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Estimating the NAIRU in Australia

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Abstract

The Non-Accelerating Inflation Rate of Unemployment (NAIRU) is a variable of interest to policy makers as it provides an estimate of the degree of labour market slack in the economy. However, the NAIRU is unobservable, and must be estimated using statistical models. This is most commonly undertaken within the Phillips curve framework, which estimates the relationship between price or wage growth and unemployment. This is a key equation for understanding economic conditions, and is used to forecast wages growth at the Australian Treasury. Australia's NAIRU was previously thought to be around 5 per cent. We have considered a range of alternative specifications for estimating the wage Phillips curve, and this working paper details Treasury's updated model. We consider specification choices that include: updating the measures of inflation and inflation expectations; the introduction of a productivity gap term; the inclusion of a structural break to allow for the flattening of the Phillips curve; and other changes to bring the model more in-line with the recent literature. The updated model produces estimates of the NAIRU between 4.5 and 5 per cent over the last few years immediately prior to the COVID-19 recession.

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1. Introduction

An important indicator of macroeconomic performance is an economy's unemployment rate, which is the proportion of the labour force unemployed and actively seeking work. As an important contributor to wellbeing, keeping unemployment low is a key focus of fiscal, labour market and monetary policy. As one measure of labour market slack, the unemployment rate also has implications for the outlook for wage growth, inflation and gross domestic product (GDP).

In Australia, the unemployment rate has fluctuated between below 2 per cent in the 1960s and 11 per cent in the early 1990s (Chart 1). Prior to the COVID-19 recession the unemployment rate had fallen to around 5 per cent, but in 2020 it rose to reach a peak of 7.5 per cent in July 2020, before declining to 5.6 per cent in March 2021.

Chart 1: Unemployment rate

Source: ABS Cat. No. 6202.0, 1364.0.15.003.

One way to assess spare capacity in the labour market is to compare the unemployment rate to the non-accelerating inflation rate of unemployment (NAIRU). The NAIRU is the point at which the unemployment rate is associated with stable wage growth and in turn inflation, all other things equal. If the unemployment rate is below the NAIRU, wage growth and inflation will tend to rise over time, and similarly, if the unemployment rate sits above the NAIRU, wage growth and inflation will tend to decline over time.

The NAIRU is not directly observable and instead must be estimated using historical economic data and econometric models. Such estimates are inherently uncertain. While a point estimate of the NAIRU can be useful for economic forecasting and assessing policy settings, it should not be taken as fixed or estimated with precision, and should be considered alongside its (typically) large standard errors. The modelling approach (state-space modelling) discussed in this paper is not well-suited to estimating unobserved variables in the middle of a shock, such as the COVID-19 recession. For this reason, we have not presented results using data more recent than 2019.

In the medium to long run the NAIRU converges conceptually to the natural rate of unemployment. The natural rate is a medium to long-run concept of unemployment that captures structural and frictional unemployment. The natural rate reflects structural features of the labour market, such as the demographic composition and the education levels of the workforce and institutional settings including workplace regulation. It also reflects the efficiency of labour market matching.

The NAIRU is also affected by structural trends in the economy, but represents the level of unemployment consistent with stable inflation in the short to medium term. Conceptually, the NAIRU also takes into account the influence of transitory, but potentially persistent, shocks on the economy, and their interaction with frictions in labour, product and financial markets. In the long run, the NAIRU converges to the natural rate of unemployment once the effects of transitory shocks to the economy have faded.

Empirical estimates of the NAIRU will then evolve over time in line with structural trends in the labour market and transitory shocks impacting on the economy and in turn the labour market. Typically estimates of the NAIRU evolve relatively smoothly through time which is consistent with the idea that movements in the NAIRU have been driven by slow-moving structural features of the labour market (Cusbert 2017). In Australia, the NAIRU is estimated to have varied through history, reaching higher levels in the mid-1990s in the aftermath of the 1990s recession, but declining in more recent years.

This paper presents a summary of specification choices used to estimate Treasury's Phillips curve. We focus on the wage Phillips curve, since the primary purpose of our NAIRU is as an input into wage forecasts. We are therefore most interested in an estimate of the NAIRU that reflects an unemployment rate consistent with stable wage inflation.

2. Literature Review

The NAIRU is commonly estimated using a state-space framework, where a 'signal' equation (a Phillips curve) and a 'state' equation (generally modelling the NAIRU as a random walk) are jointly estimated. The NAIRU can also be estimated in other ways, including within a simpler Phillips curve framework (Ball and Mankiw 2002), via joint estimation with a Beveridge curve or other labour market indicators (Dickens 2009, Crump et al. 2019), or by using a multivariate filtering approach (Blagrave et al. 2015). We focus on the state-space literature.

2.1. The Phillips curve

Phillips curve theory proposes that there is an inverse relationship between the unemployment rate and wage growth. Holding other factors equal, a lower unemployment rate is associated with higher wage growth and price inflation as the economy is operating closer to or potentially beyond capacity. Conversely, a higher unemployment rate suggests there is greater spare capacity in the economy and hence wage and price inflation will be lower.

A standard expectations-augmented wage Phillips curve is presented below (equation 1), which implies that wage inflation is driven by inflation expectations, labour productivity, the unemployment gap, and supply shocks. β is positive, so as unemployment falls, inflation increases.

$$\Delta w - \Delta z = \pi^e - \beta(U - U^*) + \nu \qquad (1)$$

where: Δw is wage growth, Δz is labour productivity growth, π^e is inflation expectations, U is the unemployment rate, U^* is the NAIRU, and ν is other supply shocks.

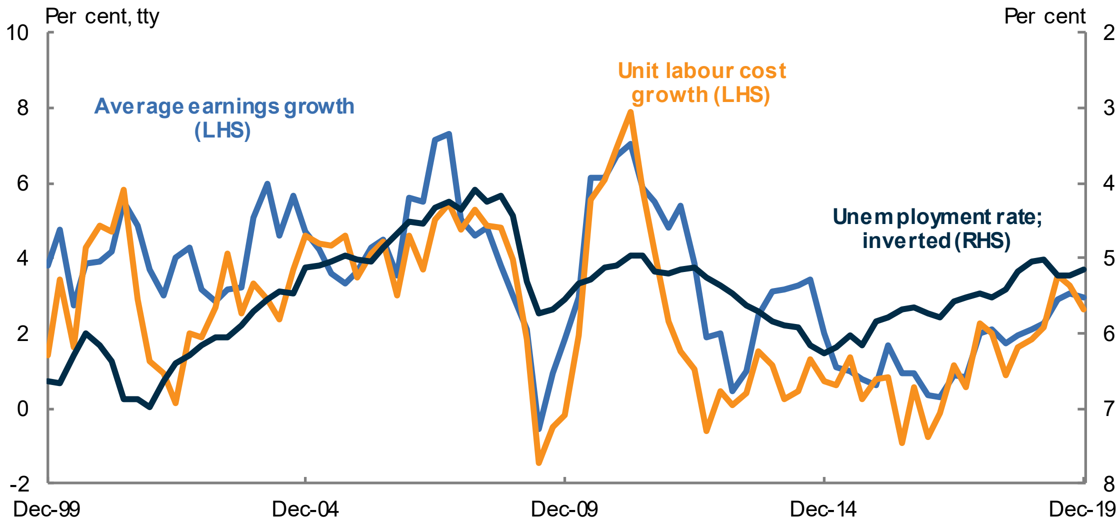
The NAIRU is the point at which the unemployment rate is associated with stable wage inflation (defined in our models as wage inflation in line with productivity growth and inflation expectations). Inflation expectations in the Phillips curve are typically measured as the weighted average of backward-looking inflation expectations (captured by recent inflation outcomes) and forward-looking expectations (captured by surveys of expectations or expectations derived from bond markets). In the long run, inflation is equal to inflation expectations, so wages grow at productivity growth plus inflation.

2.2. Gruen, Pagan and Thompson (1999)

One of the most influential studies of Phillips curves in Australia is by Gruen, Pagan and Thompson (1999), who discuss the development of the Phillips curve in Australia and estimate various price and wage Phillips curves. In particular, they build on work by Debelle and Vickery (1997) to estimate a time-varying NAIRU (treated as a unit root process) combined with expectations-augmented Phillips curves for both price and wage inflation.

Gruen, Pagan and Thompson's preferred model is based on a through-the-year wage Phillips curve (using unit labour costs (ULCs) as the wage measure) including inflation expectations, the unemployment gap, a lagged dependent variable and a 'speed limit' term. In most wage Phillips curves used in the context of the Australian NAIRU, ULCs are used as the wage measure (Chart 2). ULCs have the advantage of a longer history relative to other measures like the Wage Price Index (WPI) and Average Weekly Ordinary Time Earnings, and also strip out the effect of productivity. ULCs are a measure of output per unit of input, calculated as average earnings in the National Accounts (this is the total wage bill in the economy divided by the number of people or hours employed) divided by labour productivity.

Chart 2: Wage growth and unemployment



Note: Average earnings are from the National Accounts. Unit labour costs are average earnings divided by productivity.
Source: ABS Cat. no. 5206.0, 6202.0.

They include an unemployment gap term that captures the distance between the unemployment rate and the NAIRU. They use a non-linear unemployment gap, which means that an absolute change in the unemployment rate will have a larger effect on wage growth when it is below the estimated NAIRU. The lagged dependent variable reflects 'stickiness' and a degree of serial correlation in annual wage growth. The speed limit term accounts for the empirical finding that the speed of adjustment in the unemployment rate is important for wage growth. Other factors equal, a faster decrease (increase) in the unemployment rate will result a larger increase (decrease) in wage growth. The equation is specified accordingly:

Signal Equation:

$$\Delta_4 ulc_t - \Delta_4 p^{Ex}_{t-1} = \beta_1(\pi^e_t - \Delta_4 p^{Ex}_{t-1}) + \beta_2\left(\frac{U_t - U^*_t}{U_t}\right) + \beta_3\left(\frac{\Delta U_{t-1}}{U_t}\right) \quad (2)$$

$$+\beta_4(\Delta_4 ulc_{t-1} - \Delta_4 p^{Ex}_{t-2}) + \beta_5(\Delta ulc_{t-1} - \Delta ulc_{t-4}) + \varepsilon_t$$

State Equation:

$$U^*_t = U^*_{t-1} + \xi_t \quad (3)$$

where $\Delta_4 ulc_t$ is through-the-year growth in ULCs, $\Delta_4 p_{t-1}^{Ex}$ is through-the-year consumer price inflation excluding interest and other volatile items, π_t^e is measured inflation expectations based on the 10-year bond yield[3], U_t is the unemployment rate, U_t^* is the NAIRU, with the error terms $\varepsilon_t \sim (0, \sigma_\varepsilon^2)$ and $\xi_t \sim \left(0, \sigma_\xi^2\right)$.

The choice to use a through-the-year model was driven by volatility in the data at the time. In particular, the sample was dominated by a period when movements in labour costs were volatile and heavily dependent on regular Arbitration Court rulings. Therefore, the authors determined that annual movements were of greater economic interest, and so annual ULC movements were the preferred dependent variable for the signal equation.

The NAIRU estimated by Gruen, Pagan and Thompson (1999) increases from around 2 per cent in the late 1960s to around 6 per cent in the early 1970s. The estimated NAIRU then remains around 6 per cent for the next two decades before increasing slightly to be around 7 per cent in 1997 at the end of the sample.

Kennedy, Luu and Goldbloom (2008) updated this model in 2008, and estimated a NAIRU of 4.7 per cent in mid-2007.

2.3. RBA research

The RBA has published a number of articles on their NAIRU estimation methods. Most recently, Cusbert (2017) describes a Phillips curve framework used to estimate the NAIRU. This builds on work including Ballantyne, De Voss and Jacobs (2014) and Jacobs and Rush (2015). The Cusbert model jointly estimates a ULC Phillips curve with a price Phillips curve signal equation, with the state equation specified as in Gruen, Pagan and Thompson (1999).

Signal equation 1:

$$\Delta p_t^{TM} = \beta_1 \pi_t^e + \sum_{k=1}^{3} \gamma_k \Delta p_{t-k}^{TM} + \beta_2 \Delta ulc_{t-1} + \beta_3 \left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_4 \left(\frac{U_t - U_t^*}{U_t}\right) \tag{4}$$

$$+\beta_5 (\Delta_4 p_{t-1}^{MGS} - \Delta_4 p_{t-2}^{MGS}) + D_{<1977} \beta_6 \Delta p_{t-2}^{OIL} + \varepsilon_t$$

Signal equation 2:

$$\Delta ulc_t = \beta_7 \pi_t^e + \sum_{k=1}^{2} \delta_k \Delta p_{t-k}^{TM} + \beta_8 \left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_9 \left(\frac{U_t - U_t^*}{U_t}\right) + D_{<1977} \beta_{10} \Delta p_{t-2}^{OIL} + \epsilon_t \tag{5}$$

where Δp_t^{TM} is quarterly trimmed mean inflation, π_t^e is long-term inflation expectations, $\Delta_4 p_t^{MGS}$ is through-the-year growth in consumer import prices, Δp_t^{OIL} is the quarterly growth of the Brent oil price, with $\varepsilon_t \sim (0, \sigma_\varepsilon^2)$ and $\epsilon_t \sim (0, \sigma_\epsilon^2)$.

3 Note that in each of the models discussed, inflation expectations takes the same form as the inflation variable. So where quarterly inflation is used, inflation expectations are transformed into a quarterly measure.

The inclusion of import prices is a key point of difference to other models in the literature, and is used to account for the greater impact of foreign prices on inflation. Oil prices are also included, covering a period where they were 'correlated with large changes in prices and wages' (Cusbert 2017), but their inclusion is largely for empirical purposes. It also deviates from Gruen, Pagan and Thompson by using quarterly growth variables and dropping the lagged dependant variable from the ULC Phillips curve.

