I) Title: Non-Accelerating Inflation Rate of Unemployment

II) Contents: NAIRU, Application

III) Documentation:

- Ball, Laurence, Mankiw, Gregory N. (2002). The NAIRU in Theory and Practice. Jounal of economic Perspectives. Vol. 16
- Gordon, Robert J. (1997). The Time-Varying NAIRU and its Implications for Economic Policy. *The Journal of Economic Perspectives*. Vol. 11
- Greenslade, Jennifer V., Pierse, Richard G., Saleheen, Jumana. (2003). A Kalman filter approach to estimating the UK NAIRU. *Bank of England Working Paper*s. No. 179

In German:

- Franz, Wolfgang. (2001). News from the NAIRU? / Neues von der NAIRU? *Jahrbücher für Nationalökonomie und Statistik*, Vol. 221/3

Working Title: Model Uncertainty

Table of contents:

1. Introduction

The link between money supply, inflation and unemployment has been observed already long time ago. David Hume wrote in his 1572 essay “Of Money”: “It is easy to trace the money in its progress through the whole commonwealth; where we shall find that is must first quicken the diligence of every individual, before it increases the price of labour.” Some time later, in 1926, Irving Fisher wrote about “A statistical Relation between Unemployment and Price Changes”. This idea was again taken up by Alban William Phillips in 1958 who found a statistical relationship between unemployment and the rate of change of money wage rates in the United Kingdom from 1861-1957. Paul Samuelson and Robert Solow (1960) coined the term “Phillips curve” for this negative relationship between unemployment and inflation. In this very same context, Milton Friedman (1968) introduced the term “natural rate of unemployment” which we nowadays also call **N**on-**A**ccelerating **I**nflation **R**ate of **U**nemployment (NAIRU).
In the past, some doubts about the validity of this trade-off between inflation and unemployment have been uttered. Nowadays, however, there is agreement about the basic idea that (at least in the short run) monetary fluctuations push inflation and unemployment in opposite directions. In contrast to this agreement, economists have not yet reached a

consensus about why this trade-off arises. We haven't found a satisfying answer to why the classical theory (money is neutral) fails to hold in this case. All proposed explanations – imperfect information, long-term labour contracts, costs of price adjustment, or departures from full rationality – are based on the idea of some market imperfection.

2. From the Phillips curve to the triangle model

The simplest way of expressing a Phillips curve is

(1) $\pi = k - aU$

where π stands for inflation, U for unemployment, and k and a are parameters with $a > 0$. Phillips observed this stable relationship for the UK from 1861-1957 (he actually fitted a non-linear curve). Unfortunately this nice and simple relationship did not remain stable very much longer and observations since the early 1970s showed that one could no longer maintain this hypothesis. For the period after 1970 one could even observe a slightly positive relationship! Samuelson and Solow had already mentioned in 1960 that this short run relationship between wages and unemployment might shift over time.

The contributions from Friedman (1968) and Phelps (1967, 1968) made clear that expected inflation played an important role in the determination of actual inflation. The short run non-neutrality of money implies that an increase in expected inflation leads to an increase in actual inflation. We should therefore include inflation expectations in the Phillips curve to get what is often called the "expectations-augmented Phillips curve"

(2) $\pi = \pi^e - a\left(U - U^*\right)$

where π^e stands for the expected inflation and U^* is called the „natural rate of unemployment", which is the rate of unemployment that prevails when inflation expectations are confirmed. The parameter U^* has a similar function to k in equation (1) in that it captures all shifts in the inflation-unemployment relationship other than changes in expected inflation.

Assuming rational expectations, U^* can be interpreted as the unemployment rate the economy will eventually reach in the long run. This interpretation can be justified by observing that rational expectations are by assumption not biased and we can therefore expect to have $\pi^e = \pi$ in the long run and thus $U = U^*$. In allusion to the term "output gap" one often calls $\left(U - U^*\right)$ "unemployment gap".

It is a common practice to distinguish different types of shocks that shift the Phillips curve. So far, we only explicitly specified inflation expectations, but all other shocks were represented by shifts in U^*. Now we introduce the distinction between supply shocks z and the natural rate of unemployment U^*:

(3) $\pi = \pi^e - a\left(U - U^*\right) + z$

The distinction between z and U^* may seem somewhat arbitrary but z is supposed to reflect disruptions in the normal inflation process that can for example be caused by significant changes in oil prices or developments of the exchange rate, whereas "the natural rate U^* is thought to reflect how well the labour market matches workers and jobs. It is altered, for instance, by changes in demographics or labour-market institutions and is thought to move slowly over time." (Ball Mankiw 2002).

