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Measuring the NAIRU – A Structural VAR Approach

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Measuring the NAIRU – A Structural VAR Approach

Hongmei Zhao Vincent Hogan

Abstract

We calculate the NAIRU for the U.S. in a framework where inflation and the unemployment rate can respond to each other. The NAIRU is defined as the component of the actual unemployment rate that is uncorrelated with inflation in the long run. Using a structural VAR approach, the NAIRU and core inflation can be estimated simultaneously. Our estimation results show that the NAIRU falls dramatically at the end of 1990s and the long run vertical Phillips Curve shifts back from 6.8 per cent before 1997 to 4 per cent afterwards.

1. Introduction

At the end of 1990s, the simultaneous occurrence of low inflation and low unemployment in the U.S. focused attention on the time-varying NAIRU (Non Accelerating Inflation Rate of Unemployment). The precise estimation of the NAIRU is helpful for the unemployment rate to be a leading indicator of inflation. However, most traditional estimates of the NAIRU produce large standard errors. Staiger, Stock and Watson (1996) summarizes the precision of different estimation models and shows that, no matter modelled as a deterministic function of time like in Staiger, Stock and Watson (1997), or as an unobservable stochastic process like in Gordon (1997), or as a function of labour market variables like in Weiner (1993), taking the result in 1990 as example, the estimated NAIRU is associated with a 95% confidence interval between 5.1% to 7.7%. This indicates a number of uncertainties in predicting inflation by unemployment indicator and in implementing monetary policy. Staiger et al. (1996) has proposed the sources of causing the uncertainty of the NAIRU, one of which is the choice of the estimation models. Here we use a structural VAR approach to give a more precise estimate of the NAIRU while simultaneously providing a more reliable reference index for the central bank to set the inflation target.

The structural VAR approach is based on the work of Laubach (2001), where the NAIRU is treated as an unobservable stochastic process, and estimated from the Phillips Curve model. Different from the traditional models, Laubach (2001) separately model the unemployment process. He assumes the unemployment gap is an auto-regressive process, which implies that the changes in the unemployment rate itself yields information about the NAIRU. This extension generates a bivariate model of the NAIRU. Consequently, this method can provide a more accurate estimation than the traditional one. Laubach's results suggest that the uncertainty of the NAIRU may be because the single Phillips equation cannot describe correctly the joint movement of inflation and unemployment. We extend this idea by using a VAR model to estimate the NAIRU.

The NAIRU estimated using a structural VAR approach is defined as the component of the actual unemployment rate that is uncorrelated with inflation in the long run. This definition allows for far richer dynamics than the one in Laubach (2001). In the short run, inflation and the unemployment rate can influence each other. We do not have to assume that the unemployment rate is exogenous. In the long run, inflation is uncorrelated with the unemployment rate, which reflects the economic implication of the NAIRU since Friedman (1968), that NAIRU is the unemployment rate at which inflation tends to be stable after controlling for the supply shocks. The similar structural VAR model was used by Quah and Vehey (1995) to obtain core inflation for the U.K.

Our estimation of the NAIRU is based on the following assumptions: there are two uncorrelated disturbances that can be distinguished by their effects on inflation in the long run. The first disturbance has no long run effect on inflation, while the second one may have. The estimated NAIRU corresponds to the first disturbance. