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The Concept, Policy Use and Measurement of Structural Unemployment: Estimating a Time Varying NAIRU Across 21 OECD Countries

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ABSTRACT/RÉSUMÉ

The structural rate of unemployment and associated non-accelerating inflation rate of unemployment (the NAIRU) are of major importance to the analysis of macro and structural economic developments, although in practice these concepts are not well defined and there is considerable uncertainty and controversy concerning their measurement and policy use. The present paper reviews a range of conceptual and analytical issues and related empirical studies to examine the usefulness and limitations of such concepts. A reduced-form Phillips curve approach is found the most suitable conceptual framework for representing the NAIRU as currently used by the OECD in its policy analysis and surveillance work. Three distinct classes of NAIRU concept are identified, distinguished by the time-frame in which they are defined, which map directly into the broad requirements for macro and structural policy analysis. In line with a number of recent empirical studies, this general approach is applied across the 21 OECD member countries, using methods which combine the estimation of reduced-form Phillips curve equations for each country using alternative filtering methods which allow the identification of time-varying NAIRU indicators. Corresponding sets of Phillips curve and NAIRU estimates are reported and comparisons are made with previous OECD NAIRU estimates. These estimates are also used to illustrate the importance of the conceptual framework for the analysis of recent inflation developments and monetary policies. Overall, Kalman filter methods are found to provide the most satisfactory results and are therefore chosen as the preferred basis for future development of OECD NAIRU indicators.

JEL Code: *C13, C22, C32, E24, E31*
Keywords: Unemployment, NAIRU, Phillips curve, Kalman filter, OECD

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Les concepts de taux de chômage structurel et NAIRU (*non accelerating inflation rate of unemployment*) jouent un rôle important pour l'analyse macro-économique et des développements structurels de l'économie, même si, en pratique, ces concepts ne sont pas définis précisément, leur estimation est entachée d'incertitude et leur utilisation pour la politique économique souvent controversée. Ce papier présente une revue des concepts, discussions analytiques et études empiriques liés au NAIRU, afin de définir l'utilité éventuelle de ces concepts et leurs limites. Dans le cadre d'analyse des politiques économiques et travaux de surveillance menés par l'OCDE, le concept de NAIRU dérivé d'une courbe de Phillips de forme réduite apparaît le plus utile. Trois notions de NAIRU peuvent être distinguées, suivant l'horizon temporel de référence, et qui peuvent être directement reliées à des cadres d'analyse de politique macro-économique et structurelle. Suivant les développements récents de la littérature empirique, des NAIRUs variant dans le temps sont estimés pour 21 pays membres de l'OCDE à l'aide de techniques liant l'estimation d'une courbe de Phillips à l'identification du NAIRU. Ce papier présente les résultats d'estimation des courbes de Phillips et des NAIRUs correspondants, et les comparent aux NAIRUs précédemment estimés par l'OCDE. Une illustration de l'utilité de ces estimateurs est présentée pour la politique monétaire, avec l'analyse des mouvements récents de l'inflation. Globalement, le filtre de Kalman produit les résultats les plus satisfaisants, et sera donc utilisé pour l'estimation des NAIRUs de l'OCDE.

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THE CONCEPT, POLICY USE AND MEASUREMENT OF STRUCTURAL UNEMPLOYMENT: ESTIMATING A TIME VARYING NAIRU ACROSS 21 OECD COUNTRIES

by Pete Richardson, Laurence Boone, Claude Giorno, Mara Meacci, Dave Rae and Dave Turner[1]

Introduction and Summary

1. The notion of a structural rate of unemployment is central to dominant economic theories explaining labour market behaviour and the relationship between unemployment and inflation. However, because the concept is unobservable and not always well defined, its measurement, underlying determinants and policy relevance are subject to considerable uncertainty and controversy.[2] Nonetheless, country administrations and central banks find it helpful to make empirical estimates of the non-accelerating inflation rate of unemployment (hereafter the NAIRU), even if their policy uses are sometimes limited. The OECD has long found it useful to make such estimates as input to its various assessments of inflation pressures, fiscal positions and structural issues, as for example in the context of the OECD *Jobs Strategy* (OECD, 1999).

2. This paper examines the conceptual bases for various NAIRU-related indicators and their usefulness and limitations for monetary, fiscal and structural policy analyses. It also reviews estimation methods to situate previous OECD measures within the range of alternative concepts and estimates and goes on to look at ways in which these measures might be strengthened for policy purposes. In this regard, the paper and its detailed technical annex review the most important recent studies in this area, present revised estimates of NAIRUs for 21 OECD Member countries and evaluate some of their implications for policy analysis.

3. On the basis of a review of alternative theoretical approaches, it is concluded that a reduced-form Phillips curve framework is the most suitable for the task of measuring the NAIRU as currently used in the OECD's macro policy analysis and surveillance work. This is because it provides a direct link to the relationship between inflation and unemployment and is consistent with a variety of structural approaches. Within such a framework, it is convenient to identify three different NAIRU concepts, which can be distinguished by the time frame to which they relate: the short-term NAIRU, the NAIRU and the long-term equilibrium unemployment rate. These concepts neatly match the requirements for macro and structural policy analyses: as a useful pedagogical device to help explain macro policy reactions to short-term

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1 . The authors are all members of the OECD's Macroeconomic Analysis and Systems Management Division. An original version of this paper was prepared for discussion by Working Party No. 1 of the OECD Economic Policy Committee. The authors are grateful for earlier comments from numerous colleagues, including Jørgen Elmeskov, Michael Feiner, Stefano Scarpetta and Ignazio Visco and from Jean-Philippe Cotis, the Chairman of the working party. The views expressed are those of the authors and do not necessarily reflect those of the OECD or its Member countries. Special thanks go to Laurence Le Fouler and Isabelle Wanner for their excellent technical support throughout the study, and to Rosemary Chahed, Jan-Cathryn Davies and Doris Grimm for document preparation.

2. See, for example, the recent collection of papers in the *Journal of Economic Perspectives*, Winter 1997.

inflation developments, for measuring potential growth and structural budget balances and for monitoring progress in structural labour/product market reforms.

4. An important limitation of the reduced-form Phillips curve approach is that although it may provide fairly robust measures of the NAIRU, it gives little insight into its underlying determinants and the set of institutional factors and policy variables that influence its movement over time and differences across countries. For this a structural framework is better suited, as evidenced by its use in a wide range of empirical studies.[3] The structural approach is however generally less well suited to providing timely and robust measures of the NAIRU, given its relative complexity and its sensitivity to different specification and identification issues. It is also more difficult to apply consistently across countries. Structural and reduced-form approaches should therefore be seen as being largely complementary.

5. On a more pragmatic level, a review of the growing body of recent studies in the area supports the use of the reduced-form estimation approach; one which combines Phillips curve estimation with filtering techniques to identify a time-varying path for the NAIRU, without requiring specific information on its determinants. Such an approach provides a NAIRU concept that is well defined, is directly linked to inflation determination and is measured within a testable statistical framework, that combined with maximum likelihood estimation methods can also provide statistical confidence intervals for the NAIRU.

6. While the reduced-form approach has the advantage of providing consistent estimates of the NAIRU and short-run NAIRU concepts, such estimates are nonetheless imperfect and subject to a number of important uncertainties, in particular with respect to the model of inflation being used and the identification of relevant supply influences for individual countries. However, many of these uncertainties can be evaluated on an empirical basis, and their consequences often prove to be relatively minor given the overall degrees of uncertainty surrounding policy making. Moreover, despite this uncertainty the NAIRU remains important as an input to the policy decision.

7. In the estimation work reported here, two closely related methods are used to estimate the NAIRU for the 21 Member countries that the OECD currently makes estimates for, drawing on alternative Kalman filter and Hodrick Prescott Multivariate (HPMV) filter techniques. The general filtering approach "works" in the sense that corresponding unemployment gap measures are found to be significant within the Phillips curve framework for all countries considered, which in turn provides plausible and reliable summaries of inflationary developments for the past three decades. This result is important as the approach used gives generally stronger support for the Phillips curve than many previous studies, by allowing the NAIRU to vary over time.

8. Trends in the two sets of estimates obtained are broadly similar, and not dissimilar from those given by previous OECD methods although there are some important differences. Focussing on these, the HPMV estimates tend to be more closely centred around actual unemployment, so that unemployment gaps are typically smaller.[4] Such differences are most striking for European countries where, in the early- to mid-1980s and the period of contractionary fiscal policy of the mid- to late 1990s, the Kalman filter estimates tend to be lower and suggest larger degrees of excess supply. This is because a feature of HPMV estimates is to gravitate towards the actual unemployment rate as it rises or falls. For this reason, the Kalman filter estimates, which are less influenced by actual unemployment, are preferred as being economically more appropriate, although they are also more sensitive to the specification of the Phillips curve. The Kalman filter estimates are therefore those to be used as the starting point for a new set of

3. For further details of these see the following section and the review of methods given in the detailed technical annex.

4. As discussed later, this feature depends on the choice of specific weights used within the estimation method.

OECD NAIRU indicators, although weight will also be given to economic plausibility and possible sources of bias, drawing on a wider set of information and particular features of the countries in question.

9. As noted above, both the short-run and the more general NAIRU measures are shown to be useful predictors of inflation over a one to two year horizon. An important point to emerge concerns the factors which influence the relationship between estimates of short-term NAIRU and NAIRU concepts. Here it is shown that for some countries (in particular the United States and the United Kingdom) recent favourable short-term supply conditions have tended to lower the short-term NAIRU and thereby permitted the actual rate of unemployment to dip well below the NAIRU, without refuelling inflationary pressures. To the extent that this is likely to be a temporary phenomenon, it is all the more important not to discount the risk of future inflationary pressures. For a number of G7 countries (most notably Italy, the United Kingdom and to a lesser extent France) there is also evidence of significant inertia which can delay the adjustment of the short-term NAIRU, keeping it closer to the actual unemployment rate than to the NAIRU for prolonged periods. This implies the possibility of "speed-limit" effects, so that if the actual unemployment rate is well above the NAIRU, it will only be possible to close the gap slowly without increasing inflation.

10. NAIRU estimates also enter wider medium-term and fiscal policy assessments through their influence on corresponding measures of potential output and associated indicators of cyclical and structural budget balances. Here, the various differences in the NAIRU estimates obtained are found to have relatively few implications for estimates of potential growth although, as noted earlier, for specific historic episodes there are differences in estimates of cyclical influences on budget deficits. Overall however, the implications of such differences are likely to be small in relation to variations in actual deficits and GDP and differences in estimates of cyclical position tend to cancel out over time. Nonetheless, an important conclusion is that for fiscal policy some caution may be needed in making future projections of the NAIRU, for example in taking account of the effects of structural reforms. Here, an overly sanguine view could lead to an overestimation of potential growth and corresponding over-optimism concerning structural budget positions.

11. For structural surveillance, the NAIRU estimates obtained can only provide a means of gauging the broad level of structural unemployment and its movement over time. Comparisons between the different sets of preliminary estimates suggest a high degree of correlation in both levels and recent movements, although at times there are some differences across estimates that should be noted. However, these do not in general involve differences as to whether the NAIRU has fallen or risen, but rather the extent and timing of such movements. To the extent that NAIRU estimates for the end points are less certain, it is more difficult to use them to gauge the effectiveness of policy reforms on structural unemployment in the most recent periods.

1. The conceptual framework

12. The structural rate of unemployment and the NAIRU play a central role in the dominant macroeconomic paradigm, one which implies the absence of any long-term trade-off between inflation and unemployment: in the *long run*, unemployment depends on essentially *structural* variables, whereas inflation is a monetary phenomenon.[5] 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

5. 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).

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.

13. 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 largely undermines the structural rate and NAIRU concepts. 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.[6] Even so, less extreme forms of persistence, whereby the effects of the level of unemployment on inflation are relatively weak and slow-acting, rather that non-existent, do have policy relevant implications for the relationship between actual unemployment, the NAIRU and the associated unemployment gap, as discussed below.

14. 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.[7] 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 unemployment gap, and supply shocks.

15. Taking account of supply shocks is important in order to distinguish between one-off price changes and ongoing inflation. Within this framework, an important distinction to make is between temporary and long-lasting supply shocks.[8] 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, but the NAIRU will be unchanged once they have passed. 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.

16. Within such a framework, three distinct concepts can be identified (see Box 1 for more formal definitions): the NAIRU (with no qualifying adjective), the short-term NAIRU and the long-term

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6. A recent survey by Nickell (1998) for example cites a wide range of cross-country macroeconometric evidence supporting the view that higher levels of unemployment exert a downward effect on real wages and inflation, including Grubb (1986) and OECD (1994) to which can be added Elmeskov (1993) and Turner *et al.* (1996). He also cites a relatively large body of microeconometric evidence pointing in the same direction; by Blanchflower and Oswald (1995) and Blanchard and Katz (1997) using individual or regional data; by Nickell and Whadwani (1990) using company data; and by Holmund and Zetterberg (1991) using industry data.

7. 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).

8. These 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.).

equilibrium rate of unemployment. Each of these relate to the same basic idea of an "unemployment rate consistent with a stable inflation", but differ according to the time horizon to which they refer:

i) The *NAIRU* is defined as the equilibrium 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.

ii) 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/persistence effects. It follows that the short-term NAIRU concept will be influenced also by the level of actual unemployment.

iii) The *long-term* equilibrium unemployment rate (akin to the natural 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.

17. 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 cannot easily be measured in the Phillips curve framework. 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 protracted.

18. Nevertheless, the Phillips curve framework provides little direct insight into the factors that determine the future evolution of the NAIRU and the policy actions needed to reduce it. To better understand these issues, it is necessary to use a richer theoretical structural framework, such as the one described by Layard *et al.* (1991), in which wage and price-setting behaviour are separately distinguished.[9] Empirical studies utilising this framework, particularly those based on pooled cross-country data, provide important insights into the causes of structural unemployment, which can be viewed as the consequence of the interaction between adverse macroeconomic shocks and institutional rigidities.[10] However they are less well adapted to providing timely and robust NAIRU estimates needed for the operation of monetary and fiscal policy. As discussed in the empirical section of the technical annex, the structural approach faces important problems because of its complexity, the sensitivity of estimation results to specification issues and the problem of identifying and measuring many of the factors that the theoretical framework suggests are important, especially those relating to institutions.

9. A variety of studies use such an approach in the analysis of structural unemployment and a simplified version of the relevant framework is presented in the Appendix. See also OECD (1999), Layard *et al.* (1991), Blanchard (1998) and Blanchard and Katz (1997) for a detailed exposition and discussion of this framework.

10. For example, significant effects from the level and duration of unemployment benefits on structural unemployment are robust across many studies.

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]

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

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

where Δ is the first difference operator, π_t is inflation, U_t is the observed unemployment rate, ZLt and ZTt 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:

$$\Delta\pi_t = -\,[\beta+\theta(0)]\,(U_t - US^*_t) + e_t$$

$$\text{where } US^*_t = g\{U^*, \Delta U_{t-i}, \alpha(L)\Delta\pi_{t-1}, \nu(L)ZT_t\} \qquad [3]$$

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:

$$UL^*_t = f\{K_t + \gamma\,(1)\,zl\}/\,\beta. \qquad [4]$$

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 differentiated unemployment terms (ΔU_t). The distinction between the NAIRU and long-run equilibrium 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.

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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].

2. The use of the NAIRU in a policy context

19. As discussed in the following paragraphs, the taxonomy described above lines up well against the specific operational requirements and the uses of NAIRU-related concepts for monetary, fiscal and structural policy analysis and surveillance. Here, 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 the previous section and Box 1.

2.1 Monetary policy and inflation

20. Indicators of structural unemployment are useful for monetary policy if they help policymakers assess inflationary developments in the short term. In this respect, the short-term NAIRU concept (compared with the actual unemployment rate) is potentially the most useful (see Estrella and Mishkin, 1998 and King, 1999*a*). Such indicators can also be extrapolated on the basis of assumptions about future movements in the NAIRU and temporary supply shocks and, as shown in the later empirical section, are well correlated with inflation in the near term.

21. Given its inherent volatility, the short-term NAIRU is clearly not suitable as a target for monetary policy. Nevertheless, both the NAIRU and short-term NAIRU do provide valuable information on the inflationary process; the short-term NAIRU, in particular, is a useful pedagogical device for assessing how policy might react. Favourable temporary supply shocks, for example those associated with a sudden fall in import prices, may permit the actual unemployment rate to fall significantly below the NAIRU, without apparent inflation pressure. In effect, the short-term NAIRU may fall significantly below the NAIRU. Evidence presented later suggests that this could recently have been the position of several G7 countries (including the United States and the United Kingdom). 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.[11] A risk is that such a fall in the short-term NAIRU might be wrongly interpreted as a permanent downward shift in the NAIRU.

22. Divergences between the NAIRU and the short-term NAIRU will be greater when persistence effects are strong. In this case, departures of the unemployment rate from the NAIRU may be substantial and prolonged because the relatively weak effects of the unemployment gap on inflation do little to trigger equilibrating forces. At the same time stimulative policy actions may be deterred because closing the gap between excess unemployment and the NAIRU may generate short-term inflationary "speed-limit" effects. Evidence presented in the later empirical section suggests this may recently have been the case for a number of European economies (notably France and Italy).

23. While these NAIRU concepts are useful in principle, it is clear that they are measured with considerable uncertainty, for example, the technical annex reports a typical standard error for the G7 country estimates corresponding to 10-15 per cent of the actual unemployment rate. An important question is how a prudent policymaker should respond to this uncertainty. This has received considerable attention in recent years, using theoretical and empirical approaches.[12] A quite general result is that the level of uncertainty about the NAIRU should have little or no effect on optimal policy decisions. Following Theil (1961), NAIRU uncertainty is additive which implies that, given a linear model and a quadratic loss

11. See King (1999*a*) 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.

12. Hunt and Orr (2000) contains a broad selection of papers on this issue.

function, policies should be based on the best assessment of the cyclical position of the economy, as if it were known with certainty (see, for example, Bean 1999).[13]

24. In any case, the unemployment gap is not the only way to assess the cyclical position of the economy. The importance placed on the NAIRU needs to be assessed relative to the alternatives. For monetary policy, focusing only on current inflation is not a safe option since it risks being too backward looking. Alternative candidates include monetary aggregates and other financial variables, capacity utilisation, job vacancies, business confidence indicators, and so on. However, each of these has its own problems. For example, while capacity utilisation often gives a good indication of the state of the business cycle, it is from time to time unreliable because of its narrow sectoral coverage. Monetary and financial variables also are notoriously affected by temporary influences which have nothing to do with inflation. Overall this suggests the need for a broad approach of looking at many indicators, in which NAIRU estimates are only one component. Alternatively, the approach of "looking at many indicators" may be represented as focussing on the forecast of inflation (which incorporates all such information) as advocated by Svensson (1999). Although this has received little attention in the literature – which typically assumes a single measure of the cycle (usually an output gap) – the practical issue is how to weight the range of imperfect indicators available, such as capacity utilisation, job vacancies, confidence indicators, monetary aggregates, and so on.

25. The certainty equivalence result noted above follows because NAIRU uncertainty is treated as equivalent to random measurement error. However, errors in measuring the NAIRU are not random: they tend to be correlated through time – if the NAIRU is over-estimated this quarter, there is a very high chance it will be over-estimated next quarter. Moreover, they are often correlated with the business cycle. Intuitively, forecasters tend to over-estimate potential output growth when the economy is growing strongly and conversely when output growth is weak. In short, they tend to under-estimate the size of the gap, and therefore do not respond strongly enough if a gap opens up.[14]This problem is compounded when unemployment displays signs of hysteresis, as the policy required to bring inflation down might be more costly in terms of unemployment (Ball, 1999).

26. In contrast, other types of uncertainty can imply either a more gradualist or a more aggressive policy approach. For example, there is increasing evidence that Phillips curves are 'kinked' in the sense that inflation rises more easily than it falls: in other words, inflation is sticky downwards.[15] This could reflect downward nominal rigidities in a low inflation regime, or the impact of bottlenecks when demand rises. The main implication of this asymmetry is that policy should react more aggressively to a fall in unemployment below the NAIRU because underestimating the gap will imply a period of recession to bring inflation back down which will more than offset the gains during the period of increased activity. A second example concerns uncertainty over the persistence of inflation, perhaps due to uncertainty about how agents form expectations. In that case, prudent policy should respond more aggressively to an unemployment gap to avoid the risk of inflation becoming more firmly embedded in expectations.[16] In

13. In contrast, uncertainty can affect rules of thumb (policy rules based on just a few variables) such as Taylor rules. However, the practical importance of this result is limited because no policy maker actually uses such rules of thumb. Central banks use all available information and attempt, whether successfully or not, to make optimal decisions given their current knowledge of the economy. See Smets (1999), Wieland (1999) and Orphanides (1999) for papers that look at the effect of uncertainty on rules of thumb.

14. See Drew and Hunt (2000). This is especially the case if a statistical filtering technique is used, such as a Hodrick Prescott filter. Orphanides and van Norden (1999) present evidence on cyclical errors for the United States.

15. See Turner (1995) and Debelle and Laxton (1996) for evidence. Dupasquier and Rickets (1998) survey theoretical arguments for non-linearities.

16. Laxton, Rose and Tetlow (1994). Shuetrim and Thompson (1999).

contrast, Brainard (1967) shows that uncertainty about how strongly policy levers affect the economy should lead a prudent policymaker to be more gradualist.[17]

27. In any case, results from many of the recent studies suggest that the impact of uncertainty on the weight placed on the unemployment gap is seldom large. For example, if measurement errors are unrelated to the business cycle, the implication is to place *slightly* less weight on the NAIRU in a policy rule of thumb; in the opposite case, policy should give the NAIRU slightly more weight.

2.2 Fiscal policy and medium-term assessment

28. As for monetary policy, disentangling what is structural from what is cyclical is important for fiscal policy assessment. There are two issues here: identification of the fiscal impulse to short-term conjunctural developments and the sustainability of the fiscal position over the medium to long term.

29. In this context, estimates of the NAIRU are important inputs into the assessment of productive potential since they help define the rate of labour utilisation compatible with stable inflation.[18] This in turn determines the output gap[19], which combined with relevant tax and expenditure elasticities enables a distinction to be drawn between cyclical and structural budget positions. The structural budget position is of direct relevance to the issue of sustainability and its first difference should also provide a guide to the fiscal impulse to the short-term conjuncture.

30. The correct identification of the NAIRU is obviously important in both respects. The NAIRU will have a direct impact on the level of the output gap and thereby the assessment of medium-term fiscal sustainability. A bias in the NAIRU estimate could thus imply a risk of mis-judgement. While eventually it would become clear that such mis-judgement was taking place, substantial policy mistakes could occur in the meantime. By contrast, a "level error" in the NAIRU estimate would have little implication for first differences in the structural budget balance and thereby the assessment of fiscal impulse, which tends to be driven primarily by changes in either budget items or actual GDP. The impulse measure is, however, sensitive to changes in the level of the NAIRU.

31. Estimates of productive potential and its growth rate are important not only for fiscal analysis but also more generally for medium-term analysis and projections, which typically rely on a closing of output gaps over the medium-term.[20] In this case an over-optimistic evaluation of possible reductions in the

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17. See also Estrella and Mishkin (1998). A very recent literature on robust control considers policy rules when the true model of the economy is unknown but where the rule should be robust across a range of models "in the vicinity" of the policymakers's own model. Sargent (1998) and Onatski and Stock (1999) find that cautious policy can imply being *less* gradualist.

18. The short-term NAIRU is clearly too volatile for this purpose and intuitively it seems more appropriate to use the NAIRU, towards which the short-term NAIRU adjusts in the medium term, taking account also of the likely impact of structural reforms.

19. The NAIRU is a crucial component in the assessment of the output gap and structural balances, as carried out by the OECD (see Giorno *et al.*, 1995), the IMF and a number of Member country administrations. In particular see the body of work presented at the Perugia November 1998 workshop "Indicators of structural budget balances", as summarised in Bank of Italy (1999).

20. Given a stable and well defined NAIRU, normal equilibrating mechanisms would be expected to lead to adjustment over the medium-term compatible with a closure of output gaps and convergence of actual unemployment on the NAIRU. For a typical example of such an exercise see the OECD medium-term reference scenario as described in the "General assessment of the macroeconomic situation" chapter of *OECD Economic Outlook No. 67*, June 2000.

NAIRU over the projection period, for example those associated with the effects of structural reforms, would lead to an over-estimation of potential and actual growth performance.

2.3 Structural policy assessment

32. Structural policies have a longer term perspective and, for labour markets, one directed towards identifying the causes of and reducing structural unemployment. Whilst, in principle, measures corresponding to the long-term equilibrium unemployment rate (as identified in Box 1) may be of particular interest in such a time frame, such measures face inherent difficulties in identifying relevant influential long-term supply factors. Moreover, the precise level of the long-term equilibrium is unlikely to be of particular relevance for current monitoring purposes. A broad NAIRU concept incorporating measures of the cumulative impact of the long-lasting supply shocks but purged of the transitory influences is therefore likely to be most relevant to assessing the current structural situation of labour market, as well as its historical trend. Whilst the precise level of these indicators may be secondary to assessing structural performance, the measurement of their trend is crucial to monitoring progress in structural reforms.[21]

33. As mentioned earlier, identification problems limit this approach, but even so, estimating a reliable set of NAIRU indicators across countries is a useful step in studying the underlying determinants and the scope for future reforms. Whilst a country-specific structural approach often makes it difficult to robustly estimate the impact of long-term supply shocks, some form of pooling across countries is likely to be more productive (see for example Blanchard and Wolfers, 1999 and Scarpetta, 1996). Overall, this suggests that structural analysis and surveillance need to combine both approaches.

3. Revised NAIRU estimates and their policy implications

34. The review of relevant studies in the technical annex summarises numerous methods developed for estimating the NAIRU for policy use. On the basis of a fairly broad set of criteria, the reduced-form Phillips curve approach emerges as the method that best corresponds to the OECD's specific requirements. Such an approach has several important advantages over alternative statistical and structural methods and also improves on those previously used by the OECD (the main features of which are discussed in Box 2). By construction, it provides measures which are conceptually well defined, directly related to inflation and can be produced in a timely and consistent fashion across OECD countries.

35. In the past, the most serious weakness of using time-series estimates of the Phillips curve to measure the NAIRU and short-term NAIRU concepts has been that it is typically difficult to empirically identify the effects of individual long-lasting supply shocks. In particular, this has seriously hampered the application of the approach to countries where the NAIRU has not remained stable over time, and when this has been attempted the results have often been poor.[22] The use of filter techniques overcomes this problem by allowing a time varying NAIRU to be estimated jointly with the Phillips curve without requiring all supply factors affecting it to be specified explicitly, but rather to be embodied in the NAIRU estimate.

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21. In some respects uncertainty about the precise value of the NAIRU is less important for assessing structural labour market issues. The need to undertake structural reform is just as important whether the structural rate is 9 per cent or 10 per cent.

22. See Cotis *et al* 1996 for a discussion of this point.

Box 2. **Previous OECD NAWRU indicators**

The OECD's approach for estimating wage inflation related NAWRU indicators has evolved over time. These were originally estimated using the method described in Elmeskov (1993), but two extensions of the approach have been in use for different countries (see OECD 1999): one is derived from a modified version of the original technique; the other is based on a reduced-form approach using an HPMV filter. Both used a wage-inflation Phillips curve as a means of excluding the effects of those supply shocks that affect prices but not the labour market.

The first method, used previously for the majority of countries, was carried out in two stages.[1] In a first stage, raw NAWRU series are estimated on the basis of the following expression in which deviation of wage inflation relative to expectations is assumed to be proportional to the gap between actual unemployment and the NAWRU:

$$\Delta w - (\Delta w)^{e} = a_t\,(U\text{-NAWRU}), \qquad a < 0 \qquad [1]$$

The parameter a_t is assumed to be time-varying and the NAWRU to be constant between consecutive years.[2] In specifying the functional form of equation [1], a range of different assumptions are used to proxy expected wage inflation.

As suggested by the framework developed in the appendix, these raw estimates are in principle close to a short-term concept (as defined in Box 1), since they are affected by all supply shocks including those of transitory nature, and therefore exhibit substantial volatility. The first stage estimates are therefore subsequently smoothed using a Hodrick-Prescott filter, with the resulting series tested on the basis of the fit of corresponding Phillips curve estimates. The estimates retained are those yielding the best overall fits.[3]

For the remaining countries some further experimentation was carried out.[4] For these, NAWRU indicators and the Phillips curve were estimated jointly using an HPMV filter, along the broad lines used in this paper. However, the estimated equations used also include wage share terms to take into account the slow adjustment of real wages on productivity, as observed in these countries (though temporary supply shocks are not included). The inclusion of such long-term influences and exclusion of short-term influences in the specification means that these estimates are not strictly comparable with those obtained in the present study.

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1. This technique is used for 16 of the 21 OECD countries for which a NAWRU is currently estimated.

2. Algebraically, assuming that ΔNAWRU=0, one derives that $a_t = (\Delta^2 w - \Delta(\Delta w)^{e})/\Delta U$. The estimated values of a_t are then substituted back into equation [1] to yield time-varying estimates of the NAWRU as: $\text{NAWRU}_t = U - ((\Delta U/(\Delta^2 w - \Delta(\Delta w)^{e}))\,(\Delta w - (\Delta w)^{e})$. In estimation, observations are screened in a manual fashion to exclude periods associated with major supply shocks, i.e. where the estimated raw NAWRU is implausible.

3. For these countries, the final choice of proxy for expected wage inflation and functional form were based on the fit of corresponding Phillips curve equation estimates.

4. These countries are Germany, France, Italy, Austria and New Zealand.

3.1 Empirical results

36. As described in the technical annex, the reduced-form approach has been used to estimate NAIRUs and Phillips curves for the 21 OECD countries for which the OECD currently publishes estimates, using Kalman filter and HPMV approaches.[23] The relevant results and estimates are reported in Figure 1 and Table 1.[24] Since the theoretical framework underlying the Phillips curve gives little or no guidance to the choice between wage or price inflation as the dependent variable, a measure of consumer price inflation has been used on the grounds that such a variable is close to broad measures of inflation of most interest to policy makers. On the other hand, for small open economies, inflationary pressures may show up more readily in wages than in prices. In practice, the choice between wage or price inflation does not appear to radically alter the results, although the use of price inflation represents a change from previous OECD estimates which relate to wage inflation and hence the NAWRU.[25]

37. The most important result is that the framework "works" in the sense that the unemployment gap is significant in explaining inflation for all countries and the Phillips curves give plausible summaries of inflationary developments for the past three to four decades. Moreover, it has been possible to estimate such relationships for Japan, a country for which it is sometimes argued that unemployment is not a reliable indicator of inflationary pressure (Nishizaki, 1997) and for many small open economies where, as noted above, foreign prices exert a major role and it is often argued that inflationary pressures show up mainly in wages or the current account.

38. More specifically, for the G7 economies the estimated unemployment gaps "explain" approximately a quarter of inflation variation. The gap is also found to be significant for countries that have experienced large and sudden shifts in the unemployment rate, such as Finland and Sweden. Temporary supply shocks represented by changes in (de-trended) real non-oil import prices and real oil prices are also found to have significant effects across virtually all countries. The estimates are also found to perform well for a standard range of diagnostic tests.

39. In a sense, the Phillips curve framework is "rehabilitated" by allowing the NAIRU to vary in a relatively flexible way through time. However, the balance of variation needs to be right, too little variation in the NAIRU will result in mis-specified and unreliable inflation equations; too much variation undermines the concept and makes the NAIRU difficult to project and of limited use for policy.[26] However, during the 1990s estimated NAIRUs are found to be relatively stable: for G7 countries a typical annual change in the NAIRU being between 0.1 to 0.3 percentage points (see Figure 1).

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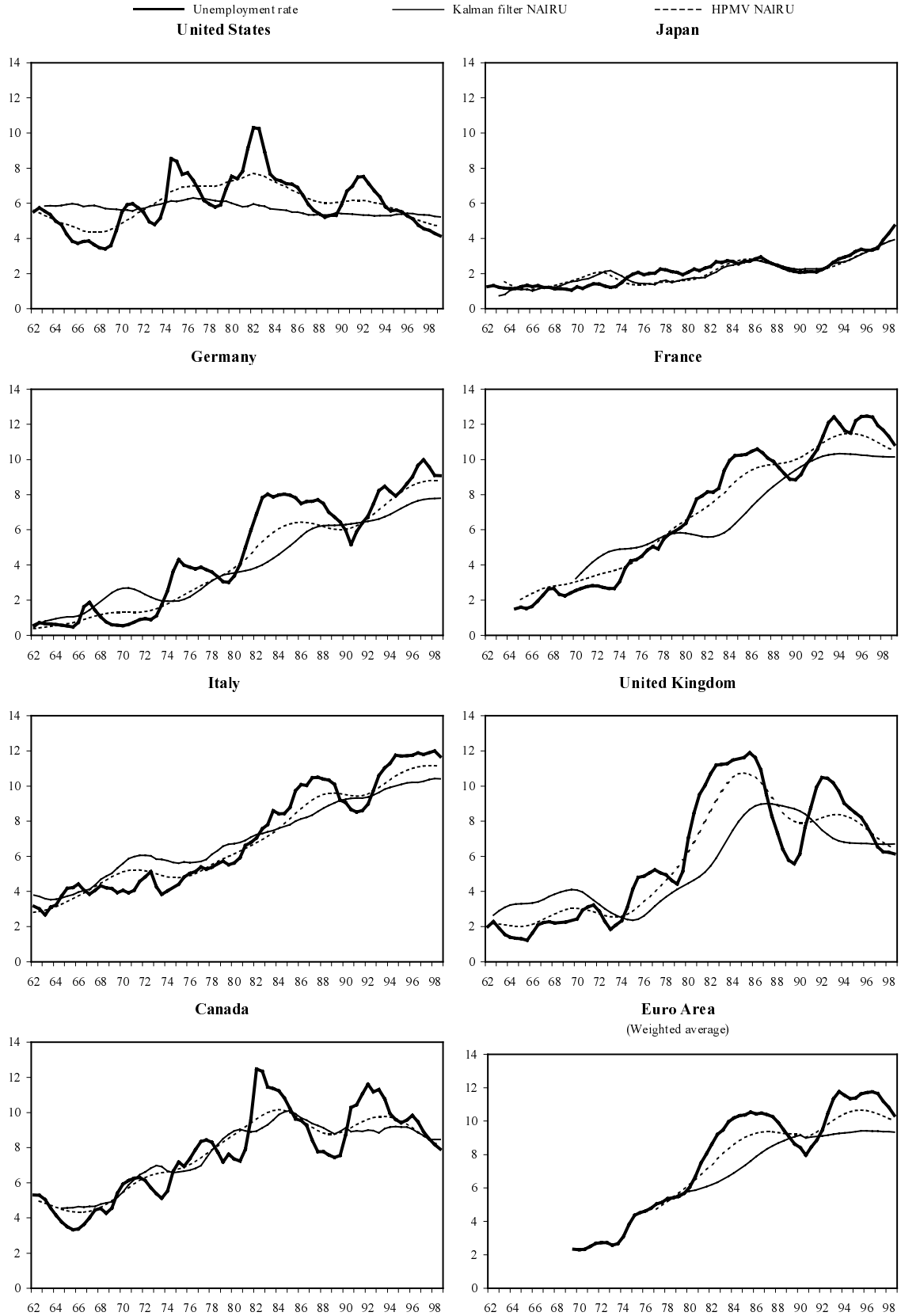
23. The HPMV filter was originally developed by Laxton and Tetlow (1992) and is currently used extensively in the Bank of Canada QPMV model. See the technical annex and also Boone (2000) for a detailed discussion of the HPMV filter as an unobservable component model, which can also be estimated as a special case of the Kalman filter.

24. Further details of the equation estimation results and the corresponding NAIRU gaps are reported in the technical annex.

25. Tests carried out with alternative wage inflation equations give broadly comparable results although these tend to be less well determined.

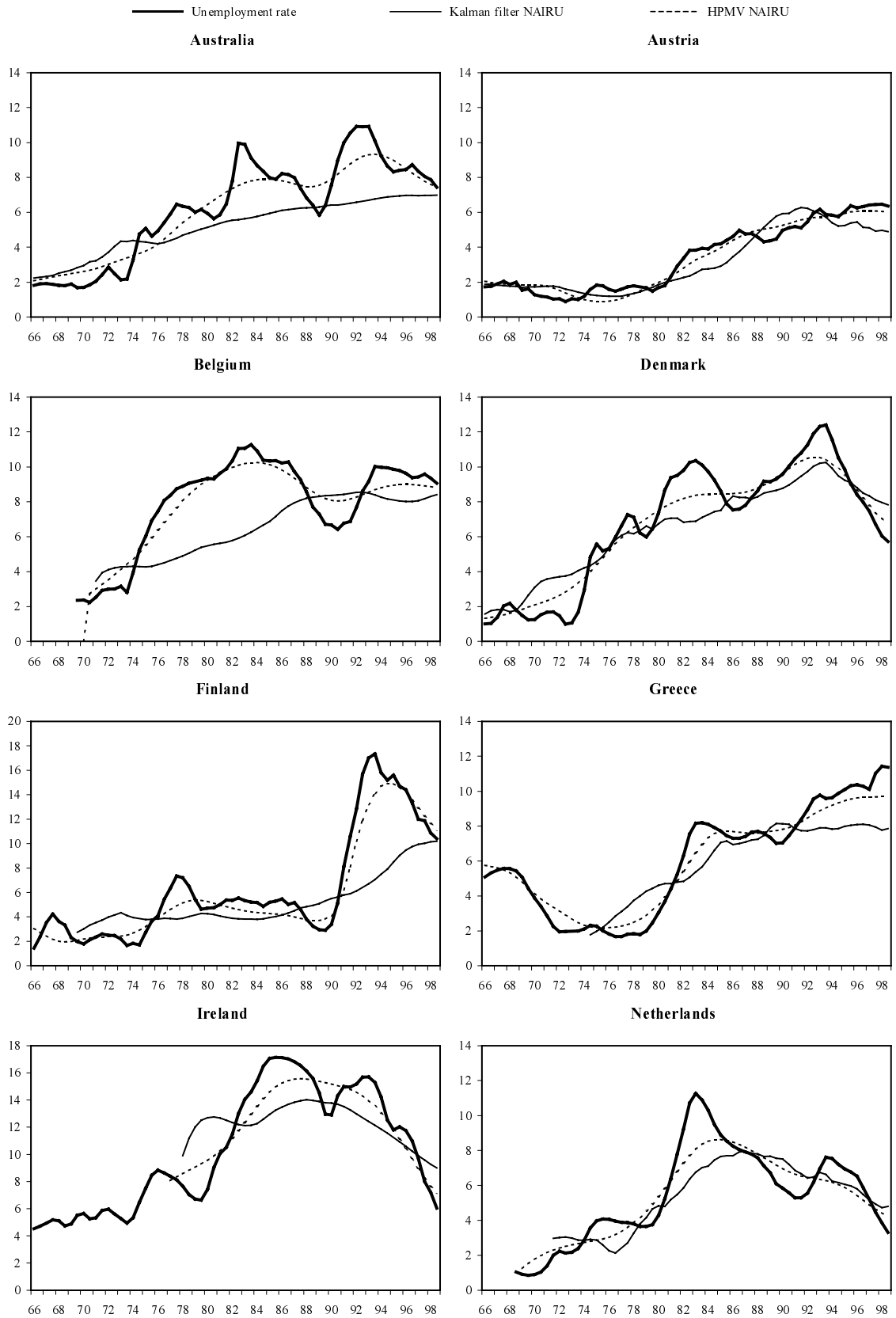
26. As discussed in the technical annex, the broad properties of such filter methods are controlled by the choice of various parameters which affect smoothness over time and related features.

Figure 1. **Unemployment rates and NAIRU estimates**



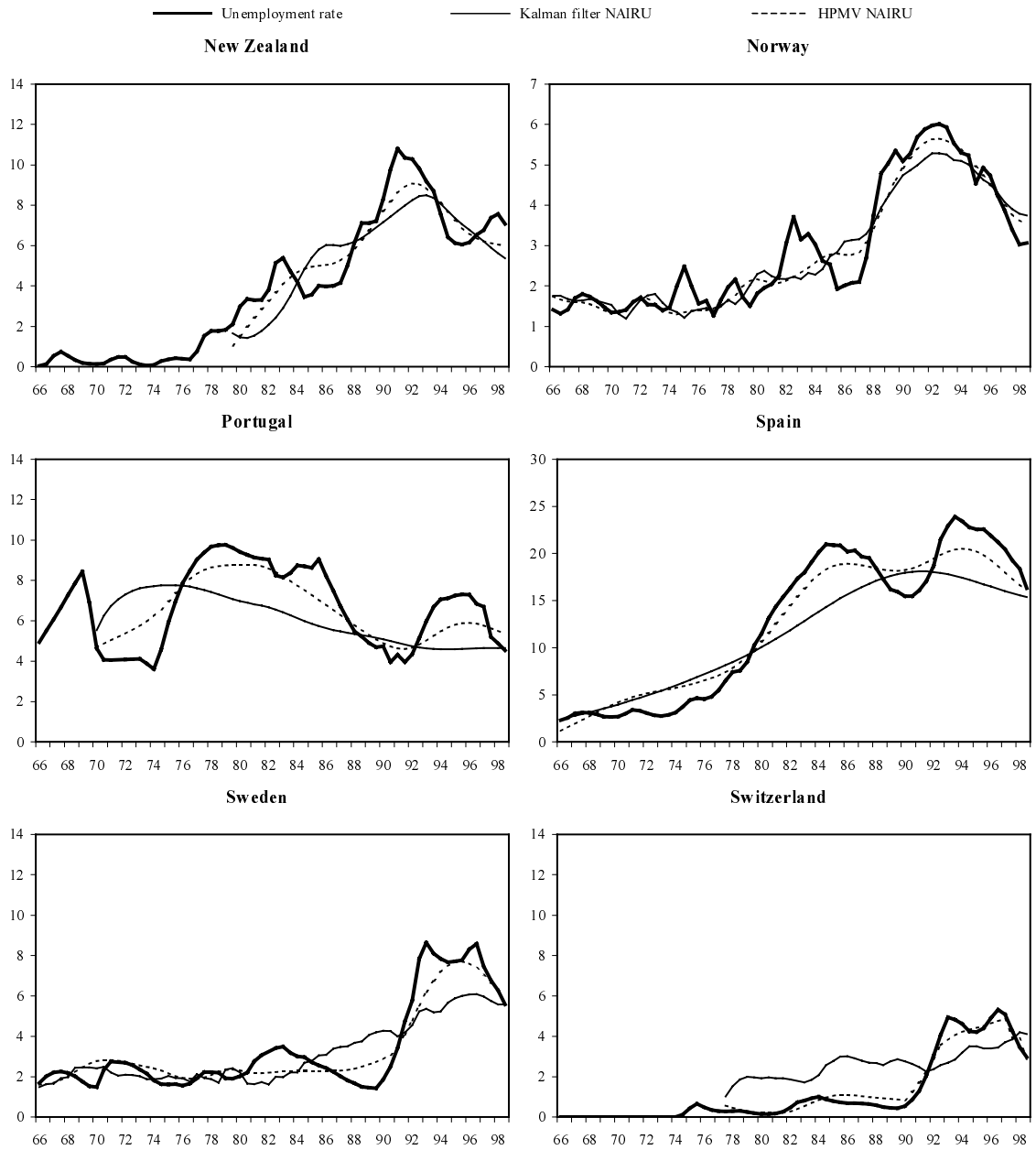
Note: For most countries a common scale has been imposed to aid comparability, but exceptions are Finland, Ireland, Norway and Spain.

Figure 1 (cont'd). **Unemployment rates and NAIRU estimates**



Note: For most countries a common scale has been imposed to aid comparability, but exceptions are Finland, Ireland, Norway and Spain.

Figure 1 (cont'd). **Unemployment rates and NAIRU estimates**



Note: For most countries a common scale has been imposed to aid comparability, but exceptions are Finland, Ireland, Norway and Spain.

Table 1. **Comparing previous and re-estimated NAIRU indicators**

	United States[2]	Japan	Germany[3]	France[2,3]	Italy[3]	United Kingdom	Canada	Australia	Austria[3]	Belgium	Denmark
Unemployment gap correlation[1]											
Previous OECD HPMV estimates	0.95	0.62	0.72	0.85	0.74	0.97	0.98	0.89	0.53	0.94	0.93
Previous OECD Kalman filter estimates	0.75	0.69	0.70	0.75	0.83	0.91	0.96	0.60	0.68	0.77	0.85
Average absolute unemployment gap											
Previous OECD estimate	0.8	0.2	0.7	0.7	0.8	1.2	0.9	0.9	0.4	0.8	0.9
HPMV estimate	0.6	0.3	0.8	0.6	0.6	0.9	0.7	0.8	0.4	0.7	0.8
Kalman filter estimate	1.2	0.3	1.3	1.2	1.0	1.9	0.9	1.9	0.7	2.2	1.2
Unemployment gap in 1999:I											
Previous OECD estimate	-1.1	1.0	1.0	0.8	1.6	-1.1	-0.2	-0.1	0.7	0.4	-2.0
HPMV estimate	-0.6	0.8	0.3	0.3	0.5	-0.3	-0.2	0.0	0.3	0.2	-1.1
Kalman filter estimate	-1.1	0.8	1.3	0.7	1.3	-0.6	-0.5	0.4	1.5	0.6	-2.1
NAIRU in 1999:I											
Previous OECD estimate	5.2	3.7	8.1	10.0	10.1	7.2	8.1	7.6	5.6	8.6	7.7
HPMV estimate	4.7	3.9	8.8	10.5	11.1	6.5	8.1	7.4	6.0	8.8	6.8
Kalman filter estimate	5.2	3.9	7.8	10.1	10.4	6.7	8.5	7.0	4.9	8.4	7.8
Change in NAIRU 1990-98											
Previous OECD estimate	-0.4	1.2	0.7	1.6	1.4	-1.5	-0.6	-0.5	0.5	0.3	-1.4
HPMV estimate	-1.2	1.5	2.8	1.0	1.6	-1.2	-0.5	-0.1	0.9	0.8	-2.3
Kalman filter estimate	-0.1	1.5	1.5	0.9	1.2	-1.9	-0.6	0.6	-0.9	-0.1	-0.7

1. Correlation between unemployment gaps over the common sample.
2. Final values are shown for 1999:II.
3. Previous OECD NAWRU estimates are not strictly comparable to the KF and HPMV estimates (see Box 2).

Table 1 (continued). **Comparing previous and re-estimated NAIRU indicators**

	Finland	Greece	Ireland	Netherlands	New Zealand[2]	Norway	Portugal	Spain	Sweden	Switzerland
Output gap correlation[1]										
Previous OECD HPMV estimates	0.80	0.87	0.89	0.94	0.94	0.85	0.39	0.79	0.83	0.79
Previous OECD Kalman filter estimates	0.98	0.87	0.79	0.93	0.98	0.93	0.30	0.72	0.84	0.95
Average absolute unemployment gap										
Previous OECD estimate	1.5	0.7	0.9	0.9	1.3	0.4	1.5	1.4	1.1	0.4
HPMV estimate	0.9	0.6	1.2	0.8	0.5	0.4	0.9	1.7	0.6	0.3
Kalman filter estimate	2.5	1.4	2.4	1.2	1.0	0.4	1.9	2.8	1.0	1.5
Unemployment gap in 1999:I										
Previous OECD estimate	-0.4	1.7	-1.3	-1.2	1.3	-1.0	-0.5	-0.2	-0.9	0.3
HPMV estimate	-0.7	1.7	-1.1	-1.0	1.1	-0.5	-0.8	0.1	-0.4	0.1
Kalman filter estimate	0.2	3.5	-2.9	-1.5	1.7	-0.7	-0.1	0.9	0.0	-1.2
NAIRU in 1999:I										
Previous OECD estimate	10.8	9.7	7.4	4.5	5.8	4.1	5.0	16.5	6.4	2.6
HPMV estimate	11.1	9.7	7.2	4.2	6.0	3.5	5.4	16.2	6.0	2.9
Kalman filter estimate	10.2	7.9	9.0	4.8	5.4	3.7	4.7	15.4	5.6	4.1
Change in NAIRU 1990-98										
Previous OECD estimate	5.6	1.7	-7.5	-2.2	-1.0	-0.4	-0.7	-1.0	4.2	2.0
HPMV estimate	8.0	1.9	-7.3	-2.5	-1.4	-1.1	0.6	-1.1	3.7	3.0
Kalman filter estimate	4.7	-0.3	-4.4	-2.7	-1.3	-0.8	-0.5	-2.2	1.4	1.2

1. Correlation between unemployment gaps over the common sample.
2. Previous OECD NAWRU estimates are not strictly comparable to the KF and HPMV estimates (see Box 2).

40. The estimated unemployment gaps produced by the two filtering approaches are found to be highly correlated with each other and with previous OECD estimates and the corresponding NAIRUs have similar long run trends; in most cases, they tend to move around each other and to lie broadly within each other's margin of uncertainty.[27] Although there are occasional large differences, most of these can be explained by the fact that the HPMV measure is anchored more tightly to the actual unemployment rate while the Kalman filter gives more weight to the estimated Phillips curve.[28] For example, across the G7 countries, the magnitude of the HPMV unemployment gap remains below 3 percentage points, while there are several countries for which the Kalman filter gap occasionally exceeds 4 percentage points. The latter method also tends to produce more prolonged unemployment gaps, and in 1980s and 1990s a higher degree of excess supply in Europe. Looking more closely at episodes where there are significant divergences for individual countries, the largest differences tend to coincide with large shocks to demand, where the Kalman filter estimates of the gap open up, whilst the HPMV estimates tend to gravitate towards the actual unemployment rate.[29] The Kalman filter estimates, are less restrictive in this respect and are therefore preferred as being economically more meaningful, although they are also more sensitive to the specification (or potential *mis*-specification) of the Phillips curve, for example, with respect to the precise definition of import price shocks. Comparing both sets of preliminary estimates with previous OECD estimates (Table 1), the latter are more similar to the HPMV estimates, although in recent years, differences between the three approaches rarely exceed 1 percentage point.[30]

3.2 The implications of revised NAIRU estimates for inflation and monetary policies

41. As previously discussed, the short-run NAIRU indicator is probably the one of greatest relevance to the operation of monetary policy though it is not an appropriate target. As shown in Box 1 and the Appendix, the Phillips curve can be rewritten so that the change in inflation is explained as a linear function of the gap between unemployment and the short-run NAIRU, so that by construction the short-run NAIRU gap will be closely correlated with contemporaneous or predicted changes in inflation (providing the Phillips curve also fits the data well). The short-run NAIRU may thus be seen as useful synthesis of information concerning current inflationary pressures (see King, 1999*a* and *b*).

42. This point is illustrated in Figure 2 which compares the Kalman filter estimates of the NAIRU and short-run NAIRU for the G7 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 example, for the United States the top left-hand panel of Figure 2 shows the unemployment rate over the period 1996 H2 to 1998 H2 to have been consistently above the estimated short-run NAIRU (which was low mainly due to the incidence of favourable supply shocks) and inflation has been falling, even though the unemployment rate was below the estimated NAIRU. Similarly the United Kingdom unemployment rate has recently been below the NAIRU, but not the short-run NAIRU, and hence there has been an absence of inflationary pressure.

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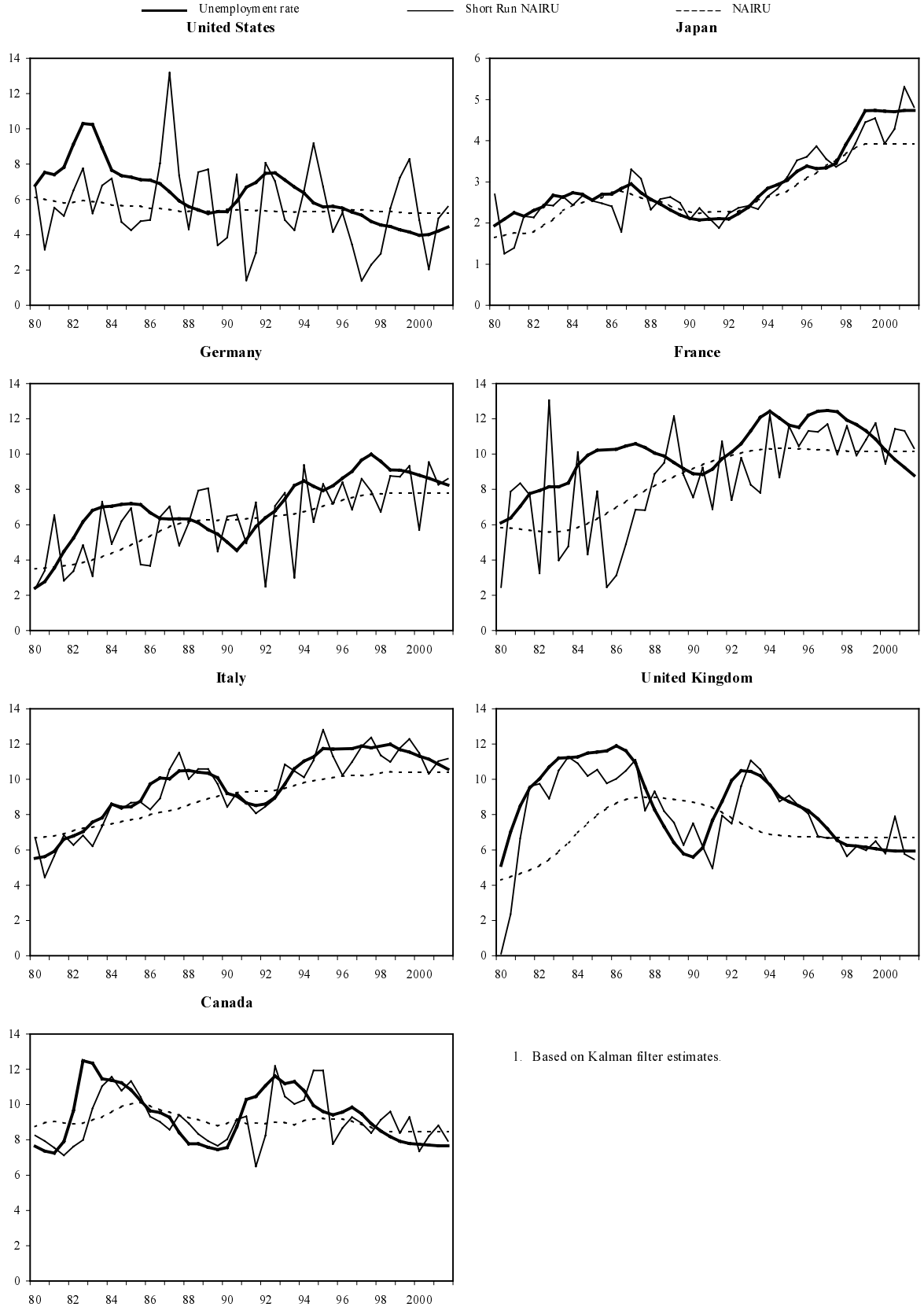
27. As reported in Table A4 and Figure A4 in the technical annex, estimated standard errors for the G7 countries associated with the Kalman filter estimates average ¾ per cent and range between ¼ per cent for Japan and one per cent for France and the United Kingdom.

28. The HPMV filter approach gives specific weight to the estimated NAIRU gap, whereas the generalised Kalman filter does not. The choice of specific weights therefore have important consequences for the respective estimates.

29. For example, the HPMV estimate for the United States is 1½ percentage points higher than the Kalman Filter estimate at the peak of the disinflation of the early 1980s. A similar pattern occurs across a number of OECD countries during the period of restrictive or contractionary policies of the early 1980s and the mid to late 1990s. As discussed in the technical annex, this property is a specific feature of the HP filter and is governed by an essentially arbitrary choice of weights.

30. As noted earlier and in Box 2, the previous OECD estimates are not strictly comparable, partly because the underlying concept is not as clearly identified as the alternatives, and partly because it is based on wage rather than price inflation. Similarities between the previous HPMV estimates reflect the common use of the HP filter.

Figure 2. **NAIRU and short run NAIRU estimates**[1]



1. Based on Kalman filter estimates.

43. In general, differences between the NAIRU and short-run NAIRU are likely to be most marked for those economies characterised by strong persistence effects. On the basis of the estimated Phillips curves, among the G7 economies, such "speed limit" effects are found to be greatest for Italy and the United Kingdom. This is largely reflected in the path of the short-run NAIRU estimates, which for these countries tend to fluctuate around the actual unemployment rate rather than the NAIRU (Figure 2). 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 increasing inflation was extremely limited (i.e. the short-run NAIRU imposes a "speed-limit" effect). By contrast the Phillips curve estimates for Germany suggest that the effect of unemployment on inflation is relatively rapid and so the short-run NAIRU fluctuates around the NAIRU. The other G7 countries can be characterised as being somewhere between these extremes. For example, for France the short-run NAIRU over much of the mid 1980s and the late 1990s is estimated to have been below the actual unemployment rate but well above the NAIRU suggesting that there may have been some scope for reducing unemployment in the short-term, but not as far as the NAIRU indicates without an increase in inflation.

44. The short-run NAIRU as calculated can also be used to forecast future inflation - as a simple function of projected short-run NAIRU gaps.[31] Such forecast rules have been evaluated on the basis of the current short-term NAIRU estimates, observed (future at any point in time) unemployment rates and the assumption that there are no future supply shocks and that the NAIRU remains constant. On this basis, the explanatory power of the short-run NAIRU gap drops as the forecast horizon is extended (Table 2): on average across the G7 countries the short-run NAIRU gap explains more than 50 per cent of the contemporaneous variation in inflation, but this falls to between 25 and 30 per cent over a future horizon of 1-2 years. As the forecast horizon is extended so that more and more information on contemporaneous and lagged information drops out of the calculation of the short-run NAIRU, the short-run NAIRU converges on the NAIRU. However, over a forecast horizon of one semester, and usually over an horizon of two to three semesters, the short-run NAIRU gap is superior to the NAIRU gap as a predictor of inflation (Table 3).[32]

31. This is analogous to the forecast rule proposed by Estrella and Mishkin (1998). There are, however, important differences. Since they do not estimate a conventional Phillips curve, but rather directly estimate an equation in which the dependent variable is future inflation (in their case at an horizon two years in the future) relative to current inflation, and the explanatory variables only contain contemporaneous and lagged information. An advantage of the approach used in the present study is that the projected short-run NAIRUs are derived consistently with more standard Phillips curve estimates, the properties of which are more easily assessed.

32. The fact that the explanatory power of the short-run NAIRU gap is not higher suggests that there is scope for improving forecasts by using information that is not incorporated in these rudimentary Phillips curve specifications (see Staiger *et al.*, 1997, Stock and Watson, 1999), as is, of course, standard practice in operating monetary policy (Stiglitz, 1997, King, 1999*b*).

Table 2. **Proportion of inflation explained by the short-run NAIRU**

a) Kalman filter estimates

	Forecast horizon (semesters)				
	0	1	2	3	4
United States	0.67	0.21	0.21	0.28	0.30
Japan	0.83	0.21	0.19	0.27	0.25
Germany	0.53	0.20	0.29	0.34	0.39
France	0.63	0.06	0.14	0.14	0.24
Italy	0.77	0.31	0.18	0.11	0.16
United Kingdom	0.84	0.34	0.38	0.32	0.31
Canada	0.59	0.27	0.29	0.29	0.30
Average G7	0.69	0.22	0.24	0.26	0.28

b) HPMV filter estimates

	Forecast horizon (semesters)				
	0	1	2	3	4
United States	0.62	0.25	0.30	0.36	0.34
Japan	0.76	0.20	0.22	0.28	0.26
Germany	0.51	0.23	0.34	0.30	0.38
France	0.39	0.08	0.20	0.24	0.30
Italy	0.70	0.30	0.17	0.12	0.17
United Kingdom	0.83	0.39	0.42	0.35	0.32
Canada	0.62	0.28	0.32	0.32	0.33
Average G7	0.63	0.25	0.28	0.28	0.29

Notes: The table reports the R^2 in a regression of the following form:

$$\pi_t - \pi_{t-k} = \theta \sum_{i=1}^{k} \left(U_{t-i+1} - \hat{US}^*_{t-i+1} \right)$$

where $\hat{US}^*$ is a projection of the short-run NAIRU from period (t-k) assuming that the NAIRU remains constant and there are no supply shocks.

Table 3. **Evaluating the relative power of short-run NAIRU and NAIRU indicators as predictors of inflation**

a) Kalman filter estimates

	Forecast horizon (semesters)				
	0	1	2	3	4
United States	S	S	(S)	S	(S)
Japan	S	S	S	S	S
Germany	S	S	(S)	-	-
France	S	S	-	N	-
Italy	S	S	S	(S)	-
United Kingdom	S	S	S	S	S
Canada	S	S	S	S	S

b) HPMV filter estimates

	Forecast horizon (semesters)				
	0	1	2	3	4
United States	S	S	S	(S)	-
Japan	S	B	B	S	S
Germany	S	S	(S)	-	-
France	S	S	-	-	-
Italy	S	S	S	-	-
United Kingdom	S	S	S	S	S
Canada	S	S	S	S	S

Notes: The table above assesses the relative power of the NAIRU and short-run NAIRU at predicting inflation. The results for a forecast horizon of 'k' semesters (K = 1…4) are based on the following regression:

$$\pi_t - \pi_{t-k} = \alpha \sum_{i=1}^{k} \left(U_{t-i+1} - U^*_{t-k} \right) + \beta \sum_{i=1}^{k} \left(U_{t-i+1} - \hat{U}S^*_{t-i+1} \right)$$

where the first term represents the gap between unemployment and a projected NAIRU which is assumed to remain constant at its value in period (t - k), and the second term is the gap between unemployment and the short-run NAIRU projected on the assumption of a constant NAIRU and no supply shocks.

In the table: 'S' (S)' indicates that the coefficient on the short-run gap term is significant at the 5 (10) per cent level and the NAIRU gap is not, 'N' indicates that the coefficient on the NAIRU gap is significant and the short-run NAIRU gap is not, '-' indicates that neither gap is significant, 'B' indicates both gaps are significant.

45. As an illustration of the relevance of the short-run NAIRU gap and factors contributing to it for predicting inflation, Table 4 reports the decomposition of mechanical projections of inflation for the G7 economies based on the Kalman filter estimates of the Phillips curve.[33] These also assume the profile of actual unemployment and supply shocks (real import prices and oil prices) to be those taken from the recent OECD *Economic Outlook No. 66* projections and for the NAIRU to be stable over the projection period.[34] Table 4 distinguishes three separate components of the projected change in inflation captured by the short-run NAIRU gap: effects from temporary supply shocks; effects from the contemporaneous gap between unemployment and the NAIRU; and "inertia" effects, which capture both the influence of past lags in inflation and dynamic effects from changes in unemployment. The projected change in the rate of inflation is given in the final column as the sum of these, which is also proportional to the short-run NAIRU gap.

46. For all of the G7 economies it can be seen that there is a significant boost to inflation coming from the steep rise in oil prices in 1999.[35] For Germany, France and Italy the inflationary effects of temporary supply shocks in 1999 (mainly oil prices, but also an above trend increase in real import prices reflecting weakness of the Euro) are seen to be sufficient to counteract the deflationary effect of a positive gap between unemployment and the NAIRU of 1 to 1 ¼ percentage points. Thus, the short-run NAIRU gap is negative for these countries in 1999 (Figure 2).

47. For the United States and Canada the unemployment rate remains consistently below the NAIRU over the projection period and this is a dominant influence leading to an increase in inflation in 2000 and 2001. This is also the case of the United Kingdom, although supply shocks are more important for 2000. Speed limit effects have little influence on the current inflation projections for these countries because unemployment remains relatively stable. For Germany the positive, albeit closing, gap between unemployment and the NAIRU is the main force reducing inflation over the projection.

48. Adverse supply shocks, partly reflecting the weakness of the Euro and lagged effects from the oil price increase in 1999, have a larger role in the projections for Italy and France. For Italy the adverse supply shocks in conjunction with speed limit effects from a falling unemployment rate may be sufficient to offset the effect of a positive unemployment gap, so projected inflation remains broadly stable over the period. For France the unemployment rate is projected to fall slightly below the NAIRU in 2001, which further contributes to a modest pick-up in inflation.

49. The projections for Japan highlight the difficulties in using a linear Phillips curve specification when inflation is already quite negative. Here a projected positive unemployment gap (which is historically large for Japan) combined with negative supply shocks (mainly yen appreciation) would imply implausibly rapid further deflation in 2000. However, the experience of the last few years suggests that at low levels of inflation the deflationary effect of a positive unemployment gap is substantially reduced. The mechanical projections reported in Table 4 are therefore based on such a modification to a linear Phillips curve specification (see the technical annex for details). Nevertheless, prices are still projected to fall at a rate of three per cent per annum in 2000.

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33. Repeating the same exercise with the Phillips curve estimated using the HPMV filter gives broadly similar results to those reported in Table 4. The main differences concern the Continental European economies where because the HPMV estimate of the NAIRU is higher, inflation is about 1 percentage point higher in 2001 for France, Germany and Italy.

34. It is emphasised that the projections published in the *Economic Outlook* take account of a far wider set of information and judgements, which are absent from the purely mechanical use of the Phillips curve reported here.

35. For the United Kingdom the lag structure of the Phillips curve implies the main inflationary impact occurs in 2000.

Table 4. **Decompostion of mechanical inflation projections based on the estimated Phillips curves**

	Unemployment rate	NAIRU gap	Short-run NAIRU gap	Contributions to predicted changes in semi-annual inflation rates, coming from: (percentage points at annual rates)			
				NAIRU gap	Supply shocks	Inertia	Total
United States							
1999	4.2	-1.0	-2.0	0.4	1.5	-0.3	1.7
2000	4.2	-1.0	1.2	0.5	-0.1	-0.7	-0.3
2001	4.6	-1.6	0.6	0.4	-0.1	0.2	0.5
Japan							
1999	4.7	0.8	0.2	-2.5	2.3	-0.5	-0.7
2000	4.7	0.8	0.6	-2.5	-1.1	1.0	-2.5
2001	4.7	0.8	-0.3	-2.5	1.9	2.0	1.4
Germany							
1999	9.0	1.2	-0.1	-0.7	1.0	-0.1	0.1
2000	8.7	0.9	1.1	-0.6	-0.1	-0.2	-0.8
2001	8.3	0.5	-0.1	-0.3	0.6	-0.2	0.1
France							
1999	11.1	1.0	-1.0	-0.5	0.9	0.0	0.4
2000	10.3	0.2	-0.1	0.1	0.8	-0.6	0.3
2001	9.6	-0.5	-1.2	0.6	0.8	-0.2	1.2
Italy							
1999	11.6	0.1	-0.4	-1.2	2.1	-0.1	0.7
2000	11.2	0.8	0.3	-0.8	-0.3	-0.1	-1.2
2001	10.7	0.3	-0.4	-0.3	0.8	0.9	1.4
United Kingdom							
1999	6.1	-0.6	-0.3	0.4	-0.6	0.5	0.3
2000	6.0	-0.7	-0.9	0.5	1.2	-0.1	1.6
2001	5.9	-0.8	0.3	0.5	-0.4	-0.7	-0.6
Canada							
1999	7.8	-0.6	-0.9	1.0	1.3	-0.5	1.7
2000	7.7	-0.7	-0.1	1.1	-0.5	-0.5	0.1
2001	7.7	-0.8	-0.7	1.2	0.4	-0.2	1.4

Notes:

The inflation rate refers to the consumers' expenditure deflator, except for Canada which uses a core-CPI deflator (excluding food and energy). The decomposition of changes in the inflation rate is calculated as the percentage change between the second halves of the year and the preceding year. Because the consumers expenditure deflator was not available for the second half of 1999, the change in the CPI in the second half of 1999 was used as a proxy to calculate the inflation rate for 1999.

Mechanical projections of inflation for 2000 and 2001 are based on dynamic forecasts using the Kalman filter estimates of the Phillips curve reported in Table A1 of Annex 2, where assumptions about the unemployment rate and supply shocks correspond to the projections published in Economic Outlook No.66 and actual price data for 1999.

4. Limitations of the approach and the scope for further work

50. The limitations and uncertainties attached to NAIRU measures are such that they may at best provide one of a range of policy indicators which need to be interpreted carefully and used in conjunction with other measures relevant to the policy issue being examined. Thus in the case of fiscal and monetary policies, the policy assessment also needs to take account of related indicators of inflation or cyclical pressures, for example those coming from surveys of capacity utilisation, industrial confidence and consumer expectations. At the same time because they are sensitive to possible biases associated with the (mis-) specification of the Phillips curve being estimated, further work may be needed to refine or improve them.

51. Such biases might be associated with two particular issues: the treatment of expectations in the estimation of the Phillips curve; and non-linearities and asymmetries in the effect of the unemployment gap on inflation. The empirical work presented here uses past lags of inflation to approximate the expectations formation process. This may be a reasonable assumption during the periods of high and variable inflation characterising the 1970s and 1980s. However, more recently expectations in many OECD countries may have become anchored by the experience of lower and more stable inflation underpinned by credible central bank commitments (sometimes in the form of an explicit inflation target).[36] Thus if expectations have become more forward looking over the past decade then estimates of the NAIRU based on purely backward-looking expectations will be biased. For example in a situation where inflation is falling towards a target that is at least partially credible, then adopting an (incorrect) assumption that expectations are entirely backward-looking is likely to mean that inflation expectations will be systematically over-estimated and the NAIRU correspondingly under-estimated. Moreover, changes in the expectation formation process will have important implications for assessing future inflationary pressures, insofar as backward-looking adaptive expectations imply more inertia i.e. the short-run NAIRU would appear to be slow to adjust. Whilst the present study does not include specific allowance for this, the possible systematic effects of changes in regime and credibility do not appear to show up in relevant stability tests on the estimated equations, although the power of such tests may be low. Thus there is scope for further analysis and testing

52. A second source of bias is that associated with non-linearities or asymmetries in the inflation response to the NAIRU gap. An example of this is the case where the inflation response might be proportionately larger when the rate of unemployment is below the NAIRU than when it is above. If this were the case, then one might infer that because inflation for many countries is currently at around roughly the same levels as thirty or more years ago, then unemployment must on average have been above the NAIRU more often than it has been below. Consequently NAIRU measures, based on methods (including those adopted in the present paper) that assume symmetrical and linear effects from the unemployment gap on inflation, will be systematically biased upwards. As discussed earlier, the monetary policy implications of such a bias are somewhat ambiguous. On the one hand estimated NAIRUs may be too high, whilst on the other policy makers may in setting monetary policies need to build in a wider safety margin in case unemployment moves closer to the NAIRU, resulting in a larger than expected inflation response.[37] While the notion that there are non-linear and asymmetric effects from the unemployment gap on inflation is appealing, it is inherently difficult to find strongly supporting empirical evidence. This is both because before such an hypothesis can be tested it is necessary to be specific about the form of the non-linearity and also because if unemployment gaps are alternatively derived on an assumption that they are symmetric it is

36. Recent work by the Bank of Canada, see Fillion and Leonard (1997), suggests that allowing for changes in the expectations formation process that may be associated with lower inflation leads to significant improvements in the fit of estimated Phillips curves for Canada.

37. A relevant discussion of the practical implications of such asymmetries for policy is given by Laxton *et. al* (1998).

(unsurprisingly) difficult to reject a maintained hypothesis that the effects of the gap on inflation are symmetric and linear.

53. A further practical problem is that estimates derived from two-sided filters are inevitably subject to greater uncertainty and revision at the end of the sample. The scope for such errors in estimating the NAIRU is likely to be larger the greater the effects of recent and ongoing structural reforms to labour markets. In those countries where such reforms took place earlier in the late-1980s to mid-1990s, for example Ireland, the Netherlands, New Zealand, Spain and the United Kingdom, the impact of reforms on estimated NAIRUs are typically quite substantial over a number of years, though relatively slow to emerge.[38] 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 the current empirical estimates. Again, at least part of these effects should be reflected in the estimated residuals in the inflation equations, with a systematic positive residual being associated with a corresponding under prediction of inflation and underestimation of the NAIRU. The preferred Kalman filter estimates should in principle adjust quickly to eliminate such residuals, but it is possible that where there is a relatively rapid downward movement in the true NAIRU, then the imposed smoothness priors used in the estimation technique will prevent the estimated NAIRU from moving quickly enough. Similarly large residuals may be indicative of one-off events such as changes in indirect taxes, which should be discounted in the estimation process.

54. Overall, it may be necessary to factor in the likely consequences of the combination of all these factors in making forward–looking assessments of the NAIRU and associated inflation developments, in assessing the impact of structural change and in improving the quality of NAIRU estimates. In this respect, the Kalman filter estimates reported in this paper provide a systematic starting point for the OECD's future NAIRU indicators, which will also need to take account of wider judgements on their robustness and plausibility in the light of specific country experiences.

38. The fall in NAIRU estimates for these countries since the implementation of labour market reforms has on average been up to ½ per cent annum, typically over a period of 4 to 5 years.

APPENDIX: THE THEORETICAL FRAMEWORK

55. 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 to extensively illustrate how institutional characteristics and macroeconomic shocks interact and affect the 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

56. 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

57. 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:

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

where Δ is the first difference operator[39], 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.

39. 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).

Wage-setting

58. 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)[40] and an increasing function of wage push factors (ZT_w and ZL_w) and labour efficiency, allowing for unanticipated wage changes $(w-w^e)$.[41] Thus:

$$w - p = b_0 - b_1U - b_2\Delta U - b_3(w - w^e) + q + ZT_w + ZL_w \qquad b_1, b_2, b_3 > 0 \qquad [2]$$

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

59. 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).[42]

$$l = c_0 - c_1U + ZL_l \qquad c_1 > 0 \qquad [3]$$

where l is the logarithm of the labour force.