Gordon (1997) goes one step further and generalizes (3) in order to obtain his "triangle model" of inflation:

(4) $\pi_t = a(L)\pi_{t-1} + b(L)D_t + c(L)z_t + e_t$

The inflation rate π_t is explained in function of lagged values of itself $a(L)\pi_{t-1}$, of present and lagged values of excess demand $b(L)D_t$, of present and lagged values of supply shocks $c(L)z_t$ and of a stochastic error term e_t. The name "triangle model" comes from the fact of including three basic determinants of inflation: inertia π_{t-1}, demand D_t and supply z_t.

In a general context, equation (4) is also a Phillips curve, since it represents a relation between a rate of change of a nominal price (π_t) and the level of a real indicator (D_t, z_t).

Note that despite the assumption of rational expectations we made in (3), Gordon implemented adaptive expectations – i.e. $\pi_t^e = a(L)\pi_{t-1}$ – in (4), which can be justified by the fact that inflation seems to have followed a random walk during the last 40 years (if π_t follows a random walk, then rational expectations = adaptive expectations).

Gordon suggests using either the output gap, or the unemployment gap or the rate of capacity utilization as proxies for excess demand D_t. For our purposes we will use the unemployment gap as a proxy:

(5) $\pi_t = a(L)\pi_{t-1} - b(L)(U_t - U^*) + c(L)z_t + e_t$

Having developed equation (5) we can now also see the subtle difference that can arise between the natural rate of unemployment and different definitions of the NAIRU. Let us first assume that there are no supply shocks and rewrite (5) as

(6) $\pi_t = d + a(L)\pi_{t-1} - b(L)U_t + e_t$

where $d = b(1)U^*$.

If inflation is to be non-accelerating we need $\pi_t = \pi_{t-1}$ and therefore that the sum of the coefficients of the lag operator on π_{t-1} is one, i.e. $a(1) = 1$. This condition ensures what is sometimes called "dynamic homogeneity". We can then solve (6) for the "no-shock-non-accelerating rate of unemployment", which is in this case equal to the natural rate of unemployment:

$U^{NS} = \dfrac{d}{b(1)} = U^*$ where NS stands for **N**o **S**hock ($z_t = 0$).

If we drop the assumption of absence of supply shocks but still retain the $a(1) = 1$ assumption we get a NAIRU different from the natural rate of unemployment:

$$U^S = \frac{d + c(L)z_t}{b(1)} = U^* + \frac{c(L)z_t}{b(1)}.$$

The monetary policy implications of the difference between U^{NS} and U^S can be shown by the example of a positive oil price shock $z_t > 0$: U^{NS} suggests that the central bank need not react to the shock, whereas U^S implies that the central bank should react by a tightening monetary policy which would result in increased unemployment, which is consistent with an increased shock-NAIRU U^S.

In general, we are more interested in the no-supply-shock NAIRU (U^{NS}) because U^S exhibits highly frequent jumps in function of the occurrence of supply shocks. This too "active" and spiky behaviour is not coherent with the concept of the natural rate of

unemployment as it has been introduced above. One often calls U^S the short-run NAIRU which will tend over time – when the shocks have been washed out – to the long-run NAIRU U^{NS}.
For the rest of this discussion we will retain the concept of the no-supply-shock NAIRU and use the terms neutral rate of unemployment and NAIRU interchangeably for it.

The attentive reader may have noticed the switch to time indexed variables that happened when going from equation (3) to equation (4). It is obvious that inflation, unemployment and supply shocks vary in function of time, but what about the NAIRU?
There are no a priori reasons why the NAIRU should not be able to fluctuate over time. Coming up with sound explanations for why it might fluctuate is harder. Several arguments have been proposed to justify changes in the NAIRU – e.g. hysteresis (failure to return to previous state after some shock), demographics, changes in government policies, openness to trade, job matching, productivity acceleration – but the reader is referred to Ball and Makiw 2002 for a more detailed discussion of those suggested reasons.

3. Estimating the time invariant NAIRU

Let us first assume that the NAIRU does not vary over time. Consider regression
(7) $\pi_t = d + a(L)\pi_{t-1} - b(L)U_t + c(L)z_t + e_t$
where the constant is $d = b(1)U^*$. Equation (7) can be seen as a particular case of (5).
In order to obtain consistent estimates with OLS we need that unemployment is contemporaneously uncorrelated with the supply shocks and that U^* is time invariant. Note however, that the former assumption is questionable and does not stand on solid ground.
Recall that when we derived the no-shock NAIRU we required that $a(1)=1$. This condition should of course be satisfied by the coefficient estimates $\sum_{i=1}^{p}\hat{a}_i = 1$. This result can be guaranteed by either explicitly restricting the $a(L)$ coefficients in regression (7) to form a sum equal to one or by rewriting (7) in first differences of inflation in order to implicitly impose dynamic homogeneity:
(8) $\Delta\pi_t = d + a(L)\Delta\pi_{t-1} - b(L)U_t + c(L)z_t + e_t$
[Proof:
$\Delta\pi_t = d + a_1\Delta\pi_{t-1} + a_2\Delta\pi_{t-2} - b(L)U_t + c(L)z_t + e_t$
$\pi_t - \pi_{t-1} = d + a_1\pi_{t-1} - a_1\pi_{t-2} + a_2\pi_{t-2} - a_2\pi_{t-3} + \ldots + e_t$
$\pi_t = d + (1+a_1)\pi_{t-1} + (a_2 - a_1)\pi_{t-2} - a_2\pi_{t-3} + \ldots + e_t$
$a(1) = 1 + a_1 + a_2 - a_1 - a_2 = 1$]
An alternative approach is to freely estimate the coefficients on lagged inflation in (7) and hope that the estimates sum to one, otherwise one has to question the validity of the regression (and of the NAIRU concept).

