THE AUSTRALIAN PHILLIPS CURVE IN THE LONG RUN
Monetary Policy Regimes and Expectations Formation

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Preface

Title of Thesis: TBA
Supervisor: Dr Alicia Rambaldi

The New Keynesian Model of the macroeconomy typically has three equations. An aggregate demand curve relates the output gap to real interest rates. The aggregate supply or Phillips curve links inflation to the output gap. The model is then closed with the addition of a Taylor rule that relates monetary policy, as measured by the short term nominal interest rate, to both the output gap and inflation rate.

A key influence on the development of this model was the Lucas critique of econometric policy analysis. This led initial versions to model expectations formation using the Rational Expectations Hypothesis. A Keynesian flavour was maintained through assuming some price stickiness. However in practice these models failed to reproduce key features of the data, especially the persistence in inflation. This has led to the growth of various ‘hybrid’ models. These relax the Rational Expectations Hypothesis by allowing for some proportion of agents to form their expectations via various rule of thumb, typically by extrapolating recent history.

While these models tend to fit the data better, the treatment of expectations is now again subject to the same Lucas critique. An alternative approach is to assume that agents form their expectations through a learning process. Unlike the Rational Expectations Hypothesis, learning models do not assume that agents know the true underlying structure of the economy but recursively update their forecasting model based on the available data. Unlike the hybrid models, agents do not follow a fixed rule of thumb but rather change their forecasting model to fit actual experience. The thesis looks at this issue from the perspective of a New Keynesian model of the Australian economy.

The thesis is structured as follows:
Chapter 1: Introduction
Chapter 2: The New Keynesian Model
Chapter 3: Learning and Expectations
Chapter 4: The New Keynesian Phillips Curve
Chapter 5: The New Keynesian Aggregate Demand Curve
Chapter 6: The Taylor Rule
Chapter 7: Policy Analysis in the New Keynesian Model
Chapter 8: Data Appendix

The following paper is based on Chapter 4.
Abstract

Studies typically find that the standard New Keynesian Phillips curve cannot adequately capture the inertia present in postwar inflation data. A common response has been to include lagged inflation in the equation, producing the Hybrid Phillips curve. However this paper demonstrates that the relationship between current and lagged inflation is not a stable feature of the long run Australian data but varies with the monetary policy regime. Modelling inflation expectations using a recursive learning process is shown to be more consistent with the data.

This allows for a modelling of policy-maker credibility which is shown in turn to affect the trade-off between inflation and output stability. It also affects the strength to which policy-makers have to react to inflation changes. This appears to be consistent with the changing behavior of monetary policy and economic volatility over the period since the 1960s.
Introduction

Much of the extensive literature on the New Keynesian Phillips Curve (NKPC) finds it necessary to include the lagged inflation rate in order to account for the observed inertia of the inflation rate. Most Australian work on the Phillips curve (for example (Andrew Stone and Wilkinson, 2005)) uses a purely backward looking approach with lagged inflation included on the basis that firms have adaptive expectations.

However this potentially raises problems with the Lucas critique under which the degree of inflation inertia might be expected to change with different monetary policy regimes.

Moreover the standard backward looking model of the Phillips curve has no role for ‘credibility’. The inflation process is assumed to be completely independent of the past success of failure of the central bank in controlling inflation. Since there is much discussion of the importance of inflation targeting policies in ‘anchoring’ expectations and therefore improving recent macroeconomic performance, this is potentially an important omission.

In order to test the relevance of the Lucas critique it is necessary to test the stability of the parameter on lagged inflation across different policy regimes. It therefore makes sense to take the model to a long sample period of data that spans a number of distinct regimes and inflation rates. Therefore, in addition to using postwar quarterly data, this paper also uses a long range of historical inflation data from Australia from 1875 to 2006.

While the issue of inflation persistence has been examined using pre-War data for the USA and UK, the available Australian data has not been used extensively (although (Pope, 1982) is an exception). These data are then used to compare the relative performance of the Phillips curve model when inflation inertia is modelled using either lagged inflation (the backward looking model) or the forecasts from a simple recursive forecasting model (the recursive learning model).

The key conclusion is that there are systematic shifts in the parameter on lagged inflation that seem to correspond to changes in monetary policy environment. This is clear evidence in favor of the relevance of the Lucas critique and cautions against the use of the standard hybrid or backward looking models for policy analysis. However it is shown that replacing lagged inflation with a learning model improves the performance of the model.

Modelling expectations formation in this way allows for changing policy-maker credibility to influence the inflation process and therefore the trade-off faced between output and price stability. Low credibility regimes tend to increase both
inflation and output variability. It is suggested that policy-makers during the 1970s overestimated their credibility (and therefore underestimated inflation persistence). This led to a failure to respond aggressively enough to the inflation shocks of the early 1970s, followed by a sustained period of high and volatile inflation.

As policy-makers learned that their credibility had declined, leading to a worsening trade-off, there was an incentive to adopt a more aggressive anti-inflation stance so as to restore credibility and improve the policy environment. This is consistent with the higher interest rate levels of the 1980s and the introduction of inflation targeting in the 1990s.

The next section of this paper outlines the problems with the NKPC both with rational and backward-looking expectations. The recursive learning approach is then presented as an alternative model of expectations formation that avoids the major problems with both versions of the NKPC. This is followed by an outline of the different Australian monetary policy regimes from the Gold Standard to Inflation Targeting, together with a description of the data.

Phillips curve models are then estimated using annual data from 1875 to 2006 and post-war quarterly data. It is shown that versions in which firms are assumed to produce their forecasts using a recursive learning model similar to recursive least squares perform better than standard backward-looking models. A learning model of inflation expectations also performs better when used in an aggregate demand equation.

The final section of the paper then discusses the implications for monetary policy.

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The New Keynesian Phillips Curve

The standard New Keynesian Phillips Curve (NKPC) relates the current rate of inflation ($\pi_t$) to expected inflation ($E_t \pi_{t+1}$) and the output gap ($y_t$) (see equation 1). (Roberts, 1995) demonstrated that Equation 1 can be derived from a number of popular models of optimal price setting under conditions of ‘stickiness’ such as Taylor’s (Taylor, 1980) staggered contracts model, Rotemberg’s quadratic price adjustment cost model (Rotemberg, 1982) and Calvo’s staggered contracts model (Calvo, 1983).

$$\pi_t = E_t \pi_{t+1} + \lambda y_t + e_t$$

(1)
In the canonical model, expectations are assumed to be formed rationally. As long as the source of the price stickiness reflects structural characteristics of the economy that are invariant to policy changes (and especially inflation changes) the model should be immune from the Lucas critique\(^1\).

A key problem with the NKPC is that, although the price level is sticky, the inflation rate is not. Therefore the model has trouble reproducing the persistence of the inflation rate (Fuhrer, 1997). It also implies that credible disinflations should be costless, a prediction that is difficult to square with the experience that, apart from instances of very high inflation, disinflations are almost universally costly (Ball, 1994).

Finally, the equation has the counterfactual implication that changes in the inflation rate should be negatively related to the output gap. This can be seen by rearranging Equation 1 to place expected inflation on the left hand side. This produces Equation 2. If expectations are formed rationally, then this implies that a high output gap today should forecast a fall in the inflation rate. Therefore inflation should fall following economic booms and rise after recessions.

\[
E_t \pi_{t+1} - \pi_t = -\lambda y_t - e_t \tag{2}
\]

The common response has been to add lagged inflation to the equation. This is typically justified on the basis that a fraction of firms either form their expectations in a backward looking fashion, or they adopt a ‘rule of thumb’ of indexing their prices. This produces the hybrid version of the NKPC of Equation 3 where the parameter \( \omega \) measures the proportion of backward looking firms in the economy.

\[
\pi_t = \omega \pi_{t-1} + (1 - \omega) E_t \pi_{t+1} + \lambda y_t + e_t \tag{3}
\]

The NKPC therefore corresponds to the case of \( \omega = 0 \). If \( \omega = 1 \) then all firms are backward looking and the equation collapses to the accelerationist Phillips curve.

However introducing this parameter now adds another potential source of vulnerability to the Lucas critique. While adopting an indexation rule or assuming that next years inflation rate will be much the same as today’s may work well if inflation is close to a random walk, these rules could be far from optimal if inflation follows a different process. This would provide a large incentive for firms to change their forecasting rule.

There is already some evidence to suggest that inflation inertia is not an inher-

\(^1\)This is not guaranteed to be the case. (Laurence Ball and Romer, 1988) demonstrate that the steepness of the Phillips curve across countries is positively correlated with inflation. This suggests that price stickiness or the frequency with which firms change prices depends on the inflation rate.
ent feature of industrial economies but may reflect the impact of the inflationary environment on expectations formation. For example (Benati, 2006) finds that UK inflation has only been persistent between the floating of the pound in 1972 and the introduction of inflation targeting in 1992. UK inflation persistence was low under both the Gold standard and the inflation targeting regime (see also (Bordo and Schwartz, 1999)). More recently a number of countries have experienced a decline in the persistence of inflation (see for example (Debelle and Wilkinson, 2002) for the case of Australia).

The finding of significant, but time varying, inertia in inflation presents a dilemma since it suggests that neither the NKPC nor its hybrid adequately capture the inflation process. One potential solution is to use a model of expectations formation that allows agents to be backward looking, but also to learn about the inflation process.

Overseas literature typically finds an important role for lagged inflation. In Australia, relatively little of the literature finds any role for forward looking expectations so that most work in this area assumes a purely backward looking version (i.e. $\omega = 1$). Moreover it is common to find a pure backward looking model used for policy analysis (for example (Rudebusch and Svensson, 1999), (Lees, 2002) and (Ball, 1999)). Therefore this paper will concentrate on using this version of the NKPC as the baseline model which is compared with an alternative learning version.

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**Recursive Learning**

Unlike rational expectations, a recursive learning approach does not require that agents know the underlying structure of the economy. However, unlike adaptive expectations, agents are able to gradually adjust their forecasting process as the underlying structure of the economy changes. They therefore use available information efficiently and do not make persistent and avoidable forecasting errors. This produces expectations that are similar to adaptive expectations in the short run, while still converging (close) to rational expectations in the long run. Recent papers in this framework include (Orphanides and Williams, 2004), (Milani, 2005) and (Lansing, 2006). The promise of this approach is that it can explain both short run inflation inertia as well as changes in the degree of inertia over time.

The implementation of this approach usually follows the constant gain learning algorithm suggested by (Evans and Honkapohja, 2001). This assumes that agents have a perceived law of motion (PLM) linking their forecast variable $y_t$ to an
information set, $X_t$ (which would typically include lagged $y$).

$$Y_t = X_t \beta_t + u_t$$  \hspace{1cm} (4)

Then as further information becomes available, they update the parameter estimates according to Equations 5 and 6 (where $y_t$ and $x_t$ represents the current period’s observations of $Y$ and $X$).

$$\beta_t = \beta_{t-1} + \kappa R_{t-1}^{-1} x_t (y_t - x'_t \beta_{t-1})$$  \hspace{1cm} (5)

$$R_t = R_{t-1} + \kappa \left( x_t x'_t - R_{t-1} \right)$$  \hspace{1cm} (6)

The parameter $\kappa$ represents the learning speed. If $\kappa = 1/t$ where $t$ represents the number of observations, then this collapses to the normal recursive least squares formula. Having a constant value for $\kappa$ allows for the parameter estimates to slowly evolve over time. This would be consistent with agents allowing for a steady rate of structural change.

There are a number of approaches that can be used to calibrate the parameter $\kappa$. (Milani, 2005) assumes that agents use an AR(1) model of inflation as their PLM. Using this to produce a series on expectations for use in a Phillips curve, he finds that a learning rate between 1.5% and 2.5% per quarter provides a good fit for the US data from 1960 to 2003. (Orphanides and Williams, 2004) find that a learning rate of between 1.5% and 2% per quarter in a VAR model provides a good fit with the survey data on inflation expectations in the Survey of Professional Forecasters from 1969 to 2002. (Branch and Evans, 2005) find that a rate of learning of 3.45% provides the best match for the Survey of Professional Forecasters from 1981 to 2005. Since these models use quarterly data, the quarterly learning rates would suggest annual rates of between 6% and 14% per annum.

An alternative approach would be to ask what rate of learning would have historically produced the best forecasts (in the sense of the lowest root mean square errors) over history. Using annual data from 1875 to 2006, an annual learning rate of 6% provides the best outcomes using the Australian data. However forecasting performance did not markedly deteriorate for learning rates in the range of 5% to 10% per annum. For the purposes of this paper, a learning rate of 8% per annum or 2% per quarter was chosen. In terms of the recursive least squares approach, this would equate to an ‘effective’ sample size (i.e. 1/t) of around 12.5 years. Data that is 8 to 9 years old are given an effective weight of around half that of current data while data that are 20 years old receive only around 20% of the weight of current data.
Australian Monetary Policy Regimes

Since the objective is to allow firms to adapt their forecasting process to changes in the actual behavior of inflation it is useful to briefly review the long-run history of Australian inflation and how it has varied under different monetary policy regimes. Figure 1 shows the level of consumer prices in Australia from 1850 to 2006. The data show the impact of a number of distinct policy regimes.

![Figure 1 Australian Consumer Prices: 1850-2006](image)

**The Classical Gold Standard**

Australia was on the gold standard from the founding of the Sydney mint in 1850 to 1915 when the first World War forced its suspension. Gold discoveries in the 1850s generated a strong rise in prices but this had largely subsided by 1860 and prices gradually fell. Inflation was quite volatile during this period, but essentially had a zero mean.

**The Interwar Period**

After a period of inflation during the war, Australia experienced a brief deflation before returning to the gold exchange standard in 1925. However gold was again abandoned during the stress of the great depression of the 1930s. Prices fell
steadily during the depression years. While the inflation of the war was never fully reversed, so that the price level remained permanently higher than in 1914, there was little ongoing inflation for the postwar period as a whole. Prices in 1939 were essentially the same as in 1919.

The Bretton Woods System

Following the second World War Australia joined the Bretton Woods system. The Korean war generated a sharp rise in commodity prices which, since Australia is a major commodity exporter, translated into higher foreign exchange reserves and money supply, followed by a sharp rise in inflation. However this burst in inflation was fairly short lived and the following 15 years saw only modest inflation rates. Although inflation was low during this time, there was nonetheless a slow but steady rise in the price level. Unlike the experience under the gold standard or the interwar period, there was only one year in which consumer prices fell (in 1963 by -0.2 per cent).

The Flexible Exchange Rate Period

By the late 1960s the unwillingness of the US to reduce its money supply growth started to generate global inflationary pressures in which Australia shared. The fixed exchange rate system was finally abandoned in 1973 and replaced with a system of a managed exchange rate and eventually a free float in 1984.

As was the case with the Korean war, higher commodity prices in the early 1970s led to rapid money supply growth and high inflation. However unlike the earlier episode, there was no rapid return to low inflation. On this occasion, when commodity prices fell, instead of this leading to a contraction in foreign exchange reserves and the money supply, the government responded to the balance of payments deterioration with a series of devaluations.

Therefore exchange rate flexibility allowed the government to avoid the large output fluctuations that would have been required to quickly bring inflation back down. Essentially the end of fixed exchange rates allowed the government to shift monetary policy more towards achieving output stability at the expense of price stability. This meant that a sharper decline in activity was avoided at the cost of ongoing high inflation.\(^2\)

\(^2\)Since our major trading partners were also experiencing high inflation a fixed exchange rate alone would not have guaranteed a quick return to price stability. This would have required a steady appreciation of the currency. However over this period Australia’s relative inflation performance gradually deteriorated until the recession of the early 1990s.
Flexible Inflation Targeting

A recession in the early 1990s was followed by lower inflation and the adoption of an inflation target by the central bank of 2 to 3 per cent in 1993. This target was ratified by the new government in 1996. Since the early 1990s inflation has remained generally low and stable at around 2.5 per cent.

Data

Figure 2 shows the annual data used in this exercise. The inflation rate is measured by the log difference of the consumer price index \((\Delta p)\), import prices are the log difference in the import price index \((\Delta pm)\). Full details of the construction of these series are in the appendix.

Excess demand in the economy is proxied by the deviation between the unemployment rate \((U_t)\) and its average level. An adjustment is made to the unemployment rate to account for an apparent downward shift in the NAIRU between 1941 and 1973. A number of studies have documented an increase in the NAIRU from around 2 per cent to around 6 per cent in the early 1970s (David Gruen and Thompson, 1999) and (Debelle and Vickery, 1998). This reversed an apparent downward shift around the time of the second World War.

Reasons for these shifts are unclear but they do seem to be correlated with the acceleration in productivity growth in the post-war period\(^3\). Some studies have found a similar pattern between NAIRU changes and the acceleration of productivity growth in the USA (Ball and Mankiw, 2002). They have suggested that this may reflect slow learning about productivity growth by workers when negotiating pay increases. Since a full examination of this issue is outside the scope of this paper, a simple shift dummy is used to account for this change.

Therefore the unemployment rate gap used in this paper is calculated using the residuals from a regression of the unemployment rate on an intercept and a dummy variable that takes the value of unity between 1941 and 1972. The coefficient on the constant is 6.75 while the coefficient on the dummy variable is -4.0 (consistent with an adjusted intercept or NAIRU of 2.75 during the early post-war period).

\(^3\)GDP per hour worked grew by an average of only around 0.5 per cent per annum from 1900 to 1939. However growth then averaged over 2.5 per cent between 1940 and 1973. Like many other countries Australia then experienced a slow down in productivity growth during the early 1970s. Between 1974 and 2006 output per hour grew only around 1.7 per cent per annum.
Figure 2  Inflation, Import Prices and Unemployment Rates 1875-2006
Estimation Results-Annual Data

Australia is a small open economy and imports averaged around 16 per cent of GDP during this period. Therefore the standard hybrid Phillips Curve is extended to allow for changes in import prices \((pm)\) to affect the domestic consumer price level.

\[
\pi_t = \omega \pi_{t-1} + (1 - \omega) E_t \pi_{t+1} + \lambda y_t + \Delta pm_t + \epsilon_t
\]  

(7)

In order to model inflation expectations under a learning process, firms are assumed to form their expectations based only on past inflation data. Their forecasting model is assumed to be an AR(2) model of inflation which is reestimated every year. When estimating their model, firms are assumed to use a 8% per annum updating rate. As mentioned above, inflation is measured by the log change in the CPI, \(\Delta p\) and the output gap is measured by the unemployment rate \(U\).

Figure 3 shows the sum of the two coefficients on the lagged inflation rates used in the learning model. This indicates that there was no persistence in the inflation process prior to the First World War. However the collapse of the Gold Standard in the mid 1930s saw a steady rise (apart from a brief spike during the Korean War) in persistence. The Bretton Woods system saw a modest degree of persistence followed by a sharp rise following the collapse in the Bretton Woods system. By the mid 1970s the inflation process is close to a random walk before falling again under Inflation Targeting.

The first equation in Table 1 reports the results from estimating the backward looking equation using data from 1950 to 2006. This is a typical sample period used for Australian macroeconomic data. The equation appears to perform well. Lagged inflation is strongly significant and the sum of the coefficients on lagged inflation and import prices is close to unity, so the hypothesis that the long run Phillips curve is vertical cannot be rejected.

The coefficient on the unemployment rate is statistically significant and implies that a 1 percentage point rise in unemployment initially raises the inflation rate by 0.274 percentage points, consistent with a sacrifice ratio of a little under 4.
However extending this equation back to 1875 in the next column demonstrates that this is not a robust result. The coefficient on lagged inflation is now significantly lower and the null hypothesis that the long-run Phillips curve is vertical is strongly rejected. Moreover the stability tests in Table 2 provide strong evidence of structural instability.

The third column of Table 1 shows the results where the price expectations series is measured by the recursive learning algorithm \( RLE_t \Delta p_{t+1} \). This shows an improvement in terms of equation fit while the coefficient on the expectations series is close to priors. The final column shows the results of combining the backward looking and learning models. This indicates that the data prefers the learning expectations series with the coefficient on the learning expectations series remains strongly significant while that on lagged inflation is small and not significant.

In terms of the coefficient on the unemployment rate, it is now higher on the learning model, consistent with a sacrifice ratio of around 3. By way of comparison (David Gruen and Thompson, 1999) and (Debelle and Vickery, 1998) use a non-linear specification in their equations. Their estimates imply that (starting from a 6% unemployment rate) the implied sacrifice ratio is 3.9 and 1.2 respectively.

In terms of stability, the mean Wald and Exp-Wald statistics (in the second column of Table 2) are both much improved while the Sup-Wald statistic is only
Table 1  Phillips Curve Equation: 1875-2006

<table>
<thead>
<tr>
<th>Model:</th>
<th>Dependent Variable: $\Delta p_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample:</td>
<td>Backward Learning Combined</td>
</tr>
</tbody>
</table>

| $Constant$ | 0.0103 | 0.0128 | -0.0006 | -0.0006 |
|           | (0.0028) | (0.0027) | (0.0029) | (0.0029) |
| $\Delta p_{t-1}$ | 0.628 | 0.383 | - | 0.020 |
|           | (0.0586) | (0.104) | (0.095) | |
| $RLE_t \Delta p_{t+1}$ | - | - | 0.789 | 0.770 |
|           | (0.064) | (0.102) | (0.102) | |
| $\Delta p_{mt}$ | 0.254 | 0.228 | 0.298 | 0.293 |
|           | (0.0645) | (0.039) | (0.042) | (0.049) |
| $U_t/100$ | -0.274 | -0.205 | -0.342 | -0.335 |
|           | (0.0969) | (0.074) | (0.068) | (0.077) |
| $Adj. R^2$ | 0.80 | 0.47 | 0.62 | 0.62 |
| $S.E.$ | 1.85% | 3.49% | 2.96% | 2.97% |
| $D.W.$ | 1.65 | 2.09 | 1.98 | 2.01 |
| $AR(4)(\chi^2(4))$ | 9.83** | 5.36 | 7.03 | 7.38 |
| $RESET(\chi^2(2))$ | 5.40* | 9.06** | 1.80 | 1.60 |
| $ARCH(\chi^2(1))$ | 0.036 | 10.75*** | 7.42*** | 8.12*** |
| $HETERO(Pval)$ | 0.046** | 0.000*** | 0.32 | 0.054* |
| $Normality(\chi^2(2))$ | 10.30*** | 26.59*** | 27.86*** | 27.89*** |
| $Slope (\chi^2(1))$ | 2.25 | 12.85*** | 1.91 | 1.80 |


* Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.

marginally worse. The peak value of the Wald Statistic for the Backward Looking model is in 1947 while the peak for the Learning Model is 1986.

Table 3 shows the results from estimating the backward looking model over various subsamples corresponding to different policy regimes. The key change in the equation is that there is no evidence of persistence in inflation prior to the Bretton Woods period or after the introduction of inflation targeting (with the coefficient on lagged inflation being insignificantly different from zero).

This result for the Bretton Woods period is quite sensitive to the inclusion of the sharp spike in inflation during the Korean war. If this sample is started in 1955 after price stability had returned, the coefficient on lagged inflation falls to 0.06 (standard error of 0.23). The null hypothesis that the long run Phillips Curve is vertical is now also rejected at the 5% significance level. The coefficient on the unemployment rate also falls to -0.07 (standard error of 0.57).
Table 2  Wald Tests for Structural Change: Phillips Curve

<table>
<thead>
<tr>
<th>Wald Test</th>
<th>5% Critical Value</th>
<th>Backward Looking</th>
<th>Learning Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>16.45(a)</td>
<td>41.02</td>
<td>44.66</td>
</tr>
<tr>
<td>Average</td>
<td>7.67(b)</td>
<td>34.59</td>
<td>8.78</td>
</tr>
<tr>
<td>Exponential</td>
<td>5.23(c)</td>
<td>29.16</td>
<td>7.67</td>
</tr>
</tbody>
</table>

Notes:
(a) Critical value from (Andrews, 1993), Table 1, $p=4$, $\pi_0 = 0.15$
(b) Critical value from (Andrews and Ploberger, 1994), Table II, $p=4$, $\pi_0 = 0.15$
(c) Critical value from (Andrews and Ploberger, 1994), Table I, $p=4$, $\pi_0 = 0.15$.
Sample is from 1875 to 2006 with 15% trimming.

Table 4 shows the performance of the recursive learning model under the same subsamples. In all cases except for the relatively brief Inter-war period, the coefficient on the expected inflation rate is positive and the fit of the equation is better than for the backward looking version. The null hypothesis that the long-run Phillips curve is vertical is also rejected less frequently than for the backward looking model. While the coefficient on the expected inflation term is incorrectly signed during the interwar period, adding lagged inflation to the equation does not improve the results - the coefficient on lagged inflation is negative.

A couple of other interesting results emerge from both sets of equations. Firstly the coefficient on import prices is essentially zero during the Gold Standard before rising to quite high levels during the Inter-War and Bretton Woods periods. It then falls after the exchange rate become more flexible. The size of the coefficient during the Inter-War and Bretton Woods periods is much larger than the share of imports in expenditure. Therefore it is possible that there could be expectations effects.

There also seems to be some tendency for the coefficient on the unemployment rate to drift downwards over time, perhaps due to an expanded social welfare safety net.
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Constant</td>
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<td>0.002</td>
<td>0.023</td>
<td>0.016</td>
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<tr>
<td></td>
<td>(0.006)</td>
<td>(0.008)</td>
<td>(0.006)</td>
<td>(0.008)</td>
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<tr>
<td>Δp_{t-1}</td>
<td>-0.104</td>
<td>-0.456</td>
<td>0.693</td>
<td>0.546</td>
<td>0.363</td>
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<tr>
<td></td>
<td>(0.087)</td>
<td>(0.203)</td>
<td>(0.094)</td>
<td>(0.100)</td>
<td>(0.304)</td>
</tr>
<tr>
<td>Δp_{m,t}</td>
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<td>0.473</td>
<td>0.370</td>
<td>0.175</td>
<td>0.009</td>
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<td>(0.204)</td>
<td>(0.095)</td>
<td>(0.089)</td>
<td>(0.060)</td>
<td>(0.031)</td>
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<td>U_{t}/100</td>
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<td>-0.529</td>
<td>-0.909</td>
<td>-0.299</td>
<td>-0.081</td>
</tr>
<tr>
<td></td>
<td>(0.126)</td>
<td>(0.157)</td>
<td>(0.747)</td>
<td>(0.153)</td>
<td>(0.085)</td>
</tr>
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<td>Adj. R²</td>
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<td>0.69</td>
<td>0.78</td>
<td>0.69</td>
<td>-0.13</td>
</tr>
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<td>S.E.</td>
<td>3.93%</td>
<td>2.55%</td>
<td>2.04%</td>
<td>1.61%</td>
<td>0.60%</td>
</tr>
<tr>
<td>D.W.</td>
<td>1.96</td>
<td>1.90</td>
<td>1.98</td>
<td>1.43</td>
<td>1.51</td>
</tr>
<tr>
<td>AR(4)(χ²(4))</td>
<td>3.41</td>
<td>1.32</td>
<td>7.51</td>
<td>6.32</td>
<td>6.78</td>
</tr>
<tr>
<td>RESET(χ²(2))</td>
<td>4.87*</td>
<td>3.63</td>
<td>11.57***</td>
<td>1.55</td>
<td>2.73</td>
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<td>ARCH(χ²(1))</td>
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<td>0.01</td>
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</tr>
<tr>
<td>HETERO(Pval)</td>
<td>0.71</td>
<td>0.38</td>
<td>0.04**</td>
<td>0.20</td>
<td>0.47</td>
</tr>
<tr>
<td>Norm(χ²(2))</td>
<td>3.88</td>
<td>0.41</td>
<td>0.22</td>
<td>1.45</td>
<td>0.29</td>
</tr>
<tr>
<td>Slope (χ²(1))</td>
<td>40.12***</td>
<td>69.95***</td>
<td>0.181</td>
<td>6.07**</td>
<td>3.65*</td>
</tr>
</tbody>
</table>

Notes: Newey-West standard errors in parentheses. AR(4): Breusch-Godfrey LM test for up to fourth order serial correlation. RESET: Ramsey’s reset test. Hetero: White’s Heteroscedasticity test (excluding cross products). Normality: Jarque-Bera test. Slope refers to a test of the null hypothesis that the long-run Phillips curve is vertical. * Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.
### Table 4  Recursive Learning Phillips Curve Equation: Subsample Estimates

**Dependent Variable:** $\Delta p_t$

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gold Standard</th>
<th>Interwar Period</th>
<th>Bretton Woods</th>
<th>Flexible Exchange</th>
<th>Inflation Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875-1914</td>
<td>-0.004</td>
<td>0.027</td>
<td>0.005</td>
<td>0.029</td>
<td>-0.004</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.009)</td>
<td>(0.006)</td>
<td>(0.006)</td>
<td>(0.014)</td>
</tr>
<tr>
<td>1919-1939</td>
<td>0.520</td>
<td>-0.473</td>
<td>0.609</td>
<td>0.503</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>(0.457)</td>
<td>(0.317)</td>
<td>(0.047)</td>
<td>(0.066)</td>
<td>(0.459)</td>
</tr>
<tr>
<td>1946-1972</td>
<td>-0.137</td>
<td>0.314</td>
<td>0.444</td>
<td>0.191</td>
<td>0.027</td>
</tr>
<tr>
<td></td>
<td>(0.180)</td>
<td>(0.063)</td>
<td>(0.094)</td>
<td>(0.055)</td>
<td>(0.022)</td>
</tr>
<tr>
<td>1973-1992</td>
<td>-0.503</td>
<td>-0.409</td>
<td>-1.356</td>
<td>-0.366</td>
<td>-0.185</td>
</tr>
<tr>
<td></td>
<td>(0.137)</td>
<td>(0.119)</td>
<td>(0.837)</td>
<td>(0.136)</td>
<td>(0.097)</td>
</tr>
<tr>
<td>1993-2006</td>
<td>0.10</td>
<td>0.63</td>
<td>0.81</td>
<td>0.78</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>3.90%</td>
<td>2.79%</td>
<td>1.89%</td>
<td>1.35%</td>
<td>0.55%</td>
</tr>
<tr>
<td></td>
<td>1.91</td>
<td>2.11</td>
<td>1.74</td>
<td>1.58</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>2.07</td>
<td>5.26</td>
<td>2.11</td>
<td>5.15</td>
<td>5.99</td>
</tr>
<tr>
<td></td>
<td>3.63</td>
<td>2.55</td>
<td>6.89**</td>
<td>0.09</td>
<td>3.06</td>
</tr>
<tr>
<td></td>
<td>0.07</td>
<td>0.08</td>
<td>0.11</td>
<td>0.01</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>0.40</td>
<td>0.18</td>
<td>0.29</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>5.41*</td>
<td>0.53</td>
<td>0.66</td>
<td>0.72</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>2.01</td>
<td>15.41***</td>
<td>0.23</td>
<td>19.97***</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes: Newey-West standard errors in parentheses.

AR(4): Breusch-Godfrey LM test for up to fourth order serial correlation.
RESET: Ramsey’s reset test. Hetero: White’s Heteroscedascity test (excluding cross products).
Normality: Jarque-Bera test. Slope refers to a test of the null hypothesis that the long-run Phillips curve is vertical.
* Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.

---

### Estimation Results-Quarterly Data

While it seems clear that the learning model performs better over the long span of annual data it is possible that this may not be the case in the more recent quarterly data. Therefore the same exercise was repeated using quarterly data from 1966Q1 to 2007Q2 using a 2% per quarter learning rate (which is equivalent to the 8% annual learning rate used above).

Figure 4 shows the quarterly data used. The CPI and import price series are the same as for the annual data. However the capacity utilisation variable is different. The output gap is measured using the ACCI/Westpac *Survey of Industrial Trends* data on the net balance of respondents who report operating at...
above normal capacity levels of output. The data are demeaned and is denoted by \( \text{Cap} \). This output gap measure provides a better fit for the data than the unemployment rate. However the key results of what follows are unchanged if the unemployment rate is used instead.

Figure 4  Quarterly Data

Firms are assumed to use a longer autoregressive process to form their forecasts (and AR(4) rather than an AR(2) model) on account of the use of quarterly rather than annual data. Adding additional lags did not improve the forecasting performance of the equation.

Preliminary estimation results also indicated that lagged expectations were generally significant. This probably reflects the combination of publication lags for the quarterly CPI data as well as possibly some ‘sticky information’ effects (Mankiw and Reis, 2002). Therefore the expectations measure used in the equations is the average of the expectations formed during the most recent three quarters.
It was also necessary to adjust the standard recursive updating formula to allow the intercept to evolve independently of the slope parameters. In the standard recursive regression model, there is a negative correlation imposed on changes in the slope parameters and intercept. This comes about because changes in the slope parameter are assumed to occur through a rotation around the mean level of inflation. Therefore a steeper slope parameter is associated with a lower intercept. This makes it difficult for the standard model to adequately capture the changes that occur when, for example, both the mean and persistence of inflation both fall at the same time such as in the early 1990s.

The strength of this negative correlation depends on the mean level of inflation. Therefore it is not much of an issue for the annual data since the mean is quite close to zero for much of the sample. However it becomes an important issue when the quarterly post-war data is used. Accordingly the standard recursive updating formula was adjusted by setting the first row and column elements in the \( R^{-1} \) matrix in Equation 5 to zero with the exception of the first element. This means that the intercept now evolves independently of the slope parameters.

The first column of Table 5 shows the results from estimating the backward looking model while Table 6 shows the corresponding diagnostic statistics. The equation performs well with all parameters correctly signed and the lagged inflation rates are generally strongly significant while the hypothesis that the long run Phillips curve is vertical cannot be rejected.

The second column of both tables show the results from estimating the learning model. The results are very similar except for a small increase in the goodness of fit. However, more importantly, the third column shows that when the two models are combined, the coefficient on the learning expectations variable remains high and significant while the coefficients on lagged inflation are small and are not statistically significant, either individually or jointly (the p-value for their joint exclusion from the equation is 0.97%).
Table 5  Phillips Curve Equation: 1966Q1-2007Q2

<table>
<thead>
<tr>
<th>Model</th>
<th>Backward</th>
<th>Learning</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.0011</td>
<td>0.0011</td>
<td>0.0011</td>
</tr>
<tr>
<td></td>
<td>(0.0005)</td>
<td>(0.0005)</td>
<td>(0.0005)</td>
</tr>
<tr>
<td>$\Delta p_{t-1}$</td>
<td>0.157</td>
<td>-</td>
<td>-0.043</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td></td>
<td>(0.145)</td>
</tr>
<tr>
<td>$\Delta p_{t-2}$</td>
<td>0.235</td>
<td>-</td>
<td>-0.046</td>
</tr>
<tr>
<td></td>
<td>(0.063)</td>
<td></td>
<td>(0.113)</td>
</tr>
<tr>
<td>$\Delta p_{t-3}$</td>
<td>0.248</td>
<td>-</td>
<td>-0.132</td>
</tr>
<tr>
<td></td>
<td>(0.069)</td>
<td></td>
<td>(0.140)</td>
</tr>
<tr>
<td>$\Delta p_{t-4}$</td>
<td>0.208</td>
<td>-</td>
<td>-0.018</td>
</tr>
<tr>
<td></td>
<td>(0.062)</td>
<td></td>
<td>(0.087)</td>
</tr>
<tr>
<td>$\Delta p_{mt}$</td>
<td>0.0653</td>
<td>0.0637</td>
<td>0.0637</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
<td>(0.0136)</td>
<td>(0.014)</td>
</tr>
<tr>
<td>$\Delta p_{mt-1}$</td>
<td>0.0267</td>
<td>0.0283</td>
<td>0.0284</td>
</tr>
<tr>
<td></td>
<td>(0.0194)</td>
<td>(0.0166)</td>
<td>(0.018)</td>
</tr>
<tr>
<td>$RLE_t \Delta p_{t+1}$</td>
<td>-</td>
<td>0.850</td>
<td>1.089</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.045)</td>
<td>(0.384)</td>
</tr>
<tr>
<td>$Cap_t$</td>
<td>0.0732</td>
<td>0.086</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td>(0.0202)</td>
<td>(0.023)</td>
<td>(0.024)</td>
</tr>
</tbody>
</table>
### Phillips Curve Equation: 1966Q1-2007Q2 - Diagnostics

<table>
<thead>
<tr>
<th>Model</th>
<th>Backward</th>
<th>Learning</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adj.$R^2$</td>
<td>0.717</td>
<td>0.732</td>
<td>0.727</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.538%</td>
<td>0.524%</td>
<td>0.529%</td>
</tr>
<tr>
<td>D.W.</td>
<td>2.00</td>
<td>2.00</td>
<td>1.98</td>
</tr>
<tr>
<td>AR(4)(χ²(4))</td>
<td>1.33</td>
<td>0.63</td>
<td>0.34</td>
</tr>
<tr>
<td>RESET(χ²(2))</td>
<td>2.82</td>
<td>1.33</td>
<td>1.86</td>
</tr>
<tr>
<td>ARCH(χ²(4))</td>
<td>5.14</td>
<td>7.07</td>
<td>6.86</td>
</tr>
<tr>
<td>HETERO(Pval)</td>
<td>0.21</td>
<td>0.02**</td>
<td>0.05*</td>
</tr>
<tr>
<td>Normality(χ²(2))</td>
<td>105.49***</td>
<td>91.38***</td>
<td>96.23***</td>
</tr>
<tr>
<td>Slope (χ²(1))</td>
<td>1.89</td>
<td>2.01</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:** Newey-West standard errors in parentheses. AR(4): Breusch-Godfrey LM test for up to fourth order serial correlation. RESET: Ramsey’s reset test. Hetero: White’s Heteroscedascity test (excluding cross products). Normality: Jarque-Bera test. Slope refers to a test of the null hypothesis that the long-run Phillips curve is vertical.

* Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.

Turning to the issue of parameter stability. Table 7 shows the recursive Wald tests for both the backward and learning models. The backward looking model strongly fails all 3 versions of the test while the learning model passes all 3 versions. Therefore the key findings from the annual data hold up using more recently quarterly data.
Table 7  Wald Tests for Structural Change: Postwar Sample

<table>
<thead>
<tr>
<th></th>
<th>Backward Looking</th>
<th></th>
<th>Learning Model</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wald Test</td>
<td>5% Critical Value</td>
<td>Value</td>
<td>5% Critical Value</td>
</tr>
<tr>
<td>Maximum</td>
<td>22.13(a)</td>
<td>39.59</td>
<td>18.35(d)</td>
<td>15.52</td>
</tr>
<tr>
<td>Average</td>
<td>12.94(b)</td>
<td>13.85</td>
<td>9.01(e)</td>
<td>4.27</td>
</tr>
<tr>
<td>Exponential</td>
<td>8.60(c)</td>
<td>15.96</td>
<td>6.13(f)</td>
<td>3.46</td>
</tr>
</tbody>
</table>

Notes:
(a) Critical value from (Andrews, 1993), Table 1, p=8, \( \pi_0 = 0.15 \)
(b) Critical value from (Andrews and Ploberger, 1994), Table II, p=8, \( \pi_0 = 0.15 \)
(c) Critical value from (Andrews and Ploberger, 1994), Table I, p=8, \( \pi_0 = 0.15 \)
(d) Critical value from (Andrews, 1993), Table 1, p=5, \( \pi_0 = 0.15 \)
(e) Critical value from (Andrews and Ploberger, 1994), Table II, p=5, \( \pi_0 = 0.15 \)
(f) Critical value from (Andrews and Ploberger, 1994), Table I, p=5, \( \pi_0 = 0.15 \)

Sample is from 1966Q1 to 2007Q2 with 15% trimming.

While these results are obtained assuming that firms use an AR(4) model of inflation to produce their forecasts, similar results are obtained if instead they are assumed to use an adaptive expectations process with a time-varying coefficient. Results from estimating a version of this model are contained in an appendix to this paper.

---

Learning Models, Real Interest Rates & Aggregate Demand

In order to further test this model of expectations formation, a standard backward looking New Keynesian aggregate demand curve was estimated over the period from 1984Q1 to 2007Q2. The dependent variable is the capacity utilisation series discussed above. The two explanatory variables are the real interest rate and the real exchange rate adjusted for the terms of trade (\( RXR \)). This later variable was constructed using the residuals from a regression of the real exchange rate on an index of real commodity prices. The nominal interest rate used in the equation is the 90 day bank bill yield (\( R90 \)).

The first column in Table 8 shows the results from estimating the aggregate demand equation using real interest rates calculated using the lagged annual inflation rate. The second column shows the results from the same equation, but using inflation expectations generated via the recursive learning approach. Both equations fit the data equally well with both the real interest rate and the exchange rate variables significant and correctly signed. However the third column shows that, when both real interest rate measures are included in the same equation, the backward looking measure has the incorrect sign.

Therefore it seems that the recursive learning approach provides a better measure of inflation expectations in this case as well.
Table 8  Aggregate Demand: 1984Q1-2007Q2

<table>
<thead>
<tr>
<th>Dependent Variable : $Cap_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong> : Backward Learning Combined</td>
</tr>
<tr>
<td><strong>Constant</strong></td>
</tr>
<tr>
<td>(0.155)</td>
</tr>
<tr>
<td>$Cap_{t-1}$</td>
</tr>
<tr>
<td>(0.032)</td>
</tr>
<tr>
<td>$r90_{t-2} - \Delta p_{t-2}$</td>
</tr>
<tr>
<td>(0.034)</td>
</tr>
<tr>
<td>$r90_{t-2} - RLE_t \Delta p_{t-2}$</td>
</tr>
<tr>
<td>(0.032)</td>
</tr>
<tr>
<td>$RXR_{t-1}$</td>
</tr>
<tr>
<td>(0.011)</td>
</tr>
<tr>
<td><strong>Adj. $R^2$</strong></td>
</tr>
<tr>
<td><strong>S.E.</strong></td>
</tr>
<tr>
<td><strong>D.W.</strong></td>
</tr>
<tr>
<td><strong>AR(4)(\chi^2(4))</strong></td>
</tr>
<tr>
<td><strong>RESET(\chi^2(2))</strong></td>
</tr>
<tr>
<td><strong>ARCH(\chi^2(4))</strong></td>
</tr>
<tr>
<td><strong>HETERO(Pval)</strong></td>
</tr>
<tr>
<td><strong>Normality(\chi^2(2))</strong></td>
</tr>
</tbody>
</table>

* Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.

Implications For Monetary Policy

The degree of inflation inertia has important implications for monetary policy. A high degree of credibility means that inflation expectations are ‘anchored’ around the target rate and will not respond to changes in the actual inflation rate. Inflation will not be very persistent and shocks will rapidly dissipate without the need for a monetary policy response.

Low credibility means that expectations are not anchored. Firms view inflation as being close to a random walk. Expected inflation will fully reflect the current inflation rate, generating a high degree of persistence. Shocks to the inflation rate will not dissipate and will require a significant monetary policy response. Therefore the trade-off between inflation and output stability will worsen.
To illustrate these ideas using a simple model, consider the New-Keynesian Phillips curve:

\[ \pi_t = \pi_t^e + \beta Q_t + \varepsilon_t \]  \hspace{1cm} (8)

Also assume that the central bank’s target inflation rate is zero and that expected inflation evolves according to:

\[ \pi_t^e = \alpha \pi_{t-1} \]  \hspace{1cm} (9)

Substituting Equation 9 into Equation 8 gives:

\[ \pi_t = \alpha \pi_{t-1} + \beta Q_t + \varepsilon_t \]  \hspace{1cm} (10)

Depending on the value of \( \alpha \), this incorporates the two extremes of high and low credibility. If \( \alpha = 1 \), then credibility is low and expected inflation will be equal to last period’s inflation rate. On the other hand if \( \alpha = 0 \), then credibility is high and expectations are fully anchored at the target rate of zero.

Also assume that the central bank can effectively target the level of the output gap. The central bank’s objective is to set the target level of the output gap so as to minimise the variance of output and inflation. Since there is only one state variable in this model (the rate of inflation), monetary policy can be described by a monetary policy response function that relates the output gap to lagged inflation:

\[ Q_t = -\gamma \pi_{t-1} \]  \hspace{1cm} (11)

Combining Equations 8, 9 and 11 gives the reduced form for the inflation process:

\[ \pi_t = \alpha \pi_{t-1} + \beta Q_t + \varepsilon_t \]  \hspace{1cm} (12)

\[ = \alpha \pi_{t-1} - \beta \gamma \pi_{t-1} + \varepsilon_t \]  \hspace{1cm} (13)

\[ = (\alpha - \beta \gamma) \pi_{t-1} + \varepsilon_t \]  \hspace{1cm} (14)

Therefore the long-run variances of inflation and the output gap are given by:

\[ \sigma^2_\pi = \frac{\sigma^2_\varepsilon}{1 - (\alpha - \beta \gamma)^2} \]  \hspace{1cm} (15)

\[ \sigma^2_Q = \frac{\gamma^2 \sigma^2_\varepsilon}{1 - (\alpha - \beta \gamma)^2} \]  \hspace{1cm} (16)
These two equations describe the trade-off between output and inflation stability. In general a more aggressive response to inflation, as represented by a higher absolute value for $\gamma$, will reduce inflation variability (up to the value where $\gamma = \frac{\alpha}{\beta}$). However this will worsen output variability (since $\gamma^2$ appears in the numerator for the expression for the variance of output).

Higher values for inflation persistence $\alpha$ will increase both inflation and output variability, worsening the trade-off between the two objectives. Therefore to the extent that higher credibility results in a more effective 'anchoring' of inflation expectations and therefore a lower value of $\alpha$, both output and inflation stability will improve.

If $\alpha = 0$, so that there is perfect credibility, then the Phillips curve collapses to:

$$\pi_t = \beta Q_t + \varepsilon_t$$  \hspace{1cm} (17)

Therefore optimal policy is simply to set the target output gap to zero and not respond to inflation at all. In this case the variance of the output gap will be zero while the variance of inflation will be $\sigma^2_{\varepsilon}$.

On the other hand if credibility is low, such that $\alpha = 1$, the Phillips curve collapses to:

$$\pi_t = \pi_{t-1} + \beta Q_t + \varepsilon_t$$  \hspace{1cm} (18)

In this case setting the output gap to zero, which is the optimal policy under high credibility, will be disastrous. The actual rate of inflation will become a random walk and therefore will have an infinite long run variance.

This sort of formulation may therefore help to explain why both inflation and output volatility rose during the 1970s and 1980s, as credibility fell and then why both improved following the introduction of inflation targeting.

This framework may also help to explain the large and sustained rise in inflation during the 1970s and 1980s. Although Australia had experienced high inflation in the past, these episodes were either brief (following the discovery of gold in the 1850s) or occurred during wartime. The experience during the 1970s and 1980s represents the only major period of high ongoing inflation during peacetime.

A key feature of this period was the initially slow response of interest rates to the rise in inflation. Figure 5 shows how between 1970 and 1975 inflation rose from 3% to 16% while interest rates (apart from a brief spike during the 'credit crunch' of 1974) rose to only 10%. Therefore the rise in inflation resulted in a substantial decline in real interest rates.
It was not until the early 1980s that nominal interest rates had risen by enough to produce higher than average real interest rates, starting a very gradual downward trend in the inflation rate.

Figure 6 shows a scatterplot of the same data between 1966Q1 and 1980Q1. In general over this period a 1 percentage point rise in the annual inflation rate was associated with only a 0.5 percentage point rise in the nominal interest rate.

Figure 7 shows that this relationship strengthened during the 1980s and 1990s with interest rates now typically rising more than the inflation rate.

Interestingly, Figure 8 shows that the latest decade of data suggests that the response of interest rates to inflation has fallen again.

Therefore one explanation for Australia’s ‘Great Inflation’ is that, during the Bretton Woods period, inflation expectations were relatively well anchored. Policy only had to respond modestly to inflation shocks. During the early 1970s, policymakers gradually lost credibility. However if they were slow to realise this, then they would have kept responding to inflation shocks in the same modest way that had been successful during the 1950s and 1960s. Only when inflation remained persistently high during the late 1970s and early 1980s would they have come to realise that they had to adopt a more aggressive policy.

Policy then became more and more aggressive until credibility was eventually re-established during the early 1990s so that the monetary authorities could revert
Figure 6  Inflation & Interest Rates: 1966Q1-1980Q1

R90 vs. Inflation

Figure 7  Inflation & Interest Rates: 1980Q2-1997Q1

R90 vs. Inflation
to a somewhat more passive stance.

In order to see whether changes in the inflation persistence, driven by the recursive learning approach described above, a small optimising model of monetary policy is used. This is based on the standard linear-quadratic optimal policy problem.

The first step is to assume that the central bank has a quadratic loss function defined over state variables, \( x_t \) and the control variable(s) \( u_t \):

\[
L_t = x_t'Rx_t + u_t'Qu_t
\]  
(19)

Its objective is to set policy so as to minimise the discounted value of current and expected future losses:

\[
\min E_t \sum_{t=0}^{\infty} \delta^t L_t
\]  
(20)

Optimisation is carried out subject to the following law of motion for the state variables:

\[
A_0 x_{t+1} = A_1 x_t + B_0 u_t + \varepsilon_{t+1}
\]  
(21)

which has the following reduced form:
\[ x_{t+1} = Ax_t + Bu_t + \bar{\epsilon}_{t+1} \quad (22) \]

To solve this problem first substitute the law of motion for the next period’s state

\[ x' Rx = - \max_u \{ x' Rx + u' Qu + \delta(Ax + Bu)' R(Ax + Bu) \} \quad (23) \]

The first order condition for a solution is:

\[ \delta(Q + \delta B' PB)^{-1} u = -B' PAx \quad (24) \]

where \( P \) is a unique symmetric negative semi-definite matrix that defines the value function \( V(x) \) as \( x' P x \) with a discount factor \( \delta \). Solving for \( u \):

\[ u = -\delta(Q + \delta B' PB)^{-1} B' PAx \quad (25) \]

This specifies how to set the policy instrument as a linear function of the state variables. Define the optimal rule as:

\[ u = -Fx \quad (26) \]

\[ F = -\delta(Q + \delta B' PB)^{-1} B' PA \quad (27) \]

Substituting the optimal rule 25 back into the value function 23 gives the Riccati equation:

\[ P = R + A' PA - A' PB(Q + B' PB)^{-1} B' PA \quad (28) \]

The matrix \( P \) has a unique solution that can be solved by iterating:

\[ P_{j+1} = R + A' P_j A - A' P_j B(Q + B' P_j B)^{-1} B' P_j A \quad (29) \]

\( P \) can then be used to solve for \( F \) in the policy rule and then substituted back into the law of motion for the state variable:

\[ x_{t+1} = Ax_t + Bu_t + \bar{\epsilon}_{t+1} \quad (30) \]

\[ = (A - BF)x_t + \bar{\epsilon}_{t+1} \quad (31) \]

This process can be applied to derive a Taylor Rule by allowing the loss function to depend on the capacity utilisation rate, the inflation rate relative to its target level and the variance of changes in the nominal interest rate. It is assumed that
the target capacity utilisation rate is zero (its mean value):

\[ L_t = (q_t)^2 + \lambda_1(\pi_t - \pi^*)^2 + \lambda_2(r90_t - r90_{t-1})^2 \quad (32) \]

Therefore the matrix R is given by:

\[
R = \begin{bmatrix}
1 & 0 \\
0 & \lambda_1
\end{bmatrix}
\quad (33)
\]

where \( \lambda_1 \) denotes the relative weight placed on inflation relative to output.

The equations used to describe the evolution of the state variables are the Phillips Curve and the aggregate demand equations described above.

\[
\pi_{t+1} = a_1\pi_t + a_2\pi_{t-1} + a_3\pi_{t-2} + a_4\pi_{t-3} + a_5\Delta pm_t + a_6\Delta pm_{t-1} + a_7Q_t + \varepsilon_{t+1} \quad (34)
\]

\[
Q_{t+1} = b_1Q_t + b_2\left(i_{t-1} - \frac{1}{(1 - a_5 - a_6)}(a_1\pi_{t-1} + a_2\pi_{t-2} + a_3\pi_{t-3} + a_4\pi_{t-4})\right) + b_3.RXR_t + \varepsilon_{t+1}^Q \quad (35)
\]

The model is closed by specifying AR(1) models for the evolution of the real exchange rate variable and the growth in import prices.

\[
RXR_{t+1} = c_1RXR_t + \varepsilon_{t+1}^{RXR} \quad (36)
\]

\[
\Delta pm_{t+1} = d_1\Delta pm_t + \varepsilon_{t+1}^{pm} \quad (37)
\]

In matrix form, the state variables evolve according to:

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & -a_5 & -a_7 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
\pi_{t+1} \\
\pi_t \\
\pi_{t-1} \\
\pi_{t-2} \\
\pi_{t-3} \\
\Delta pm_{t+1} \\
Q_{t+1} \\
RXR_{t+1} \\
i_t \\
i_{t-1} \\
i_{t-2}
\end{bmatrix}
\]
Calibration of the model is based on the estimated coefficients from the above regressions. The impact of the output gap on inflation \((a_7)\) is set at 0.1. The impact of current and lagged import prices on inflation \((a_5 \text{ and } a_6)\) are set equal to 0.06 and 0.03 respectively. The impact of lagged inflation is assumed to differ according to whether credibility is high (as in the 1960s and post 1993 periods) or low (as during the 1970s and 1980s). In the high credibility periods, inflation persistence is modest and therefore the 4 parameters \((a_1 \text{ to } a_4)\) are each assumed to equal 0.1 (giving a sum of 0.4). In the low credibility period, they are assumed to have coefficients of 0.2 (giving a sum of 0.8).

There is a high degree of persistence in the output gap so the coefficient on the lagged output gap \((b_1)\) is set to 0.9. The interest rate coefficient is \((b_2)\) is set to -0.15, implying that in the long-run a 1 percentage point rise in interest rates reduces output by 1.5 percent. The coefficient on the real exchange rate \((b_3)\) is -0.03, implying that in the long run a 10% real appreciation will (holding
commodity prices constant), reduce output by 3 percent.

The AR(1) coefficients on the real exchange rate \((c_1)\) and import prices \((d_1)\) are set at 0.8 and 0.33 respectively, based on simple AR(1) models estimated over the period.

This still leaves the preference parameters in the loss function. It was assumed for simplicity that the weights on output, inflation and interest rate volatility were all equal.

Table 9 shows the implied optimal Taylor Rule coefficients on each of the state variables in the high and low credibility environments. This indicates that the optimal response of policy to a change in the inflation rate more than doubles when the monetary authority realises that it is in a low credibility environment. The last row of the table shows the implied long run response to inflation (after accounting for the presence of a lagged dependent variable).

This shows that in the high credibility periods, a long run response of only 0.42 is necessary to a change in inflation. This is quite close to that actually observed in the above charts. In contrast, low credibility periods require a much stronger response of around 1.22, which is also quite close to that actually observed during the 1980s and early 1990s.
This suggests that the actual changes in at least one aspect of the behavior of monetary policy may be explained as the optimal response of the monetary authorities to changing credibility. Therefore it is possible to explain one of the key features of changing monetary policy over this period without having to resort to assuming changes in preferences or other factors.

**Conclusions**

This paper has compared two different approaches to modelling expected inflation in a Phillips curve. The long run of historical data indicate that the traditional approach does not provide a good explanation for the data. In particular the degree of inertia implied by the Phillips curve varies over time. Once firms are assumed to form their expectations according to a perpetual learning framework, there is little evidence of any remaining inflation inertia. This means that inflation inertia is the outcome of the underlying monetary policy regime rather than an intrinsic feature of the data.

An advantage of this approach to modelling the inflation data is that, not only does it seem to provide a better overall fit, but it also produces a framework in which changes in policy can be linked, via changes in ‘credibility’ to changes in the inflation process and therefore overall macroeconomic performance.

Further improvements could include more general models of expectations formation including extending the information set available to agents to include other data such as by using a small VAR model of the economy. Finally while it seems clear that a learning model provides a better fit to the data than a pure backward looking model, it remains to be tested against a pure forward looking or rational expectations model of inflation.

Finally there is some encouraging evidence that variations in policy credibility and the subsequent policy response could, at least in part, explain why Australia’s macroeconomic performance and monetary policy changed so much over the past four decades.
Appendix: Adaptive Expectations

While the learning model discussed above assumed that firms used an AR(4) model of inflation to produce forecasts, there is a long history of modelling inflationary expectations through adaptive expectations framework, that is:

\[ E_t \pi_{t+1} = (1 - \theta) \pi_t + \theta E_{t-1} \pi_t \]  (39)

Adaptive expectations are optimal if inflation follows an ARIMA(0,1,1) process. This is sometimes termed the random walk plus noise or Local Level Model. This model assumes that the inflation rate is composed of two components, a trend \( \pi_t \), which evolves according to a random walk and a random component, \( \varepsilon_t \).

\[ \pi_t = \pi_{t-1} + \eta_t \]  (40a)
\[ \pi_t = \pi_t + \varepsilon_t \]  (40b)

\[ \varepsilon_t \sim NID(0, \sigma^2) \]  (41)
\[ \eta_t \sim NID(0, \sigma^2_\eta) \]  (42)
\[ cov(\varepsilon_t, \eta_t) = 0 \]  (43)

The unobserved trend in inflation can be thought of as the underlying inflation target of the central bank while the random component can be thought of as the influence transitory factors like changes in food or energy prices or other shocks. The objective of the public is therefore to filter the inflation data to uncover the current target inflation rate.

