Reserve Bank of Australia

RESEARCH DISCUSSION PAPER

Modelling Inflation in Australia

David Norman and Anthony Richards

RDP 2010-03

MODELLING INFLATION IN AUSTRALIA

David Norman and Anthony Richards

Research Discussion Paper
2010-03

June 2010

Economic Analysis Department
Reserve Bank of Australia

We would like to thank Dougal Crawford for his contribution to the early stages of this work, Adam Cagliarini, Adrian Pagan and Tim Robinson for their advice, and David Jennings for his assistance with forecast comparisons. We also thank Jacqui Dwyer, Alex Heath, Jarkko Jääskelä, Mariano Kulish, John Simon and Anders Vredin for their comments. Responsibility for any remaining errors rests with us. The views expressed in this paper are those of the authors and are not necessarily those of the Reserve Bank of Australia.

Authors: normand or richardsa at domain rba.gov.au

Media Office: rbainfo@rba.gov.au

Abstract

This paper estimates a range of single-equation models of inflation for Australia. We find that traditional models, such as the expectations-augmented standard Phillips curve or mark-up models, outperform the more micro-founded New-Keynesian Phillips curve (NKPC) in explaining trimmed mean inflation, both in terms of in-sample fit and significance of coefficients. This in large part reflects the weak instruments problem in the estimation of the NKPC, and is partly corrected by including a direct measure of inflation expectations, but we still find that the unemployment rate or growth in marginal costs (unit labour cost and import prices) provides a better fit than either the output gap or level of real marginal costs. These traditional models also perform well in out-of-sample tests, relative to alternative models and some common benchmarks, with the standard Phillips curve clearly superior to these benchmarks on this test. As inflation has become better anchored and hence less variable, the magnitude of the errors of the single-equation models has declined, although the explanatory power (in terms of R-squared) has fallen together with this greater stability. We also investigate the empirical importance of some other variables that are commonly cited as determinants of inflation, and find little evidence that either commodity prices or the growth rate of money directly influence Australian underlying inflation.

JEL Classification Numbers: C53, E31

Keywords: inflation, modelling

Table of Contents

MODELLING INFLATION IN AUSTRALIA

David Norman and Anthony Richards

1. Introduction

Central banks in most advanced economies now operate with some form of either explicit or implicit inflation target, with the Reserve Bank of Australia (RBA) operating under such a framework since 1993. A natural result of this change has been an increased interest among central banks and academics in research about the inflation process.

These efforts have resulted in a large number of different models for inflation, which vary in terms of scale, and in terms of the variables assumed to drive inflation (including the output gap, unemployment rate or unit labour costs). At the RBA, a variety of approaches are used to model inflation, including single-equation models (such as that in de Brouwer and Ericsson 1995), VAR models (Gerard and Nimark 2008), factor models (Gillitzer and Kearns 2007; Gerard and Nimark 2008) and DSGE models (Jääskelä and Nimark 2008). While there are advantages to systems approaches to modelling inflation, single-equation models can also be very useful due to their simplicity. This paper outlines the broad structure of three types of single-equation models that are used as part of an array of models at the RBA: a standard Phillips curve; a New-Keynesian Phillips curve; and a mark-up model.

We find that the single-equation model approach has performed relatively well in terms of both modelling and forecasting inflation over the past two decades, with equal or better in-sample and out-of-sample performance than some standard benchmarks and VAR models. The standard errors surrounding the model predictions have also fallen since the introduction of inflation targeting. However, it is notable that the explanatory power – in terms of adjusted R-squared – of these equations has also declined over this time as inflation has become more stable. Of the three models studied, the standard Phillips curve has performed best over this time but the results from an expectations-augmented mark-up model are broadly comparable. In contrast, the New-Keynesian Phillips curve model fits the data relatively poorly, although most of this reflects issues with the use of generalised method of moments (GMM) to instrument for expected inflation, and the model fits reasonably well when we use a direct measure of inflation expectations instead. Our results show that either the unemployment rate alone, or a combination of growth in unit labour costs and the output gap help to explain the deviation of inflation from measures of inflation expectations in Australia, once we have controlled for import price shocks. After controlling for the variables discussed above, we find little role for some other variables – notably commodity prices, excess money growth – that have sometimes been suggested as important determinants of inflation.

A concern with these single-equation models, however, is that they do not impose many of the theoretical restrictions that would be standard in any structural model of inflation. For example, we find that imposing a restriction to ensure that the long-run Phillips curve is vertical results in a significant deterioration of fit for samples estimated since 1990. While there may be empirical issues or theoretical considerations that might explain this, such a result highlights the fact that reduced-form models such as those estimated in this paper are unlikely to perform well if inflation ever deviated persistently and substantially from target. Accordingly, it is appropriate to supplement the single-equation approach with results from more structural econometric models such as the Jääskelä-Nimark DSGE.

The remainder of this paper is structured as follows. The various models are introduced in Section 2, the empirical estimation is discussed in Section 3 and the results are presented in Section 4. In Section 5 we assess the role of various additional variables and coefficient restrictions that are suggested by the existing literature. Section 6 assesses the stability of these models over time and Section 7 concludes.

2. Modelling Structure and Theory

The literature identifies many ways to specify an inflation model. Setting aside the multi-equation and factor approaches discussed above, the structure of a single-equation inflation model can differ based on the variables assumed to drive inflation (most prominently, whether to use the output gap, the unemployment rate or marginal costs), how to model inflation expectations and whether to include foreign variables, among other considerations. Given this, we present variants of three types of inflation equations in this paper – both ‘standard’ and New-Keynesian Phillips curve models, and a mark-up model.

2.1 The ‘Standard’ or Expectations-augmented Phillips Curve

One category of inflation model is commonly referred to as the ‘standard’, or ‘expectations-augmented Phillips curve’ model. The original foundation for such models is the framework developed by Phillips (1958), which relates inflation to past and present values of some measure of resource utilisation such as the unemployment rate, so that reduced spare capacity contributes to higher inflation. Since the work of Milton Friedman, Edmund Phelps and others in the late 1960s and 1970s, it has been standard to augment this univariate relationship with inflation expectations, thereby avoiding the implication that there is a long-run trade-off between lower unemployment and higher inflation. Such models have been the workhorse of inflation modelling in a number of central banks over the past three decades.

Empirical estimates of the standard Phillips curve can be found in a multitude of papers. One fairly standard specification relates inflation to several years of lagged inflation (as a proxy for inflation expectations), the current unemployment gap and measures of recent supply shocks (such as the relative price of food, energy and imports). Examples of this type of model include Gordon (2005) and Brayton, Roberts and Williams (1999). A slightly different approach can be seen in papers such as Gruen, Pagan and Thompson (1999), which include a direct estimate of inflation expectations derived from the bond market.

Our specification follows this latter approach by directly including (bond market) inflation expectations. We also including the change in the unemployment rate to reflect ‘speed limit’ terms, and allow for only one supply shock – import price growth. However, our approach differs from Gruen *et al* (1999) in two respects. First, we do not allow for a time-varying non-accelerating inflation rate of unemployment (NAIRU) (although we assess the relevance of this simplification in Section 6). Second, we do not constrain our results to ensure a vertical long-run Phillips curve (although we consider the impact of this choice in Section 5.1). This results in the following standard Phillips curve model:

$$\pi_t = c + \beta E_{t-1}\pi_{t+s} + \chi\left(\frac{1}{ur_{t-i}} \right) + \sum_{j=1}^{J} \delta_j \Delta ur_{t-j} + \sum_{k=1}^{K} \gamma_k \Delta mp_{t-k} + \varepsilon_t \qquad (1)$$

Where: π, *ur* and *mp* represents inflation, the unemployment rate and import prices, respectively; Δ is the one-period change operator; and $E_{t-1}\pi_{t+s}$ represents expectations of inflation over the next *s* periods, formed in period $t-1$.

2.2 The New-Keynesian Phillips Curve

A second type of model that is widely used is the New-Keynesian Phillips curve (NKPC; see Galí and Gertler 1999, among others). This builds on the expectations-augmented Phillips curve by explicitly deriving the model from microeconomic relationships between capacity utilisation, costs, prices and nominal rigidities at the firm level. The resulting inflation equation then links the deviation of inflation from its expected level to either the output gap or real marginal cost.

The derivation of the closed economy version of the NKPC is now standard; interested readers should consult Galí (2008) for details. In an open economy setting, the derivation is similar except that it is appropriate to view consumer price inflation as determined by a weighted average of domestic and imported inflation, with the latter equal to the change in real import prices and the former determined as per the standard closed economy NKPC, but with marginal cost proxied by both real unit labour costs and real import prices.[1] The resulting open economy NKPC can then be expressed as:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda(ulc_t - p_t) + \gamma(mp_t - p_t) + \varphi\Delta(mp_t - p_t) + \varepsilon_t \qquad (2)$$

where: *ulc* and *mp* represent nominal unit labour costs and import prices (world prices, converted into domestic currency), respectively; *p* is the consumer price level; and all variables are expressed as deviations from steady state. In empirical work it is now also relatively standard to include a backward-looking inflation term in the NKPC to produce a 'hybrid' NKPC, drawing on the work of Fuhrer and Moore (1995).

1 The inclusion of both the level and change in real import prices allows for a general specification, whereby imports can be either consumption or intermediate goods.

An alternative specification is to use a measure of the output gap as a proxy for real unit labour costs, given that these are proportional under certain conditions (most notably that the capital stock is exogenously determined). However, it has been a point of considerable controversy as to whether including the output gap – defined as the deviation of actual GDP from its potential level – as the driving variable for inflation provides a better representation than other proxies for real marginal cost.[2] This may reflect the possibility that either the output gap is too imperfectly measured to be a useful proxy for real unit labour costs, or that the conditions under which they are proportional do not hold. We take an agnostic view on this debate and include both the output gap and real unit labour costs in our estimated equations. Theoretically this can be motivated by allowing the output gap to influence inflation (over and above its influence on unit labour costs) via either the cyclicality of non-wage costs (as in Leith and Malley 2007) or a procyclical effect on the mark-up of price over marginal cost (that is, firms may raise their mark-up over marginal cost when demand for their products is high).

As a result, our NKPC model can be specified as:

$$\pi_t = \beta E_t \pi_{t+1} + (1-\beta)\pi_{t-1} + \lambda rulc_t + \gamma rmp_t + \phi \Delta rmp_t + \chi ygap_t + \varepsilon_t \qquad (3)$$

where: *rulc*, *rmp* and *ygap* are real unit labour costs, real import prices and the output gap, respectively; and all variables are expressed as deviations from their sample means.

2.3 The Mark-up Model

Much of the previous Australian work on inflation modelling has tended to focus on mark-up models of inflation rather than the Phillips curve approach (see, for example, de Brouwer and Ericsson 1995, Heath, Roberts and Bulman 2004 and Bårdsen, Hurn and McHugh 2007). In this model, inflation is determined by current and lagged growth in unit labour costs and import prices, based on the theory that firms set their prices as a mark-up on costs, as in the NKPC. However, there has previously been little explicit allowance for forward-looking behaviour

2 Key players in this debate are Galí, Gertler and López-Salido (2005), who argue in favour of the marginal cost-based NKPC, and Rudd and Whelan (2005), who argue in favour of the (flex-price) output gap-based NKPC.

by firms in such models, and the presence of nominal rigidities has only been included implicitly by allowing for lags of input costs.

Nonetheless, it is straightforward to show that the NKPC can be rearranged to reflect an expectations-augmented mark-up model. Full details of this are available in Appendix A, but in short, this involves rearranging the NKPC so that it includes terms for the *growth* in *nominal* marginal costs. We also allow for the mark-up to be time-varying and positively related to the output gap. Given no change in the inflation target, this results in the following specification for inflation:

$$\pi_t = \alpha + \beta E_{t-1}\pi_{t+s} + \sum_{j=0}^{J}\lambda_j \Delta ulc_{t-j} + \sum_{k=1}^{K}\gamma_k \Delta mp_{t-k} + \chi ygap_t + \delta\Delta\pi_{t-1} + \varepsilon_t \qquad (4)$$

where the notation is as per Equations (1) and (3).[3]

3. Estimation

The estimation of these models raises a number of challenges both in terms of the dependent variable, the functional form (for example, the lag structures used in the regressions and the modelling of expectations) and the choice of particular variables used in the regressions.

3.1 Data

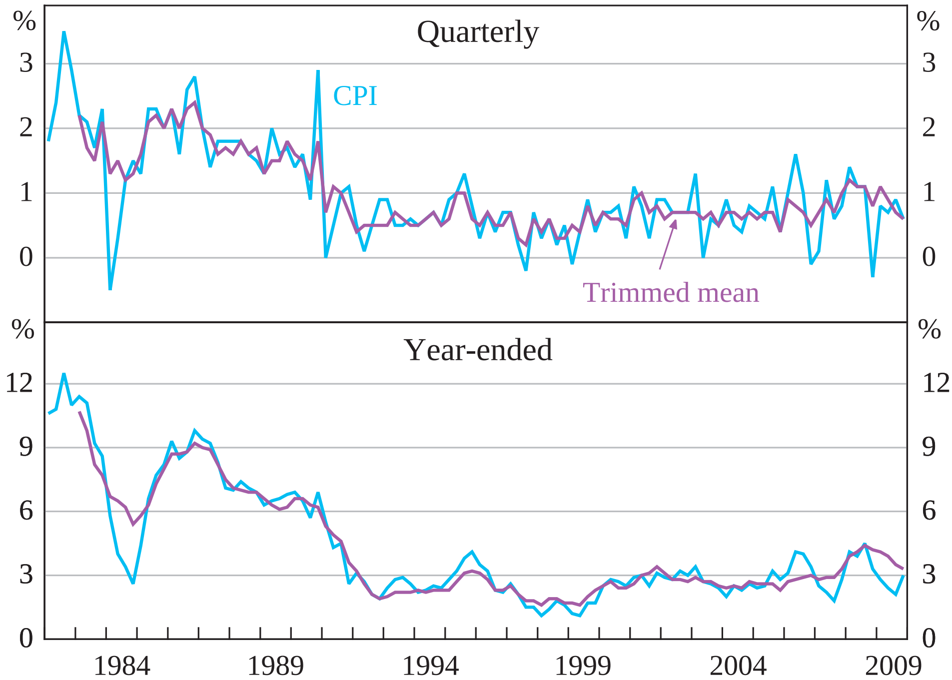
Empirical papers on inflation in different countries typically use headline measures of inflation (based on either the consumer price index or the household consumption price index). Instead, we use an underlying measure: quarterly trimmed mean inflation, where 15 per cent (by weight) of the CPI is trimmed from the upper and lower ends of the distribution of seasonally adjusted price changes in each quarter.[4] This measure is preferable to headline CPI since it provides a

3 Bårdsen *et al* (2007) argue that prices and real wages should be modelled as a system, to reflect the fact that wage growth is dependent on prices and hence endogenous in Equation (4). However, this should only be a serious econometric problem if the contemporaneous correlation is significant, which does not appear to be the case.

4 The measure of trimmed mean inflation is based on data which are adjusted for the impact of the tax changes of 1999–2000. Mortgage interest charges are omitted from the calculation of the trimmed mean prior to September 1998, and the deposit & loan facilities item is excluded from 2005.

measure of underlying inflation that abstracts from much of the noise in CPI inflation (Figure 1; see also Brischetto and Richards 2006).

Figure 1: Australian Inflation[(a)]



Note: (a) Excluding mortgage interest charges prior to September quarter 1998 and deposit & loan facilities prices since September 2005, and adjusted for the effects of tax changes of 1999–2000

Sources: ABS; RBA

Our measure of inflation expectations is derived from pricing in the bond market, and is calculated as the difference between standard and indexed bond yields at a maturity of approximately 10 years. (Alternative proxies are considered in Section 5.2, and some candidate measures are shown in Figure 2.) There are problems with this measure, including the fact that it includes any shifts in liquidity premia, its long duration (ideally we would use a one- or two-year-ahead expectation) and the fact that it is not directly observed from financial prices prior to 1993 (see Gruen, Robinson and Stone 2002).[5] However, there are no obviously superior measures and it proves to have some empirical explanatory power.

We estimate nominal unit labour costs as total labour costs divided by real GDP; we use this in preference to the measure published by the ABS which is affected by volatility in the estimate of self-employed income. For real unit labour costs, we

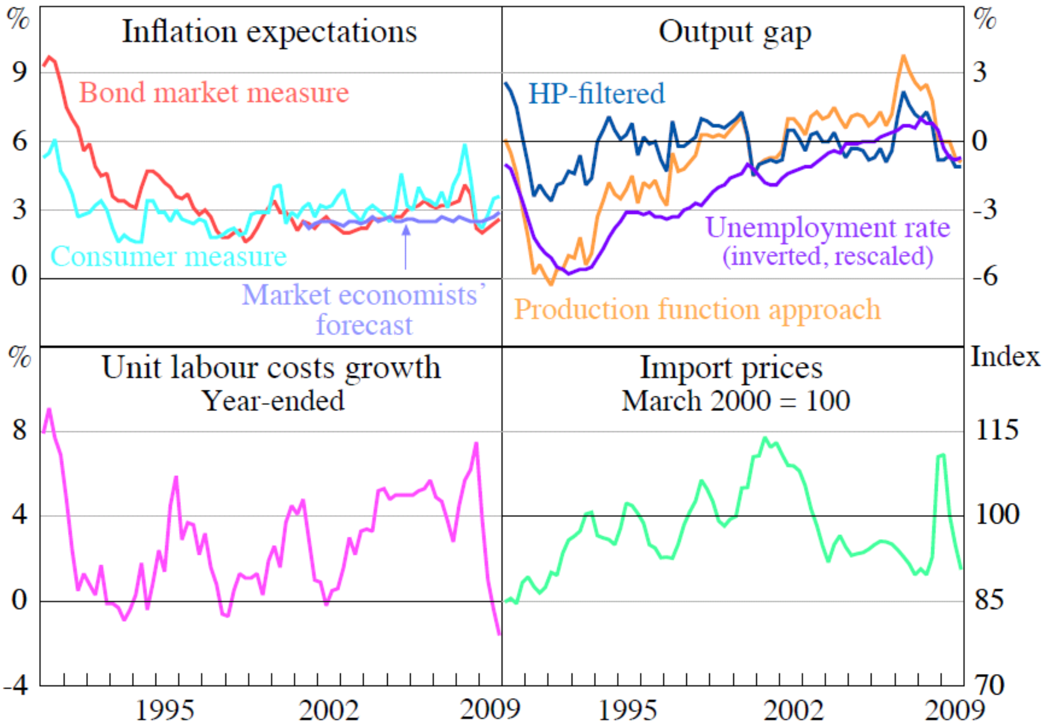
5 Prior to 1993, inflation expectations are estimated as the nominal bond yield less an assumed real bond yield based on data for other OECD countries (see Gruen *et al* 2002).

deviate from the practice in some of the US literature of using labour's share of total income, given the substantial influence that commodity prices have on the GDP deflator (and hence labour's share) in Australia. Instead, we calculate real unit labour costs by deflating nominal unit labour costs by trimmed mean inflation.

Data on import prices are in local currency and are sourced from the ABS balance of payments release, but are adjusted in three ways. First, we remove 'lumpy' imported goods (large one-off imports such as civil aircraft) and oil (due to its volatility) from the calculation to produce an underlying measure of import prices that is more likely to be representative of persistent economy-wide import prices. Second, as in some earlier papers, we remove automated data processing equipment imports due to concerns about the treatment of quality changes when measuring the prices of such imports. Third, we adjust the across-the-docks import price data to include the effect of changes in tariff rates.

Estimates of the output gap are based on a production function approach, in line with the practice favoured by the Organisation for Economic Co-operation and Development (OECD); although, broadly similar results are obtained when we use the capacity utilisation measure from the National Australia Bank business survey or a Hodrick-Prescott filtered output gap. The production approach calculates potential output growth as the weighted average of smoothed growth in the net capital stock and labour inputs (where the weight on each is the capital and labour share of total factor income, respectively) plus smoothed growth in multifactor productivity. This potential growth rate is then converted to a level of potential GDP by assuming that potential GDP was equal to actual GDP on average between 1998 and 2001 (in other words, that the output gap averaged zero over this time); the latter assumption has no effect on the regression results since the output gap is demeaned in each case.

Figure 2: Time Profile of the Determinants of Inflation



Sources: ABS; Melbourne Institute; RBA

Data for all these variables are sourced from the ABS, with the exception of trimmed mean inflation, which is from the RBA, and inflation expectations, which are from the RBA since 1993 and Gruen *et al* (2002) prior to that.[6] All data are included in log or log-differenced form, except the unemployment rate which is in levels.

The main estimation period is from the March quarter 1990 to the December quarter 2009. The rationale for excluding data prior to 1990 is that *a priori* there is the possibility of a structural break around the disinflation of the early 1990s and the introduction of inflation targeting in 1993. We find evidence in support of this (see Section 6), with rolling Chow tests clearly signalling a break in our inflation equation around March 1989 (particularly in the standard Phillips curve model). The decision to include data from 1990 rather than 1993 reflected a desire to use a slightly longer sample, including the recession at the start of the 1990s, which may improve our ability to accurately estimate coefficients.

6 Import prices are from the balance of payments release (ABS Cat No 5302.0); total labour costs and GDP are from the quarterly national accounts release (ABS Cat No 5206.0); and estimates of the capital stock and MFP are interpolated from the annual estimates published in ABS Cat No 5204.0.

3.2 Equation Specifications

The main choices regarding the specification are the appropriate econometric technique to use when estimating each equation, and whether to impose any constraints on the coefficient estimates. There are also questions about the appropriate specification of the lag structure for the right-hand-side variables. In particular, given that several of the variables are likely to feed through into inflation with relatively long lags, it is necessary to consider lag structures which preserve degrees of freedom.[7]

The approach we use is to estimate each model using various permutations, including in the way that lag structures are modelled. However, for simplicity, we present results from only one econometric specification for each type of model. Having decided on a method to preserve degrees of freedom, the exact lag length and whether to allow speed limit effects or not were chosen by minimising the Akaike information criteria (AIC).[8]

Using this approach leads us to adopt the following standard Phillips curve specification:

$$\pi_t = c + \beta E_{t-1}\pi_{t+s} + \chi\left(1 \big/ ur_{t-2} \right) + \delta\Delta^4 ur_{t-3} + \sum_{k=1}^{12}\gamma_k mp_{t-k} + \varepsilon_t \qquad (5)$$

where the coefficients on import prices (γ_k) are constrained to follow a quadratic polynomial function in order to preserve degrees of freedom. The inverse of the unemployment rate is included on account of it both providing the best fit and being theoretically consistent with an increasing effect on inflation from a given change in unemployment as it declines. Given the fact that the unemployment rate is reasonably persistent (both in level and four-quarter-change form), there is a

7 Approaches used in the inflation modelling literature include: (i) estimation of an unconstrained lag structure, with insignificant lags omitted based an on information criterion or some other testing strategy; (ii) inclusion of long lags but constraints on some of the coefficients to be the same, an approach followed by Robert Gordon in a number of papers, among others; and (iii) the assumption that lag coefficients follow a polynomial function (or Almon lags).

8 The AIC was used in preference to the Schwarz Bayesian information criterion – which more heavily penalises additional parameters – since we are more interested in finding the best-fitting model than in parsimony.

range of feasible lag selections which yield broadly similar results: here we include the unemployment rate with a two-quarter lag as suggested by the data (which may reflect the presence of nominal rigidities in both wage- and price-setting) and a lagged speed limit term as well. We include the prior period's expectation of future inflation to prevent estimation problems associated with endogeneity. Up to three years of lags of import price growth are selected by the AIC.[9] Lagged inflation is not found to be significant in this model and so is excluded from the estimation.

We estimate the NKPC using the GMM approach, as in Galí and Gertler (1999).[10] As instruments, we use four lags of inflation and two lags of real unit labour costs. We include only the current observation of the driving variables, so that our final specification is as in Equation (3). We also estimate the NKPC using direct measures of inflation expectations and ordinary least squares (OLS), as per Henzel and Wollmershäuser (2008), in order to avoid having to instrument for inflation expectations. For this specification, we include the prior period's expectation of future inflation and the first lag of all other variables to prevent endogeneity, and we do not constrain the coefficients on inflation and inflation expectations as per Equation (3), so that the specification is:

$$\pi_t = \beta E_{t-1}\pi_{t+s} + \rho\pi_{t-1} + \lambda rulc_{t-1} + \gamma rmp_{t-1} + \phi\Delta rmp_{t-1} + \chi ygap_{t-1} + \varepsilon_t \qquad (6)$$

The main decision when estimating the mark-up model is which econometric specification to use. An error correction specification has been popular in the past, given the theoretical long-run link between the price level and marginal costs. But, as discussed in Stone, Wheatley and Wilkinson (2005), it is difficult to determine whether a cointegrating relationship exists between the price level, unit labour costs and import prices without including another trending variable. Given this, our preference is for distributed lag-type models. Within this class of models, we investigate constraining the coefficients on input costs using either successive four-quarter averages (as in Gordon 2005) or a polynomial distributed lag (PDL)

9 The appropriate number of lags of imports prices was chosen prior to imposing the polynomial constraint, in order to ensure that the constraint itself did not influence the number of lags.

10 Rudd and Whelan (2005) criticise the use of GMM on the grounds that any instrument used to proxy future inflation is plausibly correlated with an omitted variable and could therefore bias the estimated coefficients. However, this claim is disputed in Galí, Gertler and López-Salido (2005) and it is still common to use the GMM approach.

specification (as in Brayton *et al* 1999). We also estimate the coefficients without any constraints. While the data provide mixed results on the validity of these constraints, we are wary of over-fitting the data (which can occur with the unconstrained model) and the constrained specification provides impulse responses that are easier to interpret. Accordingly, our preferred specification of the mark-up model is:

$$\pi_t = c + \beta E_{t-1}\pi_{t+s} + \sum_{j=0}^{9}\lambda_j \Delta ulc_{t-j} + \sum_{k=1}^{12}\gamma_k \Delta mp_{t-k} + \chi ygap_{t-1} + \varepsilon_t \qquad (7)$$

where the coefficients λ_j and γ_k are constrained to follow a quadratic PDL function. Lagged inflation is found to be insignificant in this specification and so is excluded, and while the change in the output gap is significant at the 10 per cent level, its coefficient is negative and so we exclude it from the equation.

4. Results

4.1 Main Results

The estimates of each model are shown in Table 1 (fitted values are shown in Section 4.3). Overall, we find that the models fit the data quite well. They explain around 60 per cent of the variation in quarterly underlying inflation and have root mean squared errors (RMSE) that are generally less than 0.2 percentage points. In terms of the in-sample performance of each model, we find that the standard Phillips curve model fits best, followed by the mark-up model and then the two NKPC models. This is evident from assessing each model's AIC statistic, which is clearly lowest for the standard Phillips curve (indicating superior fit) and highest for the NKPC estimated with GMM.

Table 1: Inflation Model Estimates

	Standard PC	NKPC	OLS NKPC	Mark-up model
Constant	–0.009**		0.000	0.012***
Lagged inflation		0.163	0.148	
Inflation expectations	0.403***	0.837***	0.361***	0.309***
Output gap		0.020	0.166***	0.178***
Unemployment rate	0.142***			
Δ unemployment rate	–0.003***			
Real unit labour costs		0.039	0.125***	
Δ unit labour costs				0.172*
Real import prices		0.006	0.027**	
Δ import prices	0.079***	–0.011**	–0.008	0.107***
Adjusted R^2	0.648		0.585	0.618
AIC	–9.91	–9.23	–9.75	–9.81
Log-likelihood	403.5	368.7	396.9	401.4
In-sample RMSE	0.156	0.311	0.171	0.160
Out-of-sample RMSE[(a)]	0.188	0.299	0.254	0.231
Durbin-Watson statistic	2.14		2.04	2.00

Notes: ***, ** and * represent significance at the 1, 5 and 10 per cent levels respectively. Where multiple lags are included, coefficients shown are the sum of the lags. Coefficients on the constant, output gap, level and change in unemployment rate, real unit labour costs and real import prices are multiplied by 4 to represent annualised effects.
(a) Six quarters ahead, using real-time internal RBA forecasts of dependent variables and calculated over the period since 2004.

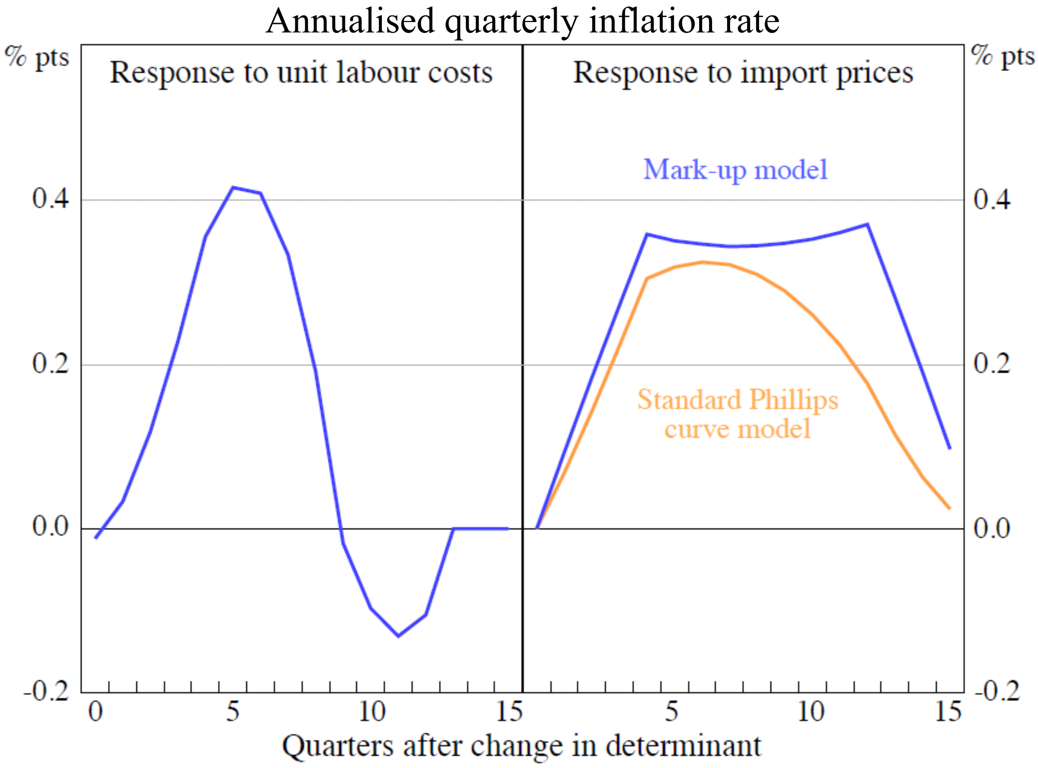
The relatively poor performance of the NKPC estimated with GMM is also evident when we look at the individual coefficients. We do not find significant coefficients on any variable in the NKPC, except those relating to inflation and the change in import prices (though the latter is incorrectly signed). This finding is robust to different specifications of the driving variables, including estimating the model with the output gap and real unit labour costs separately, and deflating real unit labour costs by other price measures (including the gross national expenditure deflator). This result should perhaps not be surprising, however, given that other authors estimate insignificant coefficients on the driving variables in NKPCs based on Australian data (for example, Kuttner and Robinson 2010).

The results for the NKPC using OLS and direct measures of inflation expectations are more favourable. In particular, the coefficients on the driving variables are all now significant and sizeable (except for that on the change in import prices), and the overall fit of the model is markedly better than that estimated with GMM. However, the model does not fit the data as well as the standard Phillips curve and mark-up models.

In contrast to the GMM-based NKPC, the coefficients on both the standard Phillips curve and the mark-up model are all correctly signed and significant. For unemployment, the coefficients on the (inverse) unemployment rate and the change in the unemployment rate imply that (other things equal) a 1 percentage point decline in unemployment (from 5 per cent) would raise the (quarterly annualised) inflation rate by around ¾ of a percentage point for four quarters (beginning two quarters after the initial change in unemployment), before the speed limit effect fades and the inflation rate subsequently settles back around ½ of a percentage point above its initial rate. The estimated coefficients on inflation expectations in the two models are broadly similar (at 0.3–0.4), as are the elasticities of inflation with respect to import prices (at 0.1). The estimated elasticity of inflation with respect to unit labour costs in the mark-up model is around two-thirds larger than this. The coefficient on the output gap implies that a gap of 1 per cent has a direct effect of 0.2 percentage points on annualised inflation, though this does not reflect the total effect since the output gap term here captures only its effects on inflation through non-wage costs and the mark-up, and not its effects on inflation via wage costs and expectations.

The effects on inflation of movements in unit labour costs and import prices in these models are shown graphically in Figure 3. With regard to unit labour costs, the mark-up model implies that, other things equal, a 2½ per cent rise in unit labour costs (roughly corresponding to the standard deviation in annualised terms) would raise the (quarterly annualised) inflation rate by around 0.4 percentage points at its peak, which occurs around five to six quarters after the increase in unit labour costs. (Assuming no effect on inflation expectations or other variables, the effect on inflation is estimated to wash out after two years.) With regard to import prices, both the mark-up and standard Phillips curve models imply a very protracted pass-through to inflation. The mark-up model implies that the inflation rate would increase by a little more than ⅓ percentage point over each of the second and third years following a 10 per cent rise in import prices before washing out after almost four years.[11] Likewise, the standard Phillips curve model implies a three-year effect on inflation from higher import prices, with the estimated rise in the inflation rate being around ⅓ percentage point over the second year and slightly less in the third year. The protracted nature of these import-price effects may partly reflect inventory behaviour (firms typically clear older stock acquired at the original exchange rate before repricing). They may also reflect a deliberate response to volatility in the exchange rate (with some firms absorbing changes in import prices into their margins until they perceive that any exchange rate shock is permanent). However, it is not clear that such explanations can explain the sizeable effect on inflation that is ongoing three years after the shock. Nonetheless, this result is robust across a range of model specifications and time periods.

Figure 3: Estimated Response of Inflation to Regressors[(a)]



Note: (a) Assuming (permanent) 2½ per cent change in level of unit labour costs and 10 per cent change in import prices

11 Dwyer and Leong (2001) suggest that just over half of any shock to the exchange rate is estimated to flow into across-the-docks import prices within the quarter, with the remainder flowing through in the following quarter.

In order to assess the performance of these models, it is useful to compare their out-of-sample forecasts with those of some standard benchmarks. In particular, we compare these models to four alternatives: a constant annualised rate of 2½ per cent (the mid-point of the inflation target); the previous quarter's year-ended underlying inflation rate; a simple vector autoregression (VAR) model that uses the same variables that are included in the mark-up model;[12] and the factor-augmented VAR (FAVAR) model developed by Gerard and Nimark (2008). Real-time estimates of the regressors in the single-equation models are taken from internal RBA forecasts; as such, this exercise is not a 'pure' test of the forecasting ability of single-equation models, since forecasts of the independent variables are derived in a different manner from that used by the VAR or FAVAR models.

With this caveat in mind, this exercise suggests that the single-equation models generally perform better than these benchmarks. Table 2 presents the ratio of the root mean squared forecast error (RMSFE) of each model to that of a constant at various horizons, calculated between 2004 and 2009. All models perform somewhat better than the constant forecast, as reflected in ratios of less than one.[13] The standard Phillips curve model has the lowest RMSFE at all horizons, outperforming the benchmark models by at least 10 per cent, and considerably more at longer horizons. The performance of the mark-up model is very similar to each of the benchmarks at shorter horizons, but modestly superior at the eight-quarter-ahead horizon. The NKPC model estimated with OLS produces better forecasts over the long horizon than the benchmarks, but tends to produce inferior results over a shorter horizon.

12 To conserve degrees of freedom, only one lag of each endogenous variable (trimmed mean inflation, inflation expectations, the output gap and quarterly growth in unit labour costs) is included, but the model is augmented with various lags of year-ended unit labour costs and import price growth to capture the same lag length as in the mark-up model.

13 The exception is the GMM-estimated NKPC (not shown), whose forecasts are found to be no better at all horizons.

Table 2: Relative Forecasting Performance

Ratio of root mean squared forecast error to that from constant forecast[(a)]

	Single-equation models			Benchmark models		
	OLS NKPC	Standard PC	Mark-up model	Lagged inflation	Simple VAR	Factor-augmented VAR
1 qtr ahead	0.834	0.708	0.856	0.790	0.803	0.764
4 qtrs ahead	0.845	0.640	0.801	0.742	0.762	0.843
8 qtrs ahead	0.810	0.590	0.818	0.872	0.863	1.009

Notes: (a) For the period 2004–2009. RMSFE for 1-quarter-ahead horizon calculated from quarterly inflation rate, while 4- and 8-quarter-ahead RMSFEs are based on the year-ended inflation rate.

4.2 Are There Benefits in Disaggregation?

An alternative approach to that used so far is to disaggregate inflation into some combination of the 90 items in the CPI, and estimate models for these disaggregated components. This allows the coefficients on input costs or expectations to vary across different types of products, although it may come at the cost of additional noise in the dependent variable. We split the sample of 90 items into two groups. The first includes items with prices predominantly determined by external factors (most importantly, the exchange rate). This largely consists of the manufactured items within the CPI, along with overseas travel; we loosely refer to this as the 'manufactures' group. The second group includes items with prices largely determined by domestic considerations, and we refer to this as the 'non-manufactures' group.[14] Based on this classification, we calculate trimmed mean inflation for each series and use this as the dependent variable.

In each case we estimated both a standard Phillips curve and a mark-up model of inflation. We present the models which fit best, with the mark-up specification

14 The main manufactured items excluded from the manufactures group are alcohol & tobacco, pharmaceuticals, and books & newspapers (whose prices appear to be largely determined domestically). Automotive fuel was excluded from both groups, as its weight dwarfs all other items in the manufactures classification where it would naturally fit. (This introduces an inconsistency with the earlier results, but it is not a material one.) Deposit & loan facilities were also excluded from the estimation, consistent with our approach at the aggregate level. The resulting grouping has some similarity to the tradable/non-tradable split published by the ABS, with the main difference being that a range of food items that are tradable are included in our non-manufactures series since their prices appear to be largely influenced by domestic factors.

clearly superior in the case of manufactured items and the standard Phillips curve marginally superior for non-manufactured items. The model for manufactures inflation is:

$$\pi_t^M = c^M + \beta^M E_{t-1}\pi_{t+s} + \lambda^M \Delta^4 ulc_{t-1} + \sum_{k=1}^{12}\gamma_k^M \Delta mp_{t-k} + \varepsilon_t \quad (8)$$

where: the superscript *M* refers to the group of manufactured items; input costs and inflation expectations are economy-wide measures (due to data limitations); and the coefficients on import prices are constrained to follow a quadratic PDL specification.[15] For inflation of the non-manufactures group (NM), the model is:

$$\pi_t^{NM} = c^{NM} + \beta^{NM} E_{t-1}\pi_{t+s} + \chi^{NM}\left(\frac{1}{ur_{t-2}}\right) + \delta^{NM}\Delta^4 ur_{t-3} + \sum_{k=1}^{12}\gamma_k^{NM}\Delta mp_{t-k} + \varepsilon_t \quad (9)$$

where the coefficients on import prices are also constrained using a quadratic PDL specification.

The results of this are shown in Table 3. Not surprisingly, import prices are an important explanator of manufactures prices, while domestic determinants (inflation expectations and labour market conditions) are more important for non-manufactures. The fitted values can be aggregated based on the relative share of manufactured and non-manufactured items in the CPI. This combination of the disaggregated models produces broadly comparable results to those from the aggregated model, in terms of in-sample fit and out-of-sample fit. In addition, the implied sensitivity of overall inflation to movements in input costs is also similar, especially for import prices (at just over 0.1). These results suggest that the gains from the disaggregate approach come primarily from its usefulness in illustrating some underlying influences, with its econometric performance providing no strong reason to prefer it.

15 The use of the year-ended change specification for unit labour costs is equivalent to the inclusion of four quarterly lags that are constrained to be equal.

Table 3: Disaggregated Inflation Model Estimates

	Manufactured items	Non-manufactured items	Aggregate results[(a)]
Constant	–0.011**	–0.003	
Inflation expectations	0.358***	0.425***	
Unemployment rate (inverse)		0.140***	
Δ unemployment rate		–0.003***	
Δ unit labour costs	0.117		
Δ import prices	0.309***	0.032	
Adjusted R^2	0.395	0.684	
In-sample RMSE	0.380	0.152	0.159
Out-of-sample RMSE[(b)]	0.477	0.209	0.246
Durbin-Watson statistic	2.42	1.75	

Notes: ***, ** and * represent significance at the 1, 5 and 10 per cent levels respectively. Where multiple lags included, coefficients shown are sum of the lags. Coefficients on constant and the level and change in the unemployment rate are multiplied by 4 to represent annualised effects.
(a) RMSE is calculated as a weighted average of manufactures and non-manufactures regressions.
(b) Six quarters ahead, using real-time internal RBA forecasts of dependent variables and calculated over the period since 2004.

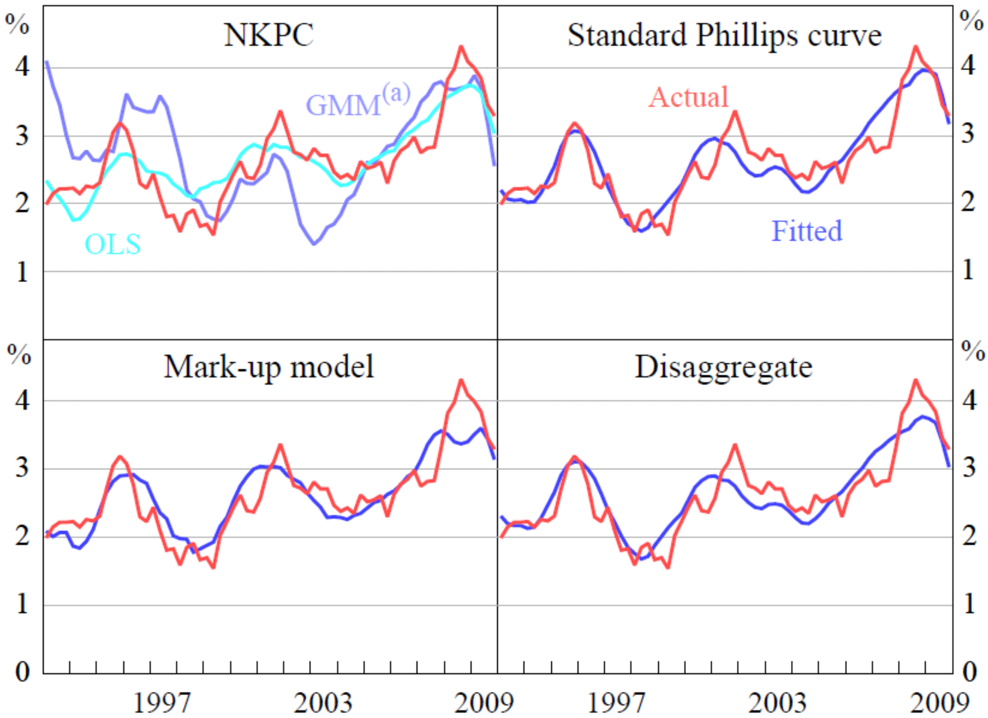
4.3 Historical Fit of the Models

Figure 4 shows the year-ended fitted values of the NKPC (estimated with both GMM and OLS), the standard Phillips curve, the mark-up model and the weighted average of the models for manufactures and non-manufactures (referred to hereafter as the 'disaggregate' model). To account for the lead of inflation in the GMM-based NKPC, the fitted values from that model are estimated using the closed form implied by the model, as in Galí and Gertler (1999) and Sbordone (2002).[16]

16 More specifically, we first estimate two recursive VAR models and a recursive autoregressive model to forecast unit labour costs, import prices and the output gap respectively, in a similar manner to Sbordone (2002). The VAR for unit labour costs (import prices) includes two lags each of the growth rate of nominal unit labour costs (import prices) and the level of the mark-up of consumer prices on unit labour cost (mark-up of consumer prices on import prices). Each model is estimated from 1982:1 to period t, and is used to forecast the driving variables 12 quarters ahead starting in $t+1$. The discounted sum of these forecasts is then included in the closed form solution, as per Galí and Gertler (1999), with equations for the characteristic roots found in Galí *et al* (2005).

Figure 4: Fitted Values of Trimmed Mean Inflation Models

Year-ended

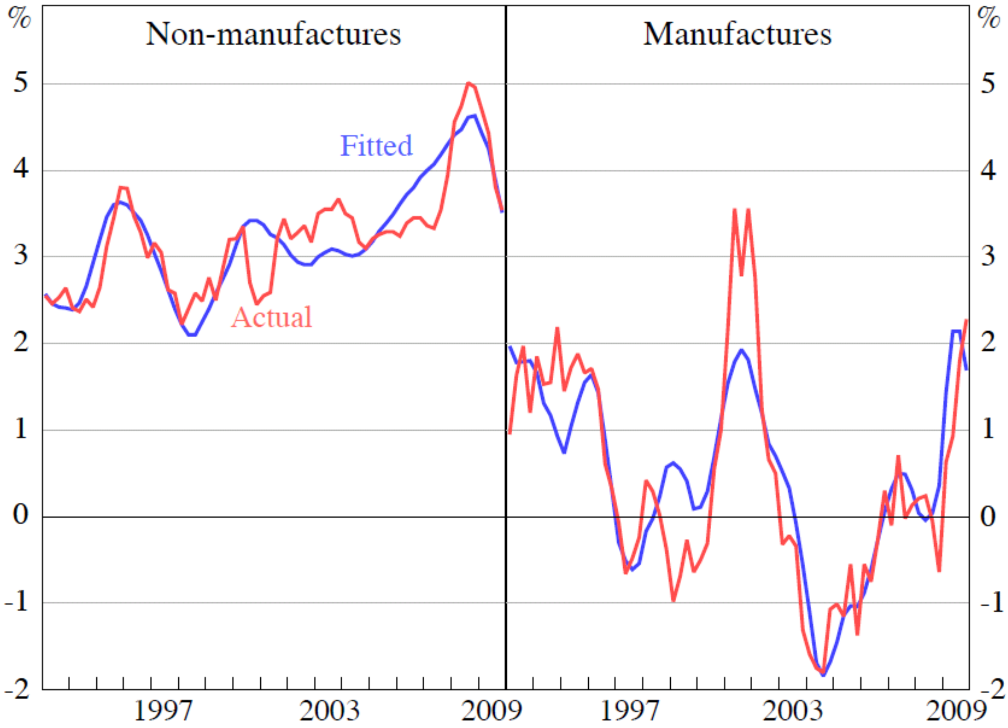


Note: (a) Estimated using closed form, corresponding to Galí and Gertler (1999) graph of 'fundamental inflation'

This evidence reinforces that obtained from the regression results that the standard Phillips curve and mark-up models provide a better description of inflation than does the NKPC. The standard Phillips curve and mark-up models track the cycle in inflation more closely, and better capture the pick-up in inflation in 1995, 2001 and 2007–2008. Likewise, the disaggregate model provides a relatively good explanation of aggregate inflation over much of the sample, with the fitted values from it resembling those from the standard Phillips curve model at most points in the sample. The relatively good performance of the disaggregate model reflects the performance of both its components (Figure 5). The manufacture and non-manufactures models both fit the data well, although the non-manufactures model suggests an earlier and smoother pick-up in domestic inflation over 2005–2008 than actually occurred, and the manufactures model does not explain the full extent of imported inflation that occurred in 2001.

Figure 5: Manufactures and Non-manufactures Trimmed Mean Inflation

Year-ended



In contrast, the GMM-based NKPC model produces large and persistent errors. This may in part reflect the simplicity of our forecasting models for the driving variables, which do not capture much of the variation in these series, although it likely also reflects the significant and persistent fluctuations in real import prices over the sample, which have a longer-lasting effect on the NKPC than other models. Using OLS to estimate the NKPC partially resolves these issues, with the model having a closer fit. Nonetheless, the OLS version of the NKPC still displays much larger errors than the other models.

All models correctly suggest a substantial acceleration in inflation between 2005 and 2008. Estimates from the standard Phillips curve are closest to the true outcome, at around 4 per cent by late 2008, while those from the other models are moderately lower than actually occurred, at around 3½–3¾ per cent. This estimated pick-up is consistent with the trend decline in the unemployment rate over that time and associated strength in unit labour costs growth, along with a sizeable output gap and fading disinflation from import prices. All models also explain the disinflation that occurred through 2009.

5. Investigating the Role of Other Variables or Restrictions

The literature on inflation models contains a much larger set of candidate variables than those used above. Furthermore, there is considerable debate about how to best proxy inflation expectations, and many other papers impose the restriction that there is no long-run trade-off between inflation and the unemployment rate or output gap, which we have not done. Given this, it is useful to check what effect such variations would have on our results. We pursue four issues: the effect of imposing a vertical long-run Phillips curve restriction on our models; whether there are better proxies for inflation expectations; what influence commodity prices have on inflation; and the possible role of money growth.[17] In each case, we adapt the standard Phillips curve, the OLS NKPC and the mark-up model with these restrictions or additional variables. The details of each regression can be found in Appendix B.

5.1 A Vertical Long-run Phillips Curve Restriction

The concept of a vertical long-run Phillips curve – that is, that there is no trade-off in the long run between unemployment and inflation – is a cornerstone of most inflation models and has a long history in the literature (beginning with the rational expectations revolution in the 1970s). Indeed, this idea underlies the pursuit of price stability by central banks in most industrial countries.

However, neither our standard Phillips curve, the mark-up model nor the OLS NKPC incorporate this standard feature. This reflects the fact that the sum of the coefficients on the right-hand-side nominal variables (inflation expectations, and growth in unit labour costs and import prices) in each of these models is significantly less than unity. This result survives when we simplify the models to represent inflation as being driven solely by inflation expectations and the output gap or unemployment rate; in that case, the coefficient on inflation expectations is significantly different from 1 for samples beginning in or after 1987. The rejection of this restriction is, however, not unique to our work; for example, both Anderson and Wascher (2000) and Williams (2006) have found such a result using US data.

17 We also looked at a possible role for the world output gap, but found no support for this (results available from the authors on request).

There are several possible explanations for this result. One relates to econometric issues, including from the relatively small sample used in estimation, or the possibility of a bias to our coefficients from measurement errors in our regressors. For example, our measure of expectations of inflation over the next 10 years is likely to be imprecisely measured (as are other measures of expectations) and only imperfectly correlated with the expectation that influences price-setting (which is likely to be for a one- or two-year horizon). However, it is hard to assess how important these effects are, and the long-run restriction is also obtained if we use a measure of shorter-term (one- or two-year) inflation expectations derived from the term structure of bond yields. Another possible explanation is suggested by Akerlof, Dickens and Perry (2000), namely that it may be ‘near rational’ for agents to devote limited attention to inflation when it is at low levels, resulting in the long-run Phillips curve appearing to be non-vertical within a range of low inflation outcomes.

Regardless of the reasons, it is clear that the models estimated above are not ‘structural’, in that they would not be robust to examining episodes of high inflation. One response to such concerns would be to impose the property of long-run neutrality on our models. This can be done by respecifying the mark-up model with the coefficients on the nominal terms constrained to sum to unity, which is equivalent to deflating all nominal variables (including the dependent variable) by inflation expectations. However, this results in a deterioration of fit, with the adjusted R-squared falling from 0.62 to 0.45, and the introduction of mild serial correlation. This serial correlation arises because the coefficients on the input cost terms increases significantly, from 0.17 to 0.48 for unit labour costs and 0.11 to 0.27 for import prices, causing the model to consistently under-predict inflation following currency appreciations and over-predict inflation following currency depreciations. Nonetheless, this model might be more robust in the event that inflation expectations become dislodged and so may be a useful addition to any suite of models.

5.2 Different Measures of Inflation Expectations

This discussion highlights some of the potential difficulties with the inflation expectations measure used in our models. While it is commonly accepted that inflation expectations are a critical influence on inflation outcomes, there is no consensus on how to model such expectations appropriately. The traditional approach has been to proxy inflation expectations with lagged inflation (as in Brayton *et al* 1999, for example), while the New-Keynesian approach of instrumenting for expected inflation using lags of inflation (as well as the output gap and unit labour costs) is essentially equivalent. Both of these, however, have well-understood limitations. An alternative approach is to use survey or financial market measures of inflation expectations (for example, Gruen *et al* 1999 and Henzel and Wollmershäuser 2008). We test the sensitivity of our results to these different approaches.

The results imply that, for both the mark-up and standard Phillips curve models of inflation, the bond market measure provides the best in-sample fit. The results of Section 4 have shown that using instruments for inflation expectations is inferior to including the bond market measures of inflation expectations. The bond market measure also provides a better fit than lagged year-ended inflation; the explanatory power falls when we include lagged inflation *instead* (Table B1) and its coefficient is insignificant when included *alongside* the bond market measure (result not shown). The bond market measure also provides a superior fit to either the Melbourne Institute's survey measure of consumer expectations (Table B1)[18] or measures of shorter-term inflation expectations implied by financial markets (result not shown). All of these results are invariant to whether the sample begins in 1990 or 1993.

---

18 One difficulty with using the Melbourne Institute's measure is that it contains a structural break in 1993, prior to which negative responses were excluded from the calculation. This results in the current series being a full percentage point above the old series in 1993. To ensure consistency back to 1990, we assume that this gap remains constant from 1990 to 1993, and adjust down the old measure accordingly.

5.3 The Influence of Oil Prices

Many papers modelling inflation include a measure of oil or other commodity prices in their equations (see, for example, Gordon 2005). In most instances, such regressions use headline rather than underlying (or 'core') inflation, providing a strong rationale for the inclusion of oil prices in the equation.[19]

To investigate whether there is a role for oil prices in explaining underlying inflation in Australia, we augment our aggregate regressions with lagged growth in (Australian dollar) crude oil prices (or the level of real oil prices in the NKPC). We test for up to six years of lags, although to preserve degrees of freedom we constrain the quarterly responses to be equal within each year.

The results from this exercise present mixed evidence on the role of oil prices (Table B1). The mark-up model provides support for a statistically significant effect of movements in oil prices; also, the overall explanatory power rises modestly compared with the baseline and a likelihood ratio test is able to reject the hypothesis that oil prices have no effect on underlying inflation at the 10 per cent level.[20] However, there are a number of concerns with these results, including the very long lag between oil price changes and underlying inflation estimated by the model (three to four years), sensitivity to the lag structure, and the insignificance of oil prices in the Phillips curve models. Overall, these results provide only limited

---

19 The international evidence on whether to include oil prices in a regression for underlying inflation is limited. One comprehensive assessment of this question is provided by Hooker (2002), who finds that while oil prices were a significant explanator of core inflation in the United States prior to 1980, they play an insignificant role thereafter. In contrast, Cheung (2009) finds that persistent movements in oil prices have been a useful predictor of core inflation since 1990 across a range of countries. While Hooker argues that his results stem from a change in policy by the Federal Reserve since 1980 to not accommodate oil price shocks, the difference between his results and those of Cheung suggests that it might instead reflect the relative stability of oil prices between 1980 and 2000. In other words, the sharp rise in oil prices between 2003 and mid 2008 could explain Cheung's finding of significant second-round effects.

20 The elasticity of inflation with respect to movements in crude oil prices in the mark-up model is estimated to be 0.018 (not including any second-round effects, for example on inflation expectations) which implies that the more than doubling of oil prices in the four years to late 2008 contributed almost ½ a percentage point to annual inflation. Rolling regression estimates suggest that this relationship is only identifiable during periods of large changes in oil prices, since the coefficients are insignificant in samples that exclude the past few years.

support for the presence of an effect on underlying inflation from oil price growth, independent of its effect via inflation expectations or the output gap.[21]

5.4 Monetary Models of Inflation

There is a long tradition of modelling inflation as a function of growth in the money supply, based on Milton Friedman and Anna Schwartz's observation that 'inflation is always and everywhere a monetary phenomenon'. While this is no longer considered to imply that central banks should target growth in the money supply, there is still some debate about whether money should be considered when modelling inflation. For example, the European Central Bank's 'two-pillar' monetary policy framework might suggest such an approach, relating short- to medium-term inflation to real factors (such as output and unemployment gaps) and medium- to long-term inflation to growth in the money supply. However, many economists of the New Keynesian tradition have argued to the contrary, suggesting that money is 'obsolete' in a properly specified model that includes a monetary policy rule (see, for example, Woodford 2007). Given these differences, it is of interest to assess whether money growth has any explanatory power for Australian inflation. This could arise for a variety of reasons unrelated to whether it is appropriate to include money in a structural model of inflation; for example, trend money growth could provide a better (or complementary) proxy for inflation expectations than the bond market measure, or might control for measurement error in unit labour costs.

We use an approach adopted by Gerlach (2004), who augments a NKPC model with a measure of trend money growth. Gerlach motivates this specification on the basis that the NKPC captures short- to medium-term movements in inflation, while trend money growth will capture the medium- to long-run movements in inflation. We implement a version of this approach, but capture the short- to medium-term dynamics of inflation with the standard Phillips curve model. Specifically, we supplement Equation (5) with a term for money growth and estimate the following specification:

21 We also tested for the inflationary effect of commodity prices more generally, using the CRB commodity price index (in Australian dollar terms). We do not find a significant coefficient on year-ended growth in commodity prices over most sample periods.

$$\pi_t = c + \beta E_{t-1}\pi_{t+s} + \chi\left(\frac{1}{ur_{t-2}}\right) + \delta\Delta^4 ur_{t-3} + \sum_{k=1}^{12}\gamma_k \Delta mp_{t-k} + \omega\Delta^4 m_{t-1} + \varepsilon_t \qquad (10)$$

where: the notation is as in Equation (1); the coefficients on import prices follow a PDL specification; and $\Delta^4 m$ represents trend excess money growth, defined as the band-pass filtered trend in the stock of money divided by nominal GDP. We test two different measures of money (M3 and broad money) and also test for a role for credit growth. The band-pass filter removes the last three years of data, leaving us with a sample that ends in the March quarter 2007.

The results from this regression provide modest evidence that growth in money or credit may be empirically relevant for future inflation over the period since 1990, once other determinants have been included: trend excess M3 growth is significant at the 10 per cent level (Table B1). However, the inclusion of this variable causes the coefficient on the level of the unemployment rate to become insignificant. Moreover, neither excess broad money – which should be more relevant on *a priori* grounds – nor credit growth are significant at anywhere near a conventional level of significance. Given the lack of uniformity in these results, and the insignificance of the level of the unemployment rate when M3 is included, we conclude that the inclusion of money in our inflation models does not impart significant benefit.

6. Changes in the Inflation Process over Time

There is a large body of evidence documenting changes in the inflation process over time. For example, a number of papers document a flattening of the Phillips curve internationally (see Kuttner and Robinson, forthcoming, for a discussion), while both Heath *et al* (2004) and Dwyer and Leong (2001) document changes in the sensitivity of Australian inflation to movements in import prices since 1990. In light of this, we examine how the behaviour of our inflation models has evolved over the past three decades, starting in 1982 when disaggregated price data become available for the calculation of trimmed mean inflation.

Rolling Chow tests suggest that a change may have occurred in the sensitivity of inflation to its determinants around 1990, with little evidence of significant change since then. The maximum value of this statistic occurs in the March quarter of 1989 for both the standard Phillips curve and mark-up models, and in the June quarter of 1991 for the OLS NKPC, although it is only significant in the case of the standard Phillips curve model. Since 1990 – the starting period for the regressions presented earlier in the paper – the Chow test is clearly insignificant for all models.

Table 4 shows the model results when estimated over two non-overlapping sample periods, the first running from 1982 to 1992 (the higher-inflation period) and the second running from 1993 to 2009 (the inflation-targeting period).[22] Perhaps the clearest difference between the estimates in each sample is the decline in overall explanatory power, as indicated by the reduction in the adjusted R-squared from 0.83 to 0.45 for the standard Phillips curve model and from 0.86 to 0.33 for the mark-up model. However, the standard errors of the models have also declined over this time, by more than one-third. Most of the reduction in these two measures reflects the exclusion of the early 1990s disinflation period, as evidence by the still-high R-squared on the results shown earlier, which commence in 1990. Overall, these two results appear to be a reflection of the much smaller medium-term variation in inflation in the more recent period.

Looking at the coefficients, there are a number of notable changes between the higher-inflation and inflation-targeting samples. Most striking, the coefficient on inflation expectations declines considerably in the inflation-targeting period, from around 0.60 to 0.25, although it remains significant in the standard Phillips curve model and approaches significance in the mark-up model (with a p-value of 0.12). (As can be seen from a comparison of these results to those over our earlier results, around half of this difference reflects the early 1990s period.)

22 The split between these two samples is based on considerations of sample size rather than the Chow tests.

Table 4: Split-sample Inflation Model Estimates

	Standard PC		Mark-up model	
	1982:Q2–1992:Q4	1993:Q1–2009:Q4	1982:Q2–1992:Q4	1993:Q1–2009:Q4
Constant	–0.038***	–0.003	–0.007	0.013***
Inflation expectations	0.683***	0.247**	0.632***	0.226
Output gap			0.089	0.135**
Unemployment rate	0.215*	0.136***		
Δ unemployment rate	–0.003*	–0.002		
Δ unit labour costs			0.103	0.220**
Δ import prices	0.237***	0.087***	0.201***	0.114***
Adjusted R^2	0.831	0.450	0.865	0.328
Standard error	0.0024	0.0015	0.0022	0.0016
AIC	–9.06	–10.11	–9.25	–9.89
Durbin-Watson statistic	1.98	1.84	2.33	1.69

Notes: ***, ** and * represent significance at the 1, 5 and 10 per cent levels respectively. Where multiple lags included, coefficients shown are sum of the lags. Coefficients on constant, output gap and level and change in unemployment rate are multiplied by 4 to represent annualised effects.

The other very stark change is the decline in the coefficients on import prices, which fall from over 0.2 in the high inflation era to 0.1 in the inflation-targeting era. This type of result is well documented in the literature. However, there is little agreement regarding why this decline in second-stage pass-through has occurred. The most prominent explanations are: changes in the composition of trade (Campa and Goldberg 2002); an increase in the prevalence of pricing-to-market at the retail level (Devereux and Engel 2001); a change in the nature of exchange rate shocks (Shambaugh 2008); and the introduction of inflation targeting, which might have encouraged firms to absorb such shocks in their margins (Taylor 2000; Gagnon and Ihrig 2004).

More broadly, there is also a decline in the sum of the coefficients on the nominal variables, with the vertical long-run Phillips curve not rejected in the first sample period. In addition, the coefficient on the unemployment rate provides further evidence for the well-documented flattening of the Phillips curve. This declines by half from the first to the second sample, with all of this decline occurring in the

1980s (as evidenced by our earlier results showing a similar coefficient to that in the inflation-targeting period).[23]

7. Conclusions

Given the goal of central banks to maintain low and stable inflation, researchers devote significant effort to modelling inflation. This paper adds to the existing literature by exploring some of the single-equation models that are used at the RBA.

A key finding of our paper is the strong performance of the standard Phillips curve and mark-up models when compared to the New-Keynesian Phillips curve over the past two decades. In particular, we find that the issue of weak instruments in the NKPC results in coefficients that are significant and correctly signed only for the inflation expectations and lagged inflation variables: the apparent insignificance of the output gap and marginal cost terms is problematic (though this is commonly also an issue in US research). Furthermore, the fit of the NKPC is clearly inferior to that of the standard Phillips curve and mark-up models. These issues with the NKPC can be somewhat alleviated by the use of a direct measure of inflation expectations, which avoids the need to instrument for this variable, although it remains the case that the more traditional models out-perform this OLS-based version of the NKPC.

One issue with the standard Phillips curve and mark-up models is that unrestricted estimates imply a medium-term trade-off between output and inflation (and fit less well when a restriction is imposed to prevent this). While this is unlikely to be a major issue when inflation is at relatively low levels, this aspect could be more problematic in the case of more extreme events. For this reason, any suite of models should include a role for other types of more theoretically based models that naturally incorporate such restrictions.

Regardless of the model chosen, it is notable that the standard error of single-equation models for inflation has fallen in the low-inflation environment prevailing over the past 15 or so years, consistent with the stability of inflation and inflation expectations over that time.

---

23 This may partly reflect changes in the NAIRU, but we suspect that this is not a major effect.

Appendix A: Derivation of the Mark-up Model of Inflation

The derivation of the expectations-augmented mark-up model of inflation used in this paper is based on Ireland's (2007) model. This model is a relatively standard New-Keynesian micro-founded model, with a representative household that maximises expected utility (flowing from consumption and holdings of real money balances) and a representative firm that maximises expected profits. The firm is found to only adjust its prices periodically, given the assumption that it faces quadratic adjustment costs to alter prices (in the spirit of Rotemberg 1982). These costs are defined as:

$$\text{adjustment costs} = \frac{\phi}{2}\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}\left(\Pi_t^*\right)^{1-\alpha} P_{t-1}(i)} - 1\right]^2 \tag{A1}$$

where *P(i)* is the price charged by (the representative) firm *i*; Π is the aggregate inflation rate and Π^* is the central bank's inflation target; α is a parameter that governs the degree to which prices are set with reference to an inflation target ($\alpha = 0$) or to past inflation ($\alpha = 1$); and $\phi \geq 0$ governs the magnitude of price-adjustment costs.

As shown in Ireland (2007, Equation (A6)), the optimal price adjustment implies:

$$\begin{aligned}\theta_t - 1 = \theta_t\left(\frac{W_t}{P_t Z_t}\right) - \phi\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}\left(\Pi_t^*\right)^{1-\alpha}} - 1\right]\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}\left(\Pi_t^*\right)^{1-\alpha}}\right] \\ + \beta\phi E_t\left\{\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}\left(\Pi_{t+1}^*\right)^{1-\alpha}} - 1\right]\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}\left(\Pi_{t+1}^*\right)^{1-\alpha}}\right]\left(\frac{Y_{t+1}}{Y_t}\right)\right\}\end{aligned} \tag{A2}$$

where: θ is the (time-varying) price elasticity of substitution for intermediate goods; *W* is the nominal wage; *Z* is the technology shock; β is the household discount factor; Λ is the marginal utility of wealth; and *Y* denotes aggregate output.

Ireland shows that this equation implies that inflation evolves as follows:

$$(1+\beta\alpha)\pi_t = \alpha\pi_{t-1} + \beta E_t\pi_{t+1} + \psi(mc_t - p_t) - e_t - \alpha\pi_t^* \tag{A3}$$

where: $(mc - p)$ represents real marginal costs; e_t represents a mark-up shock (θ_t/ϕ); and all variables are expressed as percentage deviations from steady-state level.

The model used in this paper deviates from Ireland's approach in three ways. First, we express the inflation process in a different way, in order to show that inflation can be represented as a function of *growth* in *nominal* marginal costs, rather than the level of real marginal costs. Second, we allow mark-ups to be a function of aggregate resource utilisation. Third, we define marginal costs to include both labour and import prices. Each of these changes is discussed below.

To express inflation as a function of the change in nominal marginal costs, our point of departure from Ireland's model is to take the first-order difference equation of (A3). This results in the following expression:

$$\gamma\pi_t = -(1/\phi)\Delta\theta_t + \beta E_t\pi_{t+1} + \psi\Delta mc_t - (1+\beta\alpha)\pi_{t-1} + \alpha\left(\Delta\pi_{t-1} - \Delta\pi_t^*\right) + \varepsilon_t \quad \text{(A4)}$$

where: $\gamma = (1+\beta+\beta\alpha+\psi)$; and $\varepsilon_t = \beta(\pi_t - E_{t-1}\pi_t)$ is an expectational error term that, by the assumption of rational expectations, is a white noise process.

Our second modification to Ireland's model is to assume that $-\theta_t$ – the time-varying elasticity of substitution for intermediate goods – is related to aggregate resource utilisation in the economy.[24] This assumption can be motivated by either of two explanations. The first is that marginal costs are not perfectly equated across capital and labour, such that $-\theta_t$ captures the effect of procyclical capital costs. The second is that firms' desired mark-ups over marginal cost (which are $\theta_t/(\theta_t - 1)$ according to Equation (A2)) may be procyclical if consumers' demand for goods becomes less price elastic as overall capacity utilisation rises.[25] The assumption that the output gap and mark-ups are positively correlated (that is, that mark-ups are procyclical) is non-standard in US research (see, for example, Rotemberg and Woodford 1999, where it is comprehensively argued that mark-ups

24 By assuming that the elasticity of substitution for each good is related to *aggregate* resource utilisation, rather than the firm's own utilisation, we do not influence the standard derivation of the optimal price adjustment.

25 This specification does not imply that the output gap only influences inflation via mark-ups. Rather, it presumes that the output gap affects inflation both as a partial determinant of marginal costs and as a determinant of mark-ups.

are countercyclical), but the evidence is less supportive of countercyclical mark-ups in other countries. For example, Macallan, Millard and Parker (2008) find that the mark-up is procyclical for the United Kingdom, de Brouwer and Ericson (1995) and Stone *et al* (2005) both find that the output gap enters significantly into a mark-up model of inflation in Australia, and the profit share in Australia appears to be procyclical, which cannot occur if mark-ups are countercyclical (in which case profits can rise, but not by more than output).

This modification is achieved by assuming that θ_t can be represented by the following process:

$$\theta_t = \theta_{t-1} - \theta - \lambda x_{t-1} + v_t \qquad \text{(A5)}$$

which implies that θ_t is decreasing in last period's output gap, x_{t-1}, so that the mark-up – $\theta_t/(\theta_t - 1)$ – is increasing in last period's output gap. Substituting (A5) into (A4) implies the following inflation process:

$$\begin{aligned} \gamma\pi_t = & \left(\theta/\varphi\right) + \beta E_t \pi_{t+1} + \psi \Delta mc_t + \left(\lambda/\varphi\right) x_{t-1} \\ & -\left(1+\beta\alpha\right)\pi_{t-1} + \alpha\left(\Delta\pi_{t-1} - \Delta\pi_t^*\right) + \eta_t \end{aligned} \qquad \text{(A6)}$$

where $\eta_t = \varepsilon_t + (1/\phi)v_t$.