The estimated NAIRU is thus identified and equal to $\hat{U}^* = \dfrac{\hat{d}}{\hat{b}(1)}$.

A further issue is the computation of a confidence interval for the estimated NAIRU, since $\hat{U}^*$ is calculated with a non-linear function. Staiger, Stock and Watson (1996) were the first to come up with a confidence interval for $\hat{U}^*$. They estimated the 1990 NAIRU for the USA to be 6.2% with a 95% confidence interval from 5.1% to 7.7%. This is quite imprecise and suggests that the NAIRU might vary over time.

An early (around the 1980s) approach to estimate the NAIRU was undertaken by Gordon. He tried to predict (in sample) the inflation rate by running dynamic simulations of regression equations. For the period after 1978, he found that setting the NAIRU to 6% in his simulations allowed predicting the actual inflation rate quite well for many years after the end of the regression sample period. This method of course does not permit to come up with confidence intervals.

Say something about the computation of the confidence interval? SSW1996 propose 3 different methods.

4. Estimating the time varying NAIRU

We will stick to the triangle model of inflation:

(9) $\pi_t = a(L)\pi_{t-1} - b(L)\left(U_t - U_t^*\right) + c(L)z_t + e_t$

The simplest way of allowing U^* to vary over time is to assume a random walk:

(10) $U_t^* = U_{t-1}^* + \eta_t$

where η_t is a disturbance process with $E\left[\eta_t\right] = 0$ and $Var(\eta_t) = \sigma_\eta^2$ constant. The value chosen for σ_η^2 (or of the signal-to-noise ratio $\dfrac{\sigma_\eta^2}{\sigma_\varepsilon^2}$) is crucial for the interpretation of the behaviour of the NAIRU. If for example $\sigma_\eta^2 = 0$ we are again in the time invariant situation. For any $\sigma_\eta^2 > 0$, the NAIRU is allowed to vary over time. The issue of the choice of σ_η^2 is similar to the choice of the smoothness parameter in the Hodrick-Prescott filter. If we do not impose any restrictions on the value of σ_η^2 and estimate it freely, the NAIRU will soak up all the residual variation in equation (9) and will be highly variable – showing frequent jumps, but as we decided to retain the concept of the no-shock NAIRU, we would expect it to move slowly. Gordon (1997) therefore proposes "using a 'smoothness' prior: the NAIRU can move around as much as it likes, subject to the qualification that sharp quarter-to-quarter zig-zags are ruled out." Following Gordon (1997), in practice, this implies trying out different values for σ_η^2 ranging from 0 to 0.16.

This setup can be modelled by the state space framework and thus be estimated by the Kalman filter.

5. Application: A Kalman filter approach to estimating the UK NAIRU; Greenslade Pierse and Saleheen 2003.

Question

The UK economy has experienced low levels of unemployment without much inflationary pressure in the 1990s. It has been argued that this good performance was due to a falling NAIRU that allowed the Bank of England to lead a loose monetary policy even though unemployment was low. Greenslade, Pierse and Saleheen (2003, GPS hereinafter) try to find empirical support for the hypothesis that the UK NAIRU rose until the mid-80s and fell back thereafter.

Setup

GPS use Gordon's triangle model and allow the NAIRU to change over time by letting it follow a random walk. They impose dynamic homogeneity by writing the model in first differences of inflation, similar to (8).

(11) $\Delta\pi_t = \alpha(L)\Delta\pi_{t-1} - \beta(L)(U_t - U_t^*) + \gamma(L)z_t + \varepsilon_t$ with $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$

(12) $U_t^* = U_{t-1}^* + \eta_t$ with $\eta_t \sim N(0, \sigma_\eta^2)$ and $\text{cov}(\varepsilon_t, \eta_t) = 0$.

The notation is the same as in the theoretical introduction. In state-space representation equation (11) is the measurement equation and (12) is the transition equation. Given the assumption that the error terms of both equations are uncorrelated, GPS can apply the Kalman filter to find estimates for $\alpha(L)$, $\beta(L)$, $\gamma(L)$ and an estimated path for U_t^*. It remains to note that GPS provide smoothed estimates for U_t^* rather than filtered ones.