The NAIRU estimated by Cusbert ranges between 6 and 7 per cent in the 1980s and early 1990s. After reaching a historical peak in the in the mid-1990s, the estimated NAIRU steadily declines to 5 per cent at the end of the sample (March quarter 2017). This is in line with most models developed for Australia at the time.

In 2019, the RBA revised down its estimate of the NAIRU to around 4½ per cent (Ellis 2019). More recently, RBA governor Philip Lowe noted that "it is certainly possible that Australia can achieve and sustain an unemployment rate in the low 4s" (Lowe 2021).

2.4. Chua and Robinson (2018)

A number of additional papers have modified the Gruen, Pagan and Thompson (1999) model in an attempt to improve estimates of Australia's NAIRU. Lim, Dixon and Tsiaplias (2009) attempt to account for changes in the labour market to estimate the NAIRU, rather than assuming it acts as a random walk. They allow the slope to be time-varying, to account for a changing relationship between wage growth and the NAIRU. Using this method they estimate the NAIRU to be around 5 per cent as of late 2008.

Building on Cusbert (2017), Chua and Robinson (2018) focus on the wage Phillips curve, estimating a NAIRU model with two wage signal equations. They argue that the WPI gives a clearer signal about the state of the labour market because it abstracts from changes in the composition of employment, and that this is why it is the main wage measure followed by policy makers and market economists. With WPI growth relatively low in recent years, they hypothesised that this additional signal would reveal a fall in the NAIRU. The WPI Phillips curve is estimated jointly with a ULC Phillips curve, which has a much longer sample of data available (the WPI alone does not have enough historical data available to effectively model the NAIRU in a state-space framework).

Although the WPI is constructed to be unaffected by compositional changes in employment, there is uncertainty about how much it is adjusted for changes in productivity. Chua and Robinson (2018) account for this by including labour productivity terms in equation 7.

Signal equation 1:

$$\Delta ulc_t - \Delta p_{t-1}^{TM} = \beta_1(\pi_t^e - \Delta_4 p_{t-1}^{TM}) + \beta_2\left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_3\left(\frac{U_t - U_t^*}{U_t}\right) \tag{6}$$

$$+\beta_4(\Delta ulc_{t-1} - \Delta p_{t-2}^{TM}) + \varepsilon_t$$

Signal equation 2:

$$\Delta wpi_t - \Delta p^{TM}_{t-1} = \beta_5(\pi^e_t - \Delta_4 p^{TM}_{t-1}) + \beta_6\left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_7\left(\frac{U_t - U^*_t}{U_t}\right) + \beta_8 \Delta z_t \quad (7)$$

$$+\beta_9\left(\frac{\Delta U_{t-2}}{U_{t-1}}\right) + \beta_{10}(\Delta wpi_{t-1} - \Delta p^{TM}_{t-2}) + \beta_{11}(\pi^e_{t-1} - \Delta_4 p^{TM}_{t-2}) + \beta_{12}\Delta z_{t-1}$$

$$+\beta_{13}\left(\frac{\Delta U_{t-3}}{U_{t-2}}\right) + \beta_{14}\Delta z_{t-3} + \epsilon_t$$

where π^e_t is bond-market inflation expectations, Δwpi_t is growth in the wage price index, Δz_t is growth in non-farm labour productivity on an hourly basis, with $\varepsilon_t \sim (0, \sigma^2_\varepsilon)$ and $\epsilon_t \sim (0, \sigma^2_\epsilon)$.

Chua and Robinson slightly modify the state equation to incorporate non-linearity. The paper reports that incorporating the WPI signal equation actually leads to a higher estimate of the NAIRU in recent years, with a value of 5.5 per cent at the end of the sample (September quarter 2016).

2.5. Treasury's previous approaches to estimating the NAIRU

An earlier Treasury NAIRU estimation model was documented in the 'Medium-Term Economic Projection Methodology' working paper (Bullen et al. 2014). It is based on the ULC Phillips curve presented by Gruen, Pagan and Thompson (1999) but with some amendments.

Bullen et al. assume that wages grow in line with labour productivity, expected expenditure price inflation and the lagged unemployment gap. Their wages equation takes the form of:

$$\Delta_4 w_t - \Delta_4 z_t - \Delta_4 p^{GNE}_{t-1} = \beta_1(\pi^e_t - \Delta_4 p^{GNE}_{t-1}) + \gamma\left(\frac{U_{t-1} - U^*_t}{U_{t-1}}\right) \quad (8)$$

$$+\beta_2(\Delta_4 w_{t-1} - \Delta_4 z_{t-1} - \Delta_4 p^{GNE}_{t-2})$$

$$+\beta_3\big(\Delta w_{t-1} - \Delta z_{t-1} - (\Delta w_{t-4} - \Delta z_{t-4})\big) + \varepsilon_t$$

where $\Delta_4 w_t$ is through-the-year growth in hourly average earnings, π^e_t is bond-market inflation expectations, $\Delta_4 z_t$ is through-the-year growth in productivity, $\Delta_4 p^{GNE}_t$ is through-the-year growth in the gross national expenditure deflator, $\gamma < 0$ and $\varepsilon_t \sim (0, \sigma^2_\varepsilon)$. $\Delta_4 w_t - \Delta_4 z_t = \Delta_4 ulc_t$. Their state equation is as in Gruen, Pagan and Thompson.

Bullen et al. most notably differs from Gruen, Pagan and Thompson with the removal of the change in the unemployment rate term (the 'speed limit' term) and the inclusion of a lagged instead of contemporaneous unemployment gap. They note that 'there is no loss of explanatory power when these features of the data are modelled jointly via a lagged unemployment gap' (Bullen et al. 2014). Additionally, they use the gross national expenditure deflator to model prices instead of consumer price inflation. The model uses 10-year bond market break-even measure of inflation expectations.[4]

4 This choice is standard in the literature (see for example Gruen, Pagan and Thompson (1999) and Chua and Robinson (2018)).

The use of a purely financial market measure of inflation expectations presents challenges due to its incorporation of liquidity and risk premia.

Treasury's subsequent NAIRU estimation model adapts Bullen et al. (2014), but uses the household consumption deflator as the price measure instead of the gross national expenditure deflator (because the consumption deflator is less affected by terms of trade shocks). The choice of the consumption deflator is unusual when compared to the literature, and given its volatile nature was likely affecting the estimated coefficients on inflation expectations.

The subsequent model's state equation takes the form of:

$$\Delta_4 w_t - \Delta_4 z_t - \Delta_4 p_{t-1}^{CON} = \beta_1(\pi_t^e - \Delta_4 p_{t-1}^{CON}) + \beta_2\left(\frac{U_{t-1} - U_t^*}{U_{t-1}}\right) \tag{9}$$

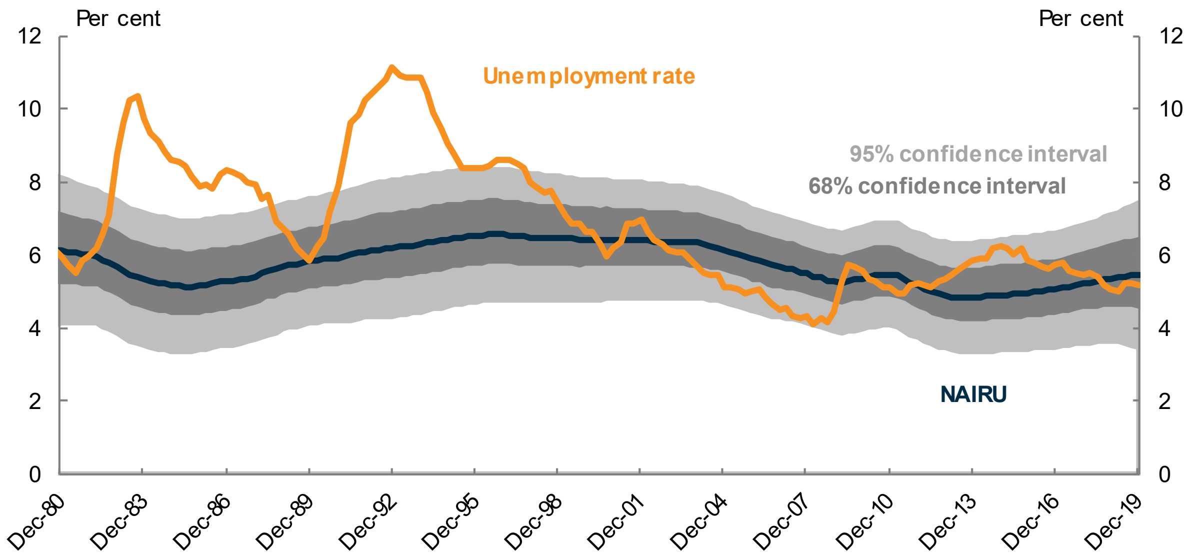
$$+\beta_3(\Delta_4 w_{t-1} - \Delta_4 z_{t-1} - \Delta_4 p_{t-2}^{CON})$$

$$+\beta_4\big(\Delta w_{t-1} - \Delta z_{t-1} - (\Delta w_{t-4} - \Delta z_{t-4})\big) + \varepsilon_t$$

where $\Delta_4 p_t^{CON}$ is through-the-year growth in the household consumption deflator, with $\varepsilon_t \sim (0, \sigma_\varepsilon^2)$. The error term of the state equation is restricted to the variance of the error term in the unemployment rate calculated as a unit root process.

Using this model, the NAIRU is estimated to be around 5½ per cent at the end of the 2019 (Chart 3, Table 1). The estimate increased during 2019, due to low productivity growth relative to real wages growth, and a slight increase in the unemployment rate. This model's NAIRU estimate has generally remained at around 5 per cent over the past few years, down from around 7 per cent in the mid-1990s.

Chart 3: Treasury's previous NAIRU model



Note: The 68 per cent confidence intervals are ±1 standard error bands and the 95 per cent confidence intervals are ±2 standard error bands.

Source: ABS Cat. no. 6202.0, Treasury.

Table 1: NAIRU model coefficients (equation 9)

Wage variable	$\Delta_4 ulc_t = \Delta_4 w_t - \Delta_4 z_t$	
Price variable	$\Delta_4 p_{t-1}^{CON}$	
π_t^e	0.21***	(0.05)
Δp_{t-1}	0.79^	
$\left(\frac{U_{t-1} - U_t^*}{U_{t-1}}\right)$	-2.87***	(0.64)
$(\Delta_4 w_{t-1} - \Delta_4 z_{t-1} - \Delta_4 p_{t-2}^{CON})$	0.60***	(0.04)
$(\Delta w_{t-1} - \Delta z_{t-1} - (\Delta w_{t-4} - \Delta z_{t-4})$	0.14***	(0.01)
σ_ε	0.01***	(0.00)
σ_ξ	0.31^	
U_t^* final state	5.56	
Sample	1968:1–2019:4	

Notes: *, ** and *** indicate significance at the 10, 5 and 1 per cent level respectively, ^ indicates a restricted coefficient, standard errors reported in parentheses.

The parameter estimates for the NAIRU model in equation 9 are presented in Table 1. Within this model, ULC growth seem to be largely determined by backward looking rather than forward looking inflation expectations (modelled with bond market expectations). The coefficient on the unemployment gap term is negative, meaning that if the unemployment rate is below the NAIRU, wages will grow above the rate of productivity growth and inflation. However, the magnitude of the coefficient is much larger than is generally estimated in the Australian literature. Estimates typically fall between -1 and -2.[5]

In Table 1, the coefficient on Δp_{t-1} is marked as a restricted coefficient. This is because we can rearrange the first half of equation 9 to leave nominal wage growth as the dependent variable:

$$\Delta_4 w_t - \Delta_4 z_t = \Delta_4 p_{t-1}^{CON} + \beta_1(\pi_t^e - \Delta_4 p_{t-1}^{CON})$$

Doing so means that the coefficient on π_t^e is equal to β_1, while the coefficient on $\Delta_4 p_{t-1}^{CON}$ is equal to $(1 - \beta_1)$. That is, they are restricted to sum to one.

5 Gruen, Pagan and Thompson (1999) estimate a coefficient on the unemployment gap term of -1.87 for the sample period 1966 to 1997. Cusbert (2017), estimates a coefficient of -1.9 (on the unemployment gap term in their ULC equation) for the sample period 1968 to 2017. Chua and Robinson (2018) estimate a coefficient of -1.64 for the sample period 1967 to 2016.

3. Treasury's approach to estimating the NAIRU

In considering alternatives to Treasury's previous NAIRU model, a range of approaches described in the literature were explored. The criteria used to assess whether changes were appropriate were based on both model performance and whether the relationships and measures used were conceptually robust. Data choices such as the prices and productivity measures and inflation expectations, as well as theoretical modifications to the NAIRU estimation model, were considered.

Our final signal equation takes the form:

$$\Delta w_t - \Delta z_t - \Delta p_{t-1}^{TM} = \beta_1(\pi_t^e - \Delta p_{t-1}^{TM}) + D_{<1993}\beta_2\left(\frac{U_t - U_t^*}{U_t}\right) + D_{\geq 1993}\beta_3\left(\frac{U_t - U_t^*}{U_t}\right) \tag{10}$$
$$+\beta_4\left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_5(\Delta z_t^* - \Delta z_t) + \varepsilon_t$$

with the state equation:

$$U_t^* = U_{t-1}^* + \xi_t \tag{11}$$

where Δw_t is hourly average earnings growth, Δp_t^{TM} is trimmed mean quarterly inflation, π_t^e is 3-year inflation expectations (described in section 3.1), Δz_t is productivity growth, Δz_t^* is growth in trend productivity (described in section 3.2), D is a structural break (prior to or since the March quarter 1993), with $\varepsilon_t \sim (0, \sigma_\varepsilon^2)$ and $\xi_t \sim \left(0, \sigma_\xi^2\right)$. See Appendix A for a full description of the variables and some summary statistics.

3.1. Inflation expectations

The level of forward-looking inflation expectations directly affects the level of the NAIRU. A higher inflation expectations series will result in a lower estimate of the NAIRU and vice versa, all other things equal. Therefore, pinning down the level of inflation expectations was considered to be a critical factor in improving the accuracy of the NAIRU estimate. However, like the NAIRU, inflation expectations cannot be observed, only estimated (Ellis 2019).

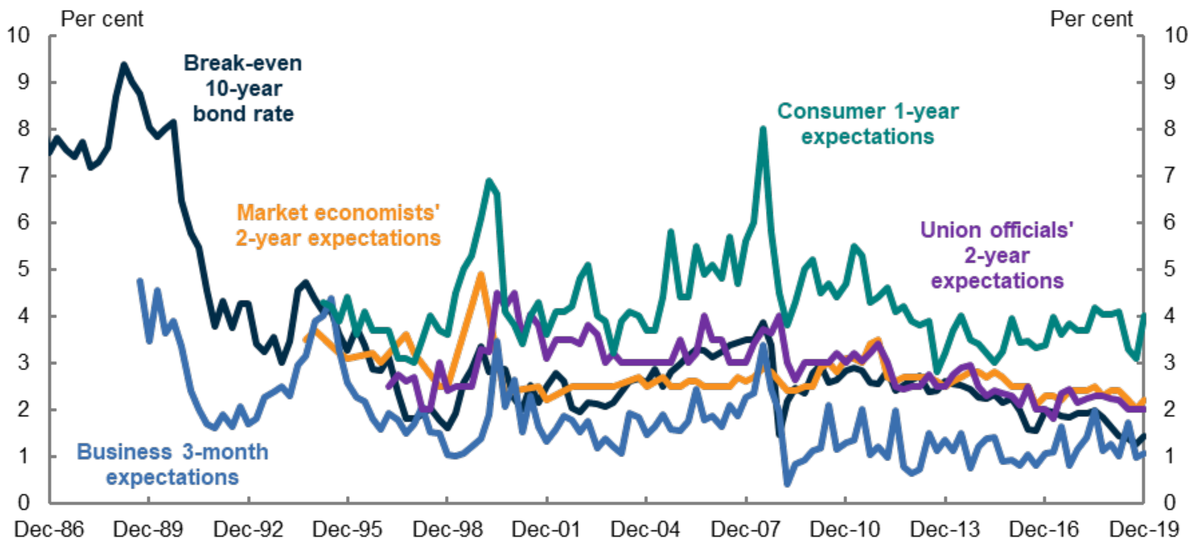
Treasury previously used the 10-year break-even bond market expectations as the measure of inflation expectations. This series may not be appropriate, however, as it includes liquidity and inflation risk premia components, which bias the expectations series (Moore 2016). Some external modellers have dealt with this by trying to estimate and abstract from the inflation risk premia (see for example Hambur and Finlay 2018), or by using financial market expectations measures alongside survey expectations series.

Given that Treasury's NAIRU estimate is mainly used as an input to wage forecasting, a series that captures expectations over shorter-term horizons (3- to 5-year inflation expectations) is preferred as it will better reflect the inflation expectations relevant to wage bargaining.

A wide variety of inflation expectations series are available for Australia, including:

- Consumer expectations: these are representative of the employee; they have an upwards bias that is adjusted for.
- Business and union expectations: these are representative of other stakeholders in wage bargaining; business inflation expectations have a downwards bias that is adjusted for.
- Professional forecaster expectations: these include Consensus expectations and surveys of market economists.
- Market-implied inflation expectations: these include break-even bond market expectations, as well as inflation swaps.

Chart 4: Example measures of inflation expectations



Source: Melbourne Institute, RBA.

Each individual series has inherent issues, and none are considered to fully capture overall inflation expectations in the economy, and certainly not for wage negotiations. There is the additional problem of the horizon: most measure very short-run expectations of two years or under, or more long-run expectations of inflation at the six- to ten-year horizon, rather than the desired 3 to 5-year range that we consider to be most influential on wage pressures in the economy. Although individual agreements and Fair Work Commission award wage increases occur more regularly, we expect that workers would still consider a medium-term horizon of inflation expectations for wage bargaining.

There is a substantial literature around estimating inflation expectations, partly due to their critical role in forecasting prices and wages. Estimating inflation expectations is crucial when modelling the NAIRU, as the Phillips curve will attribute low wages growth (that is, ULCs) to either low inflation expectations or slack in the labour market. We considered and tested multiple measures of inflation expectations for inclusion in the Phillips curve.

One simple approach is to use a single survey measure or proxy such as market-implied expectations as the measure of inflation expectations. This is the approach of the previous Treasury model and other Australian models (for example, Gruen, Pagan and Thompson 1999), which use the 10-year bond market break even measure of inflation expectations. However, as discussed above, each series, including the bond market measure, has drawbacks and none fully captures the relevant inflation expectations nor are measured on the right time horizon for wage negotiations.

Other approaches rely on econometric estimates of trend inflation and inflation expectations. Chan, Clark and Koop (2015) outline a model of inflation and survey-based long-run forecasts of inflation that allows for the estimation of the link between trend inflation and the long-run forecasts. They calibrate the trend estimate of inflation to correspond to long-run inflation expectations, so that the link between each survey and underlying expectations can be quantified. In the US, this approach has become popular due to its good forecasting properties and close approximation of US inflation dynamics (Braxa et al. 2017).

The RBA use a similar model to Chan, Clark and Koop to extract a common signal of long-term expectations from the various measures after controlling for each measure's co-movement with recent inflation (Cusbert 2017). This produces a fairly flat long-run trend series, which takes the majority of its signal from the 6 to 10-year consensus inflation forecast. Since we are interested in shorter-run inflation expectations, this model is not ideal for our wage Phillips curve.

We produce a measure of inflation expectations using a version of the Nelson-Siegel model to combine a range of inflation expectations measures following Aroubra (2018). This method maps out the term structure of inflation expectations at all time periods based on the series included and their tenors (Nelson and Siegel 1987). This allows for information to be gathered from all measures, and an inflation expectations series for a 3-year horizon to be constructed. This captures all relevant information from the available series, at the horizon relevant to wage negotiations.

The model allows for different types of expectations measures (specifically, those that average across the horizon as well as those that are expectations for a specific year).[6] Our understanding is that this is the first time this kind of inflation expectations model has been used as an input into a wage Phillips curve in Australia.

$$\pi_t^* = L_t + (C_t - S_t)\left(\frac{e^{-\lambda\tau_1} - e^{-\lambda\tau_2}}{\lambda(\tau_2 - \tau_1)}\right) + C_t\left(\frac{\tau_1 e^{-\lambda\tau_1} - \tau_2 e^{-\lambda\tau_2}}{\tau_2 - \tau_1}\right) \tag{12}$$

Using the Nelson-Siegel model in equation 12, we define π_t^* as the various measures of inflation expectations, τ_1 as the month that the expectations series is measured from, τ_2 as the tenor of the series, and λ as a decay parameter. The parameter L_t can be viewed as a long-term factor, or the 'level' of inflation expectations in the long run. S_t is the 'slope' parameter (often called the short-term factor as its loading decays to zero as the tenor increases), and C_t is the 'curvature' parameter (which increases in the short- and medium-term before decaying to zero). λ is set to maximise the loading on the curvature parameter at 24 months.[7] We hold this constant, and

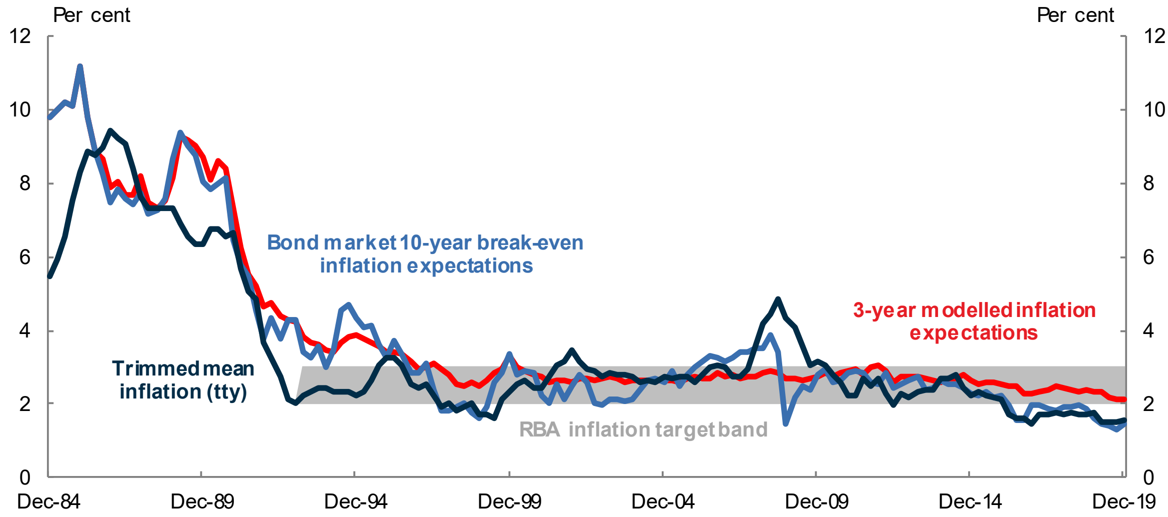
6 See Diebold and Li (2006) for the interpretation of the coefficients in the model, and Lewis (2016) which uses a similar model application to estimate the term structure of inflation expectations.

7 This choice was based on the NAIRU with the best in-sample fit as determined by the Akaike information criterion. In practice this choice made little difference to the estimated inflation expectations and NAIRU series.

estimate the model using ordinary least squares with each historical quarter of inflation expectations data. The desired tenor (36 months) can then be used alongside the estimated parameters to produce a historical series. For more information on the model specification and results, see Appendix C.

This method produces the 3-year ahead inflation expectations series presented in Chart 5, which has a level of around 2.1 per cent as at the December quarter 2019.

Chart 5: Inflation expectations



Source: Consensus Economics, Melbourne Institute, RBA, Treasury.

Applying a term structure to inflation expectation surveys recognises that we have information on inflation expectations at different time horizons and is similar to model averaging for forecasting, where expectations of future outcomes are taken from a range of sources. Each of the surveys may be a noisy measure of expectations but combining the surveys, in principle, improves our ability to capture inflation expectations over various horizons. The term structure approach also provides continuous curves, so inflation expectations for any standard horizon can be calculated.

3.2. Productivity

The ULC Phillips curves in the literature implicitly restrict the impact of labour productivity growth on wages to be equal to one, therefore assuming that all labour productivity is contemporaneously paid into wages. In reality, however, wages are likely to be sticky (that is, they will slowly adjust to changes in productivity), so labour productivity has been split into an actual and trend productivity component. Due to the way trend productivity is constructed, actual productivity fluctuates around it in a stationary cycle, so in the long run these approaches are equivalent (Chart 6). A similar method is used by the Congressional Budget Office in their NAIRU estimation (Arnold 2008).[8]

Estimating the NAIRU model with a split between trend and actual productivity improves the model fit and produces a statistically significant and sensible coefficient. The estimated coefficients imply

8 They include a 32-quarter moving average of productivity growth in their model. We find that a Kalman-filtered trend productivity term outperforms this (and other tested moving average terms) within the model.

that around half of productivity gains flow through to wages contemporaneously, while half flows through at a slower rate as the trend adjusts.

Trend productivity is estimated by applying a trend-cycle decomposition to actual labour productivity over history. This is a standard approach from the literature (for example, Watson 1986). This approach allows us to calibrate the trend more closely to estimates of trend productivity from other models, with cyclical productivity specified as an AR(2) process. The trend productivity term is estimated from a smoothed or two-sided Kalman filter. The error from this model is captured in actual productivity.

Signal equation 1: Productivity is split into its trend and cyclical components.

$$z_t = z_t^T + z_t^C \tag{13}$$

where: z_t is output per hour worked, z_t^T is the unobserved trend component and z_t^C is the unobserved cyclical component.

State equation 1: Trend productivity is modelled as a random walk with time-varying drift (δ_t).

$$z_t^T = z_{t-1}^T + \delta_{t-1} + v_t \tag{14}$$

State equation 2: The drift is modelled as a stationary process.

$$\delta_t = \alpha\delta + (1-\alpha)\delta_{t-1} + \epsilon_t \tag{15}$$

State equation 3: Cyclical productivity is modelled as an AR(2) process.

$$z_t^C = \rho_1 z_{t-1}^C + \rho_2 z_{t-2}^C + \varsigma_t \tag{16}$$

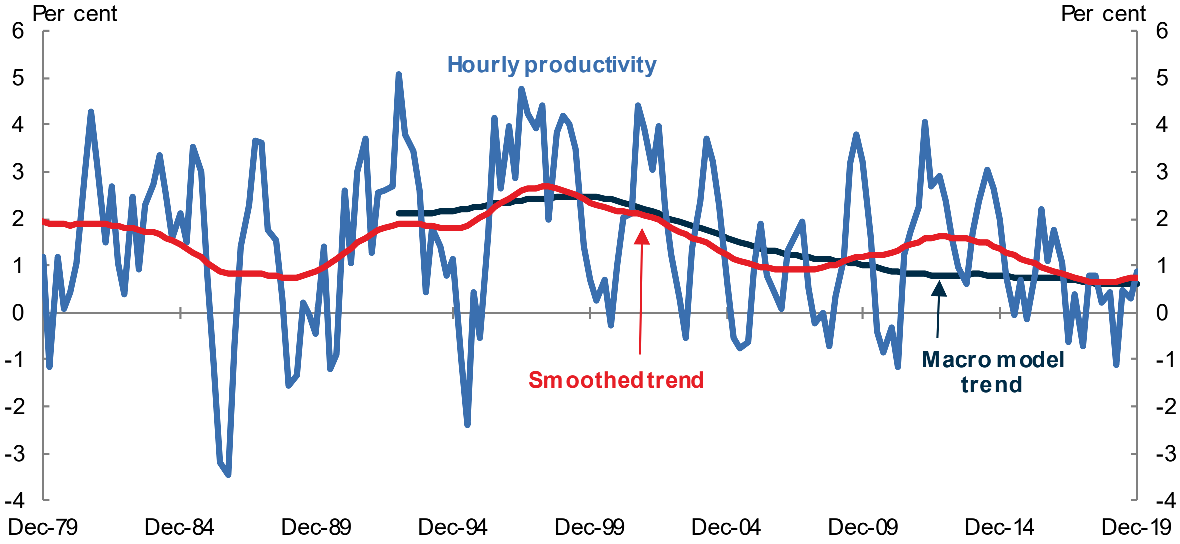
All errors are white noise processes:

$$v_t \sim (0, \sigma_v^2)\ ;\ \epsilon_t \sim (0, \sigma_\epsilon^2)\ ;\ \varsigma_t \sim \left(0, \sigma_\varsigma^2\right) \tag{17}$$

The trend-cycle decomposition is calibrated so that the estimated trend is broadly consistent with the aggregate labour productivity trend[9] from the Treasury's macroeconometric model of the Australian economy. These series are therefore quite similar in history, except for during the mining boom, where the productivity trend from the macroeconometric model abstracts from the impact of capital deepening in the mining sector on labour productivity. The trend-cycle decomposition results and robustness checks are presented in Appendix D.

9 Trend labour productivity in Treasury's macroeconometric model is estimated within each industry's labour demand equation as Labour Augmenting Technical Change. More detail on this approach is available upon request. As industry level data is only available from 1990 onwards, this series is too short for the purposes of estimating the wage Phillips curve.

Chart 6: Trend productivity comparison



Note: Through-the-year growth is shown.
Source: ABS Cat. no. 5206.0, 6202.0, Treasury.

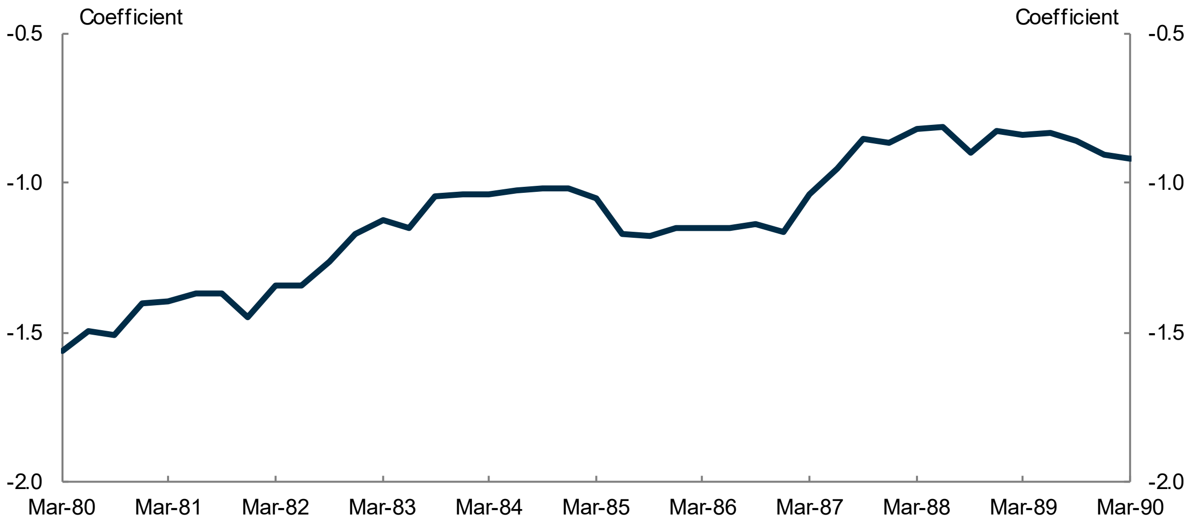
As the weighted average of trend and actual productivity is higher than actual productivity in recent years this has the effect of lowering the end point of the NAIRU by about 0.1 percentage points when compared to a specification without the productivity split. This intuitively means that the model is interpreting some of the recent weakness in productivity to be short lived, and so wages are not fully incorporating it.

One concern with including a trend variable in the model is that it can introduce end-point uncertainty to the estimate. That is, the recent data will be revised each quarter, also leading to revisions in the estimate of trend productivity and therefore of the NAIRU estimate. However, when re-estimating the NAIRU with historical data, we do not find that the inclusion of this trend term leads to notably larger volatility in the endpoint of the NAIRU estimate.

3.3. Structural break

An additional change that was explored was to add a structural break on the unemployment gap coefficient. Treasury's previous model implicitly assumed that the relationship between the unemployment gap and wage growth has remained constant across the sample period. We would expect that this relationship has likely weakened over time, due to anchoring of inflation (and wage) expectations, the globalisation of the labour market and the changing structure of the workforce, among other factors. When running the Phillips curve model with a rolling start date, the coefficient roughly halves in magnitude from 1980 to 1990 (Chart 7).

Chart 7: Coefficients on unemployment gap with rolling model start dates



Source: Treasury.

A break on the unemployment gap coefficient was found to be significant, and was chosen to be set in the March quarter 1993.[10] This corresponds with the start of the inflation targeting period in Australian monetary policy (Debelle 2018). A break in the 1990s can also be attributed to factors such as reforms to workplace regulation and increasing exposure to international trade and therefore international competition in the decade. US research has suggested a central bank that is more focussed on inflation targeting could change the relationship between unemployment and (wage) inflation (see for example Hooper, Mishkin and Sufi (2019) and McLeay and Tenreyro (2019)). As expected, the coefficient on the unemployment gap is larger in the pre-1993 sample than after. Its magnitude roughly halves from around -2.6 (β_2) for the pre-1993 period to around -1.1 (β_3) for 1993 onwards, with both being statistically significant.

In conjunction with this choice, the sample was restricted to 1980 onwards. The labour market dynamics of the 1970s are quite different to those of the subsequent years. This affects both the coefficient estimates and the variance of the NAIRU estimate with the full sample, but is magnified when a structural break is included. The exclusion of the 1970s should not be economically significant as the labour market dynamics associated with that time period (and their associated volatility) are not considered to be relevant to the determination of wages today.

3.4. Incorporation of common approaches used in the literature

Some common approaches used in the literature have also been incorporated into the updated model.[11] These include the following changes relative to the previous model:

10 Breaks on all coefficients were tested along with the variance, but were not found to be statistically significant. The choice of break point does not broadly change the evaluation metrics of the model.

11 Although some models incorporate a second prices Phillips curve signal equation, we choose to use a single Phillips curve model. In theory, these should result in similar NAIRU estimates, although in practice this is not always the case. Treasury uses the NAIRU in wage forecasting and understanding labour market dynamics, so our key focus is how the unemployment gap affects wages.

- Using quarterly growth variables: although Gruen, Pagan and Thompson (1999) use a through-the-year specification, few subsequent papers in Australia repeat this. Using through-the-year growth variables was found to result in a moving-average process in the residuals and a downwards bias in the estimate of the inflation expectations coefficient (due to stronger correlation between annual inflation and annual wages growth). In addition to using quarterly growth variables, all lags of the dependant variable were dropped as there was no evidence of auto correlation.[12]

- Adding a 'speed limit' term: this is a variable that captures the rate of adjustment of the unemployment rate. This variable is highly statistically significant. Excluding this from the model was found to upwardly bias the estimate of the coefficient on the unemployment gap, which could lead to mis-estimation of the NAIRU.

- Using a contemporaneous unemployment gap:[13] Treasury's previous specification used a lagged unemployment gap, unlike the academic literature. Although this change was not found to improve in-sample fit in the NAIRU specification, it did improve forecasting performance.

- Unrestricting variance: restricting the variance on the state equation can be used to generate a desirable (for example, smoother) estimate of the NAIRU. However, the model was able to solve and produce a reasonable NAIRU estimate with the variance freely estimated.

The choice of prices series to use (to capture backward-looking inflation expectations) was also considered. Treasury's previous model was unusual in the literature in that it used the consumption price deflator. A variety of alternative prices series were tested including the consumption price deflator, GDP deflator, domestic final demand deflator, headline inflation, weighted median inflation and trimmed mean inflation. Generally, the underlying prices series were found to have better in-sample fit. This is because they are less affected by terms of trade effects or idiosyncratic factors which are unlikely to have an impact on wage inflation. Of the underlying series available, the trimmed mean inflation rate was selected as it is more commonly used in the literature.

Using trimmed mean inflation does affect the coefficients on forward-looking inflation expectations and lagged inflation and leads to a larger weight placed on lagged inflation relative to estimated expectations (see Appendix B). This is in line with underlying inflation measures being more relevant to wage inflation.

12 The through-the-year specification is equivalent to a quarterly specification with restrictions on the lag structure.

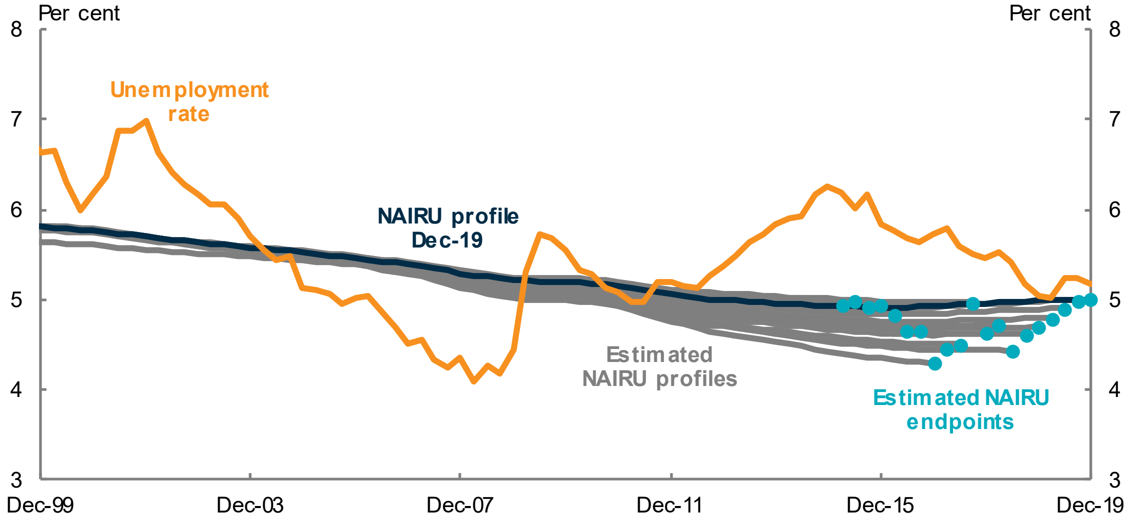
13 We also tested a linear unemployment gap (which performs worse in the framework), and changing the denominator on the gap to also be the NAIRU (which doesn't improve measures of fit, and is difficult for the model to solve due to the non-linearity of the state variable).

4. Results

4.1. Model comparison

State-space models inherently have some variability around their endpoint estimation, and wide confidence intervals. Estimating to a sample end of each quarter for the five years to 2019, the updated model provides a range of estimates between 4½ and 5 per cent (Chart 8). The updated model finds the NAIRU is estimated to be around 5 per cent as at the December quarter 2019 (Chart 9, Table 2).

Chart 8: Rolling NAIRU estimates from updated model

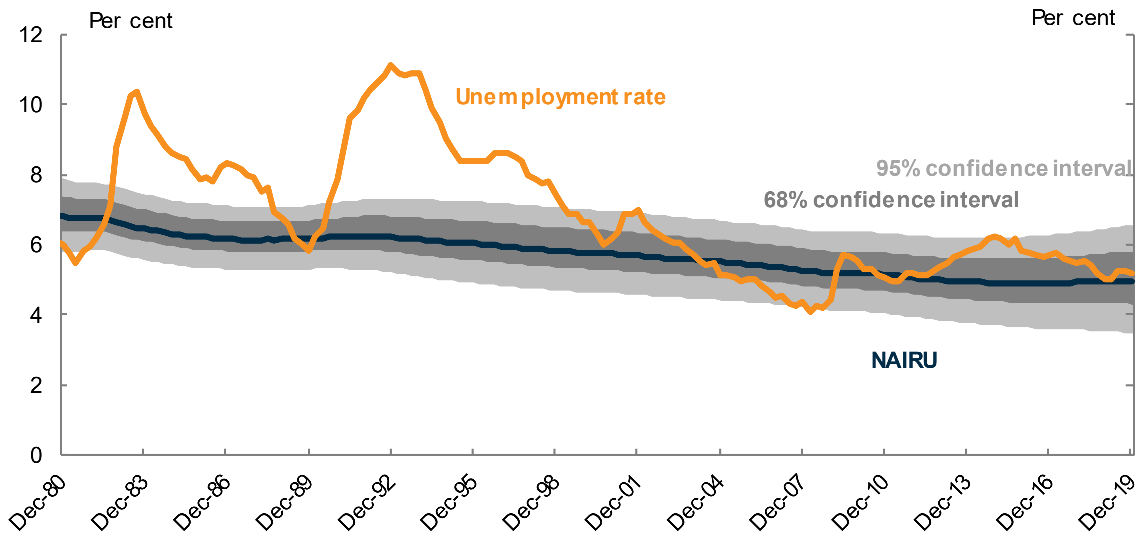


Note: Endpoints for NAIRU estimates from 2014:Q4 to 2019:Q4 are shown.
Source: ABS Cat. no. 6202.0, Treasury.

Given the general calibration and endpoint sensitivity of the NAIRU estimation, and the uncertainty of economic conditions over the near-term, we consider it prudent to characterise our best estimate of the NAIRU as being in the 4½ to 5 per cent range, around a mid-point estimate of 4¾ per cent. This reflects our estimates of the NAIRU in the five years preceding COVID-19. It also reflects our caution about over-interpreting the latest estimate, noting the last five years of incoming data has impacted on both the estimate for the current value of the NAIRU and that for the recent past (Chart 8).

