
C	- 0.0000 - 0.0	- 0.0000 (- 0.0)	- 0.0000 (- 0.0)	- 0.0000 (- 0.0)	C	0.0027 (4.0)	- 0.0003 (- 0.4)	- 0.0002 (- 0.1)
\bar{R}^2	0.33	0.10	0.00	0.33	\bar{R}^2	0.45	0.16	0.51
J test	0.4920	0.5185	0.5268	0.4964	J test	0.2911	0.4890	0.4835
LM(4)	0.4357	0.0746	0.0196	0.4478	LM(4)	0.1261	0.0000	0.0000
DW	1.99	2.02	2.01	2.00	DW	2.03	2.90	2.94
ADFR	- 6.15	- 6.55	- 6.50	- 6.12	ADFR	- 5.92	- 8.35	- 8.43
\sum	- 0.0104 [0.0656]	0.0191 [0.4795]	0.0108 [0.6472]		\sum	0.7108 [0.0699]	1.0315 [0.0769]	1.0161 [0.0947]
F	0.4230	0.4091	0.4392	0.4524	F	0.0000	0.0000	0.0000

Reported as () and [] are t -statistics and standard errors respectively. The ‘Constant Mean Rate of Inflation’ models are estimated with the constructed series, y_t , and the constructed forcing variable, x_t .

The ‘Shifting Mean Rate of Inflation’ models are estimated with the constructed series, y_t^{MS} , and the forcing variable x_t . See sections 2.2 and 2.3 for details of how the data is generated. The models are estimated with 190 observations using GMM with three lags of the dependent variable and the forcing variable as instruments. Further lags of the dependent variable and the forcing variable in the Friedman-Phelps and hybrid models are excluded on a 5% t -criterion. Reported as J Test is the significance of the Hansen test of instrument validity, LM(4) is the significance of the fourth order autocorrelation Lagrange multiplier test statistic, DW is the Durban-Watson test statistic, and ADF_R is the no intercept and no trend ADF test of the residuals where the 1%, 5% and 10% critical values are - 2.576, - 1.941 and - 1.616 respectively. \sum is the sum of the generated ‘dynamic inflation terms’. F is the F-test probability value that the estimates in the model are equal to their ‘true’ values of $\delta_f = 0$, $\delta_b = 0$, and $\delta_x = - 0.205406$ in the data generating process. 10,000 Monte Carlo models estimated with WinRATS pro 6.2.

Table 2: Phillips Curve estimates from the differenced generated data

	F-P	NK	Hybrid
Δy_{t+1}^{MS}		- 0.3772 (- 0.5)	- 0.4464 (- 0.7)
Δy_{t-1}^{MS}	- 0.6013 (- 6.6)		- 0.6006 (- 4.6)
Δy_{t-2}^{MS}	- 0.2869 (- 3.3)		- 0.3005 (- 2.3)
Δx_t	0.0129 (- 0.8)	- 0.2089 (- 0.3)	0.0375 (- 0.1)
Constant	0.0000 (0.1)	0.0000 (0.5)	0.0001 (0.1)
\bar{R}^2	*	*	*
J test	0.2397	0.2298	0.3955
LM(4)	0.0405	0.0000	0.0029
DW	2.05	2.44	2.07
ADF _R	-7.13	- 7.54	- 7.23
\sum	- 0.8882 [0.1890]	- 0. 3772 [1.1864]	- 1.3475 [5.3564]
F	0.0052	0.1725	0.2447

Reported as () and [] are t -statistics and standard errors respectively. The Δ symbol represents the lag difference such that $\Delta y_t = y_t - y_{t-1}$. The dependent variable is Δy_t^{MS} . Further lags of Δy^{MS} and Δx in the Friedman-Phelps and hybrid models are excluded on a 5% t -criterion. See the notes to Table 1 for further details concerning this table.

Table 3: Monte Carlo Bai-Perron Estimates of the Inflation Regimes

Estimated Number of Breaks k	Implied Number of Inflation Regimes	Frequency
1	2	3
2	3	365
3	4	1146
4	5	2286
5	6	2768
6	7	1893
7	8	1037
8	9	387
9	10	115

Statistical analysis of the number of breaks k .