Data

An important question is which measure of inflation one should use. A natural suggestion would be to use some measure of wage inflation, since we chose to use the unemployment gap as proxy for the excess demand in the triangle model. GPS use the Average Earnings Index (AEI) or wages and salaries per employee (WS) as a measure for wage inflation. Increasing wages will of course put a rising pressure on the prices and one can therefore also use price inflation measures in the triangle model – which is what is usually done. GPS do so by using the Retail Price Index excluding mortgage interest payments (RPIX) or the Total Final Consumers' Expenditure deflator (PC).
Chart 1 depicts the graphs of wage and price inflation from 1973 to 2000. In the long-run both measures show a similar behaviour, contrary to the short run where they can show considerably large deviations (85-91) or even movements in opposite directions (78-79).

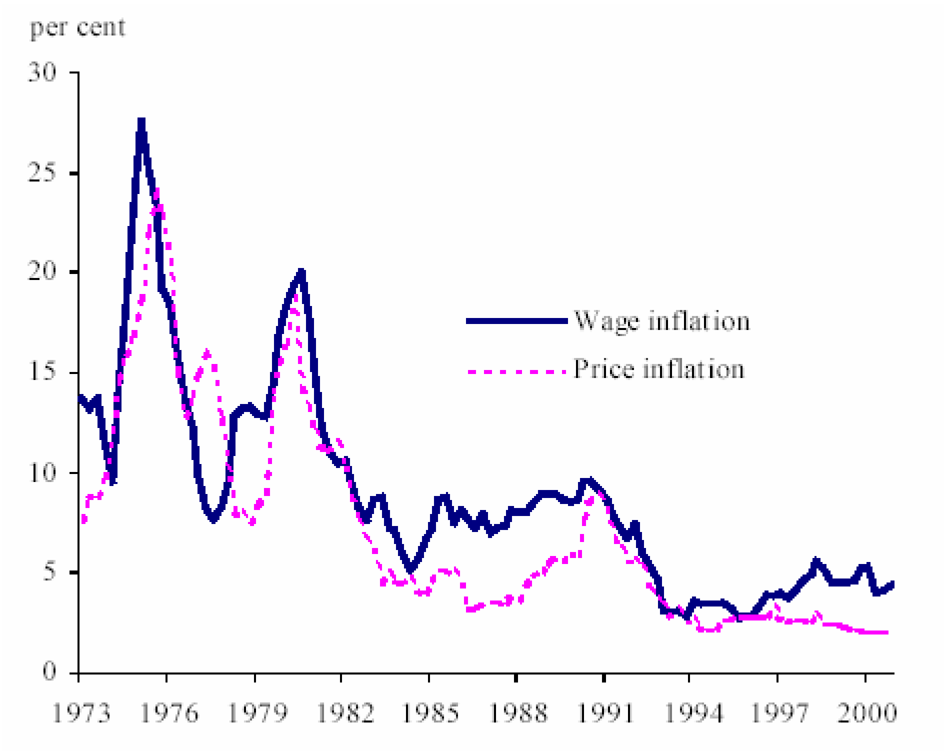

Chart 1: Wage and price inflation (annual % change); Source: GPS 2003

GPS use real import price inflation and real oil price inflation as proxies for supply shocks z_t. They set the signal-to-noise ratio to 0.16 but perform a sensitivity analysis with respect to that chosen value.
For all variables GPS use quarterly data from 1973 to 2000.

Results

GPS adopted a general to specific estimation strategy: They first included the current and lagged values of the unemployment gap, lagged annual inflation terms, lagged real import price inflation and lagged real oil price inflation terms. Insignificant terms where then excluded and GPS thus obtained different model specifications.

STATIC CONTRIBUTIONS EXERCISE AND DYNAMIC CONTRIBUTION EXERCISE!?!

Chart 2 shows the NAIRU paths for different model specifications with RPIX as the inflation measure. First, it is to note that the graphs show a relatively volatile NAIRU, but all four models seem to have very similar graphs for the NAIRU. The models indicate that the NAIRU has peaked around 1986 and has declined thereafter. Interestingly enough, the endpoints of the different models appear to be at different levels.