There are two extremes implied by this model depending on the variances of the two shocks.

- if \( \eta_t = 0 \), there are no shocks to the trend level of inflation. Therefore trend inflation is constant and the best forecast is the sample mean.
- if \( \varepsilon_t = 0 \), the transitory component is zero and therefore inflation evolves according to a random walk in which case the best forecast is the current inflation rate.

Taking first differences of equation \( E_t \) gives:
\[
\Delta \pi_t = \eta_t + \varepsilon_t - \varepsilon_{t-1} \tag{44}
\]

\[
\Delta \pi_t = u_t - \theta u_{t-1} \tag{45}
\]

where

\[
\theta = \left[ \frac{\sqrt{q^2 + 4q} - 2 - q}{2} \right] \tag{46}
\]

where \( q \) represents the signal to noise ratio:

\[
q = \frac{\sigma^2_y}{\sigma^2_\varepsilon} \tag{47}
\]

This model can be used to derive the adaptive expectations approach through the following steps:

\[
\Delta \pi_t = u_t - \theta u_{t-1} \tag{48}
\]

\[
E_t \pi_{t+1} = \pi_t + E_t(u_t - \theta u_{t-1}) \tag{49}
\]

\[
= \pi_t - \theta u_{t-1} \tag{50}
\]

\[
= \pi_t - \theta(\pi_t - E_{t-1} \pi_t) \tag{51}
\]

\[
= (1 - \theta) \pi_t + \theta E_{t-1} \pi_t \tag{52}
\]

This has an attractive property in that there is a natural measure of central bank credibility when this is defined as the impact of a change in current inflation on forecast inflation. In particular,

\[
\frac{\partial E_t \pi_{t+n}}{\partial E_t \pi_t} = \theta, \forall n \tag{53}
\]

In this case the speed at which expected inflation adjusts to current inflation is determined by the parameter \( \theta \) which can be thought of as the inverse of central bank 'credibility'. If \( \theta = 1 \), then expectations are effectively 'anchored' and therefore unaffected by current inflation developments. Conversely, if \( \theta = 0 \), then inflation is forecast as a random walk. Time variation in \( \theta \) was allowed for by using a rolling 15 year window. The results were much the same as for the AR(4) learning model - the model fit the data marginally better than the backward looking model while adding lagged inflation did not significantly improve the overall fit. However the model did fit the data slightly worse than the AR(4) model. Estimation results are in Table 10.
Table 10  Phillips Curve: Adaptive Exectations

<table>
<thead>
<tr>
<th>Dependent Variable : $\Delta p_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model :</td>
</tr>
<tr>
<td>Adaptive</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta p_{t-1}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta p_{t-2}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta p_{t-3}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta p_{t-4}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta pm_t$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$\Delta pm_{t-1}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$RLE_t \Delta p_{t+1}$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$Capt_t$</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Table 11  Phillips Curve: Adaptive Expectations 1966Q1-2007Q2 - Diagnostics

<table>
<thead>
<tr>
<th>Model</th>
<th>Adaptive</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adj. $R^2$</td>
<td>0.729</td>
<td>0.724</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.526%</td>
<td>0.532%</td>
</tr>
<tr>
<td>D.W.</td>
<td>1.92</td>
<td>1.96</td>
</tr>
<tr>
<td>$AR(4)(\chi^2(4))$</td>
<td>1.40</td>
<td>1.75</td>
</tr>
<tr>
<td>RESET(\chi^2(2))</td>
<td>0.71</td>
<td>1.06</td>
</tr>
<tr>
<td>ARCH(\chi^2(4))</td>
<td>4.58</td>
<td>4.56</td>
</tr>
<tr>
<td>HETERO(Pval)</td>
<td>0.02**</td>
<td>0.01**</td>
</tr>
<tr>
<td>Normality(\chi^2(2))</td>
<td>94.88***</td>
<td>100.05***</td>
</tr>
<tr>
<td>Slope (\chi^2(1))</td>
<td>0.36</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: Newey-West standard errors in parentheses. $AR(4)$: Breusch-Godfrey LM test for up to fourth order serial correlation. RESET: Ramsey's reset test. Hetero: White's Heteroscedascity test (excluding cross products). Normality:Jarque-Bera test. * Significant at 10% level, ** Significant at 5% level, *** Significant at 1% level.
Appendix: Data Sources

All data are annual averages based on a financial year ended 30 June after 1901. Prior data are calendar year averages.

Inflation

From 1948 to 2006 inflation is measured by the Consumer Price Index (ABS Cat. 6401.0) For the purposes of this paper an ‘Adjusted’ Headline inflation rate was calculated. The objective of this measure is to eliminate the major problems with the headline CPI while still maintaining most of the items in the basket. Therefore 3 types of adjustment are made to the headline CPI:

- a downward adjustment of 3% in the September quarter of 2000 for the introduction of the GST;
- several adjustments for the major changes in Medibank/Medicare; and
- an adjustment for conceptual problems associated with the (temporary) introduction of mortgage interest charges in the 1980s.

The adjustments for the major changes in the Medibank/Medicare system are based on the difference between the quarterly increase in the headline CPI and the CPI excluding healthcare in the quarters in which there was a major change in the Medibank/Medicare system. This data is shown in Table 12.

<table>
<thead>
<tr>
<th>Date</th>
<th>CPI All Groups</th>
<th>CPI ex. Healthcare</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 1975</td>
<td>0.70%</td>
<td>2.82%</td>
<td>-2.12%</td>
</tr>
<tr>
<td>December 1976</td>
<td>5.66%</td>
<td>2.68%</td>
<td>2.98%</td>
</tr>
<tr>
<td>December 1981</td>
<td>4.20%</td>
<td>2.90%</td>
<td>1.30%</td>
</tr>
<tr>
<td>March 1984</td>
<td>-0.46%</td>
<td>1.24%</td>
<td>-1.70%</td>
</tr>
<tr>
<td>June 1984</td>
<td>0.31%</td>
<td>1.22%</td>
<td>-0.92%</td>
</tr>
</tbody>
</table>

The justification for excluding these changes is the they reflect changes in the manner in which a service is funded rather than true price changes.

In 1986 the ABS introduced mortgage and consumer interest charges into the CPI. Interest charges were measured as the product of the nominal interest rate and, in the case of mortgages, an asset (house) price. The reason for including these charges is difficult to understand because they measure the cost of financing an asset purchase rather than the purchase price. Therefore between 1986
and 1998 (when interest charges were removed from the CPI), the CPI excluding interest charges is used.

From 1914 to 1948, the data are from (Bambrick, 1973). From 1850 to 1914 the data are from (McLean, 1999), series W6.

**Unemployment**

The unemployment rate is from ABS Cat. 6202.0. Between 1966 and 1978 (when the new Labour Force survey was introduced), the series were obtained from the publication *Seasonally Adjusted Indicators 1979*, Cat. 1308.0. Earlier data from 1861 are from (Glenn Withers and Perry, 1985), Series A, Table D. Finally data from 1856 to 1861 are from (Buckley, 1967), Index II, Table 1.

**Import Prices**

The implicit price deflator for imports is obtained from the Annual National Accounts (ABS Cat. 5204.0) from 1960 onwards. From 1901 to 1960, the source is (Butlin, 1977). From 1870 to 1901, the source is (Butlin, 1985). To estimate import prices from 1860 to 1870, it is assumed that movements in Australia’s import prices reflected changes in UK export prices, adjusted for a 3 month shipping lag. The source for UK export prices is (Mitchell, 1988).

**Capacity Utilisation**

This was sourced from the ACCI/Westpac *Survey of Industrial Trends*. It is the net balance of respondents who report operating at above normal capacity. It is demeaned by subtracting the average level of -0.19%
References