Mean: 4.99, Median: 5, Standard Deviation: 1.469, Skewness: 0.225, Kurtosis: - 0.194.

The number of breaks k is estimated in the model: $y_t^{MS} = \gamma_{k+1} + \tau_t$ using the Bai-Perron technique where y_t^{MS} is the generated mean shift inflation variable, γ_{k+1} is a series of $k+1$ constants that estimate the mean rate of inflation in each of $k+1$ inflation regimes and τ_t is a random error. Frequency is the number of y_t^{MS} series that have the estimated number of breaks. The 'true' number of breaks in the series is 8 implying 9 inflation regimes. See Appendix 2 for further details concerning the Bai-Perron technique for estimating structural breaks. Bai-Perron technique estimated using Gauss 5.0 assuming a minimum regime size of 12 periods.

Table 4: Monte Carlo Panel Estimates of the Phillips Curve using the Generated Mean Shift Variable y_t^{MS} and the Forcing Variable x_t

	Restricted Constant			Fixed Effects			
	F-P	NK	Hybrid	F-P	NK	Hybrid	ND
y_{t+1}^{MS}		0.9683 (8.0)	0.9400 (4.4)		0.1567 (0.3)	0.1408 (0.3)	
y_{t-1}^{MS}	0.5198 (8.0)		0.0260 (0.4)	0.0211 (0.3)		0.0188 (0.2)	
x_t	-0.0920 (-2.5)	-0.0237 (-0.5)	-0.0230 (-0.5)	-0.1095 (-2.5)	-0.1060 (-1.6)	-0.1100 (-1.4)	-0.1113 (-2.7)
Constant	0.0044 (5.6)	0.0003 (0.2)	0.0003 (0.3)	0.0090 (24.2)	0.0077 (18.9)	0.0077 (18.4)	0.0092 (24.6)
\bar{R}^2	-0.751	0.208	0.202	0.286	0.260	0.251	0.278
LM(1)	[0.000]†	[0.000]†	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LM(2)	[0.000] †	[0.195] †	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LM(3)	[0.000] †	[0.008]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
LM(4)	[0.000] †	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
DW	2.339	2.928	2.954	2.004	2.170	2.171	1.960
<i>F-Tests</i>	69.749	30.284	20.521	23.337	18.979	18.483	22.750
$\phi_f + \phi_b = 0$	[0.000]	[0.000]	[0.000]	[0.693]	[0.726]	[0.845]	
$\phi_f + \phi_b = 1$	[0.000]	[0.880]	[0.934]	[0.000]	[0.342]	[0.528]	
Significant Variables	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Fixed Effects				[0.000]	[0.001]	[0.002]	[0.000]
<i>F</i>	86.001 [0.000]	79.020 [0.000]	83.772 [0.000]	9.474 [0.162]	7.633 [0.216]	8.465 [0.255]	8.766 [0.141]

Reported as () and [] are t -statistics and F-test probability values respectively. The forcing variable is, x_t , and the dependent variable is, y_t^{MS} as set out in equations (2) and (3) respectively. The data are partitioned into inflation regimes as estimated by the Bai-Perron technique. Details of the number of breaks found in the inflation series are reported in Table 3. The cross section models are then estimated using the 2SLS estimator with three lags of x , and, y^{MS} as instruments. The process is repeated 10,000 times using Monte Carlo techniques with GAUSS 5.0. The data used in the modelling process is identical to that used in the estimation of the models reported in Tables 1 and 2. In the first three columns the constant (or fixed effect) in each panel is restricted to be the same such that $\phi^1 = \phi^2 = \dots = \phi^n$. The fixed effects models in columns 4 to 6 the reported constant is the weighted average of the fixed effects. LM(1) to LM(4) are the Lagrange multiplier tests of first to fourth order serial correlation in the residuals. ‘Significant Variables’ is an F-Test of $\phi_f = \phi_b = \phi_z = \phi^n = 0$. ‘Fixed Effects’ is an F-Test of significant fixed effects such that $\phi^n = 0$. F is the F-test probability value that the estimates in the model are equal to their ‘true’ values of $\delta_f = 0$, $\delta_b = 0$, and $\delta_x = -0.205406$ in the data generating process of equations (2) and (3).

Table 5: Panel Estimates of United States Phillips Curve**All Inflation Regimes**

	Restricted Constant				Fixed Effects			
	F-P	NK	Hybrid	Markup Only	F-P	NK	Hybrid	Markup Only
Δp_{t+1}^n		0.9835 (14.4)	0.6888 (5.6)			0.0636 (0.2)	0.3819 (1.0)	
Δp_{t-1}^n	0.4642 (6.1)		0.2754 (2.7)		0.1263 (1.6)		0.1748 (1.8)	
Δp_{t-2}^n	0.1477 (1.8)							
Δp_{t-3}^n	0.2805 (3.6)							
mu_t	- 0.0409 (- 2.6)	- 0.0064 (- 0.3)	- 0.0153 (- 0.9)	- 0.2106 (- 9.7)	- 0.0527 (- 2.5)	- 0.0571 (- 2.2)	- 0.0411 (- 1.5)	- 0.0581 (- 2.7)
Constant	0.0205 (2.6)	0.0032 (0.3)	0.0076 (0.9)	0.1094 (10.5)	0.0330 (3.3)	0.0356 (2.6)	0.0236 (1.5)	0.0367 (3.5)
\bar{R}^2	0.786	0.711	0.785	0.340	0.838	0.827	0.816	0.835
AR(1)	[0.031]	[0.000]	[0.000]	[0.000]	[0.844]	[0.575]	[0.000]	[0.195]
AR(2)	[0.144]	[0.020]	[0.455]	[0.000]	[0.020]	[0.033]	[0.119]	[0.024]
AR(3)	[0.088]	[0.668]	[0.668]	[0.000]	[0.760]	[0.821]	[0.728]	[0.626]
AR(4)	[0.068]	[0.197]	[0.151]	[0.000]	[0.551]	[0.542]	[0.285]	[0.729]
DW	2.121	2.769	3.027	0.485	2.048	1.886	2.665	1.82
<i>F-Tests</i>								
Parameter Constancy	[0.000]	[0.209]	[0.383]	[0.000]	[0.134]	[0.336]	[0.128]	[0.413]
$\phi_f + \phi_b = 0$	[0.000]	[0.000]	[0.000]		[0.101]	[0.8426]	[0.197]	
$\phi_f + \phi_b = 1$	[0.044]	[0.809]	[0.545]		[0.000]	[0.004]	[0.303]	
Significant Variables	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Fixed Effects					[0.000]	[0.376]	[0.977]	[0.000]

Reported as () and [] are t -statistics and F-test probability values respectively. The dependent variable is, Δp_t^n . The forcing variable is the markup, mu_t . The panels consist of 9 cross-sections with 190 observations in total and 160, 150 and 150 usable observations in the F-P, NK and hybrid models respectively. See appendices 1 and 2 for details concerning the data and the estimation of the inflation regimes. Lag length chosen by lag exclusion F-tests in all models except the restricted constant markup only model in column 4 where further dynamics do not improve the system diagnostics. Instruments are three lags of the independent variables all models. Inference is not affected by the inclusion of fewer or more lags of the instruments. In the first three columns the constant (or fixed effect) in each panel is restricted to be the same such that $\phi^1 = \phi^2 = \dots = \phi^9$. In the fixed effects models in columns 4 to 6 the reported constant is the weighted average of the fixed effects. AR(1) to AR(4) are the Arellano-Bond tests of first to fourth order serial correlation in the residuals. ‘Parameter Constancy’ is an F-tests of the estimated parameters for Δp_t^n and mu_t , are the same across inflation regimes. ‘Significant Variables’ is an F-Test of $\phi_f = \phi_b = \phi_z = \phi^n = 0$. ‘Fixed Effects’ is an F-Test of significant fixed effects such that $\phi^n = 0$. Models estimated with 2SLS using Stata/SE 8.2 and Eviews 5.1.