The NAIRU can be re-estimated each quarter with the release of new data, and is therefore subject to change. However, given the labour market upheaval in 2020 due to the COVID-19 pandemic, we do not report results beyond December 2019 at this point.

Chart 9: NAIRU estimate from updated model



Note: The 68 per cent confidence intervals are ±1 standard error bands and the 95 per cent confidence intervals are ±2 standard error bands.

Source: ABS Cat. no. 6202.0, Treasury.

Table 2: Results for alternative Phillips curve models

	Equation 9 (with full sample)		Equation 9 (with restricted sample)		Equation 10	
Wage variable	$\Delta_4 ulc_t$		$\Delta_4 ulc_t$		Δw_t	
Price variable	$\Delta_4 p_{t-1}^{CON}$		$\Delta_4 p_{t-1}^{CON}$		Δp_{t-1}^{TM}	
Expectations variable	**10-year bond market break-even expectations**		**10-year bond market break-even expectations**		**3-year modelled expectations**	
π_t^e	0.21***	(0.05)	0.23***	(0.08)	0.37	(0.24)
Δp_{t-1}	0.79^		0.77^		0.63^	
Δz_t^*					0.46***	(0.10)
Δz_t	1.00^		1.00^		0.54^	
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$					-4.59**	(1.98)
$\left(\frac{U_{t-1} - U_t^*}{U_{t-1}}\right)$	-2.87***	(0.64)	-1.90***	(0.58)		
$\left(\frac{U_t - U_t^*}{U_t}\right)$ (pre-break)					-2.73***	(0.62)
$\left(\frac{U_t - U_t^*}{U_t}\right)$ (post-break)					-1.15**	(0.55)
$(\Delta_4 ulc_{t-1} - \Delta_4 p_{t-2}^{CON})$	0.60***	(0.04)	0.65***	(0.04)		
$(\Delta ulc_{t-1} - \Delta ulc_{t-4})$	0.14***	(0.01)	0.16***	(0.02)		
σ_ε	0.01***	(0.00)	0.01***	(0.00)	0.01***	(0.00)
σ_ξ	0.31^		0.31^		0.13	(0.12)
U_t^* final state	**5.56**		**5.45**		**5.00**	
AIC	-5.52		-5.83		-6.49	
Sample	1968:1 – 2019:4		1980:1 – 2019:4		1980:1 – 2019:4	

Notes: *, ** and *** indicate significance at the 10, 5 and 1 per cent level respectively, ^ indicates a restricted coefficient, standard errors reported in parentheses.

Overall, the initial changes made (quarterly specification, speed limit term inclusion, and the switch to a contemporaneous unemployment gap) have an offsetting effect on the endpoint of the NAIRU estimate. The inclusion of a structural break and productivity split, and the use of trimmed mean inflation and our trend inflation expectations each cause a decrease in the estimated NAIRU endpoint. These changes all result in a smoother estimate of the NAIRU with smaller confidence intervals. We estimate a 68 per cent confidence interval of ±½ percentage points around the NAIRU estimate through history and ±¾ percentage points at the endpoint. Restricting the estimation sample and introducing the new inflation expectations series are the biggest contributors to the downwards revision of the estimated NAIRU endpoint compared to the old model.

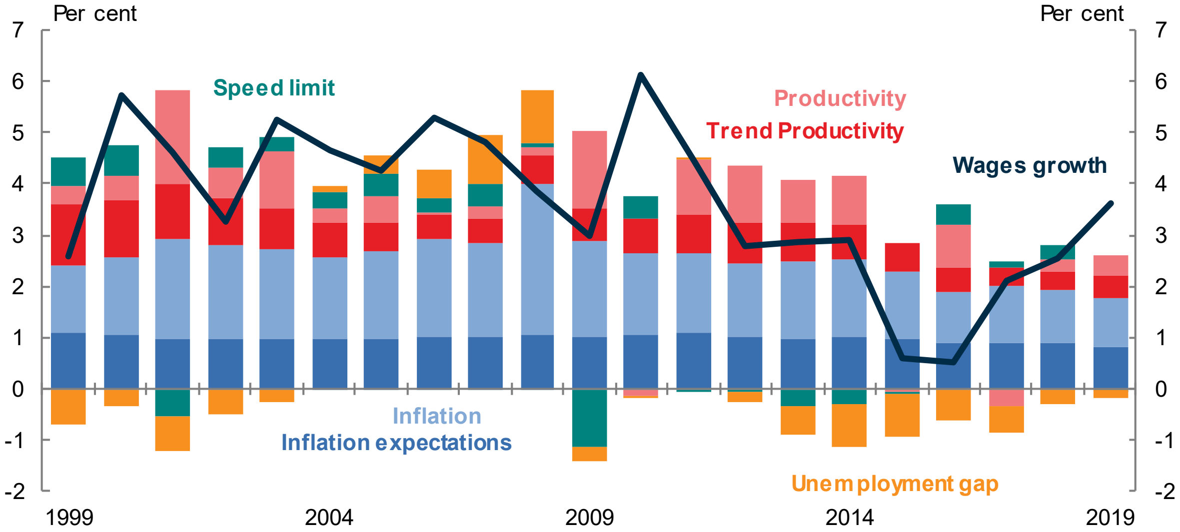
Wages growth is still largely determined by past inflation in the model, rather than forward-looking measures of inflation expectations, although the share determined by forward-looking expectations has increased relative to Treasury's previous model. In saying that, the coefficient is no longer statistically significant. This could be because the greater stability (both in the inflation measure used, and the modelled inflation expectations) could make it harder to separately identify the effect of the two series.

As discussed above, the model estimates that only around half of short-term productivity growth flows through to wages. This result is reported as statistically significant, but this should be interpreted with caution.

In terms of performance, the in-sample fit of the wage Phillips curve clearly improves compared to the previous model (Table 2). See Appendix B for a summary of all results.

The updated model can be used to decompose the drivers of wage growth (Chart 10). Strong wages growth in the mid-2000s is partially explained by a negative unemployment gap (unemployment below the NAIRU putting upwards pressure on wages). Then weaker wages growth through the mid-2010s is conversely explained by a positive unemployment gap.

Chart 10: Decomposition of annual growth in hourly wages



Note: Chart shows summed quarterly growth rates and contributions to growth. This is broadly equivalent to through-the year growth to the December quarter in each year.

Source: ABS Cat. no. 5206.0, 6202.0, Treasury.

The model finds that the NAIRU is close to the actual unemployment rate in 2019 as hourly wages growth (about 3.6 per cent through the year to the December quarter 2019) is stronger than the weighted average of inflation expectations and trimmed mean inflation (contributing around about 1.8 percentage points) and the weighted average of trend and actual productivity growth (contributing about 1 percentage points).

4.2. Other considerations

Precision of estimate

The precision of the model estimates is a further consideration. Although the mean absolute revision size is broadly comparable, the updated model has a lower standard deviation on revision size, a smaller average quarterly change in the NAIRU estimate, and a smaller average confidence interval.[14] However, it should be noted that the estimated confidence interval does not account for uncertainty in the model parameters. As the updated model includes estimated trend productivity and inflation expectations, this increases estimation uncertainty.[15]

In this regard it's worth noting that there are large confidence intervals around the estimate of the NAIRU – see Chart 9 above.

Forecasting

Another way of evaluating the performances of different models is to compare how well they forecast. We do this by pseudo out-of-sample forecasting, where we estimate trend productivity, inflation expectations and the NAIRU to a specific quarter, and then produce wage growth 'forecasts'. We can then compare these to actual data results, to see how accurate different models would have been.

Treasury generally does not consider just one model's output when considering the outlook for wages, and takes information from a range of sources. Therefore, here we are comparing relative, rather than absolute, performance.

The updated wage Phillips curve model leads to enhanced forecasting performance compared to the previous model at all horizons tested (with the outperformance statistically significant from four-quarters-ahead onwards). The main driver of this improved forecasting performance is the introduction of the structural break on the unemployment gap. Given changes in labour market dynamics over the past forty years, allowing the model to have a lower coefficient on the unemployment gap term in the inflation targeting period means it can better reflect current conditions.

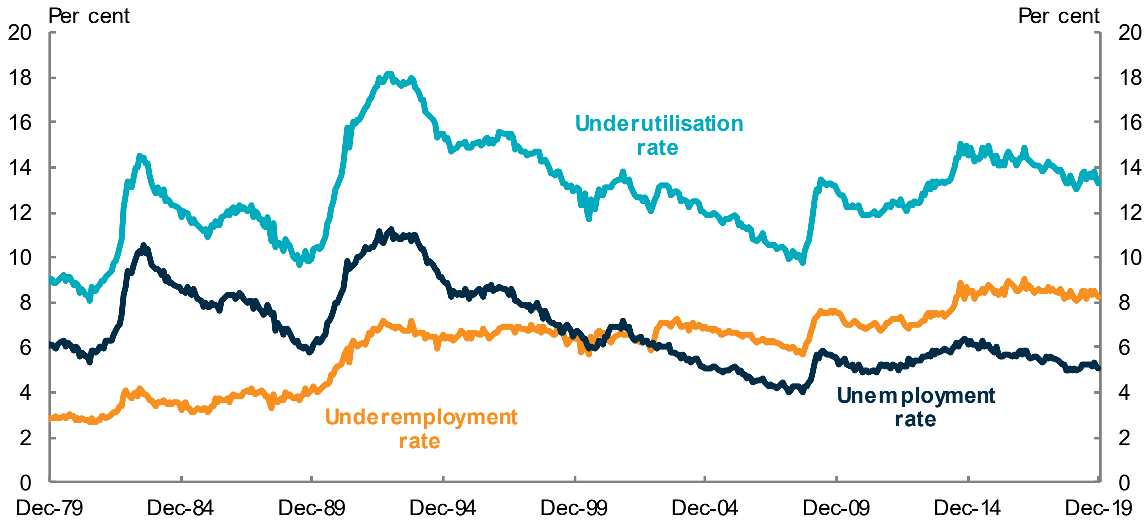
14 Note that part of the reason we have a smaller confidence interval is the exclusion of the 1960s and 1970s from the model as these were more volatile decades.

15 However, re-estimating the trend productivity at each quarter does not seem to cause the model to be more volatile. See Appendix B for a summary of some stability statistics.

Underutilisation and underemployment

The underutilisation rate is the sum of those people without jobs (unemployed) and those people with jobs but who want to work more hours (underemployed) as a proportion of the labour force. This is a good indicator of spare capacity in the labour market as it encompasses all people who are available for work. Over the past four decades, the underemployment rate has trended upwards, and has been higher than the unemployment rate since the early 2000s (Chart 11). This means that while the unemployment rate was previously a good proxy for the level of underutilisation in the economy, the underemployment rate has become increasingly important.

Chart 11: Unemployment, Underemployment and Underutilisation rates



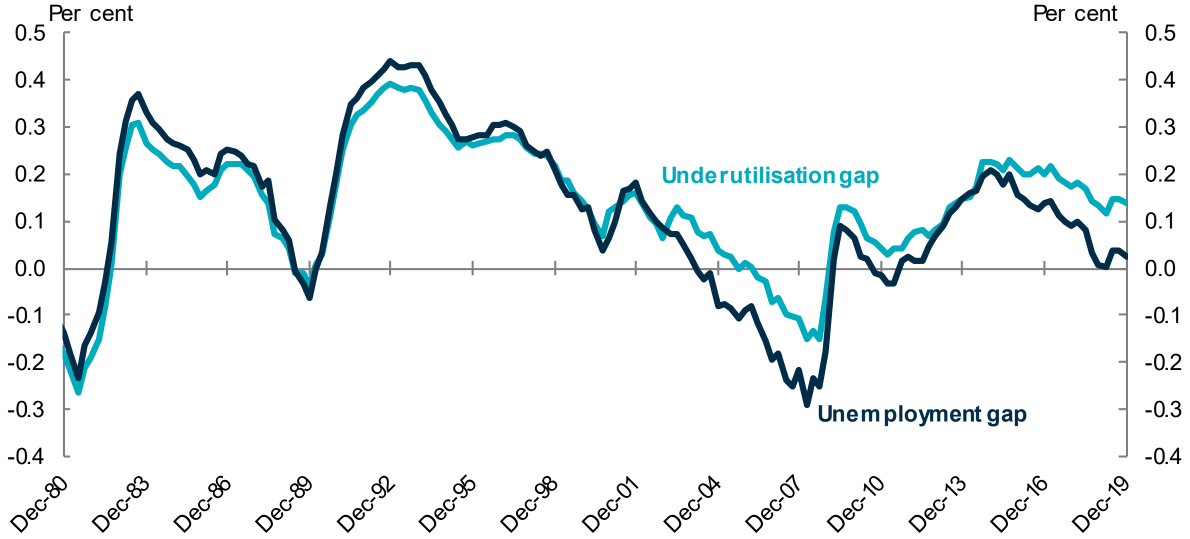
Source: ABS Cat. no. 6202.0.

As Cusbert (2017) points out, any effect of the underemployment rate on wage growth – over and above the effect of the unemployment rate – would result in lower wage growth than expected by the model. This would then cause the model's estimate of the NAIRU to decline, although it may not fully capture the impact of underemployment, in which case the actual NAIRU may be lower than the model estimate of the NAIRU.

We can test this proposition by estimating a wage Phillips curve with an underutilisation gap rather than an unemployment gap (Chart 12, Table 3).[16]

16 The speed limit term is not changed, but the unemployment gap is relative to the underutilisation rate rather than the unemployment rate. This is interesting analysis, but is not a candidate to replace the unemployment version of the model. Treasury economic projects rely on the unemployment rate returning to the NAIRU over the medium term, and so an estimate of the NAIRU based on the unemployment gap is required.