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40. 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 redundancy 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).

41. 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.

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

The different concepts of NAIRUs and the Philips curve equation

60. 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.

61. 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.

62. 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. $(w - w^e) = (p - p^e)$).

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

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

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

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

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

This *Phillips curve* is the equation to which it is 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.[43]

63. 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 $\Delta\pi = 0$:

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

where $\theta = d_1 / d_1 + d_2$

So, the short-term NAIRU can be expressed as a weighted average and actual (lagged) unemployment of the NAIRU, temporary supply shocks and lags of inflation. Similarly to Estrella and Miskhin (1998) results, 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:

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

43. 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.

TECHNICAL ANNEX

Introduction

64. This annex provides a more detailed and technical account of the OECD's recent empirical work estimating the NAIRU for 21 OECD countries along with comparisons and relative evaluations of the various results. It begins with a general review of approach and methods used in recent empirical studies of the NAIRU and on this basis it is concluded that a reduced-form Phillips curve approach is the most promising framework to provide up-to-date point estimates of the NAIRU across the range of OECD countries. Within this, two closely related methods are identified as being of particular interest for estimating time-varying NAIRUs, namely the Hodrick-Prescott multi-variate (hereafter HPMV) filter introduced by Laxton and Tetlow (1992) and the Kalman (1960) filter as described in Harvey (1992). After recalling the general form of the Phillips curve framework involved, Section 2 of this annex goes on to describe these methods and shows how they are closely related, differing only in the assumptions made about the time-series process generating the NAIRU and its relationship with actual unemployment. It also discusses a number of factors important to their practical use. Section 3 then reports the corresponding NAIRU and Phillips curve estimates obtained across the range of OECD countries for which OECD estimates of the NAIRU are currently made and then compares these both with each other and with previous OECD estimates.

1. Review of recent empirical studies of the NAIRU

65. 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 the 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 approaches in turn. In doing so, it draws on the material presented at the previous WP1 discussion of the NAIRU, but also emphasises relevant studies published since then.

1.1 Structural methods

66. 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, Grubb *et al.*, 1982, 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 (as defined in Box 1 of the main text) rather than the NAIRU which commonly appears in reduced-form Phillips curve specifications.

67. 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.

68. 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.

69. 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.[44]

70. 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).

71. 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).

72. One response to the paucity of data relating to the measurement of institutional variables is that 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.[45] 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 more robust results in this empirical literature. However, more generally, 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

44. 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).

45. Relevant studies include Nickell and Layard (1998), Elmeskov *et al.* (1998), OECD (1999), Nicoletti *et al.* (1999), Di Tella and MacCulloch (1998), Daveri and Tabellini (1997) and Blanchard and Portugal (1998).

consensus regarding their relative importance in determining structural unemployment.[46] 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 sub-periods of several years, where the final period considered is often 3-4 years in the past.

73. Structural methods provide, in principle, useful qualitative and quantitative information about the various sources of labour-market rigidities and make it possible to measure their relative size. They are, consequently, useful tools for framing and evaluating related structural policy questions and, in particular thinking about future NAIRU developments in the light of policy reform and other developments. But, in practice, it appears difficult to identify with any accuracy the specific contributions of the various factors that determine the NAIRU and the measures of the structural unemployment rate/NAIRU, which are derived with the structural approach, tend to be only indirectly related to inflation (unlike the Phillips curve approach). This often leads to confusion in the policy debate about the room for policy manoeuvre in either the short- or medium term.

1.2 Purely statistical methods

74. 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.

75. A wide range of statistical techniques have been developed to decompose time series such as the unemployment rate into cyclical and trend components.[47] The basic problem with all these methods is that they depend on arbitrary and sometimes implausible assumptions in order to make this decomposition.[48] 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).[49] 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 goes generally through the middle of the actual

46. 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."

47. 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 (Scacciavillani and Swagel, 1999); and the wavelet filter (Scacciavillani and Swagel, 1999).

48. The European Commission (1999) finds, for instance, that the Beveridge Nelson method gives estimates of the NAIRU that are more volatile than the actual unemployment rate.

49. 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.

unemployment. 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 trend unemployment rate derived is likely to be biased relative to the true NAIRU when, for example, inflation is falling.

76. 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.[50] 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.

1.3 The reduced-form approach

77. 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.

78. 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).

79. One of the first attempts at estimating time-varying NAIRUs was developed by Elmeskov (1993) and subsequently used by the OECD.[51] 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

50. 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.

51. 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.

and Nyomoen, 1998). For these reasons the methods used by the OECD to derive NAIRU indicators have evolved over time (see Box 2 of the main paper).

80. 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.[52] 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 have been 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.[53]

81. 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).[54] This filter (which belongs to the same class of models - see later) uses a Phillips curve but with a specific restriction on the shape of the unemployment gap. More specifically, the difference between the NAIRU and the observed unemployment rate is specified as a random walk term, sufficiently small that the NAIRU does not wander too "far" from the observed unemployment rate for a prolonged period of time. In this respect, the HPMV filter faces the same issues as the simple HP filter, namely that additional assumptions/adjustments are required to mitigate potential end-point problems.

82. 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 associated Phillips curve can take various specifications, which allows, in principle, for the estimation of a well-defined concept. Third, the fully specified Phillips curve allows the distinction between NAIRU and short-term NAIRU concepts within the same framework. Fourth, such indicators can be easily produced in a timely and consistent fashion across OECD countries.[55]

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52. 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 to provide standard errors for the French NAIRU that lie between 0.8 and 1.7 depending on the sample period.

53. 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.

54. The HPMV filter is 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.

55. 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 Section 3.3.

83. 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.[56] Indeed, the corresponding NAIRU estimates are likely to be dependent on the specification of the Phillips curve.[57] In some cases, such sensitivity to specification may reflect conceptual issues.[58] However, it can also relate to measurement issues for the dependent and/or the explanatory variables used in the equation. For example, including supply shocks such as import prices into the Phillips curve are likely to have a significant impact on the point estimate depending on the precise way (de-trended or not) they are specified.[59]

84. In spite of these limitations, a general conclusion of this review is that filtering methods (Kalman and HPMV filters) 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. Before reporting the results of their specific application to these countries in section 3, the following section discusses these methods in more detail, in terms of underlying theory and also a range of practical issues arising in their use.

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56. 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. 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.

57. 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.

58. For instance, as discussed in the conceptual section of the main paper, in absence of temporary supply shocks specified in the Phillips curve, the indicator estimated will be a “short-term NAIRU”. It may, therefore, be more volatile and be influenced by these temporary factors such as import-price shocks (Gordon, 1997 and 1998, and Hogan, 1998 for the United States; Irac, 1999 for France; Meyer, 1999 for Ireland).

59. Another example is the decline in computer prices, in medical care and service prices, as well as measurement problems. Gordon (1998) shows that, if not included in the model specification, the US NAIRU is around 0.4 to 1.1 percentage points lower compared to one which take these temporary factors into account.

2. Empirical framework and estimation procedures

2.1 The Phillips curve framework

85. As discussed in the previous section, a feature and important advantage of reduced-form filter estimation techniques is that they relate directly to an estimated equation explaining inflation. The Phillips curve equation used is as follows:

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

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.

86. As emphasised in the main paper, 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 alternatively with the Kalman or HPMV filters, to implicitly capture the aggregate effect of all long-lasting shocks, without requiring these shocks to be explicitly identified.

2.2 The choice of inflation and supply shock variables

87. 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 to the main text) 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.[60] 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.

88. 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).[61] 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

60. 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.

61. See, for example, Gordon (1997 and 1998), Hogan (1998), Irac (1999) and Meyer (1999).

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.[62] 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.[63]

89. A further issue is whether the unemployment gap (U-U*) should enter linearly or non-linearly. For simplicity, a linear specification was 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.[64] For Belgium, Spain, Finland and Sweden a partial solution was to have the unemployment gap enter in logarithmic terms: log (U/U*).[65] 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.[66]

2.3 The Kalman and Hodrick-Prescott multivariate filters

90. As mentioned in the review of the recent literature, 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 A1 and Boone (2000) for further technical details concerning the Kalman filter). In the empirical literature, the most commonly adopted form for the transition equation is a random walk [2a] 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 [2b].[67]

$$\Delta U^*_t = \nu^1_t, \text{ where } \nu^1_t \sim N(0, \sigma_{\nu_1}{}^2) \qquad [2a]$$

or

$$\Delta U^*_t = \varphi\, \Delta U^*_{t-1} + \nu^2_t, \text{ where } 0<\varphi<1 \text{ and } \nu^2_t \sim N(0, \sigma_{\nu_2}{}^2). \qquad [2b]$$

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62 . Preliminary OECD tests along these lines for the United States were also promising, but the results tended to be quite sensitive to the precise specification of the mark-up, such as the sectoral coverage and the exact price series used.

63. For most countries, time trends were used for the full sample and from the beginning in 1980.

64. This was the case for Belgium, Spain, Finland, Australia, and Sweden.

65. For Belgium, as for the *OECD Jobs Strategy*, OECD (1999), a standardised unemployment role was used.

66 . See Gruen *et al.* 1995, and comparable studies by the Australian Treasury and Reserve Bank.

67. Formally, equation [2b] is specified in state space form as two transition equations:

$[2b^1]\ U^*_t = (1+\varphi)\, U^*_{t-1} - \varphi\, g_{t-1} + \nu^2_t$, and $[2b^{11}]\ g_t = U^*_{t-1}$

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.

Box A1. **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 a 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*** v_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.

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:

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

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

$$P_t^* = P_t T'_{t+1} P_{t+1|t}^{-1} \quad [8c]$$

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.

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.

91. The HPMV filter can be estimated as a special case of the Kalman filter (see Boone, 2000), one where the Phillips curve equation is augmented by two equations specifying the gap between unemployment and the NAIRU as a white noise process [3a] and the *change* in the NAIRU as a random walk [3b] (although neither of these assumptions is intuitively obvious with respect to the choice of specific dynamics).[68] Thus:

$$U_t = U^*_t + \varepsilon^1_t \quad \text{where } \varepsilon^1_t \sim N(0, \sigma_{\varepsilon_1}^2) \quad [3a]$$

and

$$\Delta U^*_t = \Delta U^*_{t-1} + \varepsilon^2_t, \text{ where } \varepsilon^2_t \sim N(0, \sigma_{\varepsilon_2}^2) \quad [3b]$$

92. A key difference between the HPMV and more usual Kalman filter specifications is that it involves equation [3a], which is specified in terms of the unemployment "gap". A consequence of this feature is that the resulting NAIRU estimates are "anchored" more closely to the actual unemployment

68. Formally, equation [3a] is specified as a second measurement equation (in addition to the Phillips curve) and equation [3b] as the transition equation.

rate, rather than remaining above or below it for long periods as might occur with the more common Kalman filter specification. As implied in the above discussion, the Kalman filter technique can be used to estimate the NAIRU under a variety of alternative assumptions, including those of the HPMV filter defined by equations [3a] and [3b]. However, for the remainder of this paper, the term "Kalman filter estimates" (and variants thereof), will refer to those estimated under the specific assumptions of [2a] or [2b].

2.4 Determining the smoothness of the NAIRU

93. 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 ($\sigma_{v_1}^2$ in [2a]) relative to those in the inflation equation (σ^2 in [1]). The larger is this ratio ("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. An analogous issue when using the HPMV filter is the size of the error variances in transition equations [3a] and [3b] relative to each other and to that of the residuals of the Phillips curve equation.

94. In principle, the Kalman filter technique makes it possible to estimate all the parameters of the model using a maximum likelihood estimation procedure, 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.[69] 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, although the estimation strategy was also concerned to ensure comparability across methods i.e. that the smoothness of the NAIRUs estimated with the alternative HPMV filter and Kalman filters were also broadly similar. To achieve this, the procedure followed was to first fix the relative variances for the HPMV filter according to certain "rules of thumb", as described below. 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.[70]

95. The "rules of thumb" used to initialise the HPMV filter can be explained by setting out the calculation of the HPMV NAIRU series as the solution to the values of U* which minimise the following expression:

$$\sum \Big[\underbrace{\left(U_t - U_t^*\right)^2 + \lambda_1 \left(\Delta\Delta U_t^*\right)^2}_{\text{HP Filter}} + \underbrace{\lambda_2 e_t^2}_{\text{Phillips Curve}} \Big] \qquad [4]$$

69. This is a result 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.

70. 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.

where the first term represents squared deviations of the NAIRU from actual unemployment, the second term the rate of change of the NAIRU, and the final term the squared residuals from the Phillips curve equation, and where λ_1 and λ_2 are fixed weights. The first two terms correspond to a standard Hodrick-Prescott filter where λ_1 is a positive parameter which penalises variability of changes in the NAIRU relative to deviations of the NAIRU from the actual unemployment rate: the smaller is λ_1 the closer the estimated NAIRU is to the actual unemployment rate. Parameter λ_2 penalises errors in the estimated Phillips curve: the larger λ_2, the more the NAIRU is adjusted to reduce such errors and the more variable the resulting NAIRU series becomes (in a way this is analogous to increasing the signal-to-noise ratio in use of the Kalman filter).

96. A logical approach to choosing λ_1 and λ_2, is on the basis of priors about the relative variance of each of the terms in expression [4]; the higher the variance of the term the lower the weight it receives in the minimisation process. Thus, normalising by the variance of the first term ($\sigma_{\varepsilon_1}^2$ in [3a]), expression [4] can be rewritten as:

$$\sum\left[\left(U_t - U_t^*\right)^2 + \frac{\sigma_{\varepsilon 1}^2}{\sigma_{\varepsilon 2}^2}\left(\Delta\Delta U_t^*\right)^2 + \frac{\sigma_{\varepsilon 1}^2}{\sigma^2} e_t^2\right] \qquad [5]$$

Thus, λ_1 is set according to the relative variance of the unemployment gap ($\sigma_{\varepsilon_1}^2$) compared to that of changes in the NAIRU ($\sigma_{\varepsilon_2}^2$). In the present study this was chosen such that an unemployment gap of 2 percentage points was given equal weight (in probabilistic terms) to an acceleration of the NAIRU of 0.1 percentage points in the course of a single semester (the frequency used for the estimation work reported here), implying a value of λ_1 equal to 400 [i.e. $(2/0.1)^2$].[71] Parameter λ_2 was then set according to priors about the relative variance of the unemployment gap compared to that of the residuals in the Phillips curve. Thus, λ_2 was chosen such that an unemployment gap of 2 percentage points was given equal weight (in probabilistic terms) to an error in the Phillips curve of 0.5 percentage points, implying a value for λ_2 equal to 16 [i.e. $(2/0.5)^2$].[72] Further sensitivity analysis around these specific assumptions suggest that the parameters of the Phillips curve and the NAIRU series do not alter significantly for quite wide variation in λ_1 and λ_2.[73]

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71. Note, however, that for given variability in the change in the NAIRU, the larger the unemployment gap (i.e. the larger $\sigma_{\varepsilon 1}$, in the case of more cyclical economies), the larger λ_1. Also, for a given average level of unemployment gap, the smoother ΔU^* (i.e. the smaller σ_{ε_2}), the larger λ_1. Consequently, a priori, λ_1 could be chosen to be larger in the United States than in Continental European countries, since the US economy tends to be more cyclical and its structural unemployment rate is also probably smoother than in Europe.

72. Note also that for given variability in the change in U*, the better the fit of the Phillips curve (i.e. the smaller σ) the larger λ_2. For a given fit of the Phillips curve, the smoother ΔU^* (i.e. the smaller $\sigma_{\varepsilon 2}$), the larger λ_1. So countries with a "good" estimated Phillips curve and where ΔU^* tends to be more variable (i.e. U* tends to be variable around its trend), a bigger weight should *a priori* be given to λ_2.

73. Sensitivity analysis was conducted for values of λ_1 from 50 to 1000 (equivalent to a range from 200 to 4000 using quarterly data, which covers most values used in the empirical literature) and λ_2 from 1 to 50. Following Laxton and Tetlow (1992), Butler (1996) set λ_2=1; the above arguments suggest this value is too small, also giving results quite similar to a basic HP filter. Applied to semi-annual data, a value of λ_1=400 is broadly equivalent to the "industry standard value" of λ_1=1600 as applied to quarterly US GDP data by Hodrick and Prescott (1997).

2.5 End-point adjustment

97. An issue for concern when using both 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. To examine the degree of end-point sensitivity for both estimation methods, NAIRU estimates for two representative countries, 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. The corresponding revisions for the HPMV filter were about twice as large, suggesting the need for specific treatment.

98. To mitigate this end-point problem, two forms of end-point correction were applied to the HPMV filter:

- firstly, the unemployment series was augmented with 5-year medium-term projections of the unemployment rate consistent with the projections published in the most recent *Economic Outlook*.[74] Experiments using simple autoregressive forecasts suggest that adding forecast values is sufficient to bring the magnitude of the revisions for the HPMV NAIRU in line with that of the Kalman filter;

- secondly, an additional flatness criterion was applied to penalise movements in the NAIRU over the projection horizon, in order to reduce the weight put on the forecasts of the unemployment rate.[75]

Overall, this analysis suggests that particular caution needs to be attached to NAIRU estimates when the end-point is close to a cyclical turning point, but that the end-point problem for the HPMV filter NAIRU estimates can be substantially reduced by applying the above forms of end-point correction.[76]

2.6 Estimation procedures

99. 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.[77] 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 HPMV estimates and an initial NAIRU series

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74. The addition of forecast data is a well-known "solution" to the end-point problem when using the (pure) Hodrick-Prescott filter.

75. This form of adjustment was used by Laxton and Tetlow (1992). Formally, an additional term is added to the expression [4] being minimised, namely $\lambda_3 \Delta U^*_t$, but it is only included over the forecast horizon.

76. For both filters, it was sufficient to extend the truncated sample by 2 years to obtain stable estimates.

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

then estimated using the Kalman filter.[78] 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.

100. The HPMV filter estimation was based on an iterative procedure for all countries. Starting from initial values of the NAIRU, a Phillips curve was estimated using OLS. The residuals of this equation were then used to execute the HPMV filter estimation procedure, which provides a revised NAIRU series, which was then used to re-estimate the Phillips curve. This process was repeated until convergence was achieved, usually within five to ten iterations.

3. Comparative estimation results for 21 OECD countries

3.1 The estimation results

101. Following the procedures outlined in the previous section, it was possible to estimate Phillips curves and corresponding NAIRU estimates using both filter methods for all 21 OECD countries for which the OECD currently publishes NAIRU estimates. (See Tables A1, A2, Figure A1 and Figure 1 of the main paper). Largely identical Phillips curve specifications were used for both methods to ensure comparability of results.[79] Speed limit effects (ΔU terms) were tested for all countries and 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.[80]

102. 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 (Figure A2); the differences between the two NAIRU series are generally small.[81] The average absolute difference over the entire

78. 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.

79. 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.

80. 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.

81. 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.

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

103. Because an identical Phillips curve specification is used for the Kalman and HPMV filter methods, the estimation results have much in common. 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 across both methods. 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 Tables A1 and A2.[82] For the most part, the diagnostic test failures for any particular country are common to both the HPMV and Kalman filter specification. Among the G7 countries the most serious failure is that relating 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 and the aggregate unemployment rate, is needed to pass the test for structural stability.[83]

3.2 Comparing HPMV and Kalman filter estimates of the NAIRU

104. As stressed in the previous section, the key difference between the HPMV filter and the more conventional use of the Kalman filter is that the former has an anchor to the actual unemployment rate, whereas the latter gives greater weight to explaining inflation developments via the Phillips curve. This, in turn, explains many of the key differences in the estimation results.

105. Since HPMV NAIRU series is more closely centred around the actual profile of unemployment, the size of unemployment gaps (i.e. the difference between actual unemployment and the NAIRU) is typically smaller than when using the Kalman filter. For all the G7 countries, the HPMV unemployment gap remains below 3 percentage points, whereas there are a number of countries for which the Kalman filter gap estimates are occasionally as high as 4 percentage points. For the European countries, the second half of the 1960s and 1970s is more clearly a period of excess demand, and the 1980s and 1990s a period of excess supply according to the Kalman filter gap estimates. For example, for France the actual unemployment rate is at least a percentage point higher than the Kalman filter NAIRU in about fifteen of the years since 1980, whereas for the HPMV NAIRU this holds for only four years.[84]

106. A corollary to this is that the corresponding coefficients in the Phillips curve are larger with the HPMV than when using the Kalman filter. This implies that the Phillips curve estimated using the HPMV

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

83. 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.

84. The result for the Kalman filter conforms with that obtained by Irac (1999).

filter embodies smaller sacrifice ratios than for the Kalman filter: for the G7, excluding Japan, the sacrifice ratio averages just over one for the former compared with just over two for the latter.[85]

107. Not surprisingly, the fit of the estimated Phillips curve equations tends to be better using the Kalman filter than for the HPMV filter. The inclusion of both unemployment gaps in the common Phillips curve, usually leads to the rejection of the HPMV gap in favour of the Kalman filter gap: for all the G7 countries the Kalman filter gap remains statistically significant (to at least the 10 per cent level) while the HPMV gap is insignificant, confirming the relative explanatory power of the two measures.

108. However, since the Kalman filter estimates give greater weight to inflationary developments, they are also more sensitive to the specification (or misspecification) of the Phillips curve equation. This can be illustrated by examining the influence of the supply-side variables on the NAIRU estimates. Excluding the oil-price and (de-trended) import-inflation variables from the US Phillips curve equation gives NAIRU estimates which are higher in the 1970s and early 1980s, and lower in the late 1990s for both estimation approaches (Figure A3).[86] This reflects predominantly the influence of adverse supply shocks in the earlier period and predominantly beneficial supply shocks in the later period. However, the magnitude of this effect is larger for the Kalman filter than for the HPMV estimates: the average absolute effect of the supply shocks on the estimated NAIRU series over the entire estimation period is 0.7 percentage points with the Kalman filter and 0.3 percentage points using the HPMV filter. A similar example is provided by examining the effect of de-trending import inflation: in the case of the United States the NAIRU estimate is lowered by 0.9 percentage points in 1999 with the Kalman filter, but by one-quarter of a percentage point for the HPMV filter. The general point is that the relative strength or weakness of the Kalman filter approach depends on the degree of confidence in the particular form of the Phillips curve, which is adopted.

3.2.1 Analysis of specific episodes

109. Clearer insights into the economic reasons which underlie some of the key differences in the two sets of estimates are given by examining more closely those episodes where the difference between the alternative NAIRU estimates are greatest, as discussed in more detail below. The single episode where the largest difference occurs across a majority of countries is the first half of the 1980s, when restrictive macroeconomic policies were introduced across most OECD countries and priority was given to reducing inflation, leading to the most rapid OECD-wide deflation and the steepest rise in OECD-wide unemployment in post-war history.

110. For the United States, the largest difference between the two NAIRU estimates occurs during the period of tight monetary policy when consumer price inflation fell 10 percentage points between 1980 and 1983. Over this period the HPMV estimate gravitates fairly quickly towards the high level of actual unemployment, even though the principal cause of the latter is conventionally attributed to restrictive demand. Thus, the HPMV estimate reaches a sample-high of 7½ percentage points in the second half of 1982, significantly higher than suggested by most other studies using a variety of methods, at the same time as the actual unemployment rate reaches a post-war peak of over 10 percentage points.[87] Conversely,

85. Consistency with the output-related sacrifice ratio of about 3¾ which Turner and Seghezza (1999) estimate as being typical of most OECD countries, would require an Okun coefficient of between one-half and one-third.

86. In this context the effect of *excluding* an *adverse* supply shock from this Phillips curve *raises* the NAIRU estimate, because inflation is no longer being purged of the effect of the supply shock and hence the NAIRU must increase.

87. For example, Brayton *et. al* (1999), Gordon (1997) and Congressional Budget Office (1999), which estimate the NAIRU according to a variety of methods, find a value closer to 6 per cent over this period.

the Kalman filter estimate does not rise much above 6 per cent over this period, so implying a much larger unemployment gap (Table A3).

111. For other OECD countries, distinguishing between demand and supply influences on unemployment over this period is more difficult because the NAIRU was almost certainly rising through the early 1980s. Nevertheless, there is some evidence to suggest that the HPMV method may attribute much of the rise in unemployment that was caused by restrictive demand policies to a rise in the NAIRU. In particular, the rise in the HPMV estimate is strongly positively correlated with the contemporaneous rise in actual unemployment (Table A3), so that for most countries this period involves both the steepest increases in actual unemployment and the HPMV estimate over the estimation sample. By contrast the change in the Kalman filter estimate is not positively correlated (Table A3).[88] with the contemporaneous change in actual unemployment during this episode and the increases in NAIRU estimates are not exceptional compared to changes in other periods (such as the late 1970s or late 1980s). Consequently the Kalman filter NAIRU estimates are systematically lower (and unemployment gaps larger) than the HPMV estimates.[89]

112. These episodes suggest that the HPMV estimates could sometimes be misleading when there is a major shock to demand.[90] This occurs because, for a given choice of weights, the HPMV filter cannot easily distinguish between a rise in unemployment due to a demand shock and one which is due to an adverse supply shock. This could also explain why the Kalman filter NAIRU estimates are typically lower for many European countries during the period of contractionary fiscal policy of the mid- and late 1990s.

113. At first sight, the apparent pro-cyclicality of the HPMV NAIRU estimates has some intuitive appeal, particularly as it would seem to be consistent with evidence of the effects of unemployment persistence. However for the present estimates it reflects the specific choice of weights used in the HPMV filter - *a priori* it says nothing intrinsic about the method itself. On the more conceptual level, in the current framework, such persistence should be captured by the dynamic relationship between unemployment and inflation in the estimated Phillips curve and should therefore show-up in the properties of the short-term NAIRU estimates as opposed to the path of the NAIRU estimate itself.[91]

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88. To the extent that there is any correlation between changes in the Kalman filter NAIRU and changes in actual unemployment it is *negative* (although typically this is not statistically significant). A possible explanation is that in the early years of the demand shock when actual unemployment is rising most quickly there is little increase in the NAIRU, however during the later years (mid-1980s) as actual unemployment begins to stabilise the NAIRU may rise more quickly due to (partial) in this case the hysteresis effects as some unemployed workers become disconnected from the labour market and their human capital depreciates.

89. For some countries (United States, France, New Zealand and Sweden) there is additional econometric evidence suggesting that HPMV filter may tend to over-estimate the NAIRU during the episodes described above. In particular, the Phillips curve residuals are large enough to cause the failure of a test of the normality of residuals (Table A1), whilst the normality test is easily passed when the Kalman filter estimates are used with the same Phillips curve specification.

90. Another example, but related to a positive demand shock, is the period of expansionary fiscal policy in the United States during the late 1960s associated with increased armaments spending for the Vietnam war. The HPMV NAIRU falls to 4½ percentage points, much lower than suggested by most other estimates of the NAIRU.

91. As described in Box 1 of the main paper, the relationship between the short-run NAIRU and the NAIRU depends on a combination of short-term supply shocks and the dynamic relationship between unemployment and inflation.

3.3 Measures of uncertainty

114. 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.[92]

115. 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.* 1996).

116. In the present study the standard errors associated with the first two sources of uncertainty were derived for the G7 country estimates by use of Monte Carlo methods, following Hamilton (1986, 1994) (see Box A2, "Deriving estimated standard errors for the NAIRU using Monte Carlo methods" and also Boone (2000). For the full sample (see Table A4), these are found to range between 0.2 for Japan and 1 for France and the United Kingdom, and are well in line with those reported elsewhere in the recent literature.[93] Figure A4, reports the corresponding error bands and their evolution over time.

3.4 Comparing preliminary new estimates with previous OECD measures

117. Comparing these preliminary estimates with those given by the previous OECD method, the HPMV filter estimates of unemployment gaps are in many cases more closely correlated with previous estimates (see Table 1, main text, first panel).[94] This is not altogether surprising given the role played by actual unemployment in the HPMV and the conceptual basis of the previous NAWRU estimates. In particular, the average absolute magnitude of unemployment gaps according to previous estimates is more similar to the HPMV filter estimates and they are less prone to generate large or prolonged gaps, than sometimes occurs using the Kalman filter (see Table 1, main paper, second panel).

118. While the profile of the previous estimates over the full sample is more similar to that of the HPMV than the Kalman filter estimates, this does not generally hold in the most recent part of the estimation period (Table 1, main paper, third and fourth panels) where differences between the three sets of estimates for any one country rarely exceed 1 percentage point. Thus among the G7 countries: for the major European countries, the Kalman filter estimates are closer to the previous estimates than the HPMV estimates; for Japan all three estimates are similar; and for the United States the Kalman filter estimate is identical to previous estimates, whereas the HMPV estimate is ½ percentage points lower.

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92. 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.

93. 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.

94. As indicated in Box 2 of the main text, comparisons with previous OECD estimates are less straight-forward for a number of countries (including France, Italy and Germany), in part because the previous estimates are probably more closely related to a long-run NAIRU concept. For these countries the NAIRU was estimated using an HPMV filter with the deviation of the wage share from the sample average included in the Phillips curve specification. Given that the deviation of the wage share from its sample average for these countries is a long-lasting rather than temporary supply shock, the resulting NAIRU estimates correspond, within the theoretical framework of this paper, to a long-run concept which can only be realised as the NAIRU if, and when, the wage share returns to its sample average.

Box A2. **Deriving estimated standard errors for the NAIRU using Monte Carlo methods**

One of the advantages of using the Kalman filter is that a confidence interval for the estimated NAIRU can be derived as a by-product of the estimation method. This is computed from the variance/covariance matrix of the filtered estimate of the NAIRU (as written in equation [5] of Box 1 of this Annex) assuming that the estimated parameters of the state space model are known with certainty.[1] The estimated NAIRU is sensitive to the degree of uncertainty surrounding these parameters and, intuitively, the less significant they are, the more fragile the estimated NAIRU.

More formally, Hamilton (1986, 1994) shows that uncertainty surrounding the NAIRU estimate may be decomposed into two distinct elements: uncertainty coming from the filtering process (the side product of the Kalman filter) and uncertainty coming from the estimation of the parameters.[2] If $\hat{\theta}$ represents the set of estimated parameters described above, and θ_0 stands for the true parameters, the variance/covariance matrix of the estimated NAIRU $\hat{U}*$ may be decomposed as follows:

$$P_{t+1|t}[\hat{U}*(\hat{\theta})] = P_{t+1|t}[\hat{U}(\theta_0)] + E_{t+1|t}\{[\hat{U}*(\theta_0) - \hat{U}*(\hat{\theta})][\hat{U}*(\theta_0) - \hat{U}*(\hat{\theta})]'\} \qquad [1]$$

The first term on the right hand side reflects "filter uncertainty" (using Hamilton's notation), which is the mean squared errors provided by the Kalman filter. The second term reflects "parameter uncertainty", i.e. that in a typical sample, the estimated parameters $\hat{\theta}$ will not be exactly equal to the true parameters θ_0.

Hamilton (1994) suggests that a simple way to evaluate each source of uncertainty is to run a Monte Carlo study. This consists in simulating a large number of values for the set of parameters, drawn from the distribution of the originally estimated parameters, and computes the associated variance/covariance matrices. This gives an estimate of the sensitivity of the NAIRU to parameter uncertainty. More formally:

$$E_{t+1|t}\{[\hat{U}*(\theta_0) - \hat{U}*(\hat{\theta})][\hat{U}*(\theta_0) - \hat{U}*(\hat{\theta})]'\} = \frac{1}{N}\sum_{i=1}^{N} E_{t+1|t}[\hat{U}*(\theta^i) - \hat{U}*(\hat{\theta})][\hat{U}*(\theta^i) - \hat{U}*(\hat{\theta})]' \qquad [2]$$

where N is the number of draws (generally sufficiently large, such as 1000).

Then the filter uncertainty is given by:

$$P_{t+1|t}[\hat{U}(\theta)] = \frac{1}{N}\sum_{j=1}^{N} P_{t+1|t}[\hat{U}(\theta^j)] \qquad [3]$$

In the current study, the sum of [2] and [3] was taken as an estimate of the overall standard errors of the NAIRU estimates around their true values, as written in [1].

1. Implicitly, the size of the estimated standard errors also depends on the smoothness of the NAIRU estimates and, therefore, the chosen signal-to-noise ratio.
2. Hamilton (1986, 1994) shows that the cross product combining the two sources of uncertainty is zero.

Table A1. **Estimated Phillips curves and diagnostic tests using the Kalman filter**

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

	United States		Japan[a]		Germany		France		Italy		United Kingdom		Canada	
Sample	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[c]	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[d] *(p-values reported)*														
Chow forecast test[e]	0.76		0.99		0.87		1.00		0.97		0.99		0.80	
RESET test[f]	0.23		0.14		0.07		0.91		**0.05**		0.11		0.21	
Serial correlation[g]	0.21		**0.02**		0.10		0.10		0.19		0.88		0.53	
Normality[h]	0.97		0.71		0.20		**0.01**		0.65		0.23		0.27	
Chow breakpoint[i]	**0.02**		0.81		**0.00**		0.14		0.26		0.16		0.13	

See notes.

Table A1 (continued). **Estimated Phillips curves and diagnostic tests using the Kalman filter**

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

	Australia[b]		Austria[b]		Belgium[b]		Denmark		Finland[b]		Greece		Ireland	
Sample	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[c] *(p-values reported)*														
Chow forecast test[d]	0.84		**0.00**		0.76		0.94		0.78		0.67		0.91	
RESET test[e]	**0.03**		0.45		0.35		0.91		0.30		0.13		0.42	
Serial correlation[f]	0.81		0.16		0.51		0.10		0.84		0.48		0.90	
Normality[g]	0.88		**0.01**		0.77		0.32		0.58		0.80		0.87	
Chow breakpoint[h]	0.25		0.23		0.07		0.78		0.14		0.42		0.51	

See notes.

Table A1 (continued). **Estimated Phillips curves and diagnostic tests using the Kalman filter**

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

	Netherlands		New Zealand		Norway		Portugal		Spain[b]		Sweden		Switzerland	
Sample	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)**
Δ U									-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[c] *(p-values reported)*														
Chow forecast test[d]	0.96		0.97		0.98		0.74		0.97		0.85		0.17	
RESET test[e]	0.24		0.72		0.71		0.29		0.08		0.28		0.27	
Serial correlation[f]	0.19		0.41		0.10		0.19		0.88		0.58		0.74	
Normality[g]	0.38		0.29		0.72		0.88		0.39		0.58		0.99	
Chow breakpoint[h]	0.73		0.57		0.49		**0.01**		0.14		0.39		0.17	

See notes.

Table A2. **Estimated Phillips curves and diagnostic tests using the HPMV filter**

Estimation method: Multi-variate Hodrick Prescott filter
Dependent Variable is $\Delta\pi$.

	United States		Japan[a]		Germany		France		Italy		United Kingdom		Canada	
Sample	62:2 to 99:2		64:1 to 99:1		62:2 to 99:1		65:2 to 99:2		62:2 to 99:1		63:1 to 99:1		63:1 to 99:1	
Dynamics														
$\Delta\pi_{-1}$	-0.32	(3.0)	-0.30	(3.0)	-0.37	(4.1)	-0.26	(2.1)	-0.06	(0.6)	-0.37	(5.8)	-0.18	(2.0)
$\Delta\pi_{-2}$	-0.25	(2.6)	-0.40	(5.5)			-0.05	(0.4)	-0.32	(4.2)	-0.32	(4.6)	-0.25	(3.1)
$\Delta\pi_{-3}$			-0.23	(2.9)			-0.20	(1.9)			-0.26	(4.3)		
$\Delta\pi_{-5}$			-0.19	(2.8)										
Unemployment														
U-U*	**-0.26**	**(4.8)**	**-1.32**	**(5.4)**	**-0.34**	**(5.6)**	**-0.34**	**(2.9)**	**-0.47**	**(3.5)**	**-0.47**	**(5.8)**	**-0.42**	**(6.8)**
Δ U									-0.39	(1.5)	-0.09	(0.5)		
Δ (U^{North} - U)									-1.31	(2.8)				
Import prices														
$\omega_{-1}(\pi^m-\pi_{-1})_{-1}$	1.21	(3.8)	1.34	(4.3)	0.39	(2.8)	0.59	(2.4)	0.69	(2.9)	0.49	(2.7)	0.46	(3.4)
$\omega_{-1}\Delta\pi^m$	0.66	(2.2)	0.54	(2.0)	0.30	(2.1)	0.33	(1.4)	0.76	(4.4)	0.18	(1.3)	0.21	(1.8)
$\omega_{-1}\Delta\pi^m_{-1}$			-0.67	(2.3)									-0.15	(1.2)
$\omega_{-1}\Delta\pi^m_{-2}$														
Oil prices														
$\nu_{-1}(\pi^o-\pi_{-1})_{-1}$											0.16	(1.4)		
$\nu_{-1}\Delta\pi^o$	0.06	(5.4)	0.12	(2.1)	0.10	(3.5)	0.12	(2.2)	0.13	(3.2)	0.09	(1.2)		
$\nu_{-1}\Delta\pi^o_{-1}$	0.05	(4.0)	0.13	(2.8)					0.19	(4.6)	-0.19	(2.2)		
$\nu_{-1}\Delta\pi^o_{-2}$														
NAIRU in 99:1	4.8		3.9		8.8		10.6		11.1		6.5		8.1	
Sacrifice Ratio	1.5		0.4		1.0		1.1		0.7		1.0		0.9	
Standard error	*0.31*		*0.60*		*0.34*		*0.62*		*0.63*		*0.57*		*0.42*	
R^2	*0.68*		*0.76*		*0.51*		*0.44*		*0.70*		*0.85*		*0.62*	
adjusted-R^2	*0.64*		*0.71*		*0.48*		*0.37*		*0.66*		*0.81*		*0.58*	
Diagnostic tests[c] *(p-values reported)*														
Chow forecast test[d]	0.79		0.99		0.91		0.99		0.99		0.99		0.76	
RESET test[e]	0.13		0.08		0.77		0.85		**0.04**		0.41		0.11	
Serial correlation[f]	0.15		**0.00**		0.06		0.88		0.26		0.96		0.14	
Normality[g]	0.62		**0.04**		0.58		**0.00**		0.95		**0.00**		**0.00**	
Chow breakpoint[h]	**0.03**		0.86		**0.00**		0.49		0.22		**0.04**		**0.03**	

See notes.

Table A2 (continued). **Estimated Phillips curves and diagnostic tests using the HPMV filter**

Estimation method: Multi-variate Hodrick Prescott filter
Dependent Variable is $\Delta\pi$.

	Australia		Austria		Belgium[b]		Denmark		Finland		Greece		Ireland	
Sample	66:2 to 99:1		66:2 to 99:1		71:1 to 99:1		66:2 to 99:1		66:2 to 99:1		66:2 to 99:1		77:2 to 99:1	
Dynamics														
$\Delta\pi_{-1}$	-0.59	(7.0)	-1.00	(9.0)	0.09	(0.9)	-0.52	(4.4)	-0.66	(6.8)			-0.05	(0.3)
$\Delta\pi_{-2}$			-0.53	(4.6)	-0.48	4.99	-0.40	(3.9)	-0.26	(2.7)	-0.34	(4.6)		
$\Delta\pi_{-3}$			-0.30	(3.1)										
Unemployment														
U-U*	**-0.39**	**(4.5)**	**-0.92**	**(4.9)**	**-2.16**	**(3.7)**	**-0.28**	**(2.8)**	**-0.40**	**(3.9)**	**-0.72**	**(5.9)**	**-0.29**	**-(2.5)**
Δ U														
Import prices														
$\omega_{-1}(\pi^m-\pi_{-1})_{-1}$	0.86	(4.3)	0.51	(1.6)	0.39	(3.9)	0.33	(1.4)	1.50	(4.4)	1.54	(8.4)	0.32	(2.6)
$\omega_{-1}\Delta\pi^m$	0.58	(4.0)	0.49	(2.2)	0.27	(3.1)	0.67	(3.1)	0.34	(1.6)	1.00	(7.5)		
$\omega_{-1}\Delta\pi^m_{-1}$							0.41	(1.9)						
Oil prices														
$\nu_{-1}(\pi^o-\pi_{-1})_{-1}$			0.33	(4.1)	0.02	(0.5)								
$\nu_{-1}(\pi^o-\pi_{-1})_{-2}$														
$\nu_{-1}\Delta\pi^o$			0.18	(3.0)	0.06	(2.6)	0.11	(2.3)			0.13	(4.2)		
$\nu_{-1}\Delta\pi^o_{-1}$	0.10	(4.0)							0.22	(4.3)			0.26	(3.0)
NAIRU in 99:1	7.4		6.0		8.8		6.8		11.1		9.7		7.2	
Sacrifice Ratio	1.0		0.8		0.2		1.7		1.2		0.5		0.9	
Standard error	*0.58*		*0.53*		*0.45*		*0.68*		*0.97*		*0.66*		*0.98*	
R^2	*0.69*		*0.66*		*0.73*		*0.54*		*0.75*		*0.74*		*0.28*	
adjusted-R^2	*0.66*		*0.62*		*0.69*		*0.49*		*0.72*		*0.72*		*0.22*	
Diagnostic tests[c] *(p-values reported)*														
Chow forecast test[d]	0.94		**0.00**		0.80		0.96		0.97		0.86		0.99	
RESET test[e]	0.10		0.35		0.61		0.81		0.73		0.09		0.53	
Serial correlation[f]	0.66		0.07		0.55		0.15		0.17		0.42		0.28	
Normality[g]	0.30		0.16		0.82		0.10		0.20		0.66		0.57	
Chow breakpoint[h]	0.16		0.37		0.36		0.64		0.31		0.42		0.19	

See notes.

Table A2 (continued). **Estimated Phillips curves and diagnostic tests using the HPMV filter**

Estimation method: Multi-variate Hodrick Prescott filter
Dependent Variable is $\Delta\pi$.

	Netherlands		New Zealand		Norway		Portugal		Spain[b]		Sweden[b]		Switzerland	
Sample	72:1 to 99:1		80:1 to 99:1		66:2 to 99:1		70:2 to 99:1		67:1 to 99:1		67:1 to 99:1		78:1 to 99:1	
Dynamics														
$\Delta\pi_{-1}$	-0.64	(6.3)	-0.46	(4.8)	-0.98	(10.7)	0.05	(0.4)	-0.56	(5.1)	-0.98	(8.4)	-0.51	(3.9)
$\Delta\pi_{-2}$					-0.39	4.52	-0.40	(4.7)	-0.23	(2.2)	-0.40	(3.2)	-0.49	(4.3)
$\Delta\pi_{-3}$									-0.51	(5.1)	-0.31	(3.0)		
Unemployment														
U-U*	**-0.22**	**(3.4)**	**-0.76**	**(6.5)**	**-1.15**	**(4.0)**	**-0.47**	**(4.1)**	**-2.57**	**(5.5)**	**-3.23**	**(5.2)**	**-1.00**	**(3.6)**
Δ U									-0.39	(3.2)				
Import prices														
$\omega_{-1}(\pi^m-\pi_{-1})_{-1}$	0.31	(2.6)	1.30	(6.5)	0.39	(2.1)	0.37	(2.2)	1.25	(4.0)	1.30	(4.3)		
$\omega_{-1}\Delta\pi^m$	0.13	(1.2)	0.58	(4.7)			0.72	(5.1)	0.84	(3.0)	0.90	(3.9)		
$\omega_{-1}\Delta\pi^m_{-1}$			0.44	(3.1)										
Oil prices														
$\nu_{-1}(\pi^o-\pi_{-1})_{-1}$							0.12	(2.4)					0.64	(4.9)
$\nu_{-1}(\pi^o-\pi_{-1})_{-2}$					0.47	(4.2)								
$\nu_{-1}\Delta\pi^o$							0.14	(3.9)					0.49	(5.4)
$\nu_{-1}\Delta\pi^o_{-1}$														
NAIRU in 99:1	4.2		6.0		3.5		5.4		16.2		6.0		2.9	
Sacrifice Ratio	1.9		0.5		0.5		0.7		0.2		0.2		0.5	
Standard error	*0.52*		*0.64*		*1.07*		*0.79*		*0.84*		*1.13*		*0.55*	
R^2	*0.65*		*0.84*		*0.72*		*0.74*		*0.57*		*0.64*		*0.65*	
adjusted-R^2	*0.63*		*0.82*		*0.70*		*0.70*		*0.52*		*0.61*		*0.61*	
Diagnostic tests[c] *(p-values reported)*														
Chow forecast test[d]	0.96		0.90		0.99		0.72		0.86		0.96		0.96	
RESET test[e]	0.71		0.55		0.51		0.27		**0.00**		0.81		0.99	
Serial correlation[f]	0.55		0.50		**0.04**		0.20		0.78		0.24		0.31	
Normality[g]	0.46		**0.00**		0.69		0.73		0.16		**0.00**		0.50	
Chow breakpoint[h]	0.46		0.60		0.49		**0.01**		0.39		0.39		0.24	

See notes.

Notes to Tables A1 and A2

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 either the Kalman or HPMV filter.

π^m = inflation rate of the detrended non-oil import price of goods and services. Import prices were detrended 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.

Footnotes:

a) 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 percent 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) in the case of the equation estimated with the Kalman filter; and to -0.70 (from -1.32) in the case of the equation estimated with the HPMV filter.

b) 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, and for Belgium, Spain and Sweden in the equation estimated with the HPMV 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.

c) The p-values of the diagnostic tests are reported. Failures at the 5 per cent significance level are highlighted in bold.

d) Chow forecast test from 1995:1.

e) Ramset reset test of functional form based on the inclusion of squared and cubed fitted values.

f) Breusch-Godfrey Lagrange-Multiplier test for up to second order serial correlation of the residuals.

g) Jarque-Bera test for normality of residuals.

h) 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

Table A3. **Differences in NAIRU estimates during the disinflation of the early 1980s**[1]

Country	Period	Fall in consumer price inflation (percentage points)	HPMV estimate		Kalman filter estimate		Correlation between changes in the unemployment rate and changes in the NAIRU estimates[2]	
			Maximum gap	Average gap	Maximum gap	Average gap	HPMV estimates	Kalman filter estimates
United States	1980-83	6.5	2.1	1.1	3.8	2.6	0.88*	-0.06
Germany	1980-86	6.4	1.5	0.6	2.8	1.6	0.86*	-0.74
France	1980-86	10.4	1.4	0.8	3.7	2.5	0.15	-0.22
United Kingdom	1980-86	12.1	2.1	1.3	5.1	3.7	0.53*	-0.61
Canada	1980-85	6.3	2.0	0.6	2.7	0.9	0.49	-0.50
Austria	1980-86	4.4	0.7	0.3	1.4	1.0	0.54*	-0.14
Belgium	1980-86	6.8	0.9	0.4	5.1	4.1	0.45	-0.49
Denmark	1980-86	7.9	2.0	0.7	3.4	1.6	0.91*	-0.24
Ireland	1981-87	17.2	2.0	1.1	4.0	2.3	0.70*	-0.48
Netherlands	1980-86	6.5	3.1	0.9	4.4	2.0	0.82*	0.39
New Zealand	1980-84	10.7	1.4	0.3	2.6	1.0	0.64*	-0.55
Spain	1980-87	10.0	2.5	1.7	6.4	4.3	0.82*	0.04

1. For all countries listed, the maximum difference between the alternative NAIRU estimates occurs during this period.
2. "*" denotes that the correlation coefficient is significantly greater that zero at the 5 per cent level.

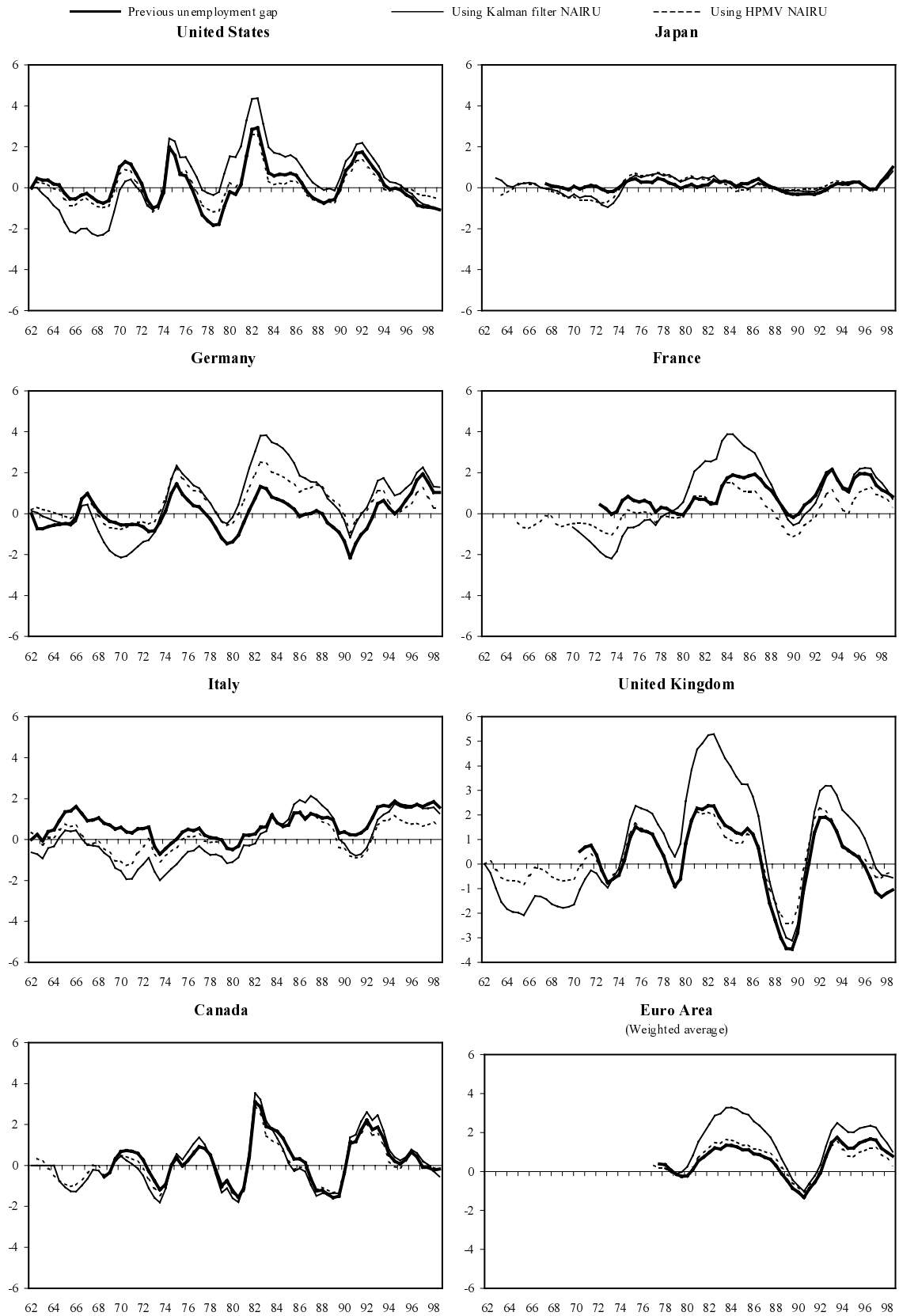
Table A4. **Estimated standard errors for Kalman filter estimates**

	Full sample	1980:1-	1990:1-	1995:1-	Value in 1999:1[a]
United States					
Average NAIRU	5.7	5.5	5.4	5.4	5.2
Standard Error[b]	0.9	0.9	0.9	1.0	1.2
Japan					
Average NAIRU	2.1	2.6	2.9	3.4	3.9
Standard Error[b]	0.2	0.2	0.2	0.2	0.3
Germany					
Average NAIRU	4.0	5.9	7.0	7.5	7.8
Standard Error[b]	0.7	0.7	0.7	0.8	1.0
France					
Average NAIRU	7.2	8.4	10.1	10.2	10.1
Standard Error[b]	1.1	1.2	1.2	1.3	1.7
Italy					
Average NAIRU	7.0	8.8	9.8	10.2	10.4
Standard Error[b]	0.7	0.7	0.7	0.8	0.9
United Kingdom					
Average NAIRU	5.4	7.2	7.2	6.7	6.7
Standard Error[b]	1.1	1.1	1.1	1.2	1.5
Canada					
Average NAIRU	7.8	9.1	8.9	8.8	8.5
Standard Error[b]	0.5	0.5	0.5	0.6	0.8

a) For the United States and France, the final NAIRU is for 1999:2.

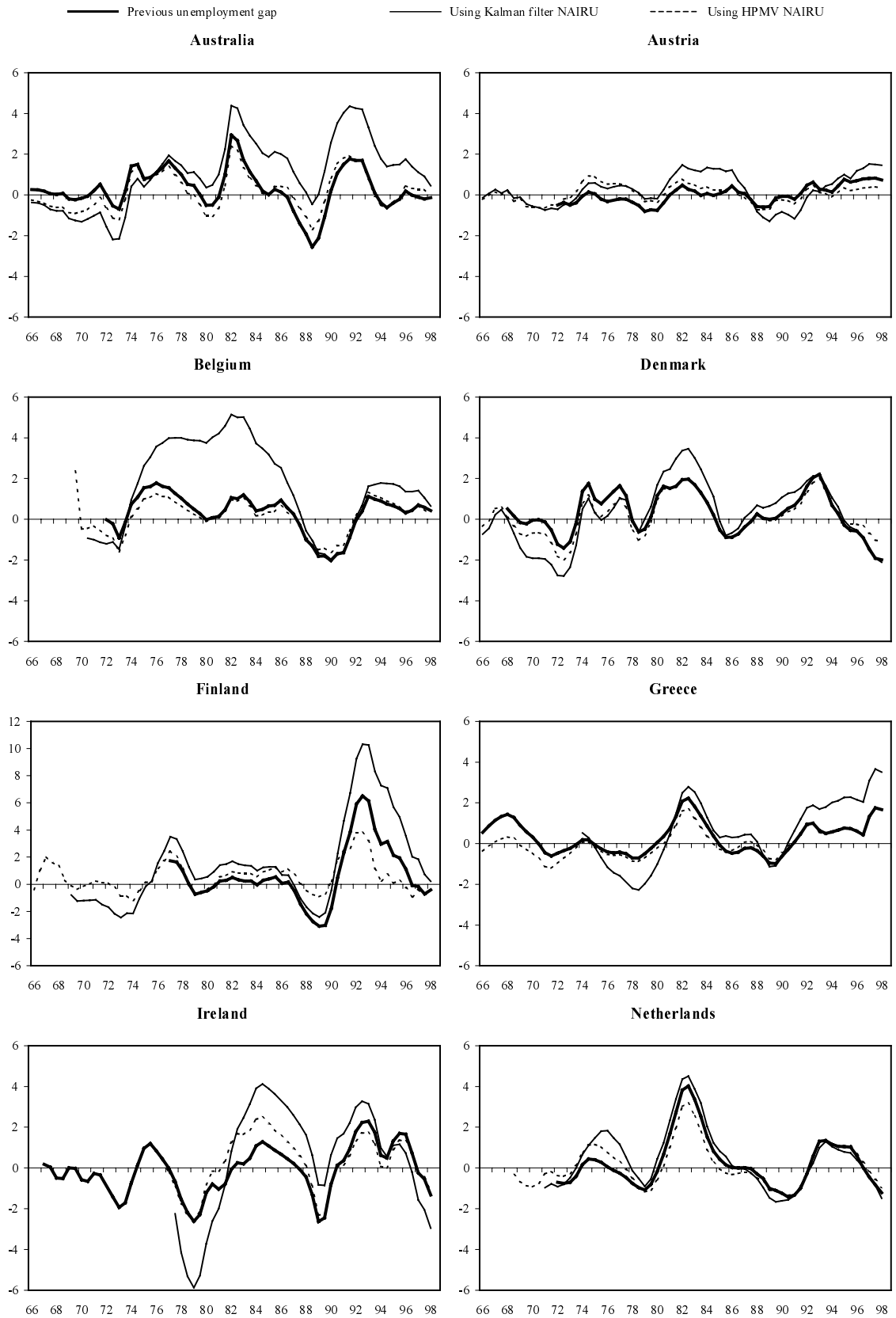
b) Average standard errors were derived using Monte Carlo methods, as described in Box 2, using 1000 iterations.