**Table 6: Panel Estimates of United States Phillips Curve
Stationary and Non-stationary Inflation Regimes**

	Stationary Inflation Regimes				Non-stationary Inflation Regimes			
	F-P	NK	Hybrid	Markup Only	F-P	NK	Hybrid	Markup Only
Δp_{t+1}^n		0.2392 (0.5)	0.4186 (0.9)			1.3338 (2.2)	1.0890 (2.2)	
Δp_{t-1}^n	0.0573 (0.7)		0.0845 (0.8)		0.7218 (2.1)		0.6563 (2.3)	
Δp_{t-2}^n								
Δp_{t-3}^n								
mu_t	- 0.0441 (- 2.2)	- 0.0438 (- 1.8)	- 0.0365 (- 1.4)	- 0.0469 (- 2.3)	- 0.4409 (- 1.7)	0.8562 (1.7)	0.5250 (1.3)	- 0.1455 (- 0.6)
Constant	0.0288 (2.9)	0.0272 (2.1)	0.0215 (1.4)	0.0306 (3.2)	0.2050 (1.8)	0.2331 (- 1.7)	- 0.2510 (- 1.3)	0.0853 (0.7)
\bar{R}^2	0.810	0.795	0.774	0.810	0.645	0.672	0.806	0.534
AR(1)	[0.429]	[0.012]	[0.000]	[0.708]	[0.199]	[0.795]	[0.743]	[0.154]
AR(2)	[0.065]	[0.090]	[0.152]	[0.068]	[0.480]	[0.019]	[0.011]	[0.062]
AR(3)	[0.546]	[0.227]	[0.245]	[0.555]	[0.134]	[0.328]	[0.368]	[0.007]
AR(4)	[0.399]	[0.305]	[0.292]	[0.403]	[0.181]	[0.038]	[0.452]	[0.243]
DW	2.051	2.378	2.747	1.94	2.624	1.812	1.839	1.306
<i>F-Tests</i>								
Parameter Constancy	[0.253]	[0.669]	[0.393]	[0.261]	[0.867]	[0.972]	[0.527]	[0.566]
$\phi_f + \phi_b = 0$	[0.481]	[0.527]	[0.326]		[0.064]	[0.075]	[0.019]	
$\phi_f + \phi_b = 1$	[0.000]	[0.046]	[0.332]		[0.432]	[0.610]	[0.203]	
Significant Variables	[0.000]	[0.000]	[0.000]	[0.000]	[0.006]	[0.023]	[0.015]	[0.010]
Fixed Effects	[0.000]	[0.600]	[0.946]	[0.000]	[0.064]	[0.152]	[0.464]	[0.007]

All modes estimated with 2SLS fixed effects estimator. Stationary inflation regimes include regimes 1, 2, 3, 6, 7, 8 and 9 with 151 observations. Non-stationary inflation regimes include regimes 4 and 5 with 18 observations. Inference is unaffected by estimating with only 1 or 2 lags of independent variables as instruments. See also notes to Table 6.

Table 7: Estimates of the Long-run Phillips Curve

Linear:
$$\overline{\Delta p} = 0.0628 - 0.1113 \bar{z}, R^2 = 0.14$$
$$(2.7) \quad (-2.4)$$

The estimated coefficient on \bar{z} is zero is rejected, $\chi_1^2 = 5.8176$, prob-value = 0.0159.

Non-linear:
$$\overline{\Delta p} = 2.1174 \exp(-11.3433 \bar{z}), R^2 = 0.13$$
$$(0.4) \quad (-2.0)$$

