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ESTIMATING THE STRUCTURAL RATE OF UNEMPLOYMENT FOR THE OECD COUNTRIES

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INTRODUCTION

An important challenge facing policy makers is to identify the rate of capacity utilisation that is sustainable, in the sense that it is associated with reasonably stable inflation, over the medium to longer term. There are different ways of measuring capacity utilisation. Looking at perhaps the most common measure, unemployment, this notion of sustainable resource utilisation is made operational in the concept of the NAIRU – the non-accelerating inflation rate of unemployment, *i.e.* the unemployment rate consistent with stable inflation.[1]

Views are mixed as to the usefulness of the NAIRU concept. Nevertheless, economists analyse future inflation trends, the sustainability of fiscal positions, and the need to undertake structural reforms to permanently reduce unemployment and for these purposes they need a benchmark to identify and distinguish sustainable and unsustainable trends in output and unemployment. The NAIRU concept provides such a benchmark. Estimates of the NAIRU make clear what assumptions lie behind policy analysis and recommendations and therefore increase the transparency of policy advice.

The measurement of the NAIRU is also controversial. By its nature, it is non-observable and depends on a wide range of institutional and economic factors. It follows that even if one accepts the concept, it can only be estimated with uncertainty. Moreover, it may well vary over time – European experience suggests that, in general, inflation would accelerate if unemployment reached the low unemployment rates associated with stable inflation in the 1960s. And at times, such as when there are large fluctuations in oil or raw material prices, it is clear that unemployment would have to rise or fall very steeply to stabilise inflation.

This paper describes the recent work by the OECD to review its procedures for deriving estimates of the unemployment rates consistent with stable inflation. The procedures have been updated and improved in several respects. Most notably, the new procedures allow the distinction between and estimation of a slow-moving NAIRU and a more volatile short-term NAIRU, which is affected by temporary factors, such as oil price fluctuations, impacting inflation in the short term.[2] They also provide a gauge to the measurement uncertainty surrounding the NAIRU estimates. The paper first develops a consistent conceptual and analytical framework in which the NAIRU can be identified and goes on to review a range of empirical methods used in a number of existing studies. On this basis it then develops a general empirical framework for estimating the NAIRU across a range of countries. It then discusses the resulting econometric estimates obtained by applying the new procedures to the OECD countries, and the scope for their further refinement given the associated range of uncertainties. And, finally, it reviews recent trends in the NAIRU estimates obtained and illustrates how they can be used to analyse inflation developments and monetary policy.

CONCEPTUAL FRAMEWORK AND RECENT STUDIES

The NAIRU and the Phillips Curve

The dominant view among economic analysts is that there is not a long-term trade-off between inflation and unemployment: in the *long run*, unemployment depends on essentially *structural* variables, whereas inflation is a monetary phenomenon.[3] In the short term, however, a trade-off exists such that if unemployment falls below the NAIRU, inflation will rise until unemployment returns to the NAIRU, at which time inflation will stabilise at a permanently higher level. The existence of a NAIRU therefore has immediate implications for the conduct of economic policies, in that: macroeconomic stimulus alone cannot permanently reduce unemployment; and any short-term improvements relative to the NAIRU resulting from stimulative policy actions will be reflected in progressively higher rates of inflation.[4]

The simplest theoretical framework incorporating the NAIRU concept in a transparent fashion is the expectations-augmented Phillips curve, which is also consistent with a variety of alternative structural models.[5] In particular, as illustrated in the Appendix, it can be derived from structural wage-price setting models of the type described by Layard *et al.* (1991). The Phillips curve also has a long empirical tradition of being used as a means of estimating NAIRU indicators. Refinements of the empirical specification led Gordon (1997) to summarise it in terms of the so-called "triangle model" with inflation being determined by three factors: expectations/inertia, the pressure of demand as proxied by unemployment and supply factors.

Inflation expectations are often slow moving, which means that the effects of demand pressures or supply shocks get built into the inflation process only gradually. With regards to demand pressures, unemployment may be important not just in terms of its level, but also its recent movements. For example rapidly falling unemployment may put upward pressure on inflation even at high levels of unemployment; an effect sometimes referred to as a "speed limit".

Taking appropriate account of supply shocks is important in order to distinguish between one-off price changes and ongoing inflation. An important distinction to make here is between temporary and long-lasting supply shocks.[6] Temporary supply shocks (for example, *changes* in real import prices or *changes* in real oil prices) are typically those which are expected to revert to zero over the horizon of one to two years, that is particularly relevant to monetary policy. Such temporary shocks may alter the rate of inflation, at any given rate of unemployment, but the NAIRU will be largely unchanged once they have passed.[7] By contrast, a long-lasting supply shock (caused by factors such as the level of real interest rates, the tax wedge, demographics, *etc.*) may permanently alter the NAIRU, so that inflation will rise or fall until unemployment adjusts.

Within such a framework, it is useful to identify three distinct concepts (see Box 1 for more formal definitions): the NAIRU (with no qualifying adjective), the short-term NAIRU and the long-term equilibrium rate of unemployment. Each of these relate to the same basic idea of an "unemployment rate consistent with stable inflation", but differ according to the time horizon to which they refer:

- The NAIRU is defined as the rate towards which unemployment converges in the absence of *temporary* supply influences (in the medium term or when their effects dissipate), once the dynamic adjustment of inflation is completed.
- The *short-term* NAIRU is defined as that rate of unemployment consistent with stabilising the inflation rate at its current level in the next period (where the precise time frame is defined by the specific frequency used in the inflation analysis, for example, the next quarter, the next semester, or the next year). It depends on the NAIRU (as defined above) but is *a priori* more volatile because it is affected by *all* supply influences, including temporary ones, expectations and inertia in the dynamic process of inflation adjustment and possible related speed-limit effects. It follows that the short-term NAIRU concept will be influenced also by the level of actual unemployment.
- The *long-term* equilibrium unemployment rate corresponds to a long-term steady state, once the NAIRU has fully adjusted to *all* supply and policy influences, including those having long-lasting effects.

Of these three concepts, the first two are relatively straightforward to identify empirically and play clearly defined roles in macroeconomic analysis and policy assessments. Because of difficulties in identifying the effects of individual long-lasting supply influences, the long-term equilibrium rate of unemployment is less easy to quantify empirically. However, while important for structural policies, the long-term equilibrium rate may be of limited relevance to macro policy, especially if the complete adjustment of the NAIRU towards the long-run equilibrium is very

Box 1. **Three NAIRU concepts**

As shown in the Appendix, the expectations-augmented Phillips curve relationship can be derived as a reduced form equation of structural wage and price setting models of the type described in Layard *et al.* (1991), which can be expressed using the following two-equation system. The first equation (1) identifies explicitly only the temporary supply shocks and the second expression (2) includes the long-lasting supply shocks, which fundamentally determine the NAIRU, subject to various long-term adjustment lags.[1]

$$\Delta\pi_t = \alpha(L)\,\Delta\pi_{t-1} - \beta(U_t - U^*_t) - \theta(L)\,\Delta U_t + \nu(L)\,ZT_t + e_t, \quad (1)$$

$$U^*_t = [K_t + \gamma(L)\,ZL_t\,] / \beta \quad (2)$$

where Δ is the first difference operator, π_t is inflation, U_t is the observed unemployment rate, ZL_t and ZT_t are vectors of respectively long-lasting and temporary supply shock variables, $\alpha(L)$, $\theta(L)$, $\gamma(L)$ and $\nu(L)$ are polynomials in the lag operator and e a white noise error term. K_t is a moving parameter capturing all other unspecified influences on the NAIRU. [2]

On the basis of these equations, three distinct NAIRU concepts can be identified:

i) The NAIRU, with no qualifying adjective, which is U^*_t in equation (2).

ii) The short-run NAIRU, US^*_t, is the value of U_t in expression (1) for which the inflation rate is stabilised at that of the previous period, *i.e.* $\Delta\pi_t = 0$, for a given NAIRU, U^*.[3]

Equation (1) can hence be rewritten as follows, using the short-term NAIRU concept:

$$\Delta\pi_t = -[\beta + \theta(0)]\;(U_t - US^*_t) + e_t,$$
where $US^*_t = g\{U^*, \Delta U_{t-i}, \alpha(L)\Delta\pi_{t-1}, \nu(L)ZT_t\}$ (3)

iii) The long-run equilibrium rate of unemployment, UL^*_t, which is the value of the NAIRU (U^*) associated with a particular realisation of the lasting supply shocks (ZL_t= zl) once there has been full adjustment:

$$UL^*_t = f\{K_t + \gamma(1)zl\} / \beta \quad (4)$$

The particular realisation of the supply-shock variables for which the long-run NAIRU is evaluated might for example be based on a projection or represent a view about the long-run steady-state of the supply shocks.

On this basis. the distinction between the NAIRU and short-run NAIRU, is given by equation (3) as a function of the temporary supply shocks and the estimated dynamics of the Phillips curve, including differenced unemployment terms (ΔU_t). The distinction between the NAIRU and long-run equilibrium

Box 1. **Three NAIRU concepts** (*cont.*)

unemployment rate concerns the speed of adjustment to long-lasting shocks (captured by the lag polynomials $\gamma(L)$ in equation (2)), and not the specific dynamic terms in the Phillips curve.

1. Equation (2) might possibly be better represented as a non-linear function of supply-shocks. For example, Blanchard and Wolfers (1999) argue that the NAIRU is a function of the interaction of supply shocks and labour market institutions and the latter may change over time.
2. This parameter might for example take into account structural and institutional factors influencing the functioning of the labour and commodity markets, including those related to the cost of gathering information about job vacancies and labour availability, and the costs of mobility.
3. The relevant time period necessarily corresponds to the frequency of equation (1).

protracted. It is particularly important to be sure that when comparing empirical estimates across different studies that they relate to a similar concept of the NAIRU.

Estimation methods in recent studies

Since the NAIRU concept is unobservable it needs to be quantified before it can be useful for policy analysis. Numerous estimation methods exist, which can be divided broadly into three categories: structural, statistical and reduced-form methods. The first group of so-called "structural methods" involves modelling aggregate wage and price setting behaviour in structural form. The NAIRU is then derived from these estimated systems, assuming that markets are in full or sometimes partial equilibrium. The second group of methods attempt to estimate the NAIRU using a variety of purely statistical techniques to directly split the actual unemployment rate into cyclical and trend components, with the latter identified as the NAIRU. The third group constitutes a compromise between the two approaches already outlined. Similarly to structural methods, they allow the NAIRU to be estimated on the basis of a behavioural equation explaining inflation; typically the expectations-augmented Phillips curve. However, they also rely on statistical techniques to impose certain identifying constraints on the path of the estimated NAIRU and/or the gap between it and the actual rate of unemployment. The rest of this section reviews the main features of these three approaches in turn, drawing on a range of recent studies.

Structural methods

Structural methods for quantifying the NAIRU typically involve estimating a system of equations explaining wage- and price-setting behaviour. These can either take the form of wage and price equations specified in levels form (see, for example, Layard *et al.*, 1991, Phelps, 1994, Cotis *et al.*, 1996, Broer *et al.*, 1998, L'Horty and Rault, 1999) or a more *ad hoc* system in which wage determination is represented by an expectations augmented Phillips curve and prices as a mark-up over unit labour costs (for example, Englander and Los, 1983). Given such specifications, an equilibrium level of unemployment can be derived as the set of values such that inflation is stable subject to firms' and workers' decisions regarding profit margins and real wages being compatible. Because such an equilibrium rate of unemployment typically assumes full adjustment of firms and workers behaviour to all shocks, the derived measure of equilibrium unemployment corresponds more closely to a measure of the long-run equilibrium rate of unemployment rather than the NAIRU which commonly appears in reduced-form Phillips curve specifications.

Structural models can provide a strong theoretical framework to explain how various macroeconomic shocks and more importantly policy instruments impact on structural unemployment, but for several reasons they do not allow specific estimates of the NAIRU to be identified with any degree of precision.