Chart 12: Unemployment and Underutilisation gaps



Note: Positive gap indicates unemployment rate above the NAIRU.
Source: Treasury.

Table 3: Results for underutilisation Phillips curve

	Unemployment Phillips curve		Underutilisation Phillips curve	
π_t^e	0.37	(0.24)	0.26	(0.24)
Δp_{t-1}	0.63^		0.74^	
Δz_t^*	0.46***	(0.10)	0.46***	(0.10)
Δz_t	0.54^		0.54^	
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$	-4.59**	(1.98)	-5.03**	(2.17)
$\left(\frac{U_t-U_t^*}{U_t}\right)$(pre-break)	-2.73***	(0.62)	-2.85***	(0.71)
$\left(\frac{U_t-U_t^*}{U_t}\right)$(post-break)	-1.15**	(0.55)	-0.97*	(0.56)
σ_ε	0.01***	(0.00)	0.01***	(0.00)
σ_ξ	0.13	(0.12)	0.30	(0.22)
U_t^* final state	**5.00**		**11.65**	
AIC	-6.49		-6.48	
Sample	1980:1 – 2019:4		1980:1 – 2019:4	

Notes: *, ** and *** indicate significance at the 10, 5 and 1 per cent level respectively, ^ indicates a restricted coefficient, standard errors reported in parentheses.

The model with an underutilisation gap gives very similar model coefficients, although the Phillips curve is flatter post-1993 in the underutilisation model. The estimated underutilisation gap is very similar to the unemployment gap prior to the early 2000s. After the early 2000s, a wedge appears between the two and the underutilisation gap is generally higher, indicating a higher degree of labour market slack than in the unemployment-based model. This supports the presence of downside risks to the model estimate of the NAIRU.

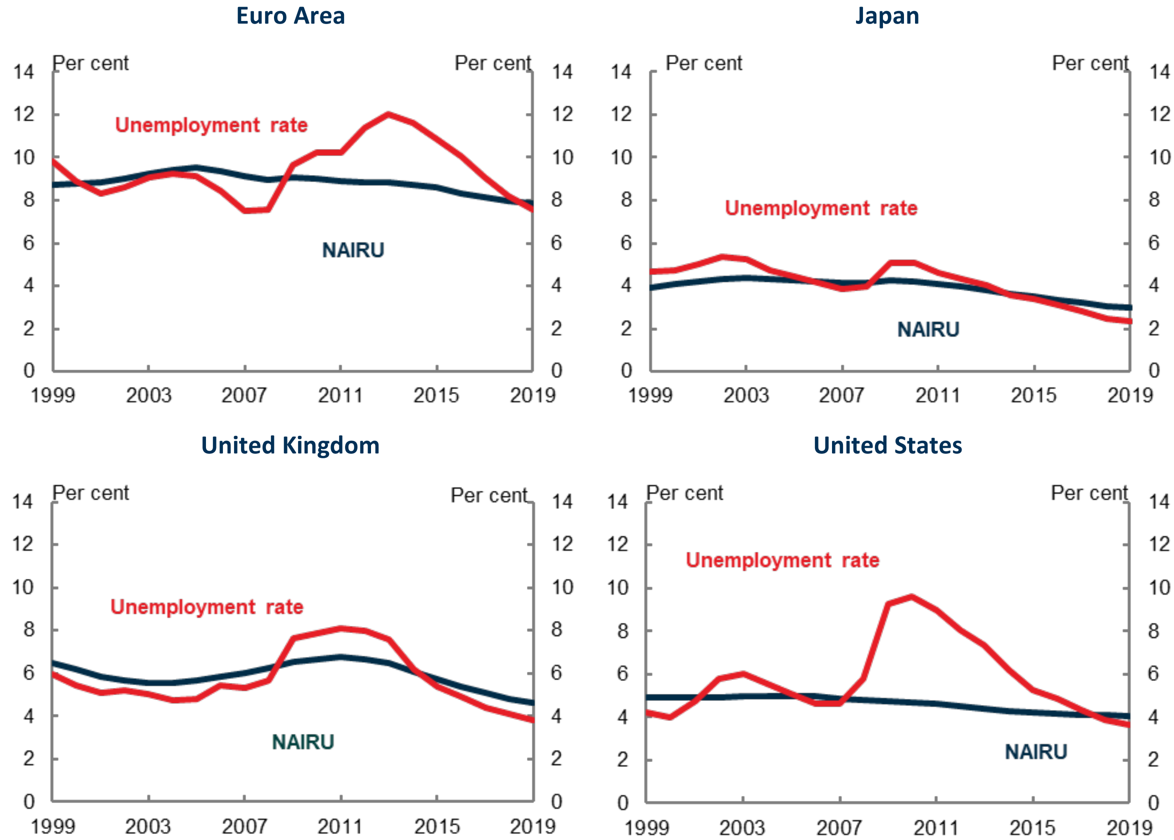
International experience

Many advanced economies (including the United States, Euro area, Japan and the United Kingdom) saw unemployment rates reaching multi-decade lows prior to the COVID-19 pandemic. Wages growth had been picking up in these economies, but they also reached lower levels of unemployment than expected before this occurred, and official estimates of these countries' NAIRUs have declined accordingly (Chart 13). As discussed below, the impact of the COVID-19 global recession on estimates of the NAIRU remains to be seen.

The United States Federal Reserve notes that the relationship between unemployment and inflation has become less clear in recent decades (Engemann 2020). They point to the introduction of inflation targeting as a key reason why the US Phillips curve has flattened, with inflation expectations becoming the key driver of inflation. As Chair Jerome Powell outlined is a speech at the Kansas City Federal Reserve's 2020 annual conference, 'The muted responsiveness of inflation to labour market tightness, which we refer to as the flattening of the Phillips curve, [has] contributed to low inflation outcomes.'

However there has also been speculation that global trends such as ageing populations could lower savings rates and increase pressure on inflation and wages (Goodhart and Pradhan 2020). This could result in rising estimates of international NAIRUs.

Chart 13: International NAIRU trends



Source: OECD.

Impact of COVID-19 pandemic on the NAIRU

The state-space approach of the updated model is not well-suited to estimating unobserved variables during a shock, such as the COVID-19 pandemic. For this reason, we have not presented results using data more recent than 2019.

The ongoing impact of this shock also remains unclear. Unemployment remains about ½ of a percentage point above its pre-pandemic level. The structural changes brought about and/or accelerated by the shock may impact on the level of the NAIRU. Persistently high levels of underemployment, a reduced willingness by workers to bargain for wage increases, or a reduction in inflation expectations could all mean that the unemployment rate must be lower before wage pressures materialise. These factors will be influenced by the strength and duration of the recovery.

During any protracted period of labour market adjustment, there is an increased risk of scarring effects, for example through poor initial-worker matching and the atrophying of skills in the long-term unemployed. Labour market scarring would mean that the pool of workers with suitable skills is actually smaller at a given unemployment rate, which would mean wage pressures might materialise at a higher level of unemployment. The recovery from the COVID-19 shock has so far been much quicker than anticipated, so there could be less scarring effects than previously expected, which would boost labour market spare capacity.

There is also some uncertainty about the outlook for inflation in the post-COVID world. RBA Governor Phillip Lowe in a recent Monetary Policy Decision (Reserve Bank of Australia 2021) noted that wage and price pressures in Australia are subdued and are expected to remain so for some years. However, there is potential for the globalisation trend to slow as the global economy emerges from the COVID-19 pandemic. This could reduce competitive pressures in goods and labour markets, and create some upwards pressures on the NAIRU. Some commentators in the US have also suggested that expansionary fiscal and monetary policy settings combined with a persistent reduction in supply and a sharp recovery in demand could lead to strong inflationary pressures as the global economy recovers (see for example, Miles and Scott 2020).

5. Conclusion

A review of alternative approaches to estimating the NAIRU has led to several changes to Treasury's Phillips curve model. Using a Nelson-Siegel model for inflation expectations allows the NAIRU estimate to reflect information from the full suite of measures of inflation expectations, and to reflect the time horizon relevant to wages bargaining. Splitting the productivity term into trend and actual productivity accounts for the observed stickiness in the response of wages to changes in productivity. Adding a structural break to allow for a changing relationship between the unemployment gap and wage growth allows for a significant flattening in the wage Phillips curve in the 1990s. Finally, using quarterly growth variables rather than through-the-year growth, adding a 'speed limit' term, using a contemporaneous unemployment gap and using trimmed mean inflation all align the updated model with recent developments in the literature.

Together, the incorporation of these approaches enhances model forecasting performance and produces an estimate of the NAIRU within a range of 4½ to 5 per cent over the five-years immediately prior to the COVID-19 recession. In our judgment, a point estimate for the NAIRU of 4¾ per cent is consistent with our modelling and the weight of international and Australian experience in recent years. That said, it is important to note that estimates of the NAIRU are inherently uncertain. The NAIRU is a latent (unobservable) variable and point estimates of the NAIRU typically come with large confidence intervals, with even larger intervals around endpoints. We estimate a 68 per cent confidence interval of ±½ percentage points around the NAIRU estimate through history and ±¾ percentage points at the endpoint.

Uncertainty surrounding the future path of the NAIRU is exacerbated in the COVID-19 environment in which the longer-term impacts of the COVID-19 recession on the Australian economy are not yet known. On one hand, the risk of labour market scarring associated with the COVID-19 recession presents an upside risk to our NAIRU estimate. Additionally, global trends such as ageing populations could lower savings rates and increase pressure on inflation and wages, which could result in higher estimates of the NAIRU. However, recent international and Australian experience suggests there are also downside risks, in particular that estimates of the NAIRU across Australia and other advanced economies may resume their decline in future years, perhaps after rising initially in response to the COVID-19 pandemic. This could reflect the continuation in the structural trends that have caused the downward trend in the NAIRU. A detailed examination of the reasons why estimates of the NAIRU have declined over time across advanced economies is beyond the scope of this paper, but is a worthwhile topic for further research.

There are reasons why the NAIRU could be lower than estimated in this paper and which help to explain the decline in the NAIRU observed in advanced economies. Higher levels of underemployment could mean that there is a greater degree of labour market slack than captured by an unemployment-based Phillips curve. Additionally, structural factors may have altered the wage and price setting dynamics in advanced economies. These include increased competition in good markets, increases in services being provided internationally, advances in technology and changes in the supply of labour and labour market regulation. This paper allows for a flattening of the slope for the Phillips curve in the 1990s, however this may not have fully captured more recent trends. Other things equal, a flatter estimated Phillips curve would be associated with a lower estimate of the NAIRU than in this paper.

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Appendix A: Summary Statistics

Treasury's NAIRU estimation model uses the following signal equation:

$$\Delta w_t - \Delta z_t - \Delta p_{t-1}^{TM} = \beta_1(\pi_t^e - \Delta p_{t-1}^{TM}) + D_{<1993}\beta_2\left(\frac{U_t - U_t^*}{U_t}\right) + D_{\geq 1993}\beta_3\left(\frac{U_t - U_t^*}{U_t}\right) + \beta_4\left(\frac{\Delta U_{t-1}}{U_t}\right) + \beta_5(\Delta z_t^* - \Delta z_t) + \varepsilon_t \quad \text{(A1)}$$

With the following state equation:

$$U_t^* = U_{t-1}^* + \xi_t \quad \text{(A2)}$$

Table A1: Summary statistics of model variables

	Description	Source	Mean*	Standard deviation*
Δw_t	Quarterly growth in average hourly earnings **	ABS Cat. no. 5206.0	1.21	1.16
Δz_t	Quarterly growth in hourly labour productivity**	ABS Cat. no. 5206.0	0.36	0.82
Δp_t^{TM}	Trimmed mean inflation**	ABS Cat. no. 6401.0	0.98	0.64
π_t^e	Modelled 3-year inflation expectations	Treasury	1.19	0.78
U_t	Unemployment rate	ABS Cat. no. 6202.0	6.83	1.78
U_t^*	NAIRU	Treasury	5.71	0.57
$D_{<1993}$	Dummy variable equal to 1 prior to 1993			
$D_{\geq 1993}$	Dummy variable equal to 1 from the March quarter 1993 onwards			
Δz_t^*	Quarterly growth in estimated trend labour productivity**	Treasury	0.36	0.14
ε_t	Error term in the signal equation			
ξ_t	Error term in the state equation			

Notes: *calculated from March quarter 1980 to December quarter 2019, **measured as log difference.