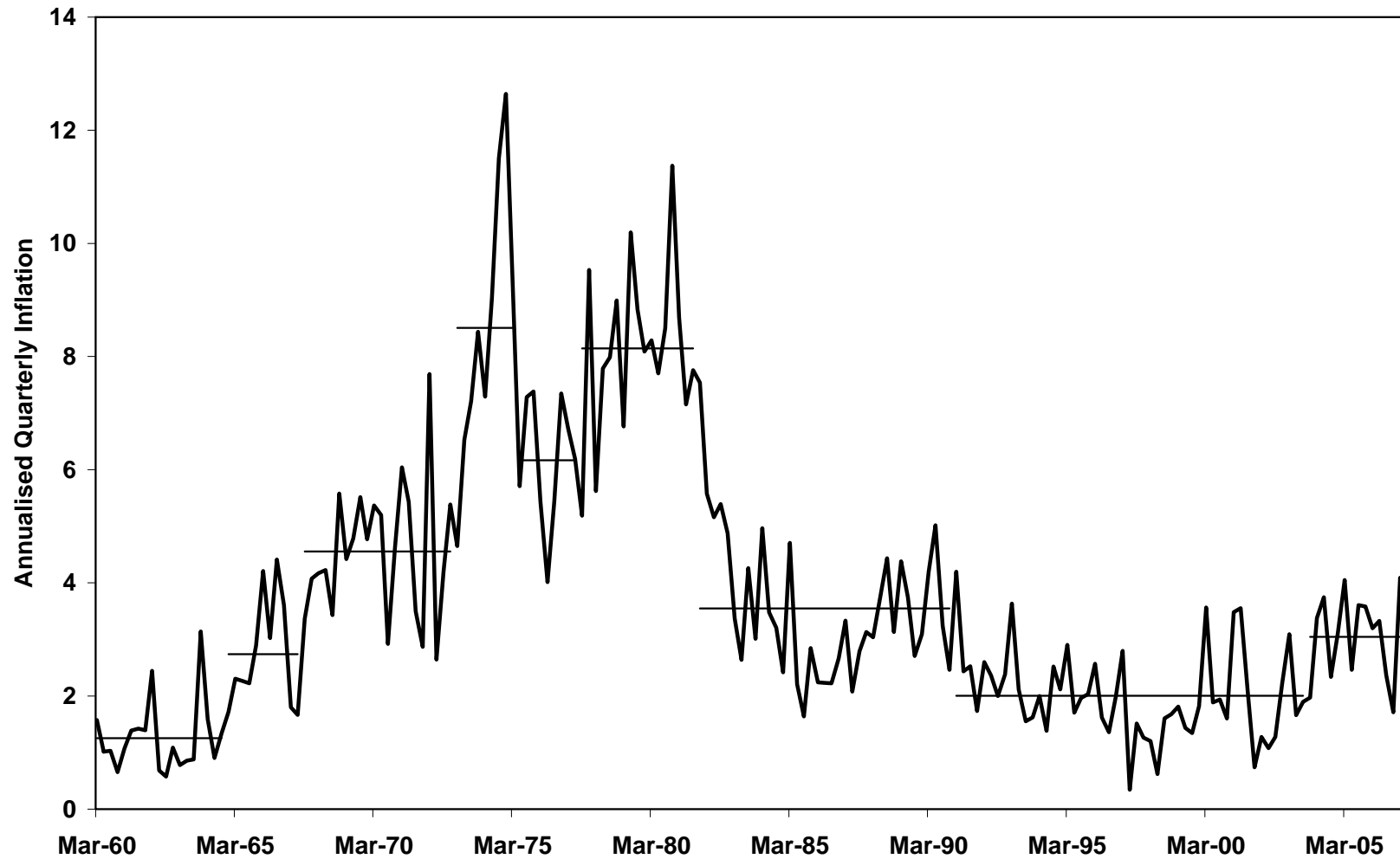
The estimated coefficient on \bar{z} is zero is rejected, $\chi_1^2 = 4.1256$, prob-value = 0.0422.

VAR-ECM (linear):
$$\Delta p = 0.1761 - 0.3503 z$$
$$(-4.5)$$

Unrestricted cointegration rank test (Trace test) for the null hypothesis $H_0: r=0$ is 15.85 {15.50} and $H_0: r = 1$ is 3.79 {3.84} indicating we can accept 1 cointegrating vector at the 5 per cent level.

Notes: Numbers in () and { } are t statistics and the 5 per cent Trace test critical values respectively.

Graph 1: United States Quarterly Inflation, Seasonally Adjusted, March 1960 – June 2007



Notes: Horizontal dashed lines indicate the nine inflation regimes identified by the Bai-Perron technique (see Appendix 2 for details). Annualised quarterly inflation is measured as the change in the natural logarithm of the price index multiplying by 400.

Graph 2: United States Inflation and the Markup