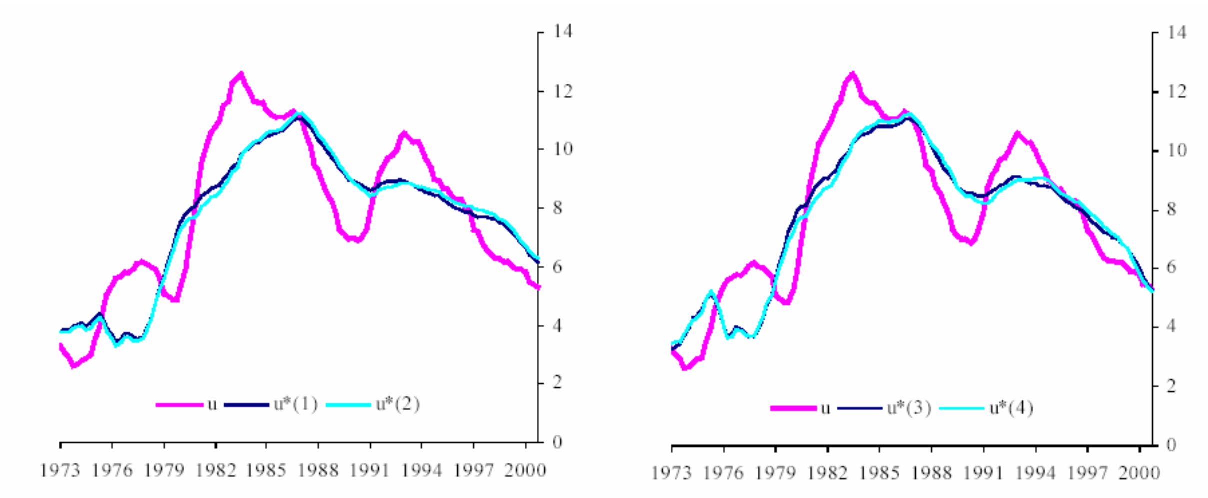

Chart 2: Unemployment and NAIRU profiles for RPIX inflation measure, models 1-4; source GPS 2003

See table A for details about the model specification.
GPS found out that when they included lagged values of unemployment, the present values of unemployment became insignificant (models 2 and 4). Since import prices may contain to some extent the same information as oil prices, a real import price less oil index is used in models 3 and 4 in order avoid potential double counting.
The last column in table A shows the regression results when PC is used as inflation measure.

Table A: Price inflation Phillips curve models estimated using the Kalman filter, 1973 Q1–2000 Q4

Dependent variable $\Delta\pi_t$ (rpix)	RPIX (1)	RPIX (2)	RPIX (3)	RPIX (4)	Dependent variable $\Delta\pi_t$ (personal consumption deflator)	PC (1)
$u_t - u_t^*$	-0.41 [-4.43]	-	-0.55 [-4.73]	-		-
$u_{t-1} - u_{t-1}^*$	-	-0.43 [-4.74]	-	-0.57 [-4.63]		-0.42 [-5.10]
$\Delta\pi_{t-2}$	-	-	-	-		-
$\Delta\pi_{t-4}$	-0.32 [-4.87]	-0.34 [-5.18]	-0.31 [-4.64]	-0.34 [-4.95]		-0.34 [-5.50]
ΔReal import price Inflation $_{t-1}$	0.34 [3.58]	0.37 [3.88]	-	-		0.34 [4.34]
ΔReal import price Inflation $_{t-4}$	0.25 [2.34]	0.25 [2.31]	-	-		0.33 [4.37]
ΔReal oil price Inflation $_{t-3}$	-	-	-	0.27 [3.03]		-
ΔReal oil price Inflation $_{t-4}$	0.22 [2.14]	0.19 [1.84]	0.35 [4.03]	-		-
ΔReal import price (Less oil) inflation $_{t-1}$	-	-	0.39 [3.75]	0.38 [3.58]		-
D79/80	-3.79 [-6.65]	-3.84 [-6.78]	-4.10 [-7.42]	-4.16 [-7.56]		-3.17 [-7.37]
D77Q4	-	-	-	-		-3.08 [-4.92]
LL	-139.5	-139.3	-141.4	-141.7		-112.7

LL is the log-likelihood, t-statistics are in parentheses.