Appendix B: Full results

Table B1: Results from cumulative model changes

	Previous Treasury model	Quarterly variables	Adding a speed limit term
Wage variable	$\boldsymbol{\Delta_4 ulc_t}$	$\boldsymbol{\Delta ulc_t}$	$\boldsymbol{\Delta ulc_t}$
Price variable	$\boldsymbol{\Delta_4 p_{t-1}^{CON}}$	$\boldsymbol{\Delta p_{t-1}^{CON}}$	$\boldsymbol{\Delta p_{t-1}^{CON}}$
π_t^e	0.21***	1.00***	0.91***
Δp_{t-1}	0.79^	0.00^	0.09^
Δz_t	1.00^	1.00^	1.00^
$\left(\frac{U_{t-1} - U_t^*}{U_{t-1}}\right)$	-2.76***	-3.08***	-2.60***
$\left(\frac{U_t - U_t^*}{U_t}\right)$			
$(\Delta_4 ulc_{t-1} - \Delta_4 p_{t-2}^{CON})$	0.60***		
$(\Delta ulc_{t-1} - \Delta ulc_{t-4})$	0.14***		
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$			-5.44***
σ_ε	0.01***	0.01***	0.01***
σ_ξ	0.31^	0.35***	0.40***
$\boldsymbol{U_t^*}$ final state	5.56	5.57	5.56
AIC	-5.52	-5.76	-5.80
Sample	1968:1–2019:4	1968:1 – 2019:4	1968:1 – 2019:4
Stability:			
Mean absolute revision	0.37	0.34	0.36
Revisions standard deviation	0.44	0.41	0.45
Average confidence interval	0.64	0.62	0.72

	Contemporaneous unemployment gap	Trimmed mean inflation	Changes so far with restricted sample
Wage variable	Δulc_t	Δulc_t	Δulc_t
Price variable	Δp_{t-1}^{CON}	Δp_{t-1}^{TM}	Δp_{t-1}^{TM}
π_t^e	0.74***	0.48**	0.29
Δp_{t-1}	0.26^	0.52^	0.71^
Δz_t	1.00^	1.00^	1.00^
$\left(\frac{U_{t-1}-U_t^*}{U_{t-1}}\right)$			
$\left(\frac{U_t-U_t^*}{U_t}\right)$	-2.05***	-1.88***	-1.65***
$(\Delta_4 ulc_{t-1} - \Delta_4 p_{t-2}^{CON})$			
$(\Delta ulc_{t-1} - \Delta ulc_{t-4})$			
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$	-5.23***	-6.08***	-6.94***
σ_ε	0.01***	0.01***	0.01***
σ_ξ	0.48***	0.44***	0.10
U_t^* final state	5.57	5.50	5.22
AIC	-5.73	-5.74	-6.28
Sample	1968:1 – 2019:4	1968:1 – 2019:4	1980:1 – 2019:4
Stability:			
Mean absolute revision	0.43	0.43	0.55
Revisions standard deviation	0.55	0.55	0.68
Average confidence interval	0.90	0.91	0.49

	Structural break	New inflation expectations series	Productivity split
Wage variable	Δulc_t	Δulc_t	Δulc_t
Price variable	Δp_{t-1}^{TM}	Δp_{t-1}^{TM}	Δp_{t-1}^{TM}
π_t^e	0.29	0.24	0.37
Δp_{t-1}	0.71^	0.76^	0.63^
Δz_t	1.00^	1.00^	0.46***
Δz_t^*			0.54^
$\left(\frac{U_t-U_t^*}{U_t}\right)$			
$\left(\frac{U_t-U_t^*}{U_t}\right) * D_{<1993}$	-2.88***	-2.88***	-2.73***
$\left(\frac{U_t-U_t^*}{U_t}\right) * D_{\geq 1993}$	-0.96	-1.01	-1.15**
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$	-5.79***	-6.01***	-4.59**
σ_ε	0.01***	0.01***	0.01***
σ_ξ	0.14	0.15	0.13
U_t^* final state	5.20	5.06	5.00
AIC	-6.30	-6.29	-6.49
Sample	1980:1 – 2019:4	1980:1 – 2019:4	1980:1 – 2019:4
Stability:			
Mean absolute revision	0.44	0.45	0.40
Revisions standard deviation	0.35	0.35	0.33
Average confidence interval	0.59	0.60	0.54

Notes: *, ** and *** indicate significance at the 10, 5 and 1 per cent level respectively, ^ indicates a restricted coefficient.

Appendix C: Inflation Expectations

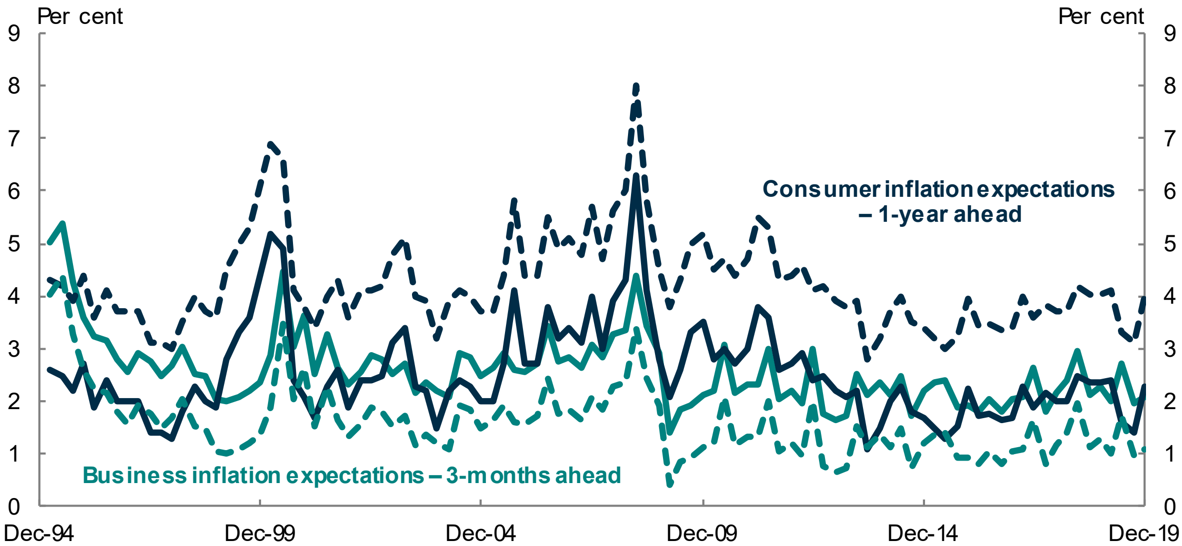
Here we present additional information and selected results from the inflation expectations model.

We use the following inflation expectations measures for this model:

- Break-even 10-year inflation rate
- Business inflation expectations – 3-months ahead
- Consumer inflation expectations – 1-year ahead
- Union officials' inflation expectations – 1 and 2-year ahead
- Market economists' inflation expectations – 1 and 2-year ahead
- Consensus inflation estimate – 2, 3, 4, 5 and 6-years out

The Business inflation expectations (3-months ahead) and Consumer inflation expectations (1-year ahead) series are judged to be biased low and high respectively. We therefore rebase these series to have a mean of 2.5 per cent or the centre of the RBA inflation target band (see chart C1). All series are backcast using the break-even 10-year inflation rate from the TMEM database.

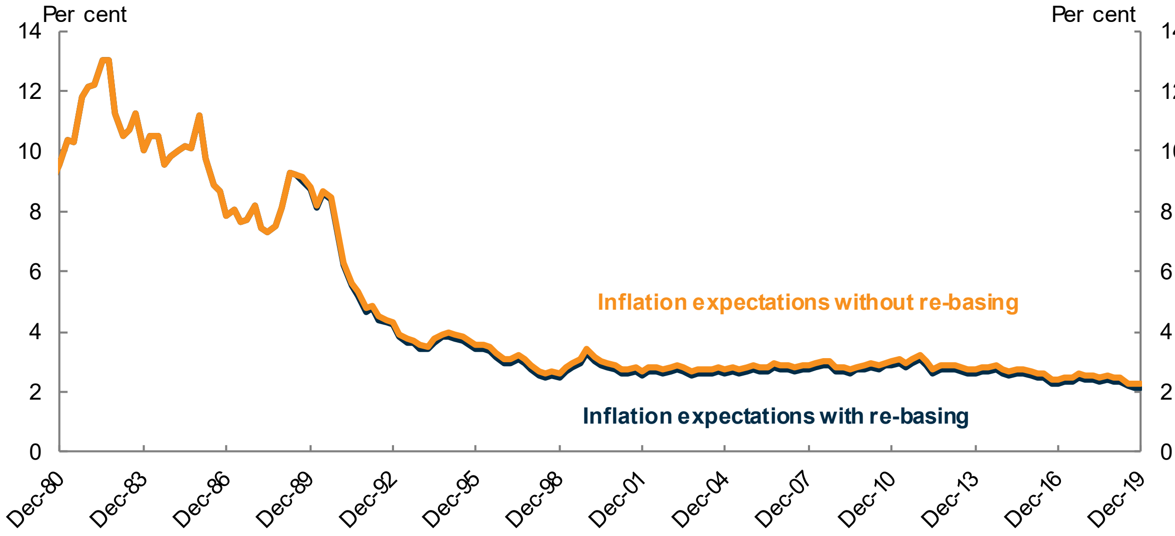
Chart C1: Consumer and business inflation expectations



Note: Dashed lines show original series, solid lines show re-based series.
Source: Melbourne Institute, RBA, Treasury.

This has a small impact on the level of the estimated inflation expectations (3 years) series (chart C2). In the December quarter 2019, the rebased series give an estimate of inflation expectations of 2.15 per cent, and the un-rebased series lead to an estimate of 2.3 per cent.

Chart C2: Consumer and business inflation expectations



Source: Treasury.

Following Aruoba (2018) we use the following equation to map each inflation expectations series into the factor model:

$$\pi_t^* = L_t + (C_t - S_t)\left(\frac{e^{-\lambda\tau_1} - e^{-\lambda\tau_2}}{\lambda(\tau_2 - \tau_1)}\right) + C_t\left(\frac{\tau_1 e^{-\lambda\tau_1} - \tau_2 e^{-\lambda\tau_2}}{\tau_2 - \tau_1}\right)$$

where π_t^* is the various measures of inflation expectations, τ_1 is the month that the expectations series is measured from, τ_2 is the tenor of the series, and λ is a decay parameter. The parameter L_t can be viewed as a long-term factor, or the 'level' of inflation expectations in the long run. S_t is the 'slope' parameter (often called the short-term factor as its loading decays to zero as the tenor increases), and C_t is the 'curvature' parameter (which increases in the short- and medium-term before decaying to zero).

We estimate this equation period-by-period using OLS, treating L_t, C_t and S_t as parameters and fixing λ, following Diebold and Li (2006).

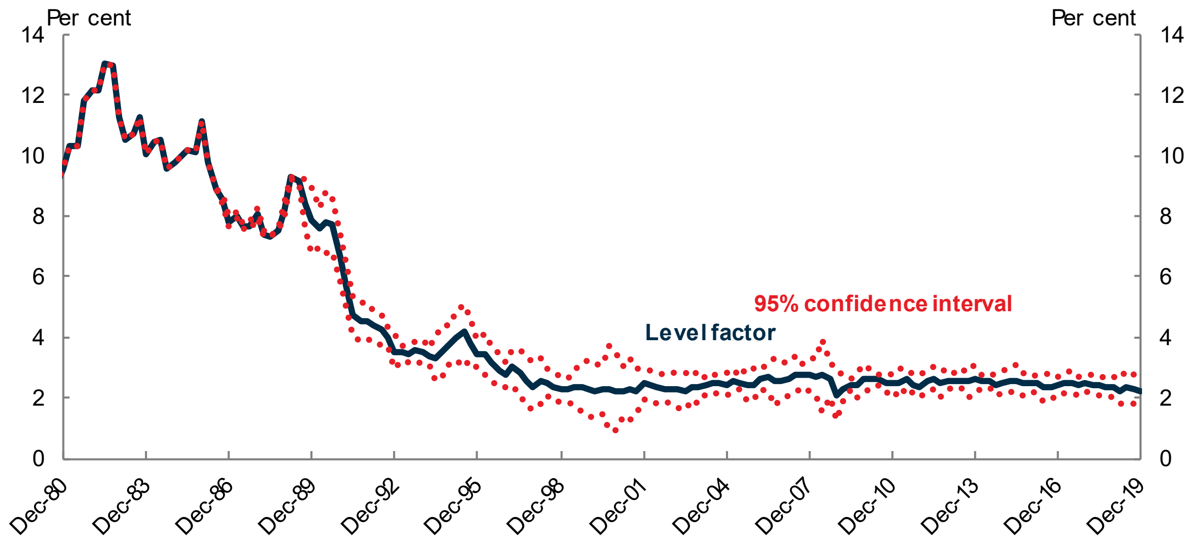
λ is set to maximise the loading on the curvature parameter at 24 months. This choice was based on the NAIRU with the best in-sample fit as determined by the Akaike information criterion. In practice this choice made little difference to the estimated inflation expectations and NAIRU series. We hold this constant, and estimate the model using ordinary least squares with each historical quarter of inflation expectations data. The desired tenor (36 months) can then be used alongside the estimated parameters to produce a historical series.

An area for future work is to convert this model to a state space model, which would allow us to smooth through the parameter and inflation expectations estimates.

Charts C3 – C5 show the extracted factors with 95 per cent confidence intervals.

The average of the estimated long-term or 'level' factor over the past two decades is 2.45 per cent, which is very close to the centre of the RBA inflation target band. This levels component is what inflation expectations asymptote to as their horizon goes to infinity, and is a good measure of the longer run credibility of the inflation target.

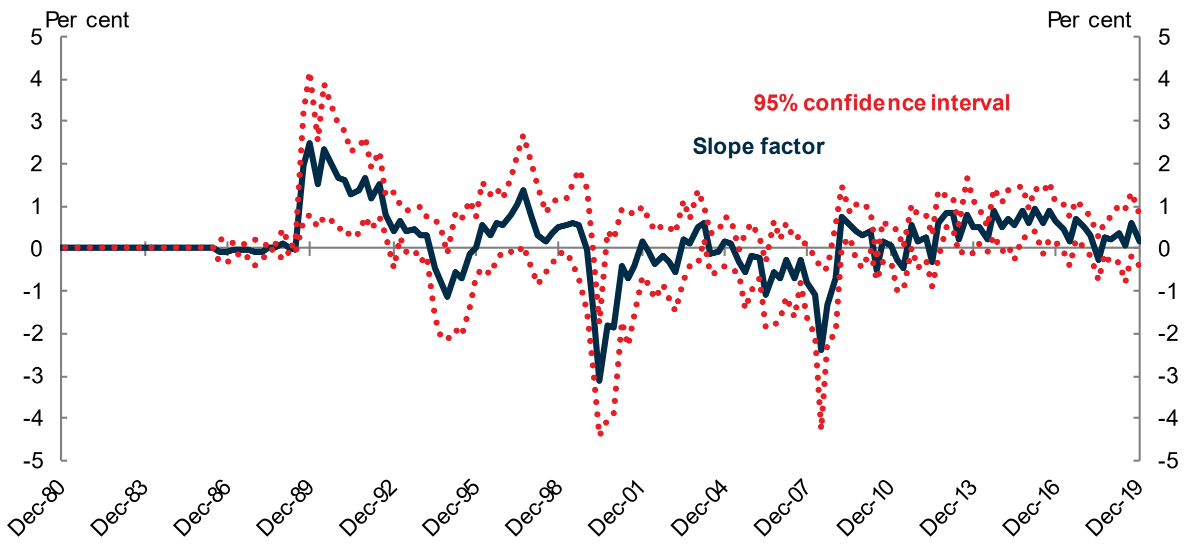
Chart C3: Level factor



Note: The 95 per cent confidence intervals are ±2 standard error bands.
Source: Treasury.