Firstly, there is considerable disagreement about the appropriate structural model to be used. For example, Rowthorn (1999) argues that the assumption of a unit elasticity of substitution between capital and labour underlying the widely used model of Layard *et al.* (1991) is implausible and leads to misleading conclusions. More generally there is disagreement from both a theoretical and empirical perspective concerning the long-run effects of changes in real interest rates, taxation and productivity growth on real wages and equilibrium unemployment.

Second, abstracting from the lack of broad agreement on the appropriate theoretical framework, there is little consensus on specification issues. Some of these issues, such as those concerning the modelling of inflation expectations or the functional form (in particular, whether or not the unemployment gap should take a linear form and whether or not it is symmetrical with respect to its effect on inflation) are also common to reduced-form modelling with a Phillips curve. However, a more general specification problem with structural modelling concerns the number and identity of explanatory variables, which is potentially large, and the sensitivity of results to the particular subset of variables chosen for inclusion in the model. This is, itself, an important limitation when the objective is to apply the same specification across many countries.[8]

Third there is a statistical identification problem regarding the estimation of both wage- and price-setting equations, to the extent that all explanatory variables which enter the former should also enter the latter, as is often suggested by theory (see Bean, 1994 and Manning, 1993). For some countries, notably the United States, it appears difficult to estimate a wage curve based on macroeconomic data because the influence of the (lagged) level of the real wage is often poorly determined, although the reasons for this result are not clear (see Blanchard and Katz, 1997).

Finally, there is considerable difficulty in quantifying many of the relevant institutional variables, such as unemployment benefits, employment protection legislation and the degree of unionisation which theory suggests might be important. Omission of such variables might be particularly problematic given the increasing recognition that the inter-action between institutional factors and macroeconomic shocks plays a key role in determining structural unemployment (Blanchard and Wolfers, 1999).

To overcome the paucity of data relating to the measurement of institutional variables, an increasing number of studies have pooled country information in order to estimate either reduced-form or structural-wage equations or reduced-form unemployment-equations.[9] This body of work has already provided some very important insights into the causes of structural unemployment. For example, the link between the generosity of benefits and structural unemployment is one of the most robust results in this empirical literature. However, while there is some agreement on the relevant macroeconomic variables (real interest rates, productivity growth, the wage share, the tax wedge, *etc.*) to be used in conjunction with a standard set of institutional variables in empirical studies, there is little or no consensus regarding their relative importance in determining structural unemployment.[10] Nevertheless, structural methods that use pooled country data probably represent the most promising approach for improving understanding of the causes of changes in structural unemployment. However, their usefulness in providing timely estimates of the NAIRU is limited to the extent that it is difficult to obtain reliable and up-to-date time series data on many of the key institutional variables. In such studies it is usually necessary to divide the analysis into subperiods of several years, where the final period considered is often several years in the past.

Purely statistical methods

Statistical methods focus entirely on the actual unemployment rate and split it into trend (NAIRU) and cyclical components. The assumption behind these approaches is that, since there is no long-term trade-off between inflation and unemployment, on average unemployment should fluctuate around the NAIRU *i.e.* self-equilibrating forces in the economy are strong enough to bring unemployment back to trend.

A wide range of statistical techniques have been developed to decompose time series such as the unemployment rate into cyclical and trend components.[11] The basic problem with all these methods is that they depend on arbitrary and sometimes implausible assumptions in order to make this decomposition. Such assumptions typically relate to the way the estimated trend is modelled, its variance and relationship with the cyclical component. For example, in the case of the Hodrick Prescott (HP) filter, trend unemployment is identified as a weighted moving average of actual unemployment, whereas it is assumed to be a random walk by the methods of Watson (1986) and Beveridge and Nelson (1981).[12] More importantly, since all information other than unemployment is ignored (notably the link between the unemployment gap and inflation) the indicators obtained are conceptually not well defined. In practice, trend unemployment estimated with these approaches is usually "centered" around actual unemployment by construction. This is in particular the case of the HP filter, which because of its simplicity is the most frequently used method. Whilst this may be a reasonable approximation when inflation is roughly stable over the estimation period, the estimated NAIRU is likely to be biased when, for example, inflation is falling.

Overall, whilst statistical methods allow indicators of trend unemployment to be estimated in a timely and consistent way across OECD countries, they suffer from a number of practical drawbacks. First, the estimated indicators are often not very well correlated with inflation and are difficult to extrapolate even in the short term.[13] Second, they tend to be least reliable at the end of the sample, the period of most interest for policy, although this problem can often be mitigated by adding a few years of forecasts to the end of the data sample, which has become standard practice. Third, most of the filters behave like simple moving averages and so perform poorly if there is a large and sudden change in the unemployment rate, for example as occurred for example in Finland and Sweden in the late 1980s and early 1990s. Fourth, there is often no way to judge the degree of precision of the results. Consequently, these methods are seldom used in recent studies to estimate NAIRUs, especially as better alternative methods are now available.

The reduced-form approach

Of the various approaches used to calculate the NAIRU, the most popular technique in recent studies is based on the expectation-augmented Phillips curve. This approach, which follows a relatively long empirical tradition, has the major advantage of being directly related to the definition of the NAIRU, *i.e.* the NAIRU is derived as that rate of unemployment which is consistent with stable inflation, subject to an expectations-augmented Phillips curve relationship. In addition, its relative simplicity and transparency make it consistent with a variety of alternative structural models and hence it is *a priori* likely to be more robust to specification errors than the corresponding structural approach.

Within this framework, as for the purely statistical approach, some identification is required to estimate the NAIRU. The simplest case is to assume the NAIRU to be constant through time (Fortin, 1989; Fuhrer, 1995; Estrella and Mishkin, 1998). For the analysis of periods as long as thirty years, this may be a valid assumption if the observed unemployment rate appears to evolve around a stable mean (as for the United States). However, this clearly is not the case for countries, such as those in Continental Europe, where the unemployment rate has trended upwards since the late 1970s (see Cotis *et al.*, 1996, for France, and the Fabiani and Mestre, 1999, for the Euro area as a whole). In such cases, a constant rate is unlikely to provide a meaningful estimate (Setterfield *et al.*, 1992).

One of the first attempts at estimating time-varying NAIRUs was developed by Elmeskov (1993) and subsequently used by the OECD.[14] This method essentially infers movements in the NAIRU from changes in (wage) inflation based on the notion of an underlying Phillips curve. It is relatively simple and gives plausible and up-to-date indicators for all OECD countries. However there are ways in which this method might be improved. First, the concept could be better defined: *a priori* it is based on a short-term NAIRU concept, but this feature is weakened by smoothing over time (which makes it closer to the "unqualified" NAIRU notion). Second, the Phillips curve relationship could be more sophisticated and the link with inflation strengthened (Holden and Nyomoen, 1998).

More sophisticated estimation techniques help achieve some of these improvements. For example, the Kalman filter, which is used often in the recent literature, allows simultaneous estimation of the NAIRU and the Phillips curve. It also provides some measure of the statistical uncertainty surrounding the NAIRU.[15] In this framework, the estimated NAIRU is time varying, derived from its ability to explain inflationary developments, subject to various constraints on its evolution over time. Such a NAIRU estimate is hence obtained without requiring all factors affecting it to be specified explicitly. In recent years, there has been a proliferation of studies using the Kalman filter in this way. The majority of these were initially applied to the United States, where prominent studies include Gordon (1997 and 1998), King *et al.* (1995), Staiger *et al.* (1997*a*), but it is now increasingly applied to other countries.[16]

As demonstrated in a later section, there is no unique way of using the Kalman filter to estimate the NAIRU. A variety of assumptions may be adopted for the behaviour of the NAIRU or the unemployment gap. In the empirical literature, the most commonly adopted assumption is to specify a random walk for the NAIRU model, although other forms are possible. A closely related case is the HPMV filter, which is an augmented version of the HP filter, and was developed by Laxton and Tetlow (1992).[17] This filter (which, as shown by Boone (2000), belongs to the same class of models) uses a Phillips curve but with a specific restriction on the properties of the unemployment gap.

Overall, reduced-form filtering methods have several important advantages over both the statistical and structural methods. First, by construction, they provide NAIRU estimates directly related to inflation. Second, the fully specified Phillips curve allows the distinction between NAIRU and short-term NAIRU concepts within the same framework. Third, such indicators can be easily produced in a timely and consistent fashion across OECD countries.[18]

Despite these attractions, filtering methods also suffer from certain drawbacks. The estimated NAIRU indicators are based on a reduced-form equation, which means that the underlying structural relationships themselves are not identified. This may make it more difficult to extrapolate the NAIRU, especially when the estimated Phillips curve incorporates only temporary supply shocks. The relationship between inflation and unemployment over time also needs to be stable and well specified.[19] The corresponding NAIRU estimates are also likely to be dependent on the specification of the Phillips curve.[20]

In spite of these limitations, a general conclusion of this review is that filtering methods within a reduced-form Phillips curve framework provide a number of improvements on previous methods for estimating NAIRUs on a timely basis across the range of OECD countries. The following section reports the results of their specific application to these countries and discusses also a range of practical issues arising in their use.[21]

THE OECD APPROACH TO ESTIMATING THE NAIRU

The estimation framework: the choice of inflation and supply shock variables

Following Gordon's "triangle model", the Phillips curve estimation framework can be expressed in the following form:

$$\Delta\pi_t = \alpha(L)\,\Delta\pi_{t-1} - \beta(U_t - U^*_t) - \theta(L)\,\Delta U_t + \gamma(L)z_t + e_t, \qquad (1)$$

where Δ is the first difference operator, π is inflation, U is the observed unemployment rate, U^* is the NAIRU, z a vector of temporary supply shock variables, $\alpha(L)$, $\theta(L)$ and $\gamma(L)$ are polynomials in the lag operator and e is a serially uncorrelated error term with zero mean and variance σ^2. As previously emphasised, only temporary supply shock variables, defined here to be those that might reasonably be expected to revert to zero over a future horizon of 1 to 2 years, are included in the Phillips curve specification. The NAIRU is then estimated with the Kalman filter, to implicitly capture the aggregate effect of all long-lasting shocks, without requiring these shocks to be explicitly identified.

In estimating equation (1), a number of choices have to be made regarding the specification of the dependent and explanatory variables. In principle, theory suggests that the dependent variable could be either a measure of price inflation or wage inflation, where the latter is adjusted in relation to productivity or trend productivity. In deriving a reduced-form Phillips-type inflation equation from structural wage- and price-setting equations, (as shown in the Appendix) it is possible to substitute out either wages or prices. Hence if there is a stable relationship between wages and prices, then the choice of which to use is not clear-cut. In the empirical work reported here, an inflation measure based on the private consumption deflator is used on the grounds that this is more representative of inflation measures targeted by policy-makers and central banks in most OECD countries, although, for some countries, the robustness of the results to using an alternative measure of wage inflation has also been examined.[22] For Canada, a measure of core inflation (excluding food and energy, as used by the Bank of Canada) was found to give more robust results and is used to provide the preferred NAIRU estimates. The unemployment variables used are as defined in the notes to the relevant tables, which for most countries correspond to the national definitions commonly used in the OECD macroeconomic projections.

In practice, the choice of temporary supply shock variables to be included was largely governed by those variables found most often to be statistically significant across the range of country specifications. In particular these include the *change* in real import prices (weighted by the degree of openness of the economy) and the *change* in real oil prices (weighted by a measure of the degree of oil intensity in production).[23] Other possible variables, for example, tax wedge terms and the deviation of productivity growth from trend, were tested in preliminary estimation but found to be much less successful and are not included in the final specifications reported here. Temporary variations in the mark-up of prices over unit labour costs are also a candidate, provided that the mark-up tends to return to trend within the time horizon relevant to monetary policy. For example, Brayton *et al.* (1999) suggest that low inflation in the United States in recent years may partly result from mark-ups returning to their historical norm. A particular concern related to the choice of temporary supply shocks included is that for most OECD countries real import prices have been trending downward over at least the last two decades, so that the expected change in real import prices over the near future (in the absence of other shocks) is likely to be negative rather than zero. For this reason, real import prices were first de-trended by regressing them on split time trends and their own lagged values.[24]

A further issue is whether the unemployment gap (U-U*) should enter linearly or non-linearly. For simplicity, a linear specification was initially assumed for all countries. However, it became clear that this was not a reasonable approximation for some countries, particularly those in which unemployment had risen considerably over the past three decades. A linear specification assumes, for example, that unemployment at 3 per cent when the NAIRU is 2 per cent has the same impact on inflation as unemployment at 12 per cent when the NAIRU is 11 per cent. This does not seem economically plausible and, in fact, led to structural breakdowns of some estimates.[25] For Belgium, Spain, Finland and Sweden a partial solution was to have the unemployment gap enter in logarithmic terms: log (U/U*).[26] For Australia, consistent with academic and official studies, a non-linear gap (U-U*/U) was found to significantly improve the robustness and significance of the estimates.[27]

Specifying the Kalman filter

There is no unique way of using the Kalman filter technique to estimate the NAIRU, but the approach followed here is similar to that of most other studies, namely augmenting the Phillips curve, as represented by equation (1) (which is referred to as the measurement equation) with one or more additional equations, defining how the NAIRU varies over time – the transition equations (see Box 2 and Boone (2000) for further technical details concerning the specification and use of the Kalman filter). In the empirical literature, the most commonly adopted form for the transition equation is a random walk (2*a*) below, which is used in the work reported here, as well as an alternative specifying the *change* in the NAIRU as a first order auto-regressive process (2*b*).[28]

$$\Delta U^*_t = \nu^1_t \text{, where } \nu^1_t \sim N(0, \sigma_{\nu 1}^2) \qquad (2a)$$

or

$$\Delta U^* t = \varphi\, \Delta U^*_{t-1} + \nu^2_t \text{, where } 0 < \varphi < 1 \text{ and } \nu^2_t \sim N(0, \sigma_{\nu 2}^2). \qquad (2b)$$

Where possible both the random walk and auto-regressive forms were estimated and the choice between the two was based largely on the statistical significance of the autocorrelation coefficient and the fit of the respective unemployment gaps in the estimated Phillips curve. The assumption of a first order auto-regressive process is of particular interest for some, mainly European countries, because it may provide evidence of slow adjustment of the NAIRU to long lasting supply shocks.

Determining the smoothness of the NAIRU

When using the Kalman filter, the volatility or smoothness of the resulting NAIRU series is determined by the magnitude of the variance of the errors in the transition equation ($\sigma_{\nu 1}^2$ in (2*a*)) relative to those in the inflation equation (σ^2 in (1)). The larger is this ratio (the "signal-to-noise" ratio) the more volatile will be the NAIRU series which, in the limit, soaks up all the residual variation in the Phillips curve equation.

In principle, the Kalman filter technique makes it possible to estimate all the parameters of the model using a maximum likelihood estimation procedure,

Box 2. **Using the Kalman filter to estimate a time-varying NAIRU**

The Kalman filter is a convenient way of working out the likelihood function for unobserved component models.[1] For that, the system must be written in a state space form, with a **measurement equation** (the Phillips curve):

$$\Delta\pi_t = \alpha_1\Delta\pi_{t-1} + \alpha_2\Delta\pi_{t-2} + \beta(U_t - U^*_t) - \theta\Delta(U_t - U^*_t)\ e_t \qquad (1)$$

in a matrix format: $y_t = Z.X_t + R.D_t + e_t$ (1')

where Z and R are vectors of parameters, X is a vector of unobserved variables (the NAIRU), while D is a vector of observed exogenous variables (lagged inflation, temporary supply shocks)

and a **transition equation:**[2]

$$U^*_t = U^*_{t-1} + \varepsilon_t \qquad (2)$$

in a matrix format: $X_t = T.X_{t-1} + \varepsilon_t$ (2')

where e_t and ε_t are iid, normally distributed with mean zero and variances $H_t = \sigma^2$ and $q_t = \sigma^2$. Q respectively. The ratio $q_t/H_t = Q$ is called the signal-to-noise ratio. T is a vector of parameters.

The Kalman filter is made up of two stages:

1. The **filtering procedure** builds up the estimates as new information about the observed variable becomes available. If a_t is the optimal estimate of the state variable X_t (the NAIRU) and P_t its variance/covariance matrix, then, given a_{t-1} and P_{t-1}, the Kalman filter may be written:[3]

$$a_{t+1|t} = (T - K_t Z)a_{t|t-1} + K_t(y_t - d_t) \qquad (3)$$

with $K_t = TP_{t|t-1}Z'F_t^{-1}$ and $F_t = ZP_{t|t-1}Z + H$ (4)

and $P_{t+1|t} = T(P_{t|t-1} - P_{t|t-1}Z'F_t^{-1}ZP_{t|t-1})T' + Q$ (5)

These equations permit the computation of the ***prediction errors*** ν_t for period t as:

$$\upsilon_t = y_t - Za_{t|t-1} - R.D_t \qquad (6)$$

to go into the likelihood function :

$$l_t = -\frac{1}{2}\log 2\pi - \frac{1}{2}\log|F_t| - \frac{1}{2}\upsilon_t F_t^{-1}\upsilon_t \qquad (7)$$

The series $\{a_t\}$ that maximises this function gives an optimal estimate of the one-sided NAIRU.

Box 2. **Using the Kalman filter to estimate a time-varying NAIRU** (*cont.*)

2. The smoothing procedure uses the information available from the whole sample of observation. It is a backward recursion which starts at time T and produces the smoothed estimates in the order T,...,1, following the equations:

$$a_{t|T} = a_t + P_t^*(a_{t+1|T} - T_{t+1}a_t) \quad (8a)$$

$$P_{t|T} = P_t + P_t^*(P_{t+1|T} - P_{t+1|t})P_t^{*\prime} \quad (8b)$$

$$P_t^* = P_t T_{t+1}^{\prime} P_{t+1|t}^{-1} \quad (8c)$$

with $a_{T|T} = a_T$ and $P_{T|T} = P_T$.

1. Standard references are Cuthbertson, Hall and Taylor (1992), Harvey (1992) and Hamilton (1994).
2. As explained in the main text, other forms of transition equations may be used. This one is used here for ease of presentation.
3. The initial values for a_0 and P_0 are important for the optimisation process to converge. The starting values may cause real trouble if the user of the Kalman filter has no prior information about it: as with all maximisation procedure, if the starting values are too far away from the true values the system will not converge. There is no standard or theoretical procedure to overcome this problem. When it is possible, a practical solution is to realise an OLS estimation first that will give an idea about the value of the parameter in the vector A. Yet, this does not help with the initial value for the variance/covariance matrix. The usual "trick" is to give this matrix an extremely high value so as to go away from the initial values of the parameters very quickly.

including the signal-to-noise ratio. In common with the findings of most other researchers using the technique, directly estimating the signal-to-noise ratio was found to give disappointing results because it typically leads to very flat NAIRUs.[29] The usual response to this problem is to carry out sensitivity analysis and choose these variances by visual inspection of the resulting NAIRU estimates. For example, Gordon (1997) suggests adopting a "smoothness prior", so that "the NAIRU can move around as much as it likes, subject to the qualification that sharp quarter-to-quarter zigzags are ruled out". Such an approach was adopted here, taking into account a number of factors including the combination of goodness-of fit and plausibility of the estimated equations and NAIRU estimates. In practice, the relevant parameterisation was found to vary significantly across countries. This reflects the differing time series properties of their actual rates of unemployment, in particular whether or not they have been stationary, as well as the differing goodness-of-fit of the estimated Phillips curves.[30]

End-point adjustments

An issue for concern when using filter procedures is the sensitivity of the NAIRU estimates for the most recent observations, which are typically of greatest interest from a policy perspective. A variety of studies (see, for example, Giorno *et al.* (1995) show that without further adjustments, the Hodrick Prescott filter may be "drawn towards" values at the end-point of the sample, thereby reducing the estimated "gap", whether or not this appropriately reflects the cyclical position of the economy in question. Boone *et al.* (2001) demonstrates that by making use of additional information about inflation, in a Phillips curve framework, Kalman filter estimates of the NAIRU are much less subject to end-point revisions than estimates from an HP filter.

To examine the degree of end-point sensitivity for both Kalman filter and HPMV estimation methods, NAIRU estimates for two countries where the cycle in unemployment has been pronounced, the United States and the United Kingdom, were obtained using truncated and full samples. On this basis, the estimated revisions to the Kalman filter NAIRUs over the period 1990-95 were found to be about one-quarter of a percentage point for the United States, with corresponding revisions for the United Kingdom found to be somewhat larger immediately after a turning point in actual unemployment but otherwise averaged about 0.4 percentage points. These revisions were about half the size of those obtained for a comparable HPMV filter and were judged sufficiently small not to warrant specific treatment. Nonetheless, this analysis suggests that particular caution needs to be attached to NAIRU estimates when the end-point is close to a cyclical turning point or where there are reasons for suspecting that there might be strong movements in the NAIRU, perhaps reflecting the effects of recent policy actions.

The estimation procedure

For most countries, Kalman filter estimation was carried out using a maximum likelihood method with the Phillips curve equation estimated jointly with the transition equation(s). However, for five of the 21 countries, direct estimation failed to produce plausible results because of difficulties in jointly identifying the NAIRU series and the coefficient on the unemployment gap.[31] For these countries an alternative iterative procedure was used, similar to that used by Fabiani and Mestre (1999), in which the Phillips curve coefficients were first imposed on the basis of preliminary estimates based on the HPMV filter, and an initial NAIRU series then estimated using the Kalman filter.[32] The resulting NAIRU series was then substituted into the Phillips curve equation and the parameters re-estimated using OLS. This process was repeated until the NAIRU series converged, usually within a few iterations.

RESULTS

This section describes the preliminary NAIRU estimates that are obtained from a Phillips curve relationship using a Kalman filter, following the framework previously outlined. However, as discussed, these estimates are subsequently adjusted for possible biases, particularly to allow for the effects of recent policy reforms given the uncertainty surrounding the empirical estimates.

The estimation results

Following the procedures outlined in the previous section, it was possible to estimate Phillips curves and corresponding NAIRU estimates using the Kalman filter method for all 21 OECD countries for which the OECD currently publishes NAIRU estimates (see Table 1). Similar Phillips curve specifications were used across countries to ensure comparability of results.[33] Speed limit effects (ΔU terms) were tested for all countries, but found to be insignificant for most of them. Occasional outlier dummies have also been used in places, such as to account for price controls in the United Kingdom in the 1970s. For the United States, special adjustments were made to the unemployment rate variable to take account of specific demographic composition effects.[34]

For approximately half of the countries, an auto-regressive process was preferred to a random walk when using the Kalman filter. In nearly all of these cases, the auto-regressive coefficient is statistically significant and typically takes a value in the range 0.6 to 0.8. Examining the four major European countries for which both specifications could be stably estimated, the differences between the two NAIRU series are generally small.[35] The average absolute difference over the entire sample estimation period is 0.4 percentage points for France and Italy, one-quarter of a percentage point in the case of the United Kingdom, and 0.1 percentage points in the case of Germany. The maximum difference between the two series over the entire sample period for all four countries is about 0.6 to 0.8 percentage points. These relatively small differences lend some support to the predominant use of the random walk assumption in the empirical literature. Nevertheless, the auto-regressive form is intuitively more appealing because it is consistent with the NAIRU adjusting only slowly to long-lasting supply shocks. Moreover, the auto-regressive form is also of interest in a short-term forecasting context insofar as changes in the estimated

Table 1. **Estimated Phillips curves and diagnostic tests using the Kalman filter**

***Estimation method*: Kalman filter**
Dependent Variable is $\Delta\pi$.

Sample	United States	Japan[1]	Germany	France	Italy	United Kingdom	Canada
	63:2 to 99:2	63:2 to 99:1	62:2 to 99:1	70:2 to 99:2	62:2 to 99:1	63:1 to 99:1	65:2 to 99:1
Dynamics							
$\Delta\pi_{-1}$	–0.33 (3.1)	–0.49 (5.7)	–0.39 (6.0)	–0.43 (3.3)	–0.11 (1.2)	–0.33 (5.2)	–0.46 (4.6)
$\Delta\pi_{-2}$	–0.24 (2.5)	–0.44 (7.4)		0.00 (0.0)	–0.33 (4.7)	–0.30 (4.3)	–0.51 (5.5)
$\Delta\pi_{-3}$		–0.34 (5.0)		–0.21 (2.1)		–0.27 (4.3)	
$\Delta\pi_{-5}$		–0.22 (4.0)					
Unemployment							
U–U*	**–0.13 (4.5)**	**–1.85 (7.9)**	**–0.19 (6.0)**	**–0.17 (3.8)**	**–0.27 (3.7)**	**–0.20 (5.6)**	**–0.50 (8.6)**
Δ U					–0.65 (2.6)	–0.26 (1.8)	
Δ (U^{North}–U)					–1.18 (2.7)		
Import prices							
$\omega_{-1}(\pi^m - \pi_{-1})_{-1}$	1.53 (4.6)	1.40 (5.6)	0.52 (3.8)	0.89 (3.6)	0.76 (3.5)	0.45 (2.5)	0.87 (5.6)
$\omega_{-1}\Delta\pi^m$	0.83 (2.8)	0.40 (1.8)	0.34 (2.5)	0.55 (2.5)	0.80 (5.1)	0.16 (1.1)	0.24 (2.1)
$\omega_{-1}\Delta\pi^m_{-1}$		–0.81 (3.3)					–0.43 (3.2)
$\omega_{-1}\Delta\pi^m_{-2}$							
Oil prices							
$\nu_{-1}(\pi^o - \pi_{-1})_{-1}$						0.21 (1.8)	
$\nu_{-1}\Delta\pi^o$	0.07 (5.9)	0.13 (2.7)	0.11 (4.0)	0.11 (2.4)	0.11 (3.0)	0.10 (1.3)	
$\nu_{-1}\Delta\pi^o_{-1}$	0.06 (4.6)	0.16 (4.1)			0.18 (4.8)	–0.21 (2.4)	
$\nu_{-1}\Delta\pi^o_{-2}$							
NAIRU in 99:1	5.2	3.9	7.8	10.1	10.4	6.7	8.5
Sacrifice Ratio	3.1	0.3	1.8	2.4	1.3	2.4	1.0
Standard error	0.32	0.50	0.33	0.55	0.59	0.58	0.44
R^2	0.67	0.83	0.53	0.57	0.77	0.84	0.59
adjusted-R^2	0.64	0.80	0.50	0.52	0.74	0.80	0.55
Diagnostic tests[3] *(p-values reported)*							
Chow forecast test[4]	0.76	0.99	0.87	1.00	0.97	0.99	0.80
RESET test[5]	0.23	0.14	0.07	0.91	**0.05**	0.11	0.21
Serial correlation[6]	0.21	**0.02**	0.10	0.10	0.19	0.88	0.53
Normality[7]	0.97	0.71	0.20	**0.01**	0.65	0.23	0.27
Chow breakpoint[8]	**0.02**	0.81	**0.00**	0.14	0.26	0.16	0.13

Table 1. **Estimated Phillips curves and diagnostic tests using the Kalman filter** (*cont.*)

***Estimation method*: Kalman filter**
Dependent Variable is $\Delta\pi$.

Sample	Australia[2]	Austria[2]	Belgium[2]	Denmark	Finland[2]	Greece	Ireland
	66:2 to 99:1	66:2 to 99:1	71:2 to 99:1	66:2 to 99:1	70:1 to 99:1	75:1 to 99:1	78:2 to 99:1
Dynamics							
$\Delta\pi_{-1}$	−0.58 (6.6)	−1.07 (9.8)	0.05 (0.4)	−0.57 (5.1)	−0.76 (8.1)		−0.23 (1.8)
$\Delta\pi_{-2}$		−0.55 (5.0)	−0.52 5.30	−0.43 (4.5)	−0.31 (3.4)	−0.44 (−5.7)	
$\Delta\pi_{-3}$		−0.31 (3.4)					
Unemployment							
U–U*	**−0.93 (3.8)**	**−1.60 (5.6)**	**−0.66 (3.5)**	**−0.23 (4.0)**	**−1.00 (3.8)**	**−0.34 (−6.4)**	**−0.22 (4.9)**
Δ U							
Import prices							
$\omega_{-1}(\pi^m-\pi_{-1})_{-1}$	0.77 (3.8)	0.89 (3.1)	0.37 (3.8)	0.46 (1.9)	1.40 (4.7)	1.21 (6.2)	0.28 (3.2)
$\omega_{-1}\Delta\pi^m$	0.54 (3.6)	0.66 (3.3)	0.25 (2.8)	0.71 (3.5)	0.24 (1.3)	0.70 (4.8)	
$\omega_{-1}\Delta\pi^m{}_{-1}$				0.40 (2.0)			
Oil prices							
$\nu_{-1}(\pi^o-\pi_{-1})_{-1}$		0.25 (3.3)	0.11 (2.3)				
$\nu_{-1}(\pi^o-\pi_{-1})_{-2}$							
$\nu_{-1}\Delta\pi^o$		0.13 (2.2)	0.08 (3.7)	0.11 (2.4)		0.09 (2.9)	
$\nu_{-1}\Delta\pi^o{}_{-1}$	0.11 (4.0)				0.21 (4.7)		0.16 (2.6)
NAIRU in 99:1	7.0	4.9	8.4	7.8	10.2	7.9	9.0
Sacrifice Ratio	0.4	0.5	0.6	2.2	0.5	1.1	1.4
Standard error	0.60	0.50	0.45	0.64	0.80	0.59	0.66
R^2	0.67	0.69	0.73	0.59	0.84	0.69	0.63
adjusted-R^2	0.63	0.65	0.69	0.55	0.82	0.66	0.57
Diagnostic tests[3] *(p-values reported)*							
Chow forecast test[4]	0.84	**0.00**	0.76	0.94	0.78	0.67	0.91
RESET test[5]	**0.03**	0.45	0.35	0.91	0.30	0.13	0.42
Serial correlation[6]	0.81	0.16	0.51	0.10	0.84	0.48	0.90
Normality[7]	0.88	**0.01**	0.77	0.32	0.58	0.80	0.87
Chow breakpoint[8]	0.25	0.23	0.07	0.78	0.14	0.42	0.51

Table 1. **Estimated Phillips curves and diagnostic tests using the Kalman filter** (*cont.*)

***Estimation method*: Kalman filter**
Dependent Variable is $\Delta\pi$.

Sample	Netherlands	New Zealand	Norway	Portugal	Spain[2]	Sweden	Switzerland
	72:1 to 99:1	80:1 to 99:1	66:2 to 99:1	70:2 to 99:1	66:2 to 99:1	66:2 to 99:1	78:1 to 99:1
Dynamics							
$\Delta\pi_{-1}$	–0.67 (7.1)	–0.60 (6.0)	–1.02 (11.7)	0.01 (0.1)	–0.63 (5.8)	–0.85 (7.1)	–0.34 (4.0)
$\Delta\pi_{-2}$			–0.43 5.20	–0.35 (4.2)	–0.25 (2.5)	–0.26 (2.0)	–0.40 (5.0)
$\Delta\pi_{-3}$					–0.51 (5.4)	–0.22 (2.0)	
Unemployment							
U–U*	**–0.20 (4.7)**	**–0.62 (7.0)**	**–1.16 (5.1)**	**–0.21 (3.9)**	**–2.62 (6.2)**	**–0.43 (3.5)**	**–0.23 (6.2)**
ΔU					–0.42 (3.5)		
Import prices							
$\omega_{-1}(\pi^m-\pi_{-1})_{-1}$	0.32 (2.9)	1.72 (7.8)	0.39 (2.2)	0.50 (2.8)	1.58 (5.0)	1.20 (3.7)	
$\omega_{-1}\Delta\pi^m$	0.12 (1.2)	0.64 (5.3)		0.80 (5.5)	0.80 (3.3)	0.95 (3.8)	
$\omega_{-1}\Delta\pi^m{}_{-1}$		0.20 (1.4)					
Oil prices							
$\nu_{-1}(\pi^o-\pi_{-1})_{-1}$				0.12 (2.2)			0.57 (6.9)
$\nu_{-1}(\pi^o-\pi_{-1})_{-2}$			0.49 (4.7)				
$\nu_{-1}\Delta\pi^o$				0.14 (3.7)			0.35 (5.6)
$\nu_{-1}\Delta\pi^o{}_{-1}$							
NAIRU in 99:1	4.8	5.4	3.7	4.7	15.4	5.6	4.1
Sacrifice Ratio	2.1	0.6	0.5	1.6	0.2	1.4	1.9
Standard error	0.49	0.60	1.01	0.80	0.80	1.24	0.36
R^2	0.70	0.88	0.75	0.74	0.60	0.57	0.86
adjusted-R^2	0.68	0.86	0.73	0.70	0.56	0.53	0.83
Diagnostic tests[3] *(p-values reported)*							
Chow forecast test[4]	0.96	0.97	0.98	0.74	0.97	0.85	0.17
RESET test[5]	0.24	0.72	0.71	0.29	0.08	0.28	0.27
Serial correlation[6]	0.19	0.41	0.10	0.19	0.88	0.58	0.74
Normality[7]	0.38	0.29	0.72	0.88	0.39	0.58	0.99
Chow breakpoint[8]	0.73	0.57	0.49	**0.01**	0.14	0.39	0.17

Table 1. **Estimated Phillips curves and diagnostic tests using the Kalman filter** (*cont.*)

Definition of variables:

All data is semi-annual and is taken from the OECD's Analytical Database (ADB), except where otherwise noted. All inflation rates are expressed as the change in the relevant price index on the previous semester, with the rate not being annualised.

π = inflation rate based on private consumption deflator. For Canada a measure of the core CPI, excluding food and energy, is used (source: Statistics Canada).
U = unemployment rate.
U^{NORTH} = unemployment rate in the Centre-North region of Italy (source: Bank of Italy with OECD interpolations).
U* = the NAIRU which is estimated using the Kalman filter.
π^m = inflation rate of the de-trended non-oil import price of goods and services. Import prices were de-trended by regressing real import prices on split time trends and lagged real import prices. The time trends included were one covering the entire sample estimation period or one beginning in 1980.
ω = weight of non-oil import prices in total demand, measured as the share by value of imports of goods and services (excluding oil) in total demand.
π^o = inflation rate of the unit value of energy imports.
ν = measure of oil supply in relation to GDP (source: Energy Balances of OECD Countries, International Energy Agency). Semi-annual values were interpolated from annual figures and most recent values were derived by extrapolation.
Δ denotes the first difference operator, subscripts denote lags.

1. For Japan the recent forecast performance of the estimated Phillips curve was substantially improved by introducing a reduced effect from the unemployment gap on inflation when inflation is already low. Specifically, when the level of inflation is below 2 per cent per annum and unemployment is above the NAIRU the coefficient on the unemployment gap is reduced in magnitude from that shown in the table: to –1.04 (from –1.85) when estimated with the Kalman filter.
2. For some countries the unemployment gap term does not take a linear form: for Austria, Belgium Finland and Spain in the equation estimated with the Kalman filter, the unemployment rate and NAIRU are specified in logarithmic form, log(U/U*); for Australia the (linear) unemployment gap is normalised on the actual rate, (U–U*)/U.
3. The p-values of the diagnostic tests are reported. Failures at the 5 per cent significance level are highlighted in bold.
4. Chow forecast test from 1995:1.
5. Ramset reset test of functional form based on the inclusion of squared and cubed fitted values.
6. Breusch-Godfrey Lagrange-Multiplier test for up to second order serial correlation of the residuals.
7. Jarque-Bera test for normality of residuals.
8. Chow breakpoint test for break in 1985:1, except for Ireland and New Zealand where a break of 1990:1 was chosen because of the shorter sample estimation period.