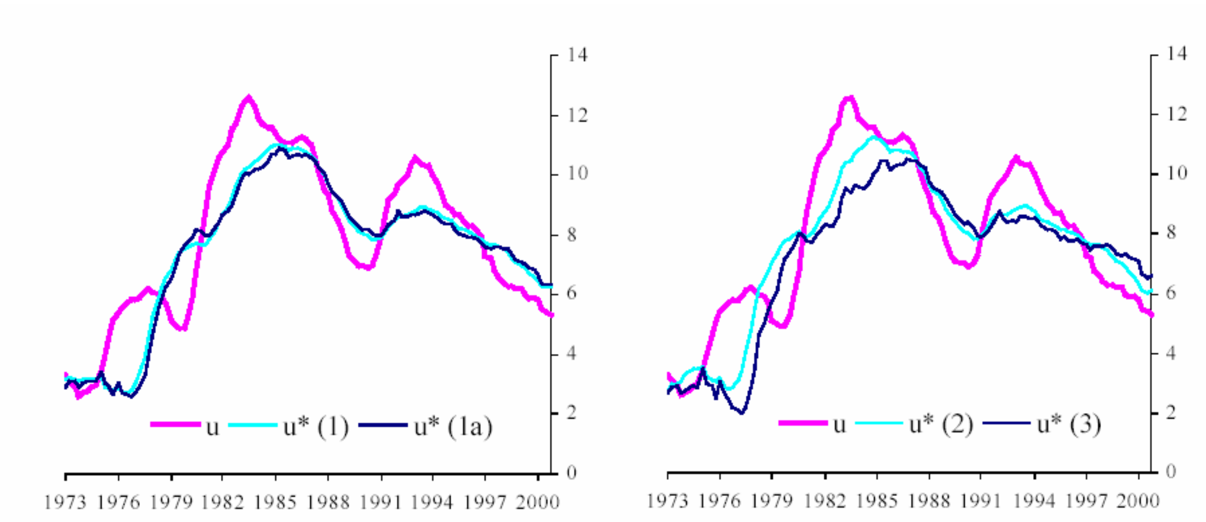

Chart 3: Unemployment and NAIRU profiles for AEI inflation measure, models 1-3; source GPS 2003

Chart 3 shows the estimated paths for the NAIRU if the earnings inflation measures are used.
See table B for details about the model specification.
GPS find that when they include a lagged value of unemployment, the coefficient on the present value becomes more negative, but the coefficient on lagged unemployment is positive (model 1a).
In model 2 GPS include a productivity measure as it might be argued that a measure of earnings inflation should be adjusted for productivity. The lagged value of unemployment was then insignificant. When GPS applied the general to specific estimation strategy, they found that only the lagged value of unemployment was significant (model 3).
The last column in table B shows the regression results when WS is used as inflation measure.

Table B: Earnings inflation Phillips curve estimated using the Kalman filter, 1973 Q1–2000 Q4

Dependent variable $\Delta\pi_t$ (average earnings index)	AEI (1)	AEI (1a)	AEI (2)	AEI (3)	Dependent variable $\Delta\pi_t$ (wages and salaries per employee)	WS (1)
$u_t - u_t^*$	-0.51 [-4.60]	-0.90 [-4.39]	-0.64 [-5.11]	-		-0.61 [-3.65]
$u_{t-1} - u_{t-1}^*$	-	0.45 [2.22]	-	-1.33 [-5.09]		-
$u_{t-2} - u_{t-2}^*$	-	-	-	1.02 [3.69]		-
$\Delta\pi_{t-4}$	-0.43 [-7.08]	-0.41 [-6.59]	-0.43 [-7.16]	-0.39 [-5.87]		-0.48 [-6.79]
ΔReal import price Inflation $_{t-4}$	0.40 [3.93]	0.43 [4.26]	0.47 [4.33]	0.38 [3.88]		0.60 [4.24]
ΔReal oil price Inflation $_{t-1}$	-	-	-	-		0.25 [1.71]
ΔProductivity			0.27 [2.21]	-		0.33 [1.91]
D74	3.11 [6.84]	3.11 [6.79]	2.98 [6.71]	3.33 [7.10]		1.44 [2.11]
LL	-155.7	-155.0	-153.2	-154.3		-187.8

A direct comparison between the NAIRU estimates based on different inflation measures is given in chart 4.
The graphs from different models exhibit a similar pattern. Nevertheless, by taking a closer look, one can make out some differences:
- The PC model shows a steeper decline than the RPIX model 1 from 1997 on.
- The WS and AEI show a similar but somewhat earlier peak than the RPIX model 2 around 1987 and RPIX(2) shows a flatter decline thereafter.

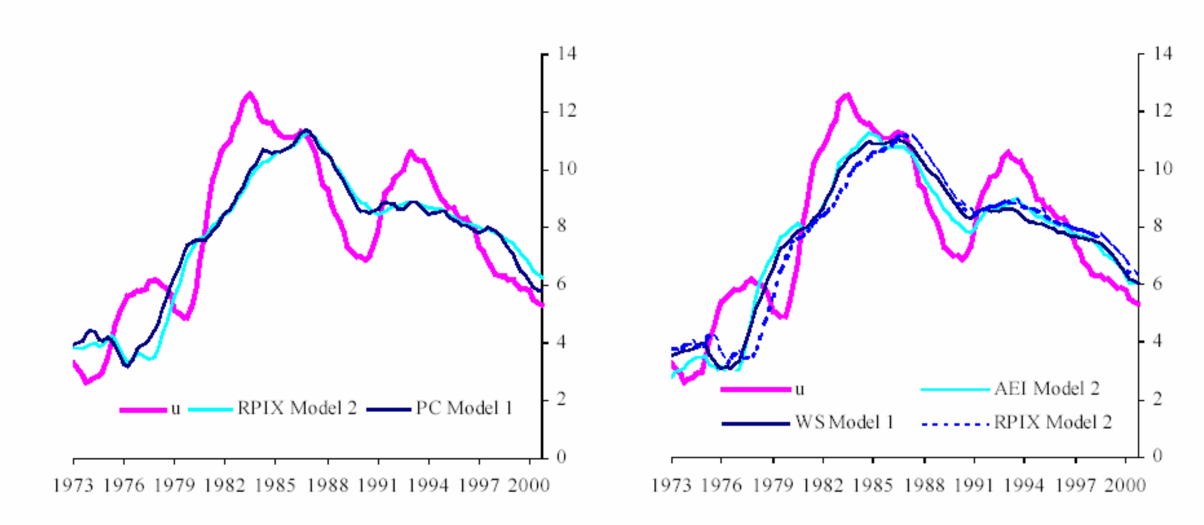

Chart 4: Comparison of NAIRU estimates using different inflation measures; source GPS 2003

Table C shows a comparison among the estimates of exact changes in the NAIRU based on different models.
Years 1980-85: All models indicate a similar rise in the NAIRU.
Years 1985-90: AEI (2) shows the largest decline.
Years 1990-95: Unemployment rose, AEI shows increase, other models a decline.
Years 1995-00: All models indicate a similar decline in the NAIRU.

Table C: Comparison of NAIRU estimates, 1980–2000

Sample/percentage points change	Actual change in unemployment	Change in u^* AEI (2)	Change in u^* WS (1)	Change in u^* RPIX (2)	Change in u^* PC (1)
1980–85	6.1	3.4	3.4	3.3	3.2
1985–90	-4.4	-3.1	-2.2	-1.7	-2.1
1990–2000	-1.7	-2.0	-2.6	-2.6	-2.7
of which 1990–95	1.9	0.3	-0.6	-0.3	0.0
1995–2000	-3.6	-2.3	-2.0	-2.3	-2.7

Before clinging too much to exact NAIRU estimates one should have a look at the confidence intervals for the estimates. We have seen in the theoretical introduction that the NAIRU estimates are in general rather imprecise.
Chart 5 shows the 90% and 95% confidence interval for the AEI 1a model. GPS only considered the filter uncertainty, which represents uncertainty that would be present even if true values of the parameters were known. Chart 5 confirms previous findings of other authors (e.g. Gordon) that NAIRU estimates are very imprecise. At almost all times we cannot say with 95% certainty that actual unemployment was above or below the NAIRU!