The third change is to specify marginal costs as a function of both labour and import costs, as in Bentolila and Saint-Paul (2003). This specification is based on the assumption that firms use a material input to produce gross output, and that the proportion of material input required per unit of gross output increases as output expands. Under these assumptions, Bentolila and Saint-Paul show that marginal costs are a function of both unit labour costs and import prices, as follows:

$$mc_t = \left(w_t - z_t\right) + \chi pm_t \qquad \text{(A7)}$$

Given this, we arrive at our final specification for the inflation process:

$$\begin{aligned} \gamma\pi_t = & \left(\theta/\varphi\right) + \beta E_t \pi_{t+1} + \psi \Delta ulc_t + \chi\psi \Delta mp_t + \left(\lambda/\varphi\right) x_{t-1} \\ & -\left(1+\beta\alpha\right)\pi_{t-1} + \alpha\left(\Delta\pi_{t-1} - \Delta\pi_t^*\right) + \eta_t \end{aligned} \qquad \text{(A8)}$$

Appendix B: Additional Regression Results

Table B1: Additional Regression Results

	Standard Phillips curve equations									
	π^e	*UR*	ΔUR	Δmp	π_{t-k}	$\Delta^4 oil$	$\Delta^4 M3$	Adj-R^2	AIC	LR-value[c]
Baseline	0.403***	0.142***	–0.003***	0.079***				0.648	–9.91	
With π_{t-k}		0.052**	–0.003***	0.040	0.166***			0.576	–9.73	
Consumer π^e	0.715***	0.047*	–0.001	0.039				0.519	–9.60	
Oil price model	0.431***	0.129***	–0.003***	0.069**		0.009		0.640	–9.86	
Money model[a]	0.270***	-0.069	–0.005***	0.071**			4.508	0.636	–9.87	3.86**
	Mark-up model equations									
	π^e	*Gap*	Δulc	Δmp	π_{t-k}	$\Delta^4 oil$	$\Delta^4 M3$	Adj-R^2	AIC	
Baseline	0.309***	0.178***	0.172*	0.107***				0.618	–9.81	
With π_{t-k}		0.057	0.209*	0.097**	0.107**			0.580	–9.72	
Consumer π^e	0.444***	0.030	0.254***	0.106***				0.614	–9.80	
Vertical restriction	0.244[b]	0.167**	0.484***	0.268***				0.480	–9.50	
Oil price model	0.340***	0.141**	0.185**	0.091***		0.018**		0.638	–9.83	7.61*
	New-Keynesian Phillips curve (using OLS)									
	π^e	*Gap*	*rulc*	*rmp*	Δrmp	π_{t-k}	*real oil*	Adj-R^2	AIC	
Baseline	0.361***	0.166***	0.125**	0.027**	–0.008	0.148		0.585	–9.75	
Oil price model	0.382***	0.163***	0.103**	0.054**	–0.010	0.096	0.001	0.591	–9.75	

Notes: ***, ** and * represent significance at the 1, 5 and 10 per cent levels respectively. Where multiple lags included, coefficients shown are sum of the lags. Coefficients on output gap, real unit labour costs, real import prices and OECD output gap multiplied by 4 to convert to annual effect; coefficients on four-quarter change in M3 and oil prices divided by 4 to convert to elasticity.

(a) Estimated from 1990:Q1 to 2007:Q1. Over that sample, the baseline model has an adjustment R-squared of 0.622 and an AIC of –9.84.

(b) No standard errors are applicable for this coefficient.

(c) Chi-squared statistic from likelihood ratio test that the baseline (restricted) model is significantly different.

References

Akerlof GA, WT Dickens and GL Perry (2000), 'Near-Rational Wage and Price Setting in the Long-Run Phillips Curve', *Brookings Papers on Economic Activity*, 1, pp 1–60.

Anderson PS and WL Wascher (2000), 'Understanding the Recent Behaviour of Inflation: An Empirical Study of Wage and Price Developments in Eight Countries', paper presented at the BIS Workshop on 'Empirical Studies of Structural Change and Inflation', Basel, 31 October.

Bårdsen G, S Hurn and Z McHugh (2007), 'Modelling Wages and Prices in Australia', *Economic Record*, 83(261), pp 143–158.

Bentolila S and G Saint-Paul (2003), 'Explaining Movements in the Labor Share', *Contributions to Macroeconomics*, 3(1), Article 9.

Brayton F, JM Roberts and JC Williams (1999), 'What's Happened to the Phillips Curve?', Board of Governors of the Federal Reserve System Finance and Economics Discussion Paper No 1999-49.

Brischetto A and A Richards (2006), 'The Performance of Trimmed Mean Measures of Underlying Inflation', RBA Research Discussion Paper No 2006-10.

Campa JM and LS Goldberg (2002), 'Exchange Rate Pass-Through into Import Prices', *Review of Economics and Statistics*, 87(4), pp 679–690.

Cheung C (2009), 'Are Commodity Prices Useful Leading Indicators of Inflation?', Bank of Canada Discussion Paper No 2009-5.

de Brouwer G and NR Ericsson (1995), 'Modelling Inflation in Australia', RBA Research Discussion Paper No 9510.

Devereux MB and C Engel (2001), 'Endogenous Currency of Price Setting in a Dynamic Open Economy Model', NBER Working Paper No 8559.

Dwyer J and K Leong (2001), 'Changes in the Determinants of Inflation in Australia', RBA Research Discussion Paper No 2001-02.

Fuhrer J and G Moore (1995), 'Inflation Persistence', *Quarterly Journal of Economics*, 110(1), pp 127–159.

Gagnon JE and J Ihrig (2004), 'Monetary Policy and Exchange Rate Pass-Through', *International Journal of Finance and Economics*, 9(4), pp 315–338.

Galí J (2008), *Monetary Policy, Inflation and the Business Cycle: An Introduction to the New Keynesian Framework*, Princeton University Press, Princeton.

Galí J and ML Gertler (1999), 'Inflation Dynamics: A Structural Econometric Analysis', *Journal of Monetary Economics*, 44(2), pp 195–222.

Galí J, ML Gertler and D López-Salido (2005), 'Robustness of the Estimates of the Hybrid New Keynesian Phillips Curve', *Journal of Monetary Economics*, 52(6), pp 1107–1118.

Gerard H and K Nimark (2008), 'Combining Multivariate Density Forecasts Using Predictive Criteria', RBA Research Discussion Paper No 2008-02.

Gerlach S (2004), 'The Two Pillars of the European Central Bank', *Economic Policy*, 19(40), pp 389–439.

Gillitzer C and J Kearns (2007), 'Forecasting with Factors: The Accuracy of Timeliness', RBA Research Discussion Paper No 2007-03.

Gordon RJ (2005), 'What Caused the Decline in US Business Cycle Volatility?', in C Kent and D Norman (eds), *The Changing Nature of the Business Cycle*, Proceedings of a Conference, Reserve Bank of Australia, Sydney, pp 64–106.

Gruen D, A Pagan and C Thompson (1999), 'The Phillips Curve in Australia', *Journal of Monetary Economics*, 44(2), pp 223–258.

Gruen D, T Robinson and A Stone (2002), 'Output Gaps in Real Time: Are They Reliable Enough to Use for Monetary Policy?', RBA Research Discussion Paper No 2002–06.

Heath A, I Roberts and T Bulman (2004), 'Inflation in Australia: Measurement and Modelling', in C Kent and S Guttmann (eds), *The Future of Inflation Targeting*, Proceedings of a Conference, Reserve Bank of Australia, Sydney, pp 167–207.

Henzel S and T Wollmershäuser (2008), 'The New Keynesian Phillips Curve and the Role of Expectations: Evidence from the CESifo World Economic Survey', *Economic Modelling*, 25(5), pp 811–832.

Hooker MA (2002), 'Are Oil Shocks Inflationary? Asymmetric and Nonlinear Specifications versus Change in Regime', *Journal of Money, Credit and Banking*, 34(2), pp 540–561.

Ireland P (2007), 'Changes in the Federal Reserve's Inflation Target: Causes and Consequences', *Journal of Money, Credit and Banking*, 39(8), pp 1851–1882.

Jääskelä J and K Nimark (2008), 'A Medium-Scale Open Economy Model of Australia', RBA Research Discussion Paper No 2008-07.

Kuttner KN and T Robinson (2010), 'Understanding the Flattening Phillips Curve', *The North American Journal of Economics and Finance*, 21(2), p 110–125.

Leith C and J Malley (2007), 'Estimating Open Economy New Keynesian Phillips Curves for the G7', *Open Economies Review*, 18(4), pp 405–426.

Macallan C, S Millard and M Parker (2008), 'The Cyclicality of Mark-Ups and Profit Margins for the United Kingdom: Some New Evidence', Bank of England Working Paper No 351.

Phillips AW (1958), 'The Relation between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861–1957', *Economica*, 25(100), pp 283–299.

Rotemberg JJ (1982), 'Sticky Prices in the United States', *Journal of Political Economy*, 90(6), pp 1187–1211.

Rotemberg JJ and M Woodford (1999), 'The Cyclical Behaviour of Prices and Costs', in JB Taylor and M Woodford (eds), *Handbook of Macroeconomics, Volume 1*, Part 2, Elsevier Science, Amsterdam, pp 1051–1135.

Rudd J and K Whelan (2005), 'New Tests of the New-Keynesian Phillips Curve', *Journal of Monetary Economics*, 52(6), pp 1167–1181.

Sbordone AM (2002), 'Prices and Unit Labor Costs: A New Test of Price Stickiness', *Journal of Monetary Economics*, 49(2), pp 265–292.

Shambaugh J (2008), 'A New Look at Pass-Through', *Journal of International Money and Finance*, 27(4), pp 560–591.

Stone A, T Wheatley and L Wilkinson (2005), 'A Small Model of the Australian Macroeconomy: An Update', RBA Research Discussion Paper No 2005-11.

Taylor JB (2000), 'Low Inflation, Pass-Through and the Pricing Power of Firms', *European Economic Review*, 44(7), pp 1389–1408.

Williams JC (2006), 'The Phillips Curve in an Era of Well-Anchored Inflation Expectations', Federal Reserve Bank of San Francisco, unpublished working paper.

Woodford M (2007), 'How Important Is Money in the Conduct of Monetary Policy?', NBER Working Paper No 13325.