Figure A1. **Revised and previous estimates of the unemployment gaps**



Note: For most countries a common scale has been imposed to aid comparability, but exceptions are Finland and Spain.

Figure A1 (continued). **Revised and previous estimates of the unemployment gaps**



Note: For most countries a common scale has been imposed to aid comparability, but exceptions are Finland and Spain.

Figure A1 (continued). **Revised and previous estimates of the unemployment gaps**

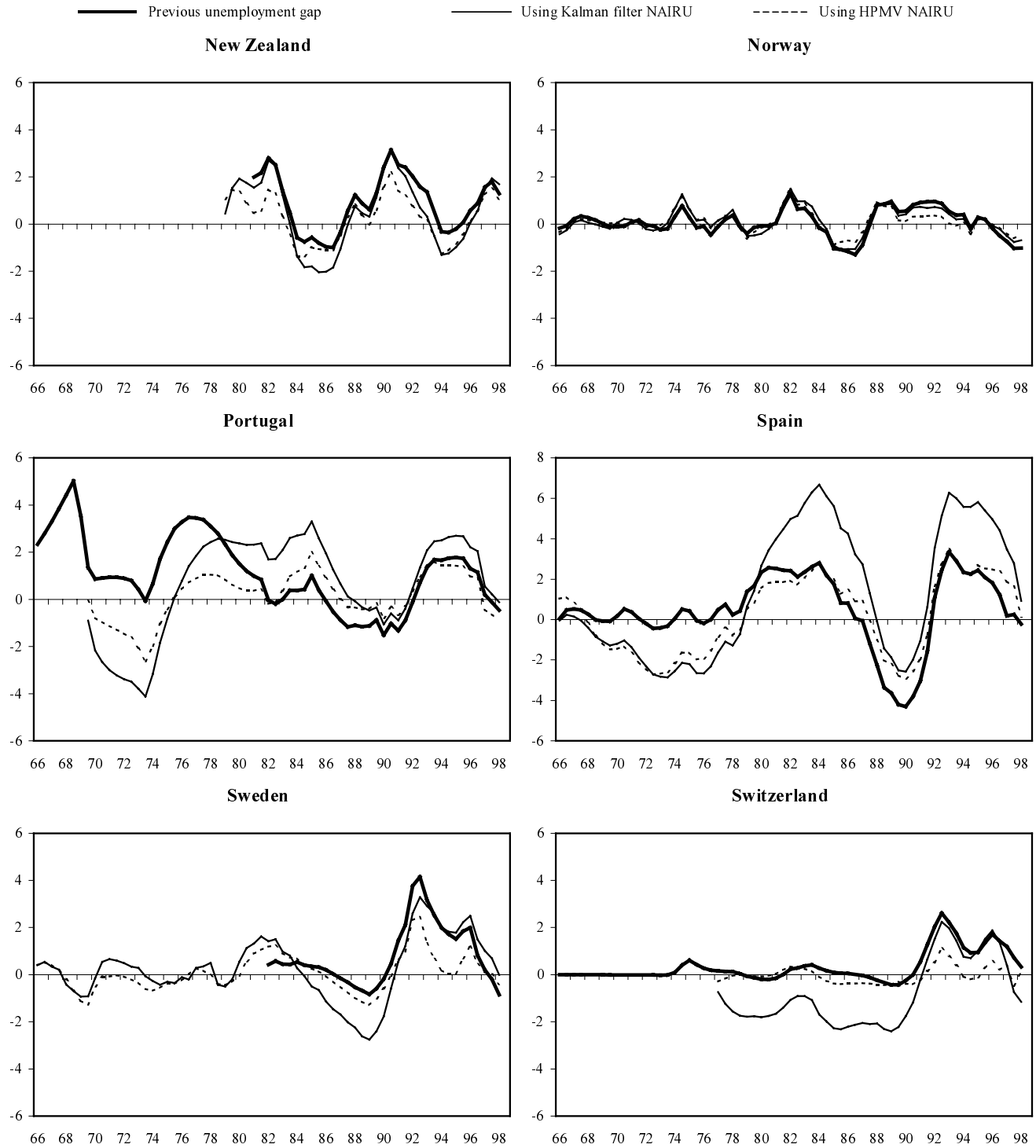


Figure A2. **Comparison of random walk and autoregressive Kalman Filter estimates**

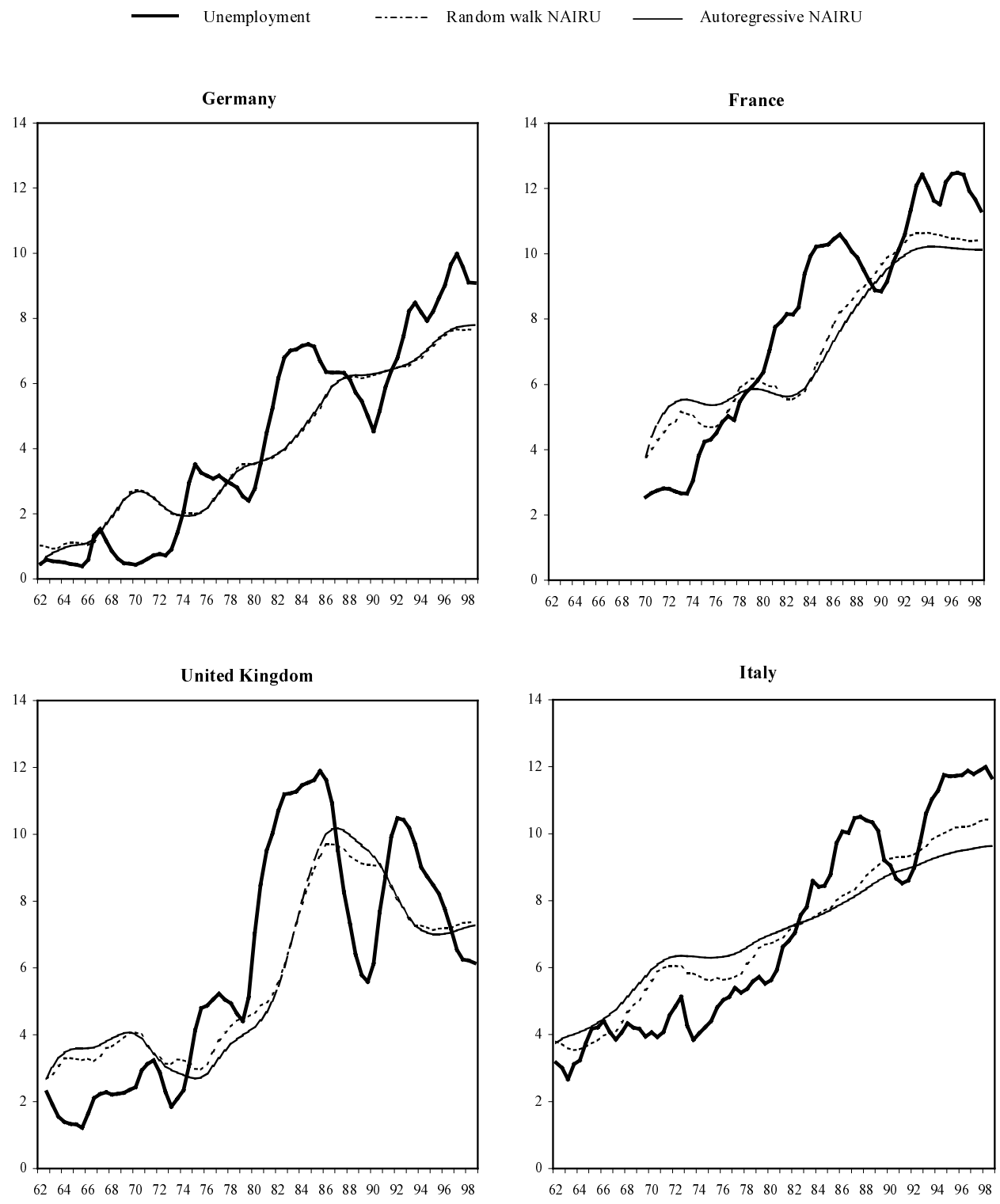
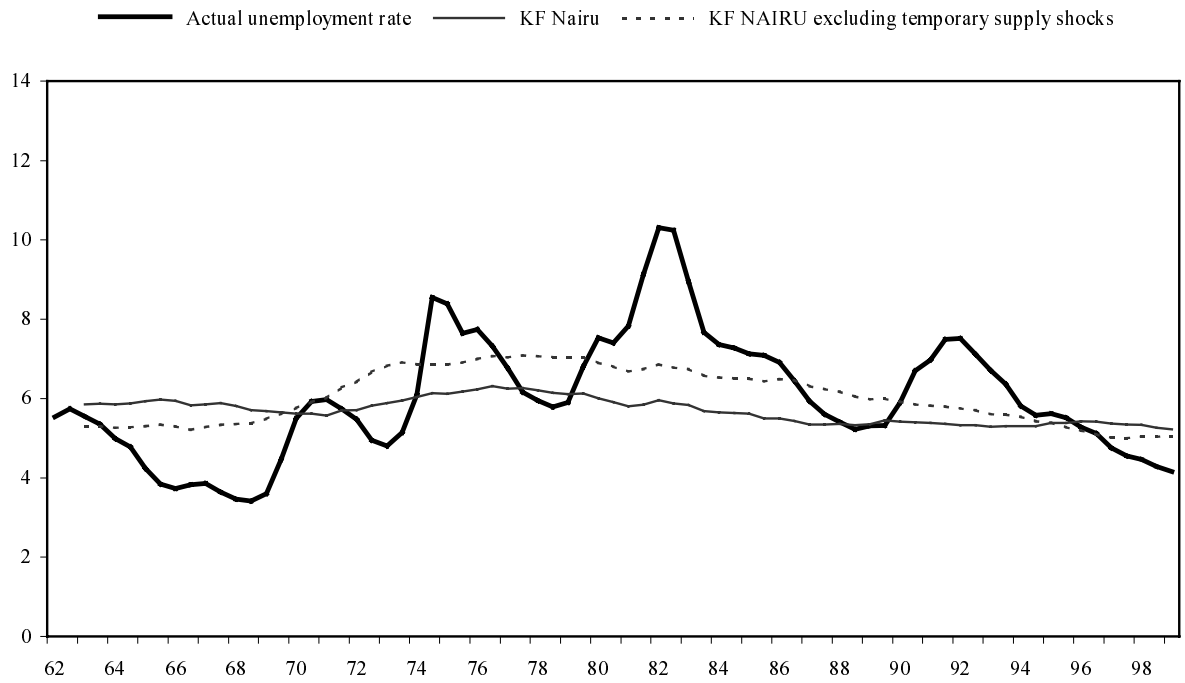


Figure A3. **Examining the influence of supply side shocks**

United States - Effects of supply-side variables on Kalman Filter NAIRU



United States - Effects of supply-side variables on HPMV Filter NAIRU

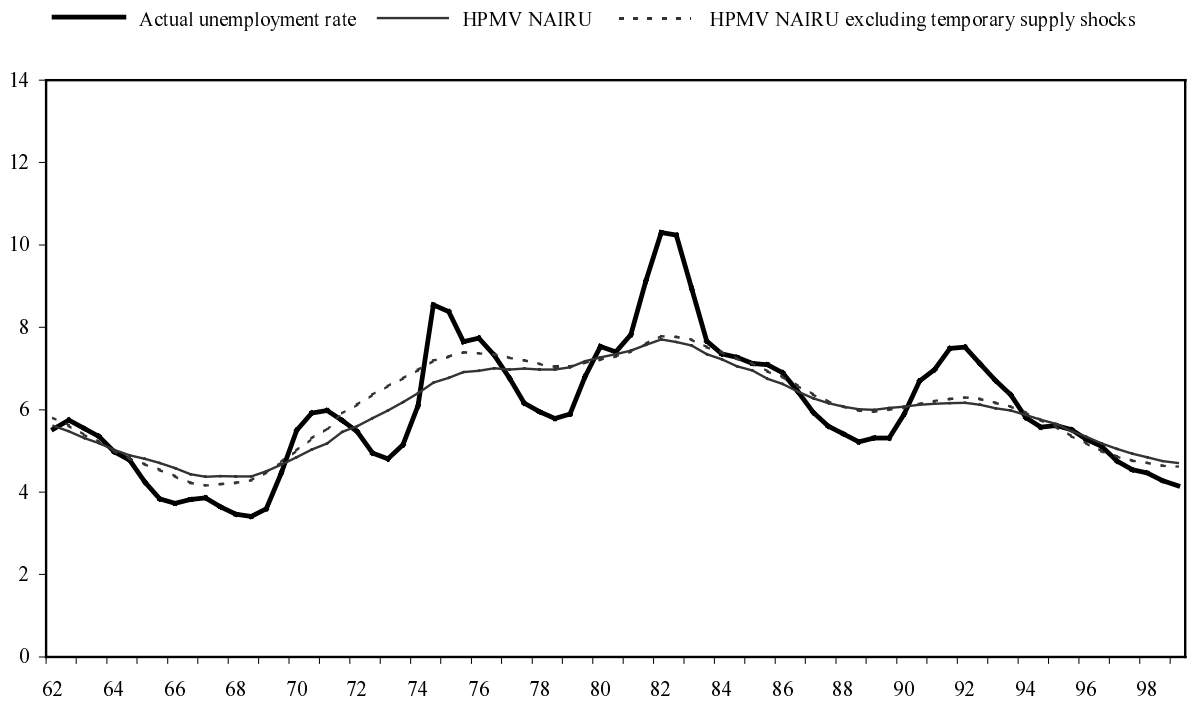
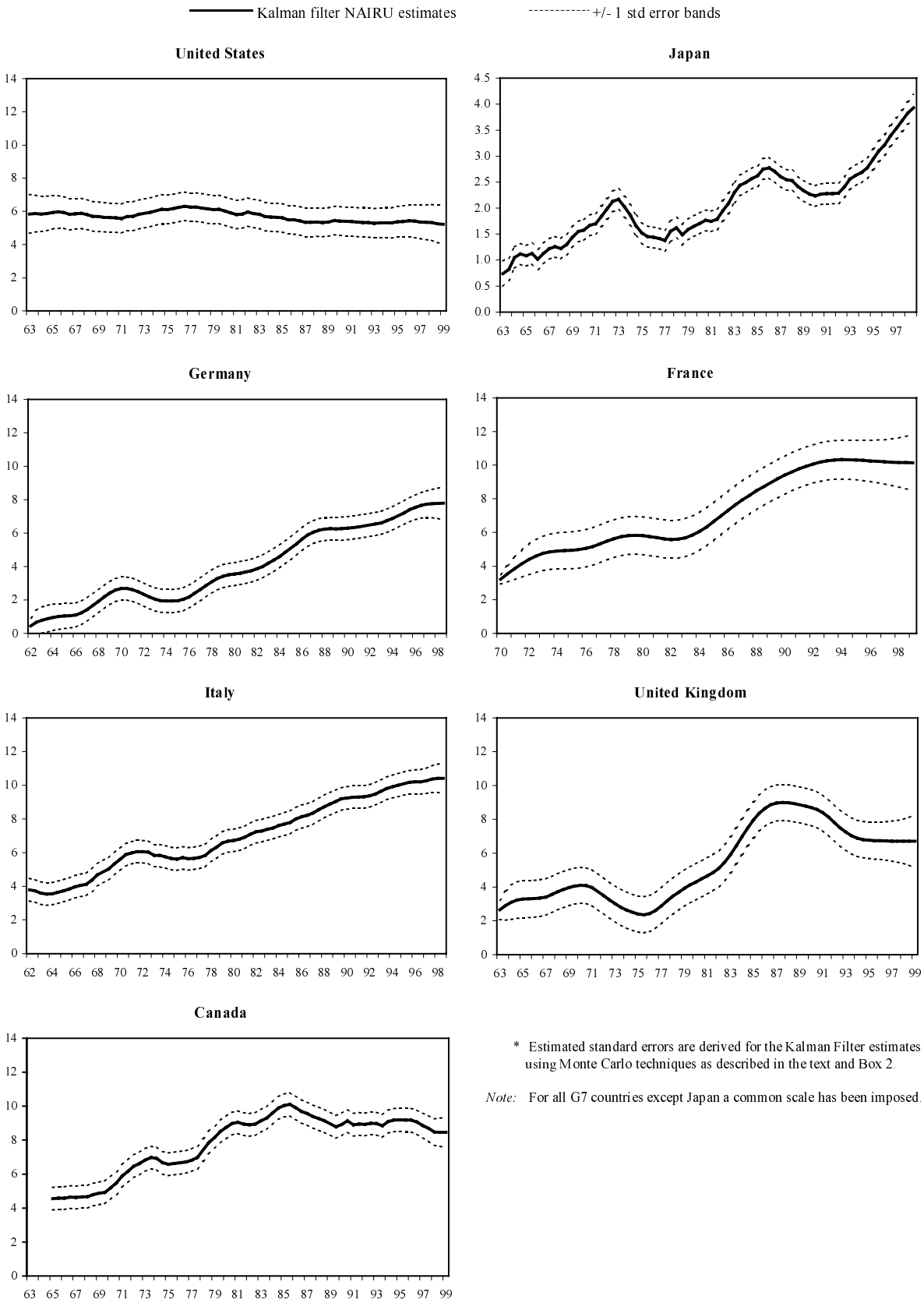


Figure A4. **Estimated error bands for Kalman filter NAIRU estimates ***



* Estimated standard errors are derived for the Kalman Filter estimates using Monte Carlo techniques as described in the text and Box 2.

Note: For all G7 countries except Japan a common scale has been imposed.

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