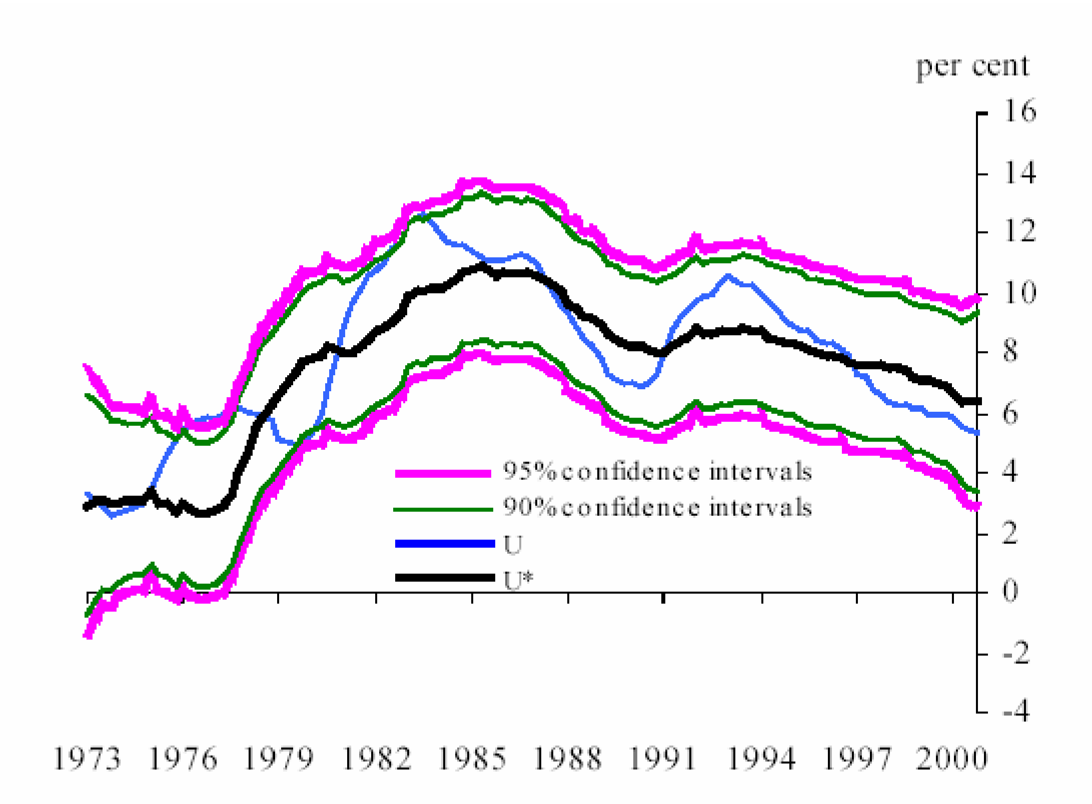

Chart 5: Standard error bands for AEI model 1a; source GPS 2003

All results presented so far have been obtained by setting the signal-to-noise ratio to 0.16. Chart 6 shows the impact of changing this value. The smaller the chosen ratio is, the flatter the NAIRU turns out to be and the resulting unemployment gap becomes spikier. The choice of the ratio does not seem to influence the timing of the peak, but the endpoints seem to vary. GPS mention that the NAIRU exhibits implausibly high variation when they freely estimate the signal-to-noise ratio, but they do not give the point estimate.

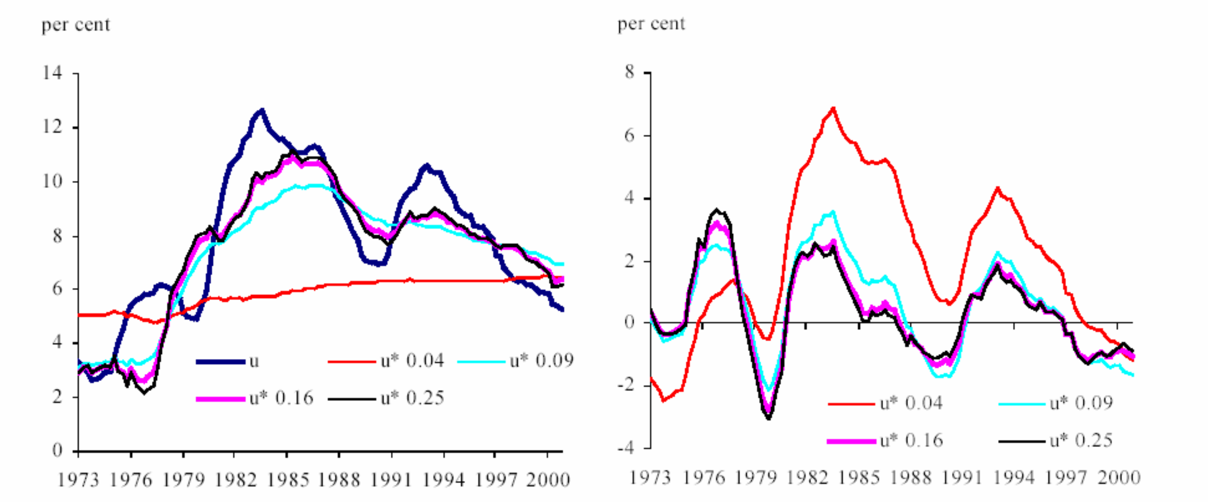

Chart 6: Different NAIRU (left) and unemployment gap (right) estimates based on alternative variances; source GPS 2003

Conclusion

GPS have found convincing evidence that the NAIRU peaked in the mid-1980s and has declined thereafter. The estimates show some sensitivity to specification changes but the general pattern remains the same. GPS show that there is “a huge amount of uncertainty surrounding the NAIRU estimates, as the confidence bands are likely to be wide.” (GPS 2003). Nevertheless, GPS state that unemployment seems to have been below the NAIRU in the late 1990s and suggest that this might put some pressure on inflation.
Finally, GPS draw the reader’s attention to the fact that they completely ignored important changes in the UK monetary policy regime (switch to inflation targeting in 1992, independence of the Bank of England in 1997) which might have changed the way inflation expectations are formed by economic agents.
You may want to check out the companion paper by Driver, Greenslade and Pierse 2003 for a more detailed analysis of the impact of inflation expectations on the NAIRU estimates.

6. Implications for monetary policy

The findings of GPS that the NAIRU estimates are rather imprecise are in line with other papers that have estimated the time varying NAIRU for different countries. Should one therefore drop the concept of the NAIRU because it is too imprecise for monetary policy? Or should a central bank actively rely on estimates of a time varying NAIRU for its inflation forecast?
The answer is no and no. First, one has to acknowledge that useful hindsight can be gained from analysing the NAIRU. In the case of GPS’s paper, we now know that the NAIRU has been declining since the late 1980s and we are one step further in understanding what has caused the good performance of the UK economy during the 1990s. In a next step we would have to look for the reasons why the NAIRU has declined. (See Gordon and Stock 1998 for some suggested reasons of the decline of the US NAIRU.) To summarize: The NAIRU did not answer all our questions but we got one step closer to the solution, in that we know where to investigate further.
The second no is due to the fact that we assumed the NAIRU to follow a random walk. The NAIRU is equally likely to increase or to decrease in the future and it is thus impossible to make useful predictions of it, which would help predict inflation.

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