List of dummy variables used in the estimation:

France	+1 in 1982:2; –1 in 1983:1
United Kingdom	–1 in 1977:2 and +1 in 1979:2; 1 in 1974:1; 1 in 1974:2 and 1975:1
Germany	–1 in 1992:2 and +1 in 1993:1; +1 in 1991:2
Italy	+1 in 1970:1 and –1 in 1970:2; –1 in 1971:2 and +1 in 1972:2; –1 in 1984:2
Japan	+1 in 1974:1 and –1 in 1974:2
Australia	+1 in 1973:2; +1 in 1976:2
Belgium	+1 in 1985:2
Finland	+1 in 1973:2
Ireland	+1 in 1982:1, 1982:2 and 1993:2
Netherlands	+1 in 1985:1, –1 in 1985:2
New Zealand	+1 in 1983:1
Norway	+1 in 1970:1
Portugal	+1 in 1976:1 and –1 in 1976:2
Switzerland	+1 in 1980:1, 1983:1 and 1985:2

NAIRU over the recent past may provide information relevant to its likely future profile.

The temporary supply shock (non-oil import and oil-price inflation) and unemployment gap terms are correctly signed and statistically significant for nearly all countries. In order to test the robustness of the Phillips curve, the estimated unemployment gaps were included in the preferred Phillips curve specification, which was then estimated by OLS and subject to a battery of standard diagnostic tests, as reported in Table 1.[36] Among the G7 countries the most serious diagnostic test failure relates to the structural stability (using a Chow breakpoint test) for Germany which may be related to the effects of reunification. For Italy the inclusion of a country-specific variable, namely the change in the difference between the unemployment rate in the Centre-North region of the country

Table 2. **NAIRU estimates and standard errors**

	1980	1985	1990	1995	1999	Standard errors[1]	
						Average	Final year
Australia	5.1	6.0	6.5	7.1	6.8	1.0	1.6
Austria	1.9	3.2	4.6	5.0	4.9	0.2	0.3
Belgium	5.5	6.8	8.4	8.0	8.2	1.3	1.3
Canada	8.9	10.1	9.0	8.8	7.7	0.6	0.9
Denmark	5.8	5.9	6.9	7.1	6.3	1.0	1.3
Finland	4.3	3.9	5.6	10.6	9.0	1.4	1.8
France	5.8	6.5	9.3	10.3	9.5	1.1	1.7
Germany	3.3	4.4	5.3	6.7	6.9	0.9	1.2
Greece	4.6	6.5	8.4	8.8	9.5	0.8	1.1
Ireland	12.8	13.2	14.1	10.8	7.1	1.2	2.0
Italy	6.8	7.8	9.1	10.0	10.4	0.8	1.1
Japan	1.9	2.7	2.2	2.9	4.0	0.2	0.3
Netherlands	4.7	7.5	7.5	6.1	4.7	1.0	1.3
New Zealand	1.6	5.1	7.0	7.5	6.1	0.6	0.8
Norway	2.2	2.6	4.6	4.9	3.7	0.5	0.6
Portugal	6.1	5.4	4.8	4.2	3.9	1.0	1.4
Spain	7.8	14.4	17.4	16.5	15.1	1.2	1.2
Sweden	2.4	2.1	3.8	5.8	5.8	0.8	1.0
Switzerland	2.3	2.9	3.0	3.3	2.4	0.8	1.0
United Kingdom	4.4	8.1	8.6	6.9	7.0	1.1	1.5
United States	6.1	5.6	5.4	5.3	5.2	0.9	1.2
Memorandum items:							
Euro area	5.5	7.1	8.8	9.2	8.8		
Weighted average of above countries[2]	5.0	5.9	6.3	6.5	6.5		

1. Estimated standard errors around initial econometric estimates.
2. Weighted by size of labour force.

Source: OECD Secretariat calculations.

and the aggregate unemployment rate, is needed to pass the test for structural stability.[37]

Measures of uncertainty and revisions to the preliminary estimates

A particular advantage of the Kalman filter is that when a direct maximum likelihood estimation method is used it is also possible to generate standard errors for the NAIRU estimates.[38]

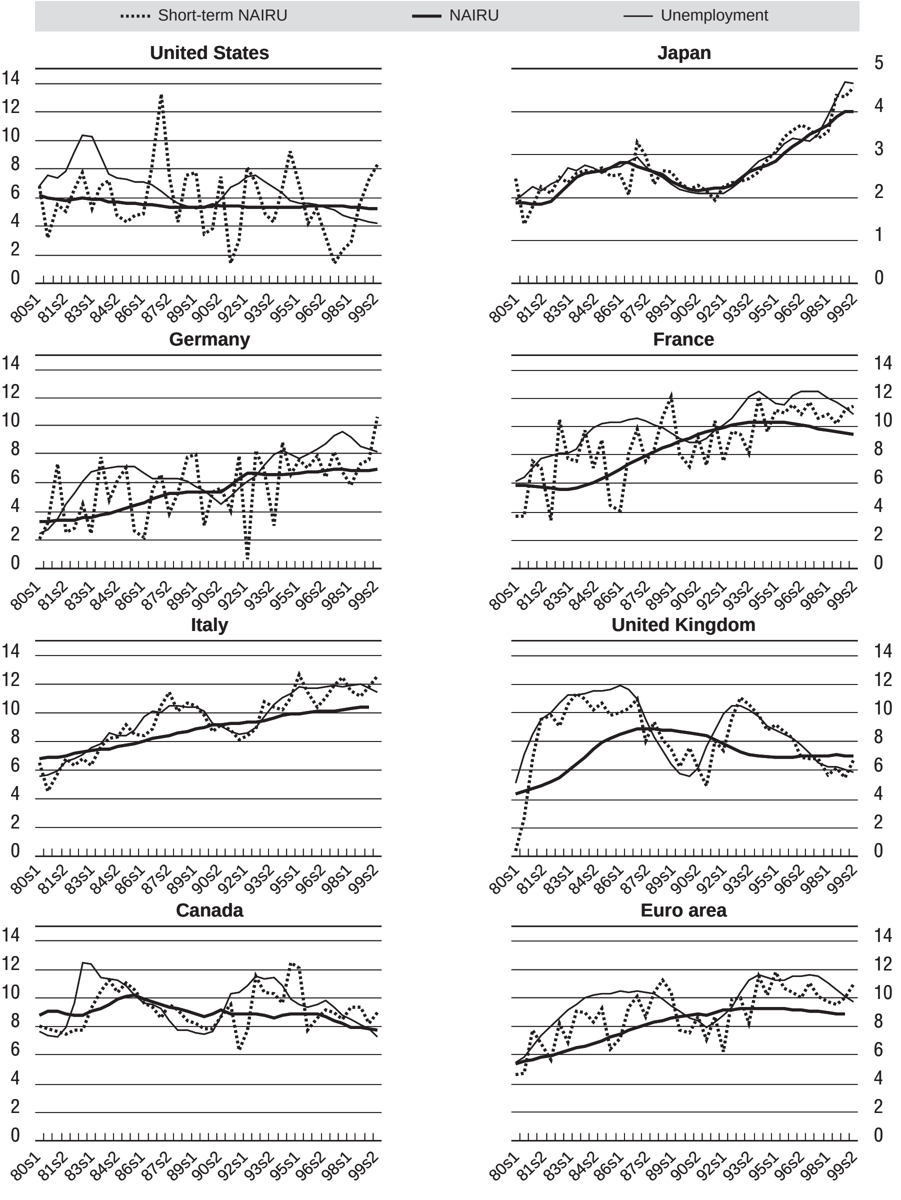
There are three sources of uncertainty surrounding the Kalman filter estimates; those because: *i*) the NAIRU is unobserved and has to be inferred; *ii*) the parameters of the model are unknown and must be estimated; and *iii*) the model specification may be wrong. In the empirical literature, the third source of uncertainty is typically ignored. The estimation techniques used normally provide a means for dealing with the first source of uncertainty in terms of the estimated prediction error variance for the state variable, at each point of time, whilst in some studies, the second source on uncertainty is dealt with either by means of Monte Carlo methods (Laubach (1999), Irac (1999)), or by using the Ansley and Kohn delta' method (Staiger *et al.* 1997).

In the present study the standard errors associated with the first two sources of uncertainty were derived by use of Monte Carlo methods, following Hamilton (1986, 1994).[39] For the full sample (see Table 2), these are found to range between 0.2 for Japan and 1 for France, the United Kingdom and Ireland, and are well in line with those reported elsewhere in the recent literature.[40] Figure 2, which follows, illustrates the corresponding error bands and their evolution over time for the major economies.

Given the range of uncertainties and the estimated error bands, the estimates generated by the econometric procedure described above were subject to scrutiny by country experts and sometimes revision for specific biases particularly to allow for the effect of recent reforms. In some cases these revisions simply involved using a more appropriate definition of inflation or unemployment in the Phillips curve estimation, which led to a better fitting Phillips curve and a profile for the NAIRU that was judged to be more plausible.[41]

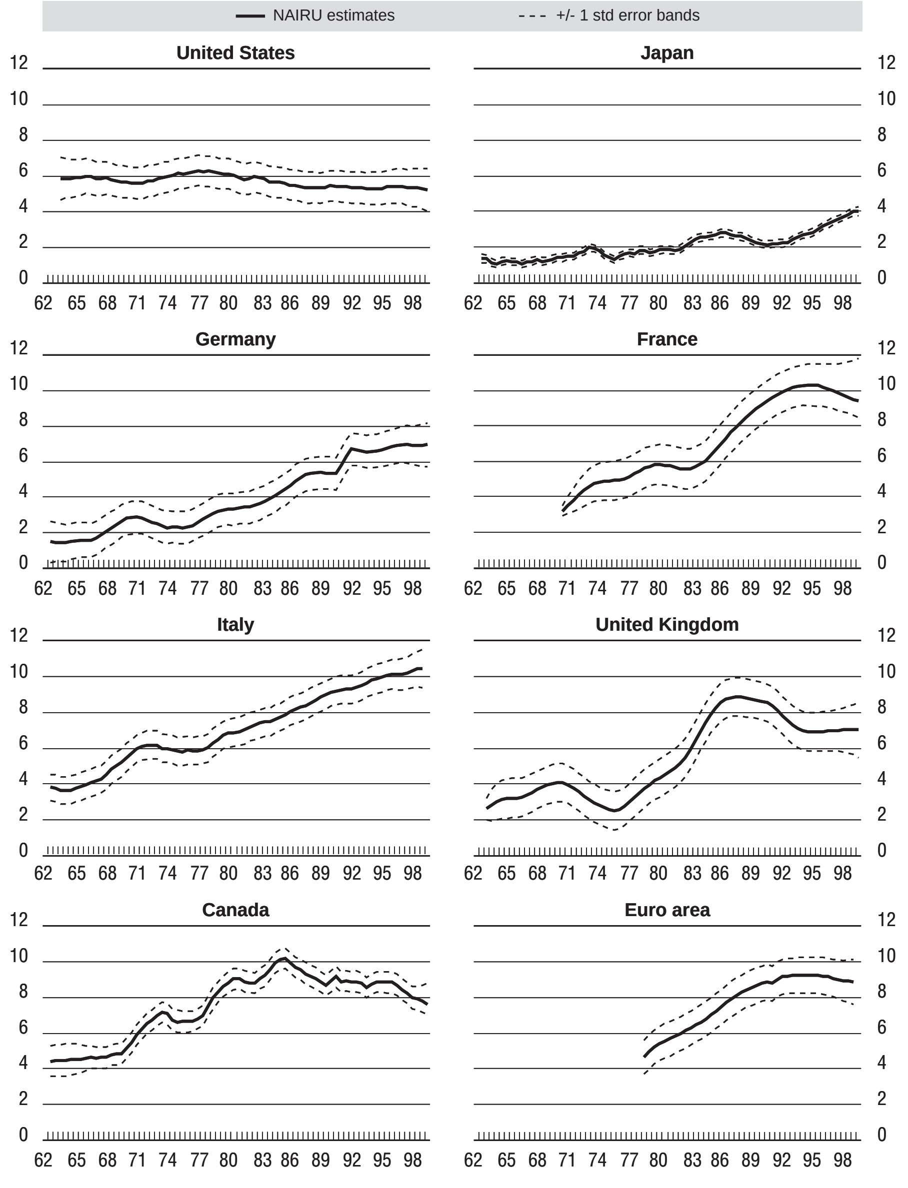
For two countries (Canada and Greece) a more fundamental change of specification to the Phillips curve involved more explicit modelling of inflation expectations. For a further three countries (Australia, France and Switzerland) the preliminary estimates appeared to contradict other information, particularly relating to the likely effect of recent labour market reforms, and so were judgementally adjusted. These latter revisions occur at the end of the estimation period where uncertainty surrounding any filter-based estimates of the NAIRU is greatest.[42] Two countries (Finland and Ireland) were considered as special cases in so far as the

Figure 1. **NAIRU and short-term NAIRU**[1]



1. Japan is shown on a different scale.
Source: OECD.

Figure 2. **NAIRU estimates and standard error bands**[1]



1. Estimated standard errors are centred around the initial econometric estimates. For France and Canada, where these initial estimates are judgementally revised (see appendix) the NAIRU is not in the centre of the band.

Source: OECD.

basic estimation framework was considered inadequate for explaining recent episodes.[43] These revisions are discussed in further detail below.

More explicit modelling of inflation expectations (*Canada and Greece*)

In the original estimation, inflation expectations in the Phillips curve for most countries are proxied by a distributed lag of past inflation rates. However, this assumption may be particularly inappropriate and lead to biased estimates of the NAIRU following a change in policy regime. Canada and Greece are two countries where allowing for such a regime change seemed appropriate and leads to significant changes in the estimated NAIRU.

Canada was one of the first countries to introduce explicit inflation targeting in 1991. Empirical evidence from the Bank of Canada suggests that this has significantly influenced inflation expectations and following this evidence, inflation expectations from 1991 onwards are modelled as a weighted average of the (mid-point of the) inflation target and a distributed lag of past inflation rates (with weights of about half on each component).[44] The inflation variable used in the Phillips curve is the core measure of CPI inflation (excluding the effects of food, energy and indirect taxes) that the Bank focuses on for the purposes of monetary policy (although formally the inflation target is formulated in terms of the headline CPI). Given that inflation has consistently undershot the (mid-point of the) inflation target, the new policy regime may have provided an anchor for inflation expectations that has prevented further disinflation. Thus, not taking into account the effect of the change in policy regime on expectations is likely to have led to the NAIRU being over-estimated over recent years. Indeed, allowing for the change in policy regime lowers the NAIRU estimate on average by 0.3 percentage points over the period since the target has been in operation and by slightly more at the end of the estimation period.[45]

Over the course of the 1990s, consumer price inflation in Greece has fallen from 20 to 2½ per cent per annum. One factor underlying this fall, at least over the past several years, may have been the effect that prospective membership of the EMU has had on lowering inflation expectations. To allow for this effect in the estimation of the NAIRU, inflation expectations from 1991 onwards are specified as a weighted average of past inflation and average euro area inflation, where the weight is estimated but allowed to increase at a linear rate over time.[46] Allowing for this regime shift implies a systematically higher NAIRU (because some of the disinflation is attributed to an expectations effect rather than the unemployment gap), that is on average nearly a percentage point higher than implied by the standard Phillips curve specification.

Allowing for the impact of recent reforms (*Australia France and Switzerland*)

As mentioned previously, a practical limitation of the estimation method concerns the greater uncertainty at the end of the sample period and, in particular, with respect to the effects of recent and on-going reforms. For those countries where such reforms took place in the late-1980s to mid-1990s (for example: the Netherlands, New Zealand, Spain and the United Kingdom), their impact on the NAIRU are typically found to be substantial but relatively slow to emerge.[47] To the extent that a number of other OECD countries are currently undergoing similar reforms, it may be too soon to see any appreciable reduction in the NAIRU reflected in current econometric estimates. In such cases, further adjustments are, therefore, made on the basis of the scale and nature of these recent reforms.[48]

In Australia there have been significant reforms to both product and labour market institutions since 1996, including changes to the coverage of industrial awards, a move towards more decentralised bargaining and ongoing deregulation and privatisation of utilities. To incorporate the effect of these changes, the NAIRU was progressively revised downwards from 1998 to 6¾ per cent in 1999 (compared with a preliminary estimate of 7¼ per cent).

For France the preliminary econometric estimates suggested that the NAIRU had been broadly stable over the 1990s (at just over 10 per cent), although the standard error surrounding the estimate is among the largest of any country. Such a profile is not easily reconciled with the structural reforms that have been implemented since 1995, in particular large cuts in social security contributions, as well as evidence that the labour market has become more flexible with a growing share of temporary and part-time employment. To reflect these reforms the NAIRU is progressively revised downward from 1995, so that by 1999 it has fallen to 9½ per cent.

Switzerland has recently undergone a major reform of the unemployment insurance system that involved a tightening of unemployment benefit eligibility criteria in 1996 and 1997, with more intensive use of active labour market policies in 1998 and with participation becoming a condition of unemployment benefit eligibility.[49] The preliminary econometric estimates of the NAIRU were adjusted to reflect these reforms; a fall of ¾ per cent is imposed from 1997 to give an estimate of the NAIRU of 2½ per cent in 1999.

Special cases (*Finland and Ireland*)

In two special cases (Finland and Ireland) the specific estimation framework is considered inadequate for explaining past and recent experiences.

Finland has been affected by a number of major shocks in the early 1990s: the bursting of an asset price bubble, a sharp terms-of-trade fall and the collapse of trade with the former Soviet Union. To reflect the impact of these shocks the profile of the estimated NAIRU has been judgementally adjusted in order to give a profile with a more pronounced rise in the early 1990s, that falls in the second half of the 1990s (consistent with supply side improvements in taxes, replacement rates and employment protection legislation) to a level of about 9 per cent in 1999.

The case of Ireland is unusual given the importance of immigration flows, which may mean that the NAIRU is more volatile than for most other countries with a greater tendency to follow the actual unemployment rate. Attempts to allow for this in the estimation process were, however, unsuccessful. Instead the econometric estimate was progressively revised downwards from 1995 to be more in line with the sharp fall in actual unemployment, so that by 1999 it had fallen to 7 per cent (compared with an econometric estimate of 9 per cent).

Recent trends in the NAIRU estimates

Combining the above judgmental adjustments with the econometric estimates gives a final set of NAIRU estimates for OECD countries reported in Table 2 and Figure 1.

Overall these estimates suggest that the extent and direction of changes in the NAIRU over the 1990s is distinctly mixed across OECD countries, although this might be favourably contrasted with the 1980s during which the NAIRU rose across virtually all of them (the United States and Portugal being exceptions). Countries where the NAIRU has risen by about 2 percentage points or more during the 1990s include Finland, Germany, Japan and Sweden, while Italy and Greece experienced a rise of just over 1 percentage point. Conversely, countries where the NAIRU has fallen by about a percentage point or more – Canada, Netherlands, New Zealand, the United Kingdom, Spain, Portugal, Ireland and Norway – include those where labour market reforms have been most extensive.[50] Nevertheless, the experience of these countries suggests that even following major reforms the NAIRU may only fall gradually (typically less than ½ percentage point per year) and with considerable lags. A striking exception is Ireland for which the NAIRU appears to have fallen by a remarkable 7 percentage points over the past decade.

There does appear to be a more uniform improvement in labour market performance across many countries in the second half of the 1990s compared with the first half, with two-thirds of the countries examined having experienced some fall in the NAIRU over the past five years. For example, Denmark, Finland, France, New Zealand and Norway have all had substantial falls in the NAIRU (of at least a percentage point) over the second half despite it rising earlier in the decade. Moreover, there are other countries (Canada, Ireland and Spain) for which the NAIRU has fallen more steeply in the second half of the 1990s. A major exception is Japan where the NAIRU has risen more steeply, by over a percentage point, in the second half of the decade. Overall, while there do seem to be signs of recent progress, there remains considerable scope for further improvement: a weighted average of the NAIRUs across all the countries examined (which cover about 82 per cent of the total OECD labour force) suggests structural unemployment in the OECD is significantly higher now than in 1980 (let alone in earlier decades). Moreover, while disparities have narrowed marginally, large differences across countries remain.

At the same time, the revised estimates imply that for most OECD countries actual unemployment has been well in excess of the NAIRU for much of the 1990s, consistent with the substantial reduction in area-wide inflation. This is particularly the case for the euro area; the average gap between unemployment and the NAIRU since 1993 is about 1¾ percentage points (Figure 1). Much of this gap is accounted for by the three largest euro area economies, for which unemployment was still between 1 and 1½ percentage points higher than the estimated NAIRU in the second half of 1999, although the gap was narrowing. Conversely, for some of the smaller euro area countries the unemployment gap has just closed (Austria and Spain) or unemployment has been below the NAIRU (Ireland and Netherlands) for a year or more. On this basis recovery is even more advanced in both the United Kingdom and United States, where unemployment has been below the estimated NAIRU for 3 and 4 years, respectively. In order to reconcile inflation outcomes with these differing profiles of the gap between unemployment and the NAIRU, it is necessary to consider the short-run NAIRU.

THE RELEVANCE OF NAIRU ESTIMATES FOR MONETARY POLICY AND INFLATION

Indicators of structural unemployment provide a useful input to the setting of monetary policy if they help policymakers assess inflationary developments in the short term.[51] In this respect, the short-term NAIRU concept may be a useful indicative synthesis of information concerning current inflationary pressures – see Estrella and Mishkin (1998) and King (1999) – even though its inherent volatility means that it is unsuitable as a target. Indeed, fluctuations in the short-run NAIRU provide an indication of which inflationary shocks policy-makers can ignore. For example, the effect of adverse temporary supply shocks that may dissipate in the near future should not be seen as necessitating a permanent rise in unemployment. In this situation, policy-makers need to assess, before taking action, whether or not inflation is likely to be consistent with policy objectives when the shock wears off.[52]

The importance of the distinction between the NAIRU and short-run NAIRU is illustrated in Figure 1, which shows estimates for the G7 and euro-area economies: periods when unemployment is higher (lower) than the short-run NAIRU generally signal periods of falling (rising) inflation, even though the short-run NAIRU gap is sometimes of the opposite sign to that of the NAIRU gap. For the United States, the top left-hand panel of Figure 1 shows the unemployment rate over the period 1996 to 1998 was consistently above the short-run NAIRU, a period during which inflation fell, even though the unemployment rate was below the NAIRU.

Since 1996 unemployment has tended to exceed both the NAIRU and the short run NAIRU for the three largest euro-area economies, implying that demand pressures have been an important influence behind the fall in inflation, at least until the end of 1998. Over the same period, favourable movements in the short-run NAIRU in the United Kingdom and United States relative to euro-area economies are explained by the relative strength of exchange rates and their effects on imported inflation. However, since 1999 the rise in oil prices has become a major factor explaining the upturn in inflation and the corresponding increases in the short-run NAIRU across most OECD countries.

For Japan the rise in inflation during 1996 and 1997 can be related to unemployment falling below the NAIRU combined with pressure from import prices following depreciation of the yen. However, since 1997 the relatively rapid rise in unemployment, to levels in excess of the rising NAIRU has played an important role in driving inflation down to negative rates. Indeed, the relatively large unemployment gap coupled with the strengthening of the yen led to a further fall in inflation in 1999, despite the sharp rise in oil prices.

If speed limit effects are strong then the short-run NAIRU will show a tendency to track the actual unemployment rate because pronounced changes in unemployment will generate considerable changes in inflation in the short-run. In these circumstances, a rapid closing of a positive gap between actual unemployment and the NAIRU may generate unacceptable short-term inflationary effects. Among the G7 economies, such effects are found to be particularly important for Italy and the United Kingdom as reflected in the path of the short-run NAIRU estimates, which for these countries tend to fluctuate around the actual unemployment rate rather than around the NAIRU (Figure 1). Thus, for both countries there have been prolonged periods during the 1980s and 1990s when the actual unemployment rate has exceeded the NAIRU, but the profile of the short-run NAIRU suggests that the scope for reducing unemployment without (temporarily) increasing inflation was limited. Recently, speed limit effects may have been particularly important for Italy in 1999 and the United Kingdom during 1996-97; in both cases the inflationary effect of a relatively rapid fall in unemployment may have outweighed the deflationary effect of unemployment remaining in excess of the NAIRU. Such speed limits may be less pronounced in other countries, but nevertheless have represented a constraint in reducing unemployment quickly, even while it has remained well in excess of the NAIRU during most of the 1990s.

Finally, the limitations of any analysis based on the NAIRU and short-run NAIRU should be emphasised, particularly that they depend on estimated econometric relationships that explain inflation developments imperfectly, and are sometimes subject to large margins of error. As illustrated in Table 2 and Figure 2, standard errors surrounding the NAIRU estimates are on average about ¾ of a percentage point across all countries, but rise above 1 percentage point at the end of the estimation period.[53] Moreover, different specification choices may lead to different policy conclusions. For example, the choice of temporary supply shocks, oil and import price inflation, in the current analysis is based on what variables explain inflation consistently well across most OECD countries, but other choices are possible.[54] These factors all suggest that the NAIRU and short-term NAIRU can only serve as one of a range of possible indicators that are useful for assessing inflationary pressures.

Appendix

THE THEORETICAL FRAMEWORK

In previous OECD work on labour market issues (in particular, see OECD, 1996 and OECD, 1999) a framework based on the system of wage and price setting equations popularised by Layard *et al.* (1991), has been used extensively to illustrate how institutional characteristics and macroeconomic shocks interact and affect labour market performance, in particular the unemployment rate. Using this framework, this appendix reviews the theoretical underpinnings of the NAIRU concepts, showing the Phillips curve to be generally consistent with this theoretical model; one that can be interpreted as a reduced form relationship derived from the interaction of wage and price setting.

The structural model

The model used assumes an economy where wages are bargained between workers and firms – the latter deciding on the level of employment, output and prices once a wage agreement has been reached (the so-called "right-to-manage" model, see Layard *et al.*, 1991; Bean, 1994). Firms are assumed to operate in markets with imperfect competition, facing exogenously determined product market conditions, capital stocks and technology. Ignoring, for simplicity, labour force growth, this simple model can be summarised using three equations: 1) price-setting; 2) wage-setting; and 3) labour supply.

Price-setting

The price equation summarises the aggregate demand for labour by firms as a function of the (decreasing) marginal product of labour. If the product market is characterised by imperfections, the equation establishes a relationship between the optimal choice of employment and real wages for the firm, where prices are fixed as a margin over labour costs:

$$p - w = a_o + a_1 n + a_2 \Delta n - a_3(p - p^e) - q + ZL_p + ZT_p \qquad a_1, a_2, a_3 > 0 \tag{1}$$

where Δ is the first difference operator,[55] n, w and p are respectively the logarithms of employment, wages (including payroll taxes) and prices, q is the logarithm of trend labour efficiency, ZL_p is a vector of variables having a "long-lasting" influence on price formation of firms, such as factors affecting the competitive structure of the market or the cost of capital. The ZT_p vector represents temporary factors affecting the price setting process (*i.e.* ZT_p represents supply shocks with zero ex-ante expectation) such as import or oil price shocks, p^e is the logarithm of expected prices.

Wage-setting

The wage equation can be obtained from different microeconomic models. Real wages are assumed to be a decreasing function of the unemployment rate (level and changes)[56] and an increasing function of wage push factors (ZT_w and ZL_w) and labour efficiency, allowing for unanticipated wage changes (w-w^e).[57] Thus:

$$w - p = b_o + b_1 U - b_2 \Delta U - b_3(w - w^e) + q + ZT_w + ZL_w \quad b_1, b_2, b_3 > 0 \qquad (2')$$

The ZL_w vector includes variables having long-lasting or "permanent" effects on the wage bargaining. This includes unemployment income support measures, indicators representative of the relative bargaining strength of unions and other relevant characteristics of the wage bargaining process as well as the degree of mismatch between skills and geographical location of job seekers and unfilled job vacancies. It might also take into account other supply factors such as changes in trend productivity growth or taxes as employees might be able to resist to downward adjustment in their after-tax real wage compensation. The ZT_w vector represents temporary factors affecting the wage bargaining process (*i.e.* ZT_w represents supply shocks with zero ex-ante expectation) like terms of trade effects. Thus, the specification of the wage setting equation encompasses various theoretical models, including those focusing on the matching process, efficiency wages and wage bargaining.

Labour-supply

Labour supply is assumed, for simplicity, to be inelastic with respect to real wages. It is a function of the unemployment rate (discouragement effect) and other factors affecting participation decisions (ZL_l), including some of the elements of the wage push (ZL_w).[58]

$$l = c_o - c_1 U + ZL_l \quad c1 > 0 \qquad (3)$$

where l is the logarithm of the labour force.

The different concepts of NAIRUs and the Philips curve equation

The *long-term equilibrium unemployment rate*, UL*, is the solution to equations (1), (2), and (3), when price and wage expectations are met (*i.e.* $(w - w^e) = (p - p^e) = 0$), the unemployment rate is stabilised ($\Delta U = 0$), there are no temporary supply shock ($ZT_w = 0$ and $ZT_p = 0$) and long-lasting supply factors have adjusted fully to their long-term equilibria ($ZL_w = zl_w$, $ZL_p = zl_p$ and $ZL_l = zl_l$):

$$UL^* = \frac{d_0 + a_1 zl_l + zl_p + zl_w}{d_1} \qquad (4)$$

where d_0, $d_1 > 0$ are functions of a_s, b_s and c_s parameters. This long-term equilibrium unemployment rate, which is fundamentally of the "natural rate" type (as stressed by Layard *et al.*, 1991), corresponds to the *long-term equilibrium concept* discussed in the main text. Its dependence on zl_l, zl_p and zl_w as well as the d_0, d_1 and a_1 parameters implies it is affected by the main institutional characteristics of the labour and product markets.

When the long-lasting supply factors are at their current values rather than their long-term equilibrium value following the response of the economy to macroeconomic shocks, one can define *the* NAIRU *concept* (*with no qualifying adjective*), U*, mentioned in the main text:

$$U^* = \frac{d_0 + a_1 ZL_l + ZL_p + ZL_w}{d_1} \qquad (5)$$

The difference between the long-run NAIRU, UL*, and the NAIRU ,U*, is that the former is associated with a particular realisation of the long-lasting supply shock variables (ZL = zl) which corresponds to the long-run steady-state of the supply shocks.

The Phillips curve, related to this NAIRU concept U*, can be obtained from equations (1), (2), (3) and (5) as a reduced form relationship, under the assumption of equal wage and price surprise (*i.e.* $(w - w^e) = (p - p^e)$).

$$\Delta p - (\Delta p)^e = \Delta w - (\Delta w)^e = -\frac{d_1}{d_3}\left(U - U^*\right) - \frac{d_2}{d_3}\Delta U + \frac{1}{d_3}(ZT_w + ZT_p + a_2 \Delta ZL_l) \quad (6)$$

Defining $\pi = \Delta p$ inflation and $\pi^e = \Delta p^e$ inflation expectation and assuming expectations are adaptive and dependent on past inflation performance:

$$\Delta p - (\Delta p)^e = \pi - \pi^e = \Delta\pi - \Delta\pi^e = \Delta\pi - \alpha(L)\Delta\pi_{-1} \quad (7)$$

where $\alpha(L)$ is a polynomial of the lag operator. Using equation [6] and [7] we obtain then:

$$\Delta\pi = \alpha(L)\Delta\pi_{-1} - \frac{d_1}{d_3}\left(U - U^*\right) - \frac{d_2}{d_3}\Delta U + \frac{1}{d_3}(ZT_w + ZT_p + a_2 \Delta ZL_l) \quad (8)$$

This P*hillips curve* is the equation referred to in the conceptual section of the main text. It is also the equation used to estimate the NAIRU (U*) in the empirical analysis.[59]

Equation (8) can also be used to define the concept of *short-term* NAIRU, US*, corresponding to the value of unemployment which stabilises inflation over two consecutive period. Solving for $\Delta\pi = 0$:

$$US^* = \theta\, U^* + (1-\theta)\, U - 1 + \frac{d_3}{(d_1 + d_2)}\alpha(L)\Delta\pi_{-1} + \frac{1}{(d_1 + d_2)}(ZT_w + ZT_p + a_2 \Delta ZL_l), \quad (9)$$

where $\theta = d_1 / d_1 + d_2$

So, the short-term NAIRU can be expressed as a weighted average of actual (lagged) unemployment, the NAIRU, temporary supply shocks and lags of inflation. Similarly to Estrella and Miskhin (1998), equation (8) can hence be rewritten to relate inflation changes directly and only to the unemployment gap measured relative to the short-term NAIRU concept:

$$\Delta\pi = -\frac{(d_1 + d_2)}{d_3}\left(U - US^*\right) \quad (10)$$

NOTES

1. As is well known, the acronym is a misnomer, the concept is correctly defined as a "non-increasing" inflation rate of unemployment.
2. Previous Secretariat estimates also relate to wage inflation and the NAWRU, as described in Elmeskov (1993) and elaborated in OECD (1999), as opposed to price inflation and the NAIRU.
3. Friedman (1968) and Phelps (1968) are jointly credited with introducing the concept of the structural or natural rate, whilst the term NAIRU was first introduced by Modigliani and Papademos (1975).
4. This "orthodox" view contrasts with the alternative of "full hysteresis", whereby the level of unemployment exerts no influence on inflation, although inflation is affected by the rate of change in unemployment. In this extreme case, unemployment is not anchored by structural variables, but will instead reflect the cumulative effect of all past shocks to the economy, including those to demand. A further implication is that unemployment can be maintained indefinitely at any level with stable inflation; which undermines the NAIRU concept. However, there is considerable empirical evidence against the hysteresis model in this extreme form; in particular, a substantial number of empirical studies suggest that the level of unemployment does have an effect on inflation, see for example the recent survey by Nickell (1998).
5. Friedman and Phelps explain the natural-rate model in terms of nominal wage rigidities in the labour market. For unemployment to remain below the natural rate, workers must be surprised by higher-than-expected price inflation into working for lower real wages *ex post* that they anticipated *ex ante*, when nominal wages were set. A similar Phillips curve can be derived from models in which nominal rigidities originate from the product market rather than the labour market if, for example, firms face costs in adjusting prices, as in the models of Calvo (1983) and Rotemberg (1982). More generally, a Phillips curve type relationship emerges as the reduced form of a variety of structural models (Roberts, 1997).
6. The latter may include, potentially, a fairly wide range of influences affecting pricing policies (changes in mark-ups, input, prices, etc.), the transformation and distribution process (competition, regulation, price controls, etc.), and wage determination (tax wedges, unionisation, income policies, etc.).
7. It is also possible that factors which permanently change the level of the wedge between the real product wage and the real consumption wage may also affect the NAIRU.
8. For a discussion of the sensitivity of NAIRU estimates coming from the structural approach to the precise way in which such models are formulated and estimated see Cromb (1993).

9. Relevant studies include Nickell and Layard (1998), Elmeskov *et al.* (1998), OECD (1999), Nicoletti *et al.* (1999), Di Tella and MacCulloch (1998), and Daveri and Tabellini (1997).
10. Reviewing the empirical literature, Blanchard and Katz (1997) conclude that, "Economists are a long way from having a good quantitative understanding of the determinants of the natural rate, either across time or across countries."; while Nickell (1998) asserts, "What we lack is a satisfactory empirical explanation of the time series pattern of OECD unemployment".
11. These methods have most commonly been developed to measure potential output. See, for example, the methods developed by Watson (1986); Beveridge and Nelson (1981); Hodrick and Prescott (1997). Other approaches include the band pass filter, which gives results that are similar to an HP filter, Baxter and King, (1995); Christiano and Fitzgerald, (1999); the running median filter and the wavelet filter, Scacciavillani and Swagel, (1999).
12. In the case of Watson (1986), it is assumed that the trend and cyclical components are uncorrelated, while they are supposed to be perfectly correlated with the Beveridge Nelson filter. This latter assumption is economically not plausible.
13. If the arbitrary parameters are "tuned" to ensure that the resulting trend unemployment is sufficiently smooth and gives a reasonable proxy to the NAIRU, then the results, however, might be useful for forecasting inflation. The Bank of England (1999), for example, finds that a simple HP filter of unemployment works reasonably well in this respect.
14. Early attempts to take possible changes in the NAIRU into account involve allowing for different means of the unemployment rate across the sample, or different growth rates (Staiger *et al.*, 1997*a* , Gordon, 1997, Fabiani and Mestre, 1999). However, these appear unsatisfactory since it is difficult, in this way, to predict the next break in the NAIRU.
15. Confidence intervals for the NAIRU can be derived, although only a few papers do so. Staiger *et al.* (1997 *a*) compute standard errors for the United States that range between 0.7 and 1.2. Irac (1999) uses a Monte Carlo approach to provide standard errors for the French NAIRU that lie between 0.8 and 1.7 depending on the sample period.
16. For example, in Bank of England (1999) it is applied to the United Kingdom, Gruen *et al.* (1999) to Australia, Irac (1999) to France, Meyler (1999) to Ireland, Apel and Jansson (1998, 1999) to Sweden, Rasi and Viikari (1998) to Finland, Orlani and Pichelman (2000) for the European Union and Fabiani and Mestre (1999) to the Euro area. There are fewer studies where the approach is applied consistently across a number of countries, although Laxton *et al.* (1998*b*) and Laubach (1999) both apply it to all the G7 countries.
17. The HPMV filter has been used to estimate the NAIRU by the Bank of Canada in the QPM model, and by OECD (1999) for a number of Member countries. Côté and Hostland (1994) also report use of a hybrid method combining an HP filter and the HPMV approach to provide estimates for Canada.
18. The approach can also be extended to encompass more complex models. Examples include adding equations that explain other price variables (CPI, PPI, wages) but using the same unemployment gap in each equation. To our knowledge, this has not been done yet, but examples of similar work to estimate core inflation can be found in Cechetti (1997) and Le Bihan and Sedillot (1999). Preliminary OECD work along these lines is reported in Richardson *et al.* (2000).

19. This might require expectations of inflation to be formally introduced in the model (Roberts, 1996, 1997). The Bank of England (1999) shows that the speed of adjustment of unemployment for the United Kingdom appears quicker when one takes expectations into accounts. However, Meyer (1999) gets a worsening of the Phillips curve for Ireland when explicitly accounting for inflation expectations. For the most part, the empirical work reported here does not attempt to explicitly allow for forward-looking expectations because of the difficulties of doing so consistently across all countries. Exceptions are the estimated Phillips curves for Canada and Greece, as discussed later, which attempt to capture the effects of changes in policy regimes on expectations.
20. For example, Debelle and Laxton (1996) find it necessary to incorporate the idea that bottlenecks may start to develop as the unemployment rate falls below the NAIRU. This, in turn, means that further increases in demand will have even larger inflationary consequences. They show that for the United Kingdom, United States and Canada, such an asymmetric Phillips curve fits the data better and gives more sensible estimates of the unemployment gap.
21. In practice, two filtering methods – the Kalman filter and the Hodrick-Prescott Multi-Variate filter – were used in preliminary estimation but, as reported by Richardson *et al.* (2000), the Kalman filter procedure was preferred in being less restrictive and subject to fewer biases with respect to end-point sensitivity and cyclicality of the NAIRU estimates.
22. For small open economies, the GDP deflator might be a better indicator of inflationary pressures because it excludes the direct effects of terms of trade variations.
23. See, for example, Gordon (1997 and 1998), Hogan (1998), Irac (1999) and Meyer (1999).
24. For most countries, separate time trends were used for the full sample and from the beginning in 1980.
25. This was the case for Belgium, Spain, Finland, Australia, and Sweden.
26. For Belgium, as for the OECD *Jobs Strategy*, OECD (1999), a standardised unemployment role was used.
27. See Gruen *et al.* 1995, and comparable studies by the Australian Treasury and Reserve Bank.
28. Formally, equation (2*b*) is specified in state space form as two transition equations:
29. $(2b^{I})\ U^*_t = (1+\varphi)\ U^*_{t-1} - \varphi g_{t-1} + \nu^2_t$, and $(2b^{II})\ g_t = U^*_{t-1}$

    Alternative specifications of the transition equation that were investigated, but without success across more than a few countries, were a random walk with stochastic drift and a random walk with deterministic drift.
29. This result is common to many such applications. Stock (1999) and Stock and Watson (1999) showed that when the true variances of (non-stationary) unobserved variables are small, the maximum likelihood estimates of the variances generally tend towards zero. Effectively, the estimation procedure gets trapped at a corner solution involving no fluctuations in the unobservable variable. This is why most of the literature tends to fix the value of the variance of the unobserved variable, or alternatively the signal-to-noise ratio. Another solution (Apel and Jansson, 1999) is to extend the model to provide more information on the evolution of the state variables (for example, adding an extra measurement equation specified in terms of an Okun rule), although such attempts sometimes give unsatisfactory results.

30. The estimation strategy was also guided by the use of comparable estimates based on an alternative HPMV filter To achieve this, the procedure followed was to first fix the relative variances for the HPMV filter according to certain "rules of thumb". Then having obtained satisfactory HPMV estimates, the variance of the error term in the transition equations for the Kalman filter was chosen to give approximately the same degree of smoothness, where smoothness was judged according to the variance of the change of the NAIRU. The first difference, rather than the level of the NAIRU, was chosen because in many countries there is a clear upwards trend in the NAIRU.

31. The countries for which the direct maximum likelihood procedure did not work are Japan, Italy, Denmark, Norway and Sweden.

32. Experimentation suggests that the best choice for the initial Kalman filter iteration is to impose a coefficient on the unemployment gap which is half that obtained from the HPMV estimation (this follows the observation that the coefficient on the unemployment gap in the Phillips curve from using the Kalman filter in maximum likelihood estimation is typically much lower than that obtained from the HPMV filter). Using this choice the iterative procedure typically converges quickly on the full maximum likelihood procedure for those countries where the latter estimates were available.

33. There are a few counties where specification differences have arisen (mainly concerning whether unemployment and the NAIRU are specified in linear or log terms) because they lead to a significant improvement in the diagnostic tests.

34. Following the seminal study by Perry (1970) it has become common place for empirical studies of the NAIRU in the United States to use a demographically adjusted unemployment rate. These alternative unemployment rates are constructed as a fixed-weighted average of unemployment rates for various demographic categories, where the weights are the labour force shares of each group in some reference year (see Katz and Krueger, 1999 for a recent example). A demographic adjustment to the unemployment rate can be calculated as the difference between the actual unemployment rate and a demographically adjusted unemployment rate. For the present study an initial estimate of the NAIRU was derived by using the demographically adjusted unemployment rate in the Phillips curve. However, the NAIRU shown in the tables and charts is directly comparable to the published aggregate unemployment rate data; it is the sum of the NAIRU from the Phillips curve and the demographic adjustment, described above.

35. It was possible to estimate an auto-regressive NAIRU for Italy, but the random walk specification was preferred because of its superior performance in explaining inflation in the Phillips curve.

36. For simplicity as well as comparability across countries, this procedure was followed even in those cases where the Kalman filter NAIRU was estimated by maximum likelihood methods.

37. The inclusion of this additional term follows Fabiani *et al.* (1997) and is intended to capture the differential inflationary effect of changes in unemployment in the Centre-North region, compared to changes in unemployment in other regions.

38. The direct (rather than iterative) maximum likelihood estimation method was used for 16 of the 21 countries for which a NAIRU were estimated when using the Kalman filter.

39. See Boone (2000) and Richardson *et al.* (2000) for further details of the derivation of estimated standard errors for the NAIRU estimates.

40. Irac (1999) reports standard errors of 0.7 to 1.2 for France, Laubach (1999) reports values between 0.6 and 2.0 for the G7 countries.
41. In the case of Spain this involved using an inflation rate based on core CPI rather than the consumers' expenditure deflator. For Denmark a standardised rate of unemployment was used in place of a register-based definition, because the latter might not be a consistent basis for estimating the NAIRU given recent policy reforms which have eliminated a number of those on the rolls who would not fit within the standardised unemployment definition. In the case of Germany a distinct break in the NAIRU series was introduced to allow for the effect of re-unification (although this change had virtually no effect on the estimated NAIRU at the end of the estimation period).
42. See Table 1 and Figure 2.
43. Finland and Ireland are also the two countries with the largest standard errors surrounding the Kalman filter NAIRU estimates.
44. See for example Perrier (1998) and J-F. Fillion (1997).
45. For Canada the econometric NAIRU estimate was also revised down 0.1 percentage points in 1999 to reflect the effect of recent reforms to the unemployment insurance system.
46. By the end of the sample the weights on lagged and euro area inflation are around 85 and 15 per cent, respectively.
47. The fall in NAIRU estimates for these countries since implementing labour market reforms has, on average, been up to ½ per cent per annum, typically over a period of four to five years.
48. For further details of the reforms, see the most recent OECD Survey relating to the country concerned.
49. For Switzerland the tighter eligibility criteria has implied a significant drop in register-based unemployment – an effect which the Kalman filter can pick up only gradually.
50. Previous analysis has found that there is a correlation between falling structural unemployment and the extent to which *Job Study* recommendations have been implemented, see OECD (1999).
51. Here and in the following paragraphs discussing the policy usefulness of the NAIRU, it should be noted that to avoid confusion the terms "NAIRU" (*i.e.* without qualifying adjective) and "short-run NAIRU" are used strictly according to the definitions of Box 1.
52. See King (1999) for a discussion of how the appreciation of sterling in 1996 and 1997 was assessed by the Bank of England's Monetary Policy Committee in broadly these terms.
53. See Richardson *et al.* (2000) for a description of the Monte Carlo methods used to calculate these standard errors.
54. For example, Brayton. *et al.* (1999) suggest that variations in the mark-up of prices over unit labour costs explain low inflation in the United States in recent years.
55. The first difference operator appears here as a result of lagged response in employment, often caused by the presence of adjustment costs on labour inputs (see, for example, Lindbeck and Snower, 1988).
56. The presence of ΔU in the wage-setting schedule can be justified by the behaviour of both firms and workers. On the basis of the "insider-outsider" hypothesis, it could be argued that real wages may be more responsive to the threat of large-scale redun-

dancy and rising unemployment than to the level of unemployment *per se*. Likewise, in the context of rising unemployment, the proportion of short-term unemployed (*i.e.* those most likely to compete directly with the employed) generally increases and this could put more downward pressure on wages than a stable level of unemployment (see, for example, Blanchard and Summers, 1987 and Layard *et al.* 1991).

57. Wage and price surprises appear in equations (1) and (2') in this form as a result of aggregation. They are derived from the absence of knowledge of aggregate values of those variables that are contemporaneously set at the microeconomic level by workers and firms (see, for instance, Layard *et al.* 1991). Other inertial effects (such as the staggering of wage contracts) can be allowed for in the same way without changing the qualitative properties of the model.

58. For the simplicity of exposition ZL_l vector is supposed to incorporate only factors having a long-lasting or permanent influence on labour supply.

59. Note that prices and wages play a similar role in the derivation of the reduced-form Phillips curve equation, so that *a priori* this equation may be based on either variable.

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