The average slope of the inflation expectations curve, which is defined as the difference between long-and short-term expectations, is effectively flat at -4 basis points. Interestingly, the average slope through the 2000s was negative at -46 basis points indicating that long-run expectations were actually lower than short-run expectations over that period. Then the average through the 2010 was positive at 38 basis points, indicating that long-run expectations have been higher than short-run expectations recently.

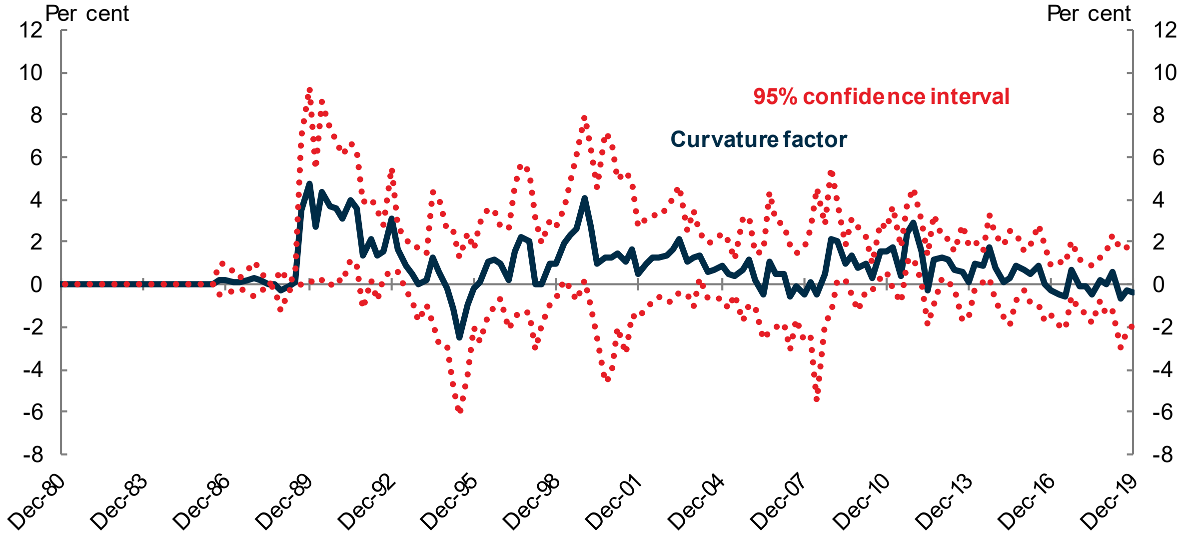
Chart C4: Slope Factor



Note: The 95 per cent confidence intervals are ±2 standard error bands.
Source: Treasury.

The curvature factor has a mean of 79 basis points, showing that medium-term forecasts are typically higher than short- and long-term forecasts, giving the inflation expectations curve a mild concave shape on average.

Chart C5: Curvature Factor



Note: The 95 per cent confidence intervals are ±2 standard error bands.
Source: Treasury.

Appendix D: Trend Productivity

Trend productivity is estimated by applying a trend-cycle decomposition to actual labour productivity over history. This is a standard approach from the literature (for example, Watson 1986, Clark 1987).

This approach allows us to calibrate the trend more closely to the estimates of trend productivity from Treasury's macroeconometric model of the Australian economy, with cyclical productivity specified as an AR(2) process. The trend productivity term is estimated from a smoothed or two-sided filter. The error from this model is captured in actual productivity.

Signal equation:

$$z_t = z_t^T + z_t^C$$

where: z_t is log output per hour worked, z_t^T is the unobserved trend component and z_t^C is the unobserved cyclical component.

State equations:

Trend productivity is modelled as a random walk with time-varying drift (δ_t):

$$z_t^T = z_{t-1}^T + \delta_{t-1} + v_t$$

The drift is modelled as a stationary process:

$$\delta_t = \alpha\delta + (1-\alpha)\delta_{t-1} + \epsilon_t$$

Cyclical productivity is modelled as an AR(2) process:

$$z_t^C = \rho_1 z_{t-1}^C + \rho_2 z_{t-2}^C + \varsigma_t$$

All error are white noise processes:

$$v_t \sim (0, \sigma_v^2)\ ;\ \epsilon_t \sim (0, \sigma_\epsilon^2)\ ;\ \varsigma_t \sim \left(0, \sigma_\varsigma^2\right)$$

The model results are presented in Table D1.

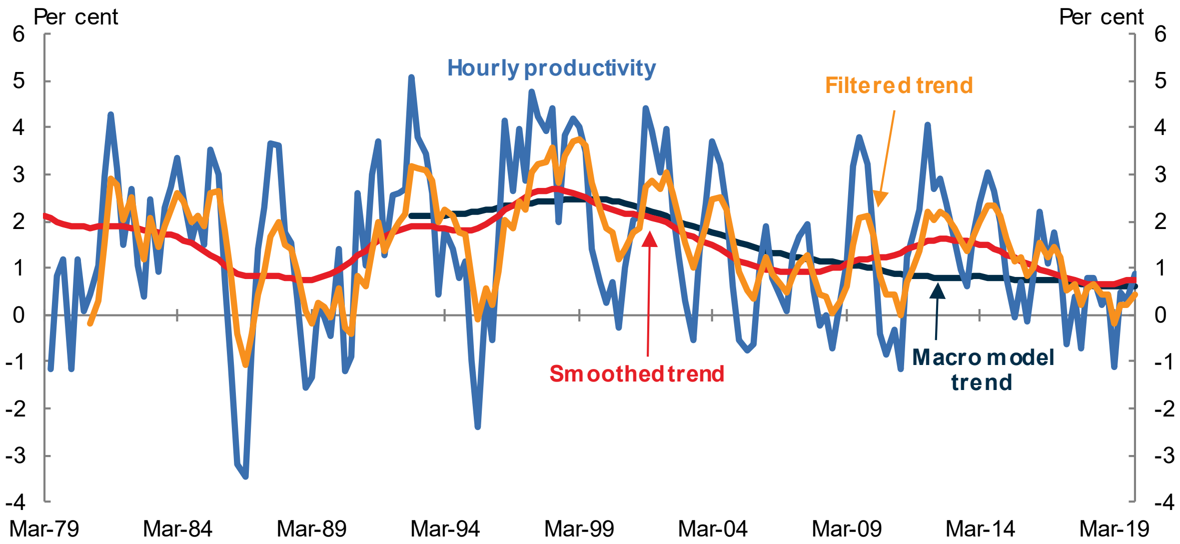
Table D1: Model results

Parameter	Results
α	0.07^
ρ_1	0.60***
ρ_2	0.10
δ	0.003***
v_t	9.12E-07
ϵ_t	0.0006***
ς_t	0.008***
$\Delta_4 z_t^T$ final state	0.75%
Sample	1978:1 – 2019:4

The model is calibrated so that the estimated trend is broadly consistent with the aggregate productivity trend from the macroeconometric model of the Australian economy. In the December quarter 2019, the macroeconometric model had trend productivity growth of 0.5 per cent annually, and the trend-cycle decomposition gives trend productivity growth of 0.75 per cent annually.

The two-sided Kalman filter estimate used here to estimate trend productivity can result in inconsistent parameter estimates. As a robustness check, we also use the filtered or one-sided trend to test the sensitivity of the NAIRU estimate to this change (Chart D1).[17]

Chart D1: Productivity trend comparison



Note: Through-the-year growth is shown.
Source: ABS Cat. no. 5206.0, 6202.0, Treasury.

This does not give as smooth a trend, but it is useful as a robustness check. The model results using each trend is shown in Table D2, and the estimated NAIRUs are shown in chart D2.

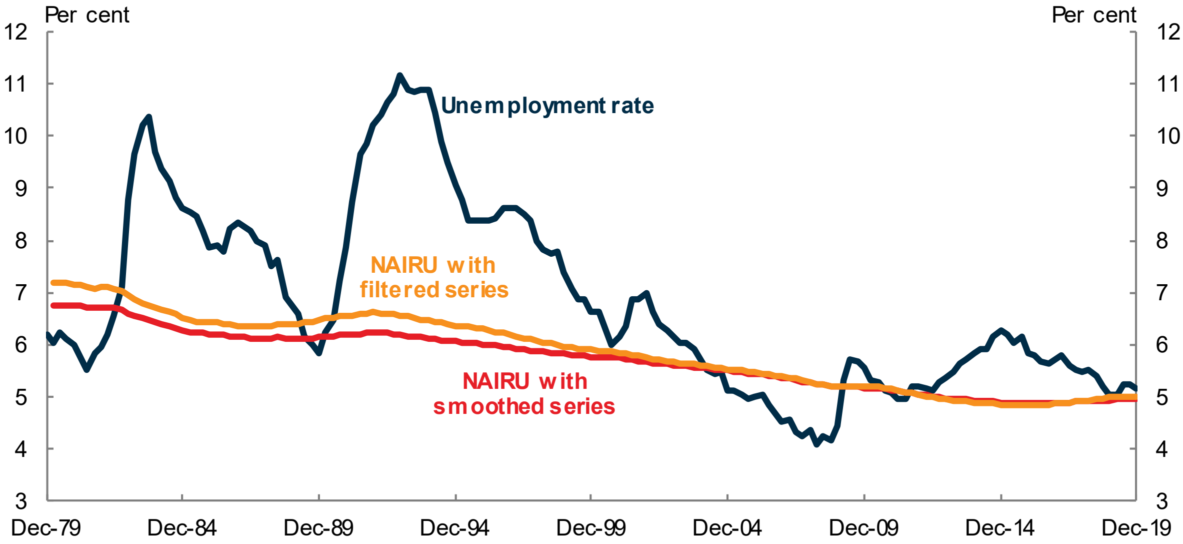
17 The one-sided trend is very similar to the trend extracted using a modified Beveridge Nelson filter (Kamber, Morley and Wong 2018).

Table D2: Phillips curve model results

	Smoothed trend	Filtered trend
π_t^e	0.37	0.25
Δp_{t-1}	0.63^	0.75^
Δz_t	0.46***	0.30**
Δz_t^*	0.54^	0.70^
$\left(\frac{U_t - U_t^*}{U_t}\right) * D_{<1993}$	-2.73***	-2.80***
$\left(\frac{U_t - U_t^*}{U_t}\right) * D_{\geq 1993}$	-1.15**	-1.14**
$\left(\frac{\Delta U_{t-1}}{U_t}\right)$	-4.59**	-4.51**
σ_ε	0.01***	0.01***
σ_ξ	0.13	0.16
$\boldsymbol{U_t^*}$ **final state**	**5.00**	**5.01**
AIC	-6.49	-6.43
Sample	1980:1 – 2019:4	1980:1 – 2019:4

Notes: *, ** and *** indicate significance at the 10, 5 and 1 per cent level respectively, ^ indicates a restricted coefficient.

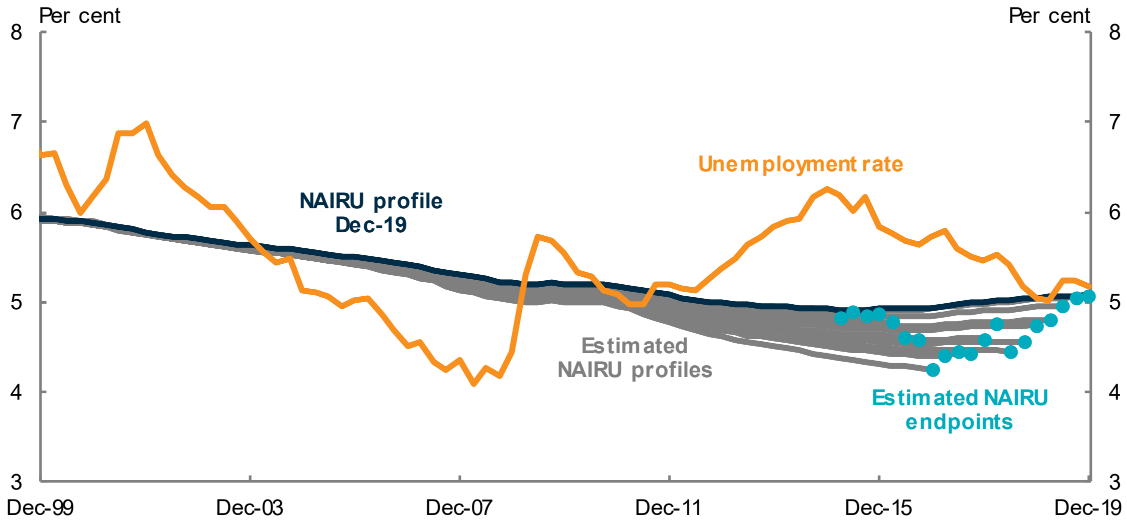
Chart D2: NAIRU comparison with smoothed and filtered productivity trends



Source: ABS Cat. no. 6202.0, Treasury.

Using the filtered trend series give quite similar parameter estimates. Estimating to a sample end of each quarter for the five years prior to the COVID-19 recession, and using the filtered productivity trend provides the same range of estimates as when the smoothed trend is used – mostly between 4½ and 5 per cent (Chart D3).

Chart D3: Rolling NAIRU estimates with filtered trend productivity



Note: Endpoints for NAIRU estimates from 2014:Q4 to 2019:Q4 are shown.
Source: ABS Cat. no. 6202.0, Treasury.