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Non-stationary Inflation and Panel Estimates of United States Short and Long-run Phillips Curves

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ABSTRACT

This paper argues that because United States inflation has been non-stationary over the past five decades the vast body of empirical research that proceeds without adequately accounting for the non-stationarity in the data is invalid. Using fifty years of United States inflation data the standard results in the Phillips curve literature are shown to be due to unaccounted shifts in the mean rates of inflation over the period. Short and long-run Phillips curves for the United States are then estimated using time series panel data techniques which account for these shifts in mean.

Keywords: Phillips curve, inflation, panel data, non-stationary data
JEL Classification: C22, C23, E31

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1. INTRODUCTION

This paper is an empirical examination in the tradition of Popper of three modern theories of the Phillips curve.[1] While it is difficult to empirically examine the Phillips curve theories directly, the theories make very strong predictions concerning the statistical properties of inflation and it is these predictions that we examine empirically. First, we demonstrate that the empirical methodology employed in the standard literature to examine modern theories of the Phillips curve is invalid in that it is inconsistent with our understanding of the statistical process of inflation. Furthermore, given this understanding we should logically expect the standard empirical approaches to produce severely biased estimates. This is also demonstrated. Finally we proceed to estimate Phillips curves for the United States using a time series panel data approach that is congruent with our understanding of the statistical process of inflation. This empirical methodology is uniquely applied to the analysis of the predictions and we find that all three modern theories are not supported by the data. It is also found that the important prediction of the 'modern' theories that the long-run Phillips curve is 'vertical' is only approximately true. At low to moderate rates of inflation it is shown that the long-run Phillips curve has a significant, small but most likely economically important positive slope.

A straightforward taxonomy of 'modern' Phillips curve theories can be thought of in terms of restrictions to the reduced form hybrid Phillips curve 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}, and a 'forcing' variable, x_t, and written:[2]

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1 Popper (1959) argues that a theory is 'scientific' if it produces predictions that can be falsified in an empirical sense. All three modern theories are therefore 'scientific' in the sense used by Popper and this paper suggests one methodology that will empirically examine the predictions of the theories directly and therefore indirectly examine the validity of the theories themselves.

2 Modern Phillips curve theories include Friedman-Phelps expectations augmented, New Keynesian and hybrid theories as well as the New Classical and real business cycle theories of inflation. See Henry and Pagan (2004) for a clear exposition of the hybrid Phillips curve. The 'forcing' variable represents excess demand and is measured in the literature in a variety of ways including the gap between the unemployment

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

where the error term, ε_t, is due to the random errors of agents and the shocks to inflation. In the purely backward looking Friedman (1968) and Phelps (1967) (F-P) expectations augmented Phillips curve model, agents hold adaptive expectations implying that $\delta_f = 0$ and $\delta_b = 1$. In the purely forward-looking rational expectations New Keynesian (NK) Phillips Curve models of Clarida, Gali and Gertler (1999) and Svensson (2000) $\delta_b = 0$ and the $\delta_f = 1$. Finally, the more general hybrid model of Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001) assumes that there are both backward and forward-looking price setting agents and that $\delta_f + \delta_b = 1$. For the long-run Phillips curve to be vertical requires $\delta_f + \delta_b = 1$ in all three models of inflation.[3]

The vertical long-run Phillips curve is a central tenant of 'modern' Phillips curve theories of inflation since Friedman (1968) and Phelps (1967) and implies that inflation may be non-stationary with multiple long-run rates of inflation.[4] Indeed, a large measure of Friedman's success in establishing the existence of the vertical long-run Phillips curve was in predicting the 'breakdown' of the original Phillips curve identified by Phillips (1958). The 'breakdown' was due to changes in the expected rate of inflation associated with changes in the long-run rate of inflation and therefore concomitant with inflation being non-stationary.

Consider now the estimation of Phillips curves with the last fifty years of United States inflation data. If the forcing variable in equation (1) is stationary with a constant mean then our prior empirical belief concerning the estimated values of δ_f, δ_b and $\delta_f + \delta_b$ depends on

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rate and its long-run level, the gap between real and potential output, real marginal costs, and labour's income share.

3 In the New Keynesian and hybrid models δ_f and δ_b sum to the discount rate and so is close, but not equal, to 1. However, so that the long-run Phillips curve is vertical, empirical researchers either impose the coefficients to sum to one or impose this restriction following testing (for example, see Rudd and Whelan 2006).

4 The term 'non-stationary' is used in this paper to mean all statistical processes other than stationary with a constant mean and includes stationary with shifting means.

what we believe is the 'true' statistical process of inflation.[5] For example, if we believe inflation is stationary with a constant mean then $-1 < \delta_f + \delta_b < 1$. If integrated of order 1 or trend stationary then we would expect that estimates of $\delta_f + \delta_b$ to be insignificantly different from 1. Alternatively, if inflation is a stationary process with shifting means then the estimate of $\delta_f + \delta_b$ will be biased towards 1. Importantly, if the shifts in mean are frequent and/or large then estimates of $\delta_f + \delta_b$ will be insignificantly different from 1.[6] These conclusions are not affected by the choice of estimator or the inclusion of more complicated dynamics such as adding further lags in inflation to equation (1).

An important question, therefore, is what is the 'true' statistical process of inflation over the past fifty years? Inflation with a constant mean will not stand up to any serious scrutiny as this would imply that there is only one long-run rate of inflation, one expected rate of inflation and one short-run Phillips curve over the past fifty years. It is also very unlikely that inflation is truly an integrated variable as inflation in the United States (and developed economies in general) appears to be bounded below at around zero and above at some moderate rate. We can also rule out that inflation is trend stationary unless the trend is a proxy for a systematic unidirectional change in the central bank's target rate of inflation.

The final alternative is that inflation is stationary with shifting means.[7] The dynamics of inflation in 'modern' Phillips curve theories since Friedman (1968) and Phelps (1967) start with a discrete shift in monetary policy that leads to a discrete shift in the long-run rate of inflation. In the short-run, inflation displays stationary perturbations around its long-run rate. Consequently, we may expect inflation to be a stationary process with shifts in mean where the latter represent changes in the long-run rate of inflation due to changes in monetary policy.

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[5] This is in contrast with our prior theoretical beliefs concerning the same parameters.

[6] This is a generalisation of the Perron (1989) argument that large shifts in mean in a trend stationary process may lead to the erroneous acceptance that the data contains a unit root. That is, the estimate of $\delta_f + \delta_b$ in equation (1) is insignificantly different from 1. See also Banerjee and Urga (2005).

[7] Another alternative is that inflation is integrated of order greater than 1. It is hard to imagine how this process would be generated and so this alternative is excluded from this discussion.

Return now to the estimated value of $\delta_f + \delta_b$ in equation (1). If we believe that the data is stationary with frequent shifts in mean then we must simultaneously believe that estimates of $\delta_f + \delta_b$ will be biased towards 1 *unless we account for these shifts in the mean rate of inflation* in the estimation process.

Graph 1 shows United States inflation measured as the quarterly change in the natural logarithm (multiplied by 400) of the seasonally adjusted consumer price index (CPI) for the period March 1952 to September 2004.[8] One of the striking characteristics of United States inflation is its similarity to the inflation processes in the developed and many of the developing economies over the past fifty years. After a protracted period of low inflation in the 1950s and early 1960s, inflation began to increase towards the end of the 1960s. The high inflation in the 1970s and early 1980s associated with two Organisation of Petroleum Exporting Countries (OPEC) oil price increases is then followed by a discrete reduction in inflation early in the 1980s (the 'Volker deflation') and then again in the early 1990s at the time of a large recession.

These visual shifts in mean inflation can be shown more formally by applying the Bai and Perron (1998, 2003a, 2003b) technique to estimate multiple breaks in the mean rate of inflation.[9] This technique identifies seven shifts in the mean rate of inflation and therefore eight 'inflation regimes' over this fifty year period. The mean rates of inflation for each inflation regime are shown on Graph 1 as horizontal solid thin lines. From a purely visual perspective, the Bai-Perron technique appears to have identified all the large shifts in mean inflation over the period. However, the technique may have missed two of the smaller shifts in mean inflation in 1955-1957 and 1997-1999 and possibly some small movements in mean inflation within the other inflation regimes.

The empirical Phillips curve literature reveals a strange dichotomy in the economics profession. Since the work of Yule (1926), Granger and Newbold (1974, 1977), Box and Jenkins (1976), Plosser and Schewert (1978), Hendry (1980) and Phillips (1986) on 'spurious' regressions, applied time series economists are careful when estimating models to

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8 See Appendix 1 for details and sources of the data used in this paper.

9 See Appendix 2 for details concerning the estimation of inflation regimes using the Bai-Perron technique.

deal appropriately with non-stationary data. The dichotomy is that even though applied time series economists are in general careful in this respect, nearly all of the empirical work on the 'modern' Phillips curve fails to adequately account for the shifts in the mean rates of inflation and makes use of estimation techniques that are suitable for models where the data is stationary with a constant mean.

A small sample of the extensive early modern Phillips curve literature might include Gordon (1970, 1975, 1977, and 1997), McCallum (1976), Sumner and Ward (1983), Alogoskoufis and Smith (1991), Roberts (1995).[10] Similarly, a sample of the more recent New Keynesian and hybrid Phillips curve literature might include 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).[11] A wide range of estimators are used in these papers including ordinary least squares, generalised least squares, instrumental variables, full information maximum likelihood and generalised method of moments (GMM). However, none of these papers account for the shifts in mean inflation in the estimation process and therefore the estimates of $\delta_f + \delta_b$ are biased upwards. Furthermore, if the shifts in mean inflation are large and/or frequent this will lead to the erroneous acceptance of the hypothesis that $\delta_f + \delta_b = 1$.[12] It is surprising that Phillips curve models are popularly estimated in this way without accounting for the shifts in mean inflation given that the modern Phillips curve literature along with the 'breakdown' of the original Phillips curve leads us to expect that inflation is stationary with shifting means.

That the shift in the mean rate of inflation affects the estimates of Phillips curve models is partially recognised in the literature. Levin and Piger (2002) argue that once a single shift in mean is accounted for in the data, inflation no longer contains a unit root. In a similar vein, Ball (2000) argues that the sum of the lags in inflation in the Phillips curve model is less than

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10 The Phillips curve literature is substantial. A search using EconLit of titles and keywords containing 'Phillips Curve' returns around 450 and 1000 pieces of work respectively since 1969.

11 Most of the New Keynesian and hybrid models are estimated with the generalised method of moments estimator. Pesaran (1981, 1987), Stock, Wright, and Yogo (2002), Mavroeidis (2004, 2005) and Dufour, Khalaf and Kichian (2006a, 2006b) argue it is inappropriate to estimate Phillips curve models with GMM estimators when the data is integrated or near integrated. As demonstrated empirically below, once the shifts in mean are accounted for, the inflation data is not integrated and so this criticism is not relevant.

12 See footnote 6.

one during periods when inflation is stable (i.e. when inflation has a constant mean). The implication of these papers is that if the shifts in mean affect estimates of the Phillips curve then one should systematically account for all of the shifts in the mean rates of inflation when estimating the models.

Even when inflation is recognised to follow a non-stationary process the shifts in mean are usually not adequately accounted for in the estimation of the Phillips curve models. The first group of work in this literature includes papers by King and Watson (1994) and Stock and Watson (2007) who find inflation data contains a unit root. These papers do not question the source of the unit root in the data. Consequently only two types of statistical processes are considered for inflation. The first is stationary with a constant mean and the second is an integrated process. The possibility that inflation is stationary with shifting means and that this is what is generating the apparent unit root in the inflation data is not considered even though we might expect this from the modern Phillips curve theories. These papers proceed to estimate Phillips curve models by differencing the inflation data to remove the unit root.

The second group of work includes Cogley and Sbordone (2005, 2006) and Ireland (2007) who explicitly acknowledges inflation is non-stationary. These papers model the central bank's target rate of inflation as a random walk process. If we consider agents make errors randomly around the target rate of inflation this implies that inflation also follows a random walk which given the bounded nature of inflation cannot be strictly true. More importantly on an empirical level, this assumption means that the dependent variable in their estimated models is simply the first difference of inflation.[13] In practice, therefore, both groups of papers account for the non-stationary behaviour of inflation by differencing the inflation data. If the 'true' statistical process for inflation is stationary with shifting means then differencing the data leads to biased estimates and incorrect inference.

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[13] The dependent variable of these papers is $\Delta p_t - \Delta p_t^*$ which is the difference between inflation and trend inflation, Δp_t^*. In turn, trend inflation is assumed to follow a random walk such that $\Delta p_t^* = \Delta p_{t-1}$ and so, on a practical level, the dependent variable is $\Delta p_t - \Delta p_{t-1}$ which is the first difference of inflation.

This assertion can be demonstrated with the following Monte Carlo analysis. Consider generating a random variable, y_t:[14]

$$y_t = ran\,(0, \sigma)_t \qquad (2)$$

where $ran\,(0, \sigma)$ is a random draw from a normal distribution with mean zero and standard deviation, $\sigma = 1.665956$. The standard deviation is equivalent to that of the inflation data de-meaned for the shifts in mean inflation shown in Graph 1. Generating the series, y_t, 10,000 times, the average value of the ADF test statistic assuming a constant and four lags is – 6.45 which indicates the series is a stationary process as expected. The first column of Table 1 reports the mean values of a first order autoregressive (AR(1)) model of the generated series, y_t, which indicates the lagged value of y_t is not significant as in the 'true' model of equation (2).

Now generate a second series, z_t, which is identical to, y_t, except for the addition of the seven shifts in mean inflation identified in the inflation data with the Bai-Perron technique:

$$z_t = ran(0, \sigma)_t + \mu_t^i \qquad (3)$$

where μ_t^i is the value of the mean rate of inflation in regime i. The series is again generated 10,000 times to obtain the average values of the statistics and parameters of the estimated models. The ADF test statistic of z_t with a constant and four lags is now -2.56 which leads us to not reject the null hypothesis of a unit root in z_t at the 5 per cent level of significance.

If we proceed to estimate an autoregressive model of the second generated series, z_t, we find that three lags of the series are individually and collectively significant and sum to 0.8275. The results are reported in the second column of Table 1. Finally, if we mistakenly interpret the results of the ADF test on z_t as evidence that the data is integrated we might proceed by taking the first difference of the data before estimating an AR(2) model of Δz_t.

[14] The random data is generated using WinRATS pro 6.2 with a 'seed value' of 171293.

Unfortunately, this re-parameterisation of the inflation data does not lead to the recovery of the ‘true’ underlying model of a random variable as the estimated model identifies two significant lagged values of Δz_t that sum to – 0.8522. This is reported in column 3 of Table 1. If we unravel the estimates from the AR(2) model of Δz_t to provide the implicit estimates of the AR(3) model of z_t we arrive at:

$$z_t = 0.4191 z_{t-1} + 0.3096 z_{t-2} + 0.2713 z_{t-3} + 0.0204$$

where the sum of the dynamic terms sum to 1 due to the restriction imposed by differencing the data. Importantly, this restriction does not account for the actual form of non-stationarity in the data and so does not lead to the identification of the ‘true’ underlying model of a random variable.

This simple Monte Carlo analysis demonstrates a number of the assertions from above. First, the Perron (1989) argument that shifts in mean may lead to the erroneous conclusion that the data is integrated and contains a unit root is valid. Second, the bias on the lagged dependent variables is substantial and upwards. In the AR(3) model of the generated series z_t the unaccounted shifts in mean have introduced a positive bias of 0.83 from the true value of zero. Third, taking the first difference of the data does not eliminate the bias in the estimates. Instead, the re-parameterisation of the model through differencing the data increases the bias to 1.00 from the true value of zero. Fourth, the standard diagnostics reported in Table 1 of the AR(3) model of z_t and the AR(2) model of Δz_t provide no indication that the modelling process itself is inappropriate. Consequently, an understanding of the likely biases involved in the modelling process must be drawn from the researcher’s broader knowledge of the data.

We might conclude, therefore, that the extensive empirical literature that examines the veracity of ‘modern’ Phillips curve theories by estimating the coefficients on the leads and lags in inflation in models based on equation (1) either directly or indirectly by differencing the data is invalid as the shifts in the mean rate of inflation are not explicitly accounted for. The estimates will be imprecise and biased towards accepting the hypothesis that the sum of the leads and lags in inflation is 1. Furthermore, once the shifts in mean are accounted for in the estimation process, the sum of the estimated coefficients on the dynamic inflation terms (i.e. the leads and lags of inflation) must be less than 1. If this is not the case then the inflation data remains non-stationary suggesting that the shifts in mean have not been properly accounted for in the estimation process.

Three propositions that follow from the discussion so far are considered in the next three sections. First, inflation is non-stationary. In the next section this proposition is established by considering what the implications are if the converse is true. That is, what are the implications if inflation is stationary with a constant mean? As the converse can be rejected as inconsistent with our understanding of the inflationary process we can conclude that inflation must be non-stationary. The second proposition is that estimating Phillips curve models without taking into account that inflation is non-stationary leads to biased estimates of δ_f and δ_b and, in turn, incorrect inferences concerning the underlying behaviour of economic agents. The final proposition is that the estimates of δ_f and δ_b in the Phillips curve literature are a direct result of estimating the models with non-stationary inflation data. In short, the empirical results published in the standard literature over the past thirty five years that do not account for the non-stationary properties of the inflation data are 'spurious' regressions.

Having demonstrated that the standard empirical results are due to unaccounted shifts in the mean rate of inflation, Section 5 estimates a Phillips curve model of United States inflation that allows for these shifts in mean. The data are separated into eight 'inflation regimes' where inflation is stationary with a constant mean in each regime. 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, time series panel techniques.[15] The estimated models allow the identification of individual short-run Phillips curves for each inflation regime and indirectly allow us to identify the long-run Phillips curve. Once the shifts in mean are accounted for, the panel estimates suggest that (i) there is no significant evidence that expected inflation as measured in the standard hybrid Phillips curve literature influences inflation; (ii) lagged inflation has a coefficient significantly less than 1 which is

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[15] I am thankful to Hassan Molana who suggested during a conversation concerning the identification of inflation regimes that, once inflation has been transformed into a stationary process with a constant mean in each inflation regime, panel data techniques are a valid estimation procedure.

inconsistent with the 'strict' adaptive expectations version of the Friedman – Phelps Phillips curve model of inflation; (iii) the long-run Phillips curve has a small and significant positive slope in line with the views expressed in Ross and Wachter (1973), Friedman's (1977) Nobel lecture, Akerlof, Perry and Dickens (1996, 2000) and Russell and Banerjee (2006); and (iv) there is evidence that the long-run curve is non-linear and becomes steeper with higher levels of mean inflation.[16]

2. Proposition One - Inflation is not stationary with a constant mean

There are few statements that we can be confident about in macroeconomics. One of them is that inflation over the past fifty years has not been stationary with a constant mean. Leaving aside evidence from unit root tests that are notoriously unreliable due to their low power, the statement logically follows by considering what the implications are if the converse of this statement is true. If inflation is stationary with a constant mean then there is a unique long-run rate of inflation and this would imply that:

(i) The question 'what is the long-run rate of inflation?' is valid. Furthermore, the answer must be invariant to whether you are standing in 1950, 1974, 1989, 1995 or 2008 and if you are looking into the future or into the past. A common method of estimating the long-run rate of inflation is to simply measure the mean rate of inflation over the sample under consideration. For the period March 1952 to September 2004, annualised United States CPI inflation had a mean of around 3 ¾ per cent compared with a mean of around 4 ¾ per cent since March 1970 and a mean of around 2 ½ per cent for the last ten years (see Graph 1). If there is a constant long-run rate of inflation then the obvious question is which data period provides the 'true' long-run rate of inflation. The usual response to this argument is to say there are 'breaks' in the inflation series in the 1970s, 1980s and 1990s. This response simply acknowledges that there have been shifts in the mean rate of inflation. That is, the long-run rate of inflation is not constant.

(ii) Institutional arrangements have no impact on the long-run rate of inflation. For example, the targeting of inflation, money or exchange rates, the level of independence of the

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[16] Akerlof *et al.* (1996, 2000) argues that at very low rates of inflation the long-run Phillips curve has a negative slope but at low to moderate rates the curve has a positive slope.

central bank, or the personalities of the governors of the central bank (i.e. Volker versus Greenspan versus Bernanke, or conservative versus expansionary central bankers) will have no effect on the constant long-run rate of inflation. Instead, these issues can at most influence how fast inflation returns to the long-run rate of inflation and not the long-run rate itself.

(iii) All the monetary economics and macroeconomics literature that describes the dynamics associated with changes in the long-run rate of money growth is irrelevant as only one growth rate of money is consistent with the long-run rate of inflation. Similarly the debate surrounding the optimum rate of inflation is meaningless if, in a practical sense, there is only one rate of inflation in the long run.[17]

(iv) The long-run Phillips curve in an applied sense is a single point as there is only one rate of inflation in the long run. There is also only one short-run Phillips curve as there is only one expected rate of inflation associated with the unique long-run rate of inflation. This means that economies with low inflation in the 1960s and 1990s are on the same short-run Phillips curve as during the high inflation of the 1970s and 1980s. Furthermore, given there is no change in the long-run rate of inflation then the original Phillips curve did not 'breakdown'. Therefore, the arguments of Friedman (1968) and Phelps' (1967) concerning the vertical long-run Phillips curve are not relevant on a practical level. Furthermore, Phillips' (1958) original arguments are valid in terms of a stable trade-off between inflation and the unemployment rate. Finally, any theoretical discussion of the dynamics that an economy will display during the transition between different long-run rates of inflation is meaningless as the economy cannot experience any change in the long-run rate of inflation.

Unless we are willing to accept what is implied by a constant long-run rate of inflation we must conclude that inflation does not have a constant mean. That is, inflation is non-stationary. If we further accept that inflation is not an integrated or trend stationary variable for the reasons given above then we must also conclude that inflation is stationary with shifting means.

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[17] See Friedman (1969) and Tobin (1972) as well as Braun (1994), Chari, Lawrence, Christiano and Kehoe (1996) and Feldstein (1999).

3. PROPOSITION TWO – THE STANDARD ESTIMATES ARE BIASED

To demonstrate that the estimates of the coefficients are biased and due to overlooked non-stationarity in the data we estimate the hybrid and F-P Phillips curve models over the sample March 1952 to September 2004 with two series of inflation data.[18] The first series is the actual inflation data and the second is the inflation data de-meaned for the shifts in mean inflation in each of the eight inflation regimes reported in Graph 1.

Estimating the Phillips curve models with actual and de-meaned inflation presents two possible outcomes. If the actual inflation data is stationary with a constant mean then the estimated coefficients on the inflation terms in the models estimated with actual and de-meaned inflation will be the same. De-meaning the inflation data will only affect the size of the constant. The second possible outcome is when the inflation data are stationary with shifting means. In this case, the models estimated with the de-meaned inflation data will provide unbiased estimates while the models estimated with the actual non-stationary inflation data will provide estimates where the sum of the coefficients on the explanatory inflation terms is biased towards 1.

The forcing variable, x_t, is the gap between the actual unemployment rate, U_t, and the potential unemployment rate, U_t^*, and is measured as the United States unemployment rate adjusted for a broken trend in June 1978.[19] To conform to the recent hybrid Phillips curve literature, the models are estimated using GMM with instruments of three lags of both inflation and the de-trended unemployment rate.[20] The hybrid Phillips curve encompasses both the F-P and NK models with a single lead and a single lag in inflation. The Friedman-Phelps model is estimated with three lags of inflation. In both models the number of lags of inflation is chosen by a 5 per cent *t* criterion.

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18 The New Keynesian model restricts $\delta_b = 0$ in the hybrid model. As this restriction is comprehensively rejected by the data the New Keynesian estimates are not reported so as to simplify the exposition.

19 The break in trend was identified using the Perron (1998) technique.

20 The results and conclusions presented here do not depend on GMM and are robust to any form of estimation technique including ordinary least squares and two stage least squares as long as the technique is only appropriate for stationary data with a constant mean.

The estimated hybrid and Friedman-Phelps (F-P) models using the actual inflation data are reported in Table 2 as models 1 and 2 respectively. The results are in line with estimates published in the literature and demonstrate that the sum of the estimates of δ_f and δ_b is insignificantly different from 1 in both models.[21] Estimates from the hybrid model also identify the dominant role played by expected inflation and the forward looking agents. However, note that the models are badly mis-specified in terms of serially correlated errors. In the F-P model, the sum of the lags of inflation is insignificantly different from 1.

The results of estimating the Phillips curve models with the de-meaned inflation data are reported in columns 3 and 4 in Table 2. In the hybrid model where the data can distinguish between the competing F-P and NK models, we now find no significant role for expected inflation and a coefficient on lagged inflation similar in size to that in the F-P model. As expected when estimating the F-P model with de-meaned data which is now stationary with a constant mean, the sum of the coefficients on lagged inflation is 0.53 and significantly less than 1. The F-P model now appears well specified while the hybrid model that incorporates the insignificant expected inflation remains badly mis-specified.

Note that the unemployment term in the hybrid model estimated with actual inflation is insignificant (Table 2, column 1). This is a common finding in the literature and motivates Gali and Gertler (1999) to substitute this term with labour's income share which they find significant. We do not replace the insignificant unemployment term as once we account for the shifts in the mean rate of inflation the unemployment term is significant with the expected sign in the Phillips curve models (Table 2, columns 3 and 4). It appears the stationary 'forcing' variable is insignificant because it is incapable of explaining the non-stationarity in the inflation data.

In summary, when the models are estimated with de-meaned data, expected inflation is insignificant in the hybrid model and both models comprehensively reject the hypothesis that $\delta_f + \delta_b = 1$. This is in contrast with the same models estimated with the actual non-stationary inflation data where expected inflation is significant and we accept $\delta_f + \delta_b = 1$.

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21 The results can be compared with those reported in Table 1 of Galí, *et. al.* (2005) or any of the hybrid

4. PROPOSITION THREE – THE STANDARD RESULTS ARE DUE TO SHIFTS IN MEAN INFLATION

In the previous section we show that the standard results of the 'modern' Phillips curve literature disappear if the shifts in the mean rate of inflation are accounted for in the data. Some observers may feel that the results are in some way due to how the inflation data were de-meaned. This section, therefore, undertakes the opposite experiment by making use of the 'mean-shift' inflation series z_t from equation (3).

The 'mean-shift' inflation series, z_t, is used as the explanatory inflation series in the Phillips curve models where the dependent variable remains actual inflation, such that:

$$\Delta p_t = \hat{\delta}_f \, E_t\left(z_{t+1}\right) + \hat{\delta}_b \, z_{t-1} + \hat{\delta}_U \left(U - U^*\right)_t + \omega_t \qquad (4)$$

Note that in equation (4), the only information contained in the explanatory variables that is relevant to explaining the dependent variable (which is actual inflation) is the shift in mean contained in z_t and the forcing variable, $\left(U - U^*\right)_t$. This model is again estimated 10,000 times using Monte Carlo techniques so as to recover the mean values of the estimates.

The mean values of the estimates from the hybrid and F-P versions of equation (4) are reported in Table 3 and are very similar to the estimates reported in the first two columns of Table 2. In the hybrid model, the estimated coefficient on expected inflation is 1.2751 (0.7055 in Table 2) and the coefficient on lagged inflation is insignificant and – 0.0927 compared with a significant estimate of 0.2946 in Table 2. The sum of the coefficients on the hybrid and F-P models are still insignificantly different from 1 (hybrid: 1.1824 compared with 1.0001 in Table 2 and F-P: 0.8993 compared with 0.9283 in Table 2).

This experiment points strongly to why expected inflation is a significant explanatory variable in the standard hybrid Phillips curve literature. The mean-shift inflation series contains no relevant information for explaining actual inflation other than the size and timing of the shifts in mean inflation. The hybrid model in column 1 of Table 3 shows that the coefficient on

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Phillips curve papers cited in Section 1.

expected inflation is insignificantly different from 1. This can only be due to the shifts in mean contained in the mean-shift inflation series. Simultaneously, the lag in inflation is insignificant. It appears that the estimation procedure explains the shift in the mean rate of actual inflation by the expected inflation term and not the lag in inflation. Having explained the actual shift in mean inflation, the mean-shift inflation data contains no further information and so the lag in mean-shift inflation is insignificant. One might hypothesise that if the lag in inflation did contain some relevant information concerning actual inflation then the lag in inflation would also be significant in the hybrid model. If correct then this hypothesis implies that in the standard empirical hybrid Phillips curve literature, expected inflation is significant (and large) due to the unaccounted shifts in mean inflation while lagged inflation is significant (and small) due to the information content of the inflation data other than the shifts in mean inflation.

It appears, therefore, that the shifts in mean alone generate results very similar to those in the standard literature. Furthermore, if the shifts in mean are accounted for in the estimation processes then the standard results (i.e. $\delta_b = 1$ in the F-P model; $\delta_f + \delta_b = 1$ and $\delta_f > \delta_b$ in the hybrid model) disappear. We may conclude, therefore, that the results reported in the modern Phillips curve literature are dominated by, and are as a direct result of, the shifts in the mean rate of inflation that are not accounted for in the estimation of the models.

5. PANEL ESTIMATES OF UNITED STATES PHILLIPS CURVES

Having demonstrated that the standard estimation techniques are inappropriate for estimating Phillips curves when inflation is non-stationary, we now proceed to estimate short and long-run Phillips curves assuming explicitly that inflation is stationary with shifting means. Based on this assumption, we separate the data into the eight inflation regimes already identified using the Bai-Perron technique. We then organise the data as time series of eight individual inflation regimes. As the data are stationary with a constant mean in each regime by construction this allows us to analyse the data using standard unbalanced panel estimation techniques to simultaneously estimate the short-run Phillips curves for each of the inflation regimes.

In the model that we wish to estimate, the number of inflation regimes, *n*, is small (in our case

8) and the number of time periods, *t*, is large relative to *n* and the regimes are unbalanced. Furthermore, although there is a time dimension within each regime, the time periods are not aligned across regimes. As such, the model does not conform neatly to the usual estimation of macroeconomic panel data.[22] However, two broad estimators of the model present themselves. The random effects estimator assumes the coefficients of the model are not fixed parameters to be estimated but random parameters from a distribution which is mean zero and constant variance. Important assumptions are that the random effects are uncorrelated with the other explanators and that the inflation rate is a random draw from a distribution which is common across regimes. With the inflation regimes defined by different mean rates of inflation the distributions of the regimes are not common by construction. Therefore, the random effects model is conceptually inappropriate.[23]

The fixed effects estimator accounts for the different mean rates of inflation across regimes by introducing a constant for each regime. This estimator is sometimes referred to as the 'within estimator' for it uses the within regime, and not the between regime, variance in the data. There are therefore as many constants as regimes and as the number of regimes increase relative to the number of time periods there is a loss of efficiency as we only have *t* observations to estimate the *n* constants. As the fixed effects in the model have a straightforward economic interpretation and the number of regimes is small we present the fixed effects estimates below.

The panel fixed effects specification of the hybrid Phillips curve model of equation (1) can be written;

$$\Delta p_t^i = \phi^i + \phi_f \, E_t^i \left(\Delta p_{t+1}^i\right) + \phi_b \, \Delta p_{t-1}^i + \phi_U \, U_t^i + \eta_t^i \qquad (5)$$

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

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[22] See Smith and Fuertes (2003) for an excellent introduction to time series panel estimation and Baltagi (2001) and Hsiao (2003) for more detailed studies.

[23] The random effects model is also strongly rejected by the data.

regimes.[24] The hypothesis that the coefficients ϕ_f, ϕ_b and ϕ_U are the same across regimes cannot be rejected by the data leading to the restricted model in equation (5) (see the notes to Table 5).

Panel estimation of Phillips curve models allows us to:

(i) Estimate the constants, ϕ^i, or fixed effects, that allow for different mean rates of inflation in each inflation regime;

(ii) Estimate the coefficients on expected, ϕ_f, and lagged inflation, ϕ_b, to examine the veracity and size of the forward and backward looking behaviour of agents;

(iii) Estimate the short-run Phillips curve for each of the eight inflation regimes; and

(iv) Calculate the implied long-run rate of unemployment for each inflation regime where long-run inflation is assumed equal to the mean rate of inflation for that regime.

There is a large literature on the biases in estimating dynamic panels when *t* is small relative to a large *i*.[25] The problem is that an unmodelled shock to inflation in one period will simultaneously affect the estimated constant (i.e. the fixed effect) and the estimated error which violates one of the assumptions of the fixed effects modelling procedure.[26] However, as the number of time periods increase for a given number of individuals the correlation between the fixed effect and error term declines as the shocks average out over time and any individual shock has only 1/*t*-1 impact on the estimated constant.[27]

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24 Conceptually this assumption is likely to hold as the time periods are not aligned across inflation regimes.

25 For example, see Arellano and Bond (1991), Arellano and Bover (1995), Blundell and Bond (1998) and Bond (2002).

26 See Nickell (1981).

27 One way to overcome the problem of 'dynamic panel bias' when *t* is very small is to difference the data so as to eliminate ϕ^i from equation (6). See the references cited in footnote 25. Estimating the model with the Arellano-Bond estimator does not affect the results in an economic or quantitative sense.

An important question for our purposes is when does *t* become 'large'? A 'rule-of-thumb' is that *t* is large when it is sensible (in terms of degrees of freedom) to estimate individual equations for each regimes. In our case the regimes are unbalanced with most of the regimes consistent with this rule but some of the shorter inflation regimes are not. However, we proceed to estimate the fixed effects model using all inflation regimes and note that very similar results are obtained by estimating the model with only the longer inflation regimes. This issue is returned to at the end of Section 5.1.

Finally, it is likely that inflation and the unemployment rate are determined simultaneously and so the contemporaneous unemployment rate is endogenous and not weakly exogenous in the estimated model. Furthermore, our measure of expected inflation suggests it will be correlated with the error term. We address these problems by estimating the fixed effects model using two stage least squares (2SLS) where the instruments are two lags of inflation and the unemployment rate.

5.1 Panel estimates of the United States Phillips curve

Reorganising the data as an unbalanced time series panel does not in itself affect the standard results of the Phillips curve literature. This is easily demonstrated by estimating equation (5) with the constant, ϕ^i, restricted to be the same across all eight inflation regimes. This is equivalent to estimating the model assuming the mean rate of inflation is the same for each inflation regime as in the standard empirical literature. Two stage least squares estimates of the hybrid and Friedman-Phelps Phillips curve models with the restricted constant are provided in Table 4. Note the results are very similar to those reported for the respective models in the first two columns of Table 2 and in the standard Phillips curve literature. For the hybrid model, the sum of the estimated coefficients on the lead and lag of inflation is insignificantly different to 1 ($\phi_f + \phi_b = 0.9693$) and that there is a significant role for both forward and backward looking agents. For the F-P model the sum of the estimated coefficients on the three lags in inflation is also insignificantly different from 1 ($\sum \phi_b = 0.9810$).

Two stage least squares panel estimates of the fixed effects hybrid model are reported in column 1 of Table 5. A further lag in inflation and the unemployment rate are insignificant.[28] As with the de-meaned data in Section 3 we are unable to identify a significant role for expected inflation in the inflationary process and the sum of the estimated coefficients on the inflation terms is 0.4736 which is significantly less than 1.

Excluding the insignificant expected inflation term, the estimated Friedman-Phelps model is reported in column 2 of Table 5. Further lags in inflation and the unemployment rate remain insignificant.[29] The estimated coefficient on lagged inflation is now 0.3323 which remains significantly less than 1. The unemployment rate is significant and negative with a value of - 0.3159. These estimates are similar to the F-P estimates using the demeaned inflation data of 0.5302 and – 0.3259 respectively (see Table 2, column 4) and suggest that the short-run Phillips curve for each inflation regime has a significant negative slope as we might expect.

The Bai-Perron technique results in two regimes (numbers 4 and 5 identified in Appendix 2) being defined by the minimum quarters constraint in the estimation of the inflation regimes. Consequently the means of the data in these two regimes may not be constant in a statistical sense. To examine whether these two regimes are in some way 'driving' the results reported in Table 5, the models were re-estimated with these two regimes excluded. The results are not affected in any meaningful way. In the hybrid model, expected inflation remains insignificant and both the sum of the dynamic inflation terms, $\phi_f + \phi_b = 0.4929$, and lagged inflation, $\phi_b = 0.3133$, are significantly less than 1. In the F-P model the coefficient on lagged inflation is significantly less than 1, $\phi_b = 0.3133$, and the unemployment rate is significant and negative, $\phi_U = -0.3135$. The results are very similar to those reported in Table 5 in terms of estimated coefficients and the diagnostics of the model.

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28 Liklihood ratio omitted variable tests reject the inclusion of Δp^i_{t-2}, $F_{(1, 175)}$ = 0.7902, prob-value = 0.3753 and U^i_{t-1}, $F_{(1, 175)}$ = 0.9063, prob-value = 0.3424.

29 Liklihood ratio omitted variable tests reject the inclusion of Δp^i_{t-2}, $F_{(1, 184)}$ = 0.0376, prob-value = 0.8465 and U^i_{t-1}, $F_{(1, 184)}$ = 1.0309, prob-value = 0.3113.

5.2 Calculating the Implicit Long-run Phillips curve

Assuming that the long-run rate of inflation is equal to the mean rate of inflation in each regime, $\overline{\Delta p}^{i}$, the implied long-run unemployment rate for inflation regime *i*, $\tilde{U}^{i}$, can be calculated from the estimates of equation (5) as:

$$\tilde{U}^{i} = \frac{1}{\phi_U}\left[\overline{\Delta p}^{i}\left(1 - \phi_f - \phi_b\right) - \phi^{i}\right] \tag{6}$$

If the implicit long-run unemployment rates from each inflation regime lie on the long-run Phillips curve then the locus of eight combinations of long-run rates of inflation and unemployment will loosely identify the long-run Phillips curve. This allows us to examine whether or not the long-run Phillips curve is vertical as in the strict versions of the 'modern' Phillips curve theories or displays a negative or positive slope. We may also be able to observe any non-linearity in the long-run Phillips curve.

The standard approach to testing the slope of the long-run Phillips curve assumes a null hypothesis that the curve is vertical (i.e. test if $\phi_f + \phi_b = 1$ in equation 1). Given the bias and imprecision of the estimation techniques involved the null hypothesis is usually accepted. Leaving aside the estimates are biased, the imprecision in the estimates mean that if the standard null hypothesis is accepted then it is likely that $\phi_f + \phi_b$ will also be insignificantly different from alternative null hypotheses, such as, 0.9 or 1.1. These alternative null hypotheses lead to very different conclusions concerning the slope of the long-run Phillips curve in the standard literature. The standard null hypothesis is therefore an *a priori* restriction on the empirical examination of the slope of the long-run Phillips curve - a restriction that is avoided by calculating the long-run Phillips curve from the panel estimates.

Using the implicit long-run unemployment rates and the mean rates of inflation in each regime, ordinary least squares (OLS) estimates of linear and quadratic long-run Phillips curves are provided in the top portion of Table 6. Based on the adjusted $\overline{R}^2$ criteria and that the 'true' long-run Phillips curve cannot be linear if it has a slope, the non-linear model appears a better description of the long-run Phillips curve.[30]

The estimated linear and non-linear long-run Phillips curves in the top portion of Table 6 suggest the long-run relationship has a small positive slope. Higher mean rates of inflation are associated with higher long-run rates of unemployment. However, having identified a positive slope to the long-run Phillips curve, an important question is whether or not the long-run curve is vertical? As these curves are long-run in nature, causation between the variables is less important. Consequently, it is equally valid to estimate the long-run relationship with the unemployment rate as the dependent variable and inflation as the independent variable. The OLS linear and quadratic estimates of the long-run Phillips curve with unemployment as the dependent variable are reported in the lower portion of Table 6.

The advantage of specifying the long-run Phillips curve in this way is that if the curve is vertical as in the standard literature then it is horizontal when the unemployment rate is the dependent variable. The test of a vertical long-run Phillips curve in the standard literature is equivalent to testing whether or not the independent long-run inflation terms are insignificantly different from zero. Tests of this restriction are reported in the lower portion of Table 6 and are strongly rejected by the data suggesting that the long-run Phillips curve in the standard sense has a significant positive slope.

The long-run estimates reported in Table 6 can be compared with those of Russell and Banerjee (2006). They also argue that the 'true' statistical process of inflation is stationary with frequent shifts in mean but that this can be approximated by an integrated process. Using the same data as in this paper they estimate the long-run (in the sense of Engle and Granger 1987) United States Phillips curve as $\Delta p_t = \delta_1 + 2.714U_t$ which displays a very similar positive slope to the linear long-run Phillips curve derived from the panel estimates and reported in Table 6 of $\Delta p_t = \delta_2 + 2.1190U_t$.

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[30] If the long-run Phillips curve is linear and not vertical then as mean inflation increases the rate of unemployment would eventually become negative with a negative slope or greater than 1 with a positive slope. Both outcomes are outside the possible range for measures of the unemployment rate. Therefore the 'true' long-run Phillips curve cannot be linear over the full range of inflation if the long-run curve is not vertical. However, over the range of inflation experienced by the United States (and other developed economies) over the past fifty years the long-run Phillips curve may be approximately linear.

It appears, therefore, that what is important when identifying the long-run Phillips curve is to first recognise that the data are non-stationary and then estimate the long-run Phillip curve in such a way that it does not bias the estimates nor impose invalid restriction on the data. An example of the former is estimating the models without accounting for the shifts in the mean rate of inflation. An example of the latter is differencing the inflation data in response to an erroneous belief that the data is integrated.

5.3 A visual representation of the short and long-run Phillips Curves

Graph 2 provides a visual representation of the panel estimates of the F-P Phillips curve model of equation (5) reported in column 2 of Table 5. The thin negatively sloped lines marked SRPC 1 to SRPC 8 are the estimated short-run Phillips curves for each of the eight inflation regimes once the short-run inflation dynamics are accounted for. Each short-run curve is drawn for the observed range of unemployment rates in that particular inflation regime. Also shown on the graph are the actual combinations of inflation and the unemployment rate for the eight inflation regimes with the data from each regime represented by a different symbol. Shown as large crosses on the graph are the combinations of the implicit long-run rates of unemployment and the mean rate of inflation for each inflation regime. The solid line with a positive slope labelled LRPC is the OLS estimate of the non-linear long-run Phillips curve reported in Table 6.

Note that the implicit long-run rates of unemployment are not simply the mean rates of unemployment for each inflation regime. Instead, the implied long-run unemployment rates lie towards, or beyond, the end of the observed short-run curves in most regimes. In cases where mean inflation is increasing (i.e. regimes 3, 4, and 6) the implied long-run unemployment rate is towards the right hand end of the short-run Phillips curve and towards the left hand end when mean inflation is shifting down (regimes 5, 7, and 8). This is exactly as predicted in modern theories of the Phillips curve since Friedman and Phelps.

6. EXPLANATIONS OF THE POSITIVE SLOPE TO THE LONG-RUN PHILLIPS CURVE

That the long-run Phillips curve has a positive slope may unsettle some observers who might argue that the finding simply reflects the simultaneous impact of supply shocks on both inflation and unemployment. Supply shocks, such as the OPEC oil price increases in the

1970s, simultaneously increase both inflation and the rate of unemployment leading to a positive correlation between the variables. This is a persuasive argument for a short-run positive relationship. However, in the long run the series differ in an important way. Increases in unemployment are likely to be highly persistent due to lags in retraining, the low mobility of workers, and the slow adaptation of capital to the new 'post-shock' economic environment. This is in stark contrast with the impact of supply shocks on inflation which should be short-term and transitory in an economy such as the United States where there are few or no price controls. Consequently, the supply shocks may introduce a positive bias in the estimates of the short-run Phillips curve but not in the estimates of the long-run Phillips curve.

In contrast with the false long-run correlation implied by the supply shocks argument, a number of authors argue explicitly that the long-run Phillips curve has a positive slope over some, if not all, of the range of inflation. Ross and Wachter (1973) develop a model that includes a non-competitive sector where prices are administered and non-clearing. This sector is modelled as an informal cartel where prices are fixed over a given planning horizon and firms believe that the costs associated with queuing customers are greater than the costs of queuing workers. Consequently, the non-competitive sector pays a wage premium to induce workers to queue for employment. In this model an increase in the rate of inflation initially causes the average real wage and the queue of workers to fall over the planning horizon. However, firms respond at the end of the planning horizon when they adjust prices and wages by increasing the real wage so as to again lengthen the queue of workers. The higher real wage implies the rate of unemployment is higher in the long run. The authors admit that this may not describe a 'true' long-run equilibrium as the institutional details of the model are unlikely to be invariant to the rate of inflation in the long run. In particular, the fixed planning horizon in the model may adjust in the long run in response to changes in the mean rate of inflation.

Friedman's (1977) Nobel lecture in part focuses on some of the institutional details. Friedman begins by arguing that there are three conditions for there to be a unique natural rate of unemployment and a vertical long-run Phillips curve. First, the variability of inflation at high and low mean rates of inflation needs to be the same. Second, there are no impediments to the adjustment of prices. And third, contracts are fully indexed. Friedman argues that these conditions are not met when there is an increase in mean inflation because economic agents find it difficult to adjust to the associated new institutional and political arrangements. This difficulty results in the long-run Phillips curve appearing to have a positive slope that may persist for many decades. However, in what Friedman calls the 'long-long-run' the three conditions are met and the Phillips curve is again vertical.

On some levels this explanation appears convincing. However, if agents are as sophisticated and rich in information as postulated by Friedman in his model it seems inconceivable that firms take many decades to adjust to the new institutional arrangements. Furthermore, since the 1950s we have not observed periods where inflation has displayed a constant mean for many decades. This suggests that agents in the 'real world' may never come to understand the 'true' institutional arrangements and therefore it is unlikely that Friedman's three conditions are ever met. Consequently, Friedman may be right in his 'long-long-run' but may have little opportunity to demonstrate the empirical relevance of the argument due to the lack of suitable data.

Akerlof *et al.* (2000) develops a model based on the psychological literature of decision making where the long-run Phillips curve has a positive slope over some range of inflation rates.[31] The price setting model incorporates a group of 'near rational' firms who do not base their actions on an unbiased forecast of inflation. At very low rates of inflation the cost of departing from fully rational behaviour is small. However, as inflation increases the cost of the departure also increases and the proportion of near-rational firms declines. As a result, a small increase in inflation when inflation rates are very low leads to lower rates of unemployment and a negative slope to the long-run Phillips curve. As more and more firms become fully rational with increasing inflation there is some threshold where the long-run rate of unemployment begins to rise and the long-run Phillips curve has a positive slope. Finally above some high rate of inflation all firms are fully rational and the long-run Phillips curve is vertical.

The Akerlof *et al.* (2000) explanation of a positive slope to the long-run Phillips curve also appears convincing. The long-run Phillips curve they estimate using annualised percentage

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[31] See Akerlof *et al.* (2000) for details of the relevant psychological literature.

change in the CPI (as also used in this paper) has the inflection between the negative and positive sloping portions of the long-run Phillips curve at an inflation rate of around 3 ½ per cent and the curve is vertical above an inflation rate of about 7 per cent.

However, the empirical work in Akerlof *et al.* (2000) proceeds without adequately allowing for the non-stationary properties of inflation and, in particular, that inflation is most likely stationary with shifting means.[32] The estimates are therefore biased and unreliable but can be compared with those presented in Graph 2 where the non-linear long-run Phillips curve does not approach the vertical until slightly above 10 per cent inflation and there is no evidence of a negative long-run Phillips curve at very low rates of inflation. The lack of evidence supporting the negative sloping portion of the long-run Phillips curve may simply be due to the data not containing sufficiently low rates of inflation.

A further explanation of the positive slope to the long-run Phillips curve can be drawn from Russell (1998), Russell, Evans and Preston (2002) and Chen and Russell (2002). These papers develop models of non-colluding price setting firms with missing information. All three papers focus on different aspects of the missing information and predict a negative relationship between inflation and the markup. Importantly, it is argued that the missing information is not of a type that can be discovered in the long run and, therefore, the negative relationship will persist in the long run.[33] The negative long-run inflation-markup relationship implies that higher mean rates of inflation are associated with high real wages relative to productivity. Consequently, if unemployment is positively related to the real wage relative to productivity then higher inflation will lead to higher rates of unemployment and a positive slope to the long-run Phillips curve.

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32 Akerlof *et al.* (2000) estimates $\pi_t = d + \Phi\left(D + E\pi_{Lt}^2\right)\pi_t^e - eu_t + gX_t + \varepsilon_t$ (equation 17, page 29), where π_t is the rate of inflation, Φ is the cumulative standard normal density function, π_L represents the effects of past inflation on the likelihood that firms are rational in terms of inflation, π^e is inflationary expectations, u is a measure of current and lagged unemployment rates, and d, D, e, and g are unconstrained parameters that provide indirect estimates of the long-run Phillips curve. As the shifts in mean inflation contained in π_t, π_L, and π^e are not accounted for in the estimation procedure the estimates of the parameters will be biased and most likely imprecise.

33 Banerjee, Cockerell and Russell (2001), and Banerjee and Russell (2001a, 2001b, 2004, 2005) identify a negative long-run relationship in the Engle and Granger (1987) sense between inflation and the markup of

7. IMPLICATIONS AND CONCLUSION

This paper argues that it is legitimate to model inflation as a stationary process with shifting means. Once the shifts in mean inflation are accounted for in the estimation process, the standard results of the modern empirical Phillips curve literature of the last thirty five years disappear. In particular, (i) there is no significant role for expected inflation as commonly measured in the hybrid model (see column 3 of Table 2 and column 1 of Table 5); (ii) the sum of the coefficients on lagged inflation is significantly less than 1 by a wide margin in the Friedman-Phelps expectations model (see column 4 of Table 2 and column 2 of Table 5); and (iii) we can identify a small and significant positive slope to the long-run Phillips curve. It appears from the empirical analysis above that the standard results of the modern Phillips curve literature are due to a combination of ignoring the non-stationary properties of the inflation data and the use of inappropriate estimation techniques. One might conclude, therefore, that the standard Phillips curve estimates are 'spurious' in the sense of Granger and Newbold (1974) and Perron (1989).

In the standard Phillips curve literature, finding the sum of the estimated coefficients on the dynamic inflation terms equal 1 is taken as important evidence that the underlying behavioural theories are correct and that the long-run Phillips curve is vertical. The behavioural emphasis on the estimated coefficients on the dynamic inflation terms is entirely misplaced. For example, the hybrid Phillips curve papers of Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001) use the estimates of δ_f and δ_b in equation (1) to choose between the competing Phillips curve models on the basis of the veracity of the different underlying behavioural assumptions of each model. If the size of the estimated coefficients is due to the important 'model-defining' behaviour of economic agents then this behaviour should not only be present over the whole sample but also during all sub-samples. In other words, if the behaviour is present and stable then the estimated individual coefficients should be stable and sum to 1. With inflation stationary with shifting means over the past fifty years as argued here then estimates of the sum of δ_f and δ_b are likely to be insignificantly different from 1. However, within each stationary episode (or inflation regime) where the

prices on unit labour costs. The 'robustness' of the estimates is demonstrated for a range of developed economies over different sample periods and levels of aggregation.

mean in constant, we know that the sum of the estimated coefficients, $\delta_f + \delta_b$, must be less than 1.[34] Therefore, the estimates of δ_f and δ_b must be unstable when inflation is stationary with shifting means and therefore do not have a behavioural interpretation unless we accept the underlying behaviour of the models is similarly unstable.

The standard literature interprets a finding of $\delta_f + \delta_b = 1$ in equation (1) as evidence that the long-run Phillips curve is vertical. This interpretation is similarly misplaced. Consider three possible statistical processes for inflation and the forcing variable. First, if inflation is an integrated variable and the forcing variable is stationary with a constant mean then the standard interpretation would be correct.[35] However, while it may at times be useful to model inflation as an integrated variable it cannot by truly integrated due to the apparent upper and lower bounds to inflation. Second, if both the forcing variable and inflation are stationary with constant means then in the long-run both variables attain their respective unique mean values. Furthermore, $\delta_f + \delta_b$ must be less than one and the data can only identify one long-run combination of inflation and the unemployment rate. Equation (1) would then be estimating one short-run Phillips curve associated with one long-run rate of inflation and one expected rate of inflation. The data in this case does not contain any information concerning different long-run rates of inflation and therefore cannot identify the long-run Phillips curve even if it is vertical in a world with changing mean rates of inflation.[36]

The third alternative is when inflation is stationary with large and frequent shifts in mean. In this case $\delta_f + \delta_b = 1$ irrespective of whether or not there is a long-run relationship between inflation and the forcing variable. To examine the slope of the long-run Phillips curve one needs to calculate the long-run value of the forcing variable for each and every long-run, or

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34 Akerlof *et al.* (2000), Brainard and Perry (2000) and Russell and Banerjee (2006) use three different approaches to demonstrate the instability of the estimated dynamic inflation terms in the Phillips curve model using United States data.

35 This can be explained in two inter-related ways. First, there can be no long-run relationship (in the sense of Engle and Granger 1987) between an integrated variable and the forcing variable if the later is stationary with a constant mean. Second, in the long-run the forcing variable will attain its constant mean but if inflation is integrated it has a non-constant mean and so no relationship between the variables is possible in the long run.

36 The irony is that the popular estimation techniques are now valid but the long-run Phillips curve cannot be identified.

mean, rate of inflation. This requires us to first estimate the short-run Phillips curve associated with each long-run rate of inflation and then use these estimates to calculate a single long-run value of the forcing variable for each of the estimated short-run Phillips curves.

The panel estimates in Section 5 provide such estimates of the eight short-run Phillips curves associated with the eight mean (or long-run) rates of inflation that have been identified in the data. From these estimates the long-run values for the unemployment rate are calculated and combinations of the long-run rates of inflation and unemployment are used to identify the slope of the long-run Phillips curve. Estimates of the long-run Phillips curve derived in this way are reported in Table 6 and shown in Graph 2. These estimates suggest that the long-run Phillips curve has a significant and important positive slope where higher mean rates of inflation are associated with higher long-run rates of unemployment. Furthermore, there is evidence that the long-run curve is not linear and becomes steeper with higher mean rates of inflation.

Therefore, the finding that $\delta_f + \delta_b = 1$ in the standard Phillips curve literature should not be interpreted as evidence that the long-run Phillips curve is vertical nor validation of the proposed underlying behavioural theories. Instead the finding should alert the researcher that (i) the inflation data is non-stationary; (ii) the estimation technique is inappropriate; and (iii) the estimates are biased and imprecise.

The analysis above raises a number of questions. First, is the estimated slope of the long-run Phillips curve important? The estimated non-linear long-run Phillips curve (as shown in Graph 2 and Table 6) suggests that the increase in mean inflation during the 1970s from around 4 ½ to 11 per cent per annum was associated with an increase in the long-run rate of unemployment of around 2 ½ percentage points. Shifts in unemployment of this magnitude for moderate increases in inflation would appear to be important in both economic and social senses.

Second, are these empirical results in some way dependent on how the Bai-Perron technique identified the eight inflation regimes? Consider the case where the ‘true’ number and dates of the inflation regimes differ from those identified using the Bai-Perron technique. The identified inflation regimes used here will then contain some residual non-stationarity and there will be an upward bias in the estimates of δ_f and δ_b. As the Bai-Perron technique is unlikely to have identified the 'true' number and dates of the inflation regimes we might conclude that the estimates provided above of δ_f, δ_b and $\delta_f + \delta_b$ are the upper bounds of estimates based on the 'true' inflation regimes. Therefore, finding that (i) expected inflation plays no significant role in the inflation dynamics; (ii) δ_b is significantly less than 1; and (iii) $\delta_f + \delta_b$ is significantly less than 1 are not the result of incorrect identification of the inflation regimes by the Bai-Perron technique. Instead, given the Bai-Perron technique is unlikely to have identified the inflation regimes exactly, this technique makes it more (rather than less) difficult to overturn the standard results of the empirical Phillips curve literature which has been shown here to rely on some non-stationarity in the data.

Third, are these results inconsistent with the modern theories of the Phillips curve? The answer is yes and no. The yes answer is in the following sense. Consider a period when inflation is stationary with a constant mean such as since the early 1990s in the United States. The strict interpretation of the modern theories requires that $\delta_f + \delta_b$ always equals 1 in equation (1). This conflicts with the initial assumption that we are considering a period when inflation is stationary with a constant mean which means, by definition, that $\delta_f + \delta_b < 1$. When inflation has a constant mean it appears that agents cannot conform to the Friedman-Phelps, New Keynesian or hybrid theories of the Phillips curve.

However, when there is an increase in mean inflation it does appear from the estimates reported above that economic agents adjust their expectations so that the short-run Phillips curve shifts upwards. Further empirical analysis is required to answer the difficult question of how agents adjust expectations in response to shifts in the mean rate of inflation. This upward shift may be associated with forward and/or backward looking behaviour of agents. But it is a heroic and very narrow assumption that all agents behave in only one way as in the Friedman-Phelps and new Keynesian models or in only one of two ways as in the hybrid model. It may well be that agents indulge in a variety of ways to adjust prices and their behaviour depends in part on the economic environment. In an important sense, the results reported above open the way for a richer modelling of how agents actually adjust prices.

Finally, is the original Friedman-Phelps insight of a vertical long-run Phillips curve correct? The answer is ‘yes’ to a first approximation. If the long-run Phillips curve is non-linear as argued above and shown in Graph 2 then over the range of inflation from zero to infinity the long-run Phillips curve is vertical to a first approximation. However, over the smaller range of inflation experienced by the United States over the past fifty years there appears to be a significant positive slope to the long-run curve. Consequently, the Friedman-Phelps insight is only approximately true and this paper empirically demonstrates that the second order of the approximation appears to be both significant and economically important at the low to medium rates of inflation experienced by the United States over the past fifty years.

8. REFERENCES

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APPENDIX 1 THE DATA

The consumer price index (CPI) and unemployment rate data are seasonally adjusted and obtained directly from the United States of America, Bureau of Labour Studies (BLS). The monthly data for the period March 1952 to November 2004 was downloaded on 25 November 2004. The quarterly data is the average of the monthly data. The mnemonics in Table A1 are those from the BLS database.

Table A1: Sources and details of the data manipulation

CPI inflation: The monthly CPI is the US city average, all items, 1982-84=100, ID: CUSSR0000SA0. CPI inflation is the change in the natural logarithm of the quarterly CPI multiplied by 400 to give the annualised rate.

Unemployment rate: The unemployment rate is the number of people over 16 years of age as a percentage of the non-institutionalised civilian population, ID: LNS14000000.

The unemployment rate appears to have an increasing linear trend up to the middle to late 1970s and then a slight declining linear trend thereafter. Perron (1998) unit root test confirms this and identifies a shift in the constant and break in trend in June 1978. The de-trended unemployment rate, $\left(U - U^*\right)_t$, is obtained by regressing the unemployment rate on a constant, a 'shift' dummy for June 1978 to September 2004, trend, a truncated trend that is zero up to and including March 1978 and then increasing in unit steps between June 1978 and September 2004, and a 'spike' dummy for June 1978.

APPENDIX 2 IDENTIFYING THE SHIFTS IN THE MEAN RATE OF INFLATION

The Bai and Perron (1998, 2003a, 2003b) technique 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:

$$\Delta p_t = \gamma_{k+1} + \tau_t \tag{A2.1}$$

where Δp_t is United States CPI 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 final model is chosen using the Bayesian Information Criterion. The model is estimated using quarterly data for the period March 1952 to September 2004. The results of the estimated model 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 written in Gauss was kindly made available by Pierre Perron on his personal internet site.

Table A2: Estimated Inflation 'Regimes' using the Bai-Perion Technique

	Variable	*Dates of the 'Inflation Regimes'*	*Estimate*	*Standard Error*	*t-Value*
1	γ_1	March 1952 to September 1955	0.001040	0.000894	1.2
2	γ_2	December 1955 to December 1966	0.004687	0.000533	8.8
3	γ_3	March 1967 to September 1972	0.011323	0.000746	15.2
4	γ_4	December 1972 to March 1975	0.023194	0.001131	20.5
5	γ_5	June 1975 to September 1977	0.014975	0.001131	13.2
6	γ_6	December 1977 to March 1981	0.027216	0.000956	28.5
7	γ_7	June 1981 to June 1990	0.010038	0.000588	17.1
8	γ_8	September 1990 to September 2004	0.006329	0.000482	13.1

Table 1: Monte Carlo Analysis of Shifts in the Mean of a Variable

	1	2	3	
	No Shifts in Mean	**Shifts in Mean**	**Differenced Data**	
Dependent Variable ⇨	y_t	z_t		Δz_t
y_{t-1}	- 0.0047 (- 0.1)	0.3585 (5.0)	Δz_{t-1}	- 0.5809 (- 8.2)
y_{t-2}		0.2556 (3.6)	Δz_{t-2}	- 0.2713 (- 4.0)
y_{t-3}		0.2134 (3.1)		
Constant	-0.0007 (- 0.0)	0.6703 (2.8)	Constant	0.0204 (0.1)
$\overline{R}^2$	0.00	0.54	$\overline{R}^2$	0.26
LM(4)	0.5131	0.1859	LM(4)	0.0606
DW	1.99	2.04	DW	2.08
ADF_R	- 6.46	- 6.57	ADF_R	- 7.69
$\sum_{i=1}^{3} y_{t-i}$		0.8275 {0.0588}	$\sum_{i=1}^{2} \Delta z_{t-i}$	- 0.8522 {0.1200}

This table reports autoregressive models of the data generated in line with equations (2) and (3) in the paper. Monte Carlo techniques were employed to generate 10,000 data series of 211 observations (equivalent to the actual data sample) and the mean values of the estimated coefficients and statistics are shown in the table. The distributions of these estimated coefficients and statistics are uni-modal and largely un-skewed. If the median values of the estimated coefficients and statistics were reported (instead of the means) the results are very similar and the inference of the analysis is unaffected. The models are estimated with ordinary least squares estimator and further lags of the independent variables are excluded on a 5% *t*-criterion. Models estimated with WinRATS pro 6.2 with a seed value of 171193.

Reported as ( ) and { } are the t-statistics and standard errors respectively. Reported as LM(4) is the significance of the fourth order autocorrelation Lagrange multiplier test statistic of the residuals, 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. The Δ symbol represents the lag difference such that $\Delta z_t = z_t - z_{t-1}$.

Table 2: Demonstrating Proposition Two

Model ⇒ Independent Variable ⇓	Actual Inflation Data		De-meaned Inflation Data	
	1	**2**	**3**	**4**
	Hybrid	**F-P**	**Hybrid**	**F-P**
Δp_{t+1}	0.7055 (7.1)		- 0.0209 (- 0.1)	
Δp_{t-1}	0.2946 (3.6)	0.5217 (7.6)	0.4721 (6.1)	0.4374 (6.1)
Δp_{t-2}		0.0333 (0.4)		- 0.0895 (- 1.2))
Δp_{t-3}		0.3733 (5.2)		0.1823 (2.4)
$\left(U - U^*\right)_t$	- 0.0238 (- 0.4)	- 0.4458 (- 4.5)	- 0.2906 (- 2.0)	- 0.3259 (- 4.0)
Constant	- 0.0305 (- 0.3)	0.2739 (1.7)	0.0018 (0.0)	- 0.0073 (- 0.1))
Sum of Dynamic Inflation Terms	1.0001 {0.0303}	0.9283 {0.0440}	0.4512 {0.3013}	0.5302 {0.0787}
$\overline{R}^2$	0.79	0.78	0.19	0.23
S.E.E	1.3952	1.4322	1.4768	1.4363
J-Test probability	[0.0060]	[0.0013]	[0.1221]	[0.2361]
LM(1) test probability	[0.0000]	[0.0253]	[0.0000]	[0.2128]
LM(4) test probability	[0.0000]	[0.2570]	[0.0000]	[0.1285]
ADF test residuals	- 8.2	- 5.9	- 6.1	- 6.6

Standard errors reported as { }, *t*-statistics reported as ( ), and F test probability values as [ ]. Models 1 and 2 are estimated using actual inflation data. Models 3 and 4 are estimated with inflation data de-meaned for the 8 inflation regimes shown in Graph 1 and reported in Appendix 2. Details concerning the de-trending of the unemployment data and the de-meaning of the inflation data are provided in the Data Appendix 1 and 2 respectively. Sample is 208 observations for the period March 1952 to September 2004.

The models are estimated by GMM in WinRATS pro 6.2 with three lags of both inflation and the unemployment rate as instruments. The J-test is the Hansen (1982) test for instrument validity. Rejection of the J-Test implies the instruments are invalid. LM(1) and LM(4) are Largrange Multiplier tests for first and fourth order serial correlation of the residuals respectively where the null hypothesis is no serial correlation. ADF test is the augmented Dickey-Fuller unit root test of the residuals where the 1 and 5 per cent critical values are – 2.576 and - 1.941 respectively.

Table 3: Demonstrating Proposition Three

Model ⇒ Independent Variable ⇓	Dependent Variable: Actual Inflation Δp_t 1 Hybrid	2 F-P
z_{t+1}	1.2751 (4.8)	
z_{t-1}	- 0.0927 (- 0.4)	0.2703 (5.5)
z_{t-2}		0.3139 (6.9)
z_{t-3}		0.3151 (6.6)
$(U - U^*)_t$	- 0.2874 (- 1.7)	- 0.4602 (- 4.1)
Constant	- 0.6961 (- 1.3)	0.3447 (1.4)
Sum of Dynamic Inflation Terms	1.1824 {0.1472}	0.8993 {0.0630}
$\overline{R}^2$	0.07	0.71
J-Test probability	[0.2961]	[0.4510]
LM(1) test probability	[0.0000]	[0.0000]
LM(4) test probability	[0.0000]	[0.0000]
ADF test residuals	- 5.4	- 5.5

The models are estimated with 209 observations and re-estimated 10,000 times using Monte Carlo simulation techniques. The variable, z_t, is constructed as the mean for each of the inflation regimes plus a random variable taken from a normal distribution which is mean zero and with a standard deviation of 1.665956. The results reported are the means of the estimates from the Monte Carlo simulation of the model estimated in WinRATS pro 6.2 with a ‘seed’ of 171193. Inference is unchanged if the median value of the estimates is reported instead of the mean value. The models are estimated by GMM with three lags of both inflation and the unemployment rate as instruments.

Standard errors reported as { }, *t*-statistics reported as ( ), and F-test probability values as [ ]. The dependent variable in models 1 and 2 is the actual inflation rate. The dependent variable in models 3 and 4 is the ‘mean-shift’ inflation variable, z_t. Details of the tests are provided in the notes to Table 2.

Table 4: 'Fixed Constant' Panel Estimates of United States Phillips Curves

Hybrid Model

$$\Delta p_t^i = 0.5309 + 0.4882\Delta p_{t+1}^i + 0.4811\Delta p_{t-1}^i - 0.0704U_t^i$$
$$(1.6) \quad (4.2) \quad (4.3) \quad (-1.1)$$

$\overline{R}^2$ = 0.85, Durban-Watson statistic 2.88. Hypothesis tests: $\Delta p_{t+1}^i + \Delta p_{t-1}^i = 0$ is rejected, $F_{(1,183)} = 922.5585$, p-val = 0.0000, and $\Delta p_{t+1}^i + \Delta p_{t-1}^i = 1$ is accepted $F_{(1,183)} = 0.9224$, p-val = 0.3381. Instruments: two lags of inflation and the unemployment rate.

Friedman-Phelps Model

$$\Delta p_t^i = 1.812 + 0.6280\Delta p_{t-1}^i - 0.0803\Delta p_{t-2}^i + 0.4233\Delta p_{t-3}^i - 0.1980U_t^i$$
$$(2.7) \quad (8.1) \quad (-0.9) \quad (5.0) \quad (-2.7)$$

$\overline{R}^2$ = 0.69, Durban-Watson statistic 2.03. Hypothesis tests: $\sum_{i=1}^{3}\Delta p_{t-i}^i = 0$, is rejected, $F_{(1,182)} = 287.1956$, p-val = 0.0000, and $\sum_{i=1}^{3}\Delta p_{t-i}^i = 1$ is accepted $F_{(1,182)} = 0.2568$, p-val = 0.6130. Instruments: three lags of inflation and two lags of the unemployment rate.

Phillips curve models are estimated with 187 observations in 8 cross-sections using EViews 5.1. Reported as ( ) are *t*-statistics. Models estimated with 2SLS and with the constant restricted to be the same across all 8 inflation regimes such that $\phi^1 = \phi^2 = ... = \phi^8$ in equation (5).

Table 5: Fixed Effects Panel Estimates of United States Phillips Curves

Dependent Variable ⇒	**Inflation** Δp_t^n	**Inflation** Δp_t^n
Model ⇒ **Independent Variable ⇓**	**1** **Hybrid**	**2** **F-P**
Δp_{t+1}^n	0.1376 (0.6)	
Δp_{t-1}^n	0.3360 (5.4)	0.3323 (5.5)
U_t^n	- 0.2643 (- 2.3)	-0.3159 (- 3.9)
Regime 1	1.2458 (2.1)	1.5050 (3.1)
Regime 2	2.400 (2.5)	2.9630 (6.1)
Regime 3	3.5974 (2.5)	4.4935 (8.4)
Regime 4	7.0605 (2.5)	8.6598 (10.0)
Regime 5	5.1537 (2.5)	6.2960 (7.4)
Regime 6	7.6389 (2.4)	9.6695 (10.7)
Regime 7	3.9048 (2.5)	4.8105 (7.2)
Regime 8	2.8041 (2.5)	3.34486 (6.7)
$\overline{R}^2$	0.75	0.60
AR(1) AR(2) AR(3) AR(4)	[0.000] [0.004] [0.004] [0.313]	[0.509] [0.097] [0.003] [0.256]
F-Tests		
$\phi_f + \phi_b = 0$	[0.040]	[0.000]
$\phi_f + \phi_b = 1$	[0.023]	[0.000]
$\phi_f = \phi_b = \phi_U = \phi^i = 0$	[0.000]	[0.000]
$\phi^i = 0$	[0.541]	[0.000]

Reported as ( ) and [ ] are *t*-statistics and F-test probability values respectively. Estimated hybrid and F-P models have 8 cross-sections and 187 and 195 usable observations respectively. Instruments: two lags of inflation and the unemployment rate in both models. AR(1) to AR(4) are the Arellano-Bond tests of first to fourth order serial correlation in the residuals. Models estimated in levels with 2SLS using Stata/SE 8.2 and Eviews 5.1. Tests of coefficient constancy: hybrid model, Δp_{t+1}^i, F(7, 169) = 0.75, [0.6306], Δp_{t-1}^i, F(7, 169) = 0.26, [0.9686], U_t^i, F(7, 169) = 0.61, [0.7496]. F-P model, Δp_{t-1}^i, F(7, 178) = 0.36, [0.9252], U_t^i, F(7, 178) = 1.68, [0.1154].

Table 6: Estimates of the Long-run Phillips Curve

Inflation as the Dependent Variable

Linear:
$$\overline{\Delta p} = -8.1765 + 2.1190\,\tilde{U} \quad , \; \bar{R}^2 = 0.91$$
$$(-4.6) \qquad (7.6)$$

The estimated coefficients on $\tilde{U}$ is zero is rejected, $F_{(1,6)} = 57.4170$, prob-value = 0.0003.

Non-linear:
$$\overline{\Delta p} = 2.5189 - 1.5445\,\tilde{U} + 0.2964\,\tilde{U}^2 \quad , \; \bar{R}^2 = 0.94$$
$$(0.4) \qquad (-0.7) \qquad (1.6)$$

The estimated coefficients on $\tilde{U}$ and $\tilde{U}^2$ are jointly zero is rejected, $F_{(1,6)} = 37.8068$, prob-value = 0.0010.

Unemployment Rate as the Dependent Variable

Linear:
$$\tilde{U} = 4.0754 + 0.4273\,\overline{\Delta p} \quad , \; \bar{R}^2 = 0.91$$
$$(12.4) \qquad (7.6)$$

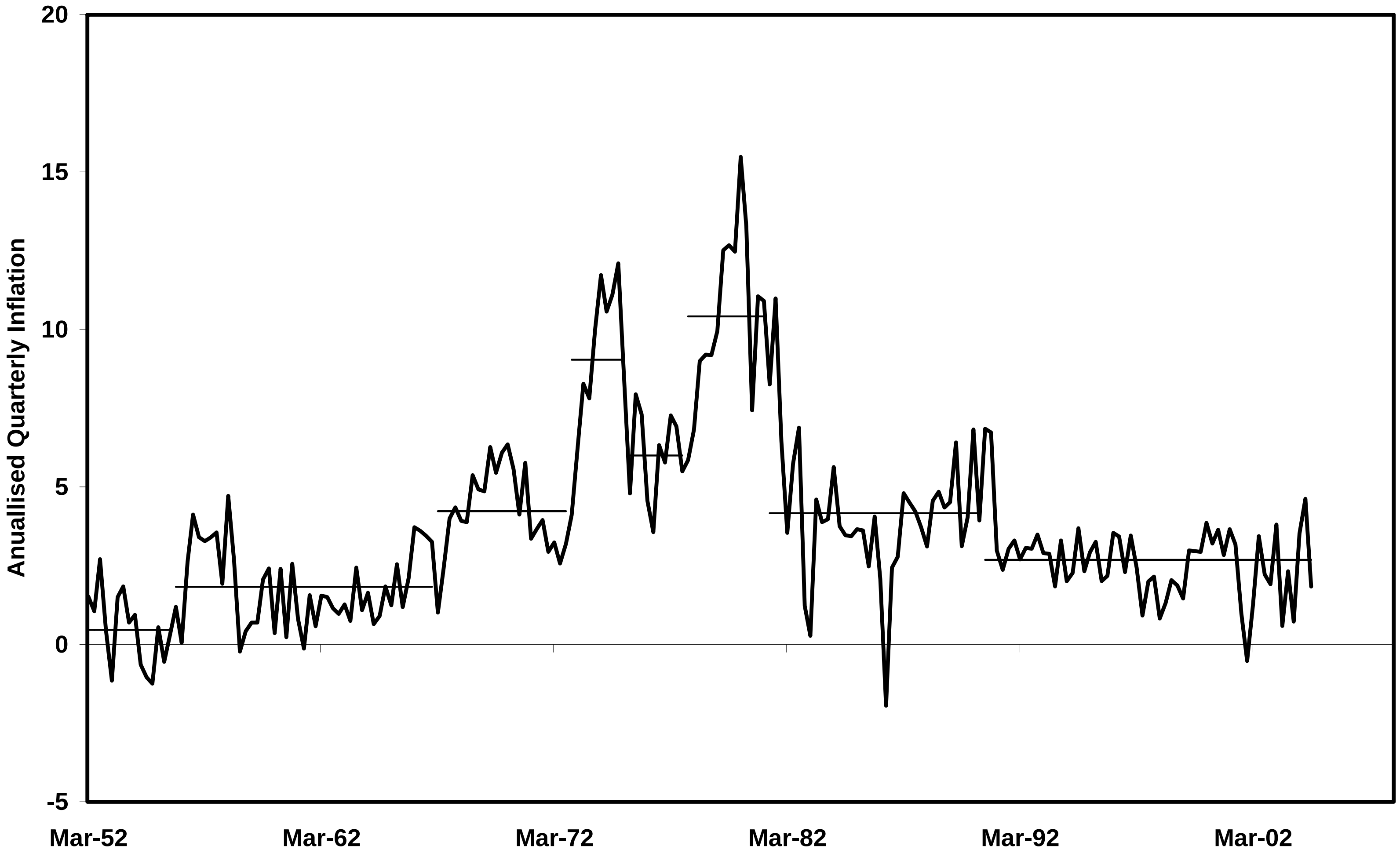
The estimated coefficient on $\overline{\Delta p}$ is zero is rejected, $F_{(1,6)} = 57.4170$, prob-value = 0.0003.

Non-linear:
$$\tilde{U} = 3.7601 + 0.6014\,\overline{\Delta p} - 0.0156\,\overline{\Delta p}^2 \quad , \; \bar{R}^2 = 0.92$$
$$(7.0) \qquad (2.5) \qquad (-0.8)$$

The estimated coefficients on $\overline{\Delta p}$ and $\overline{\Delta p}^2$ are jointly zero is rejected, $F_{(1,6)} = 26.9817$, prob-value = 0.0021.

Notes: Numbers in brackets are *t* statistics.

Graph 1: United States Quarterly CPI Inflation, Seasonally Adjusted, March 1952 – September 2004



Notes: Horizontal thin lines indicate the mean rates of inflation in the eight inflation regimes (see Appendix 2 for details).

Graph 2: United States Phillips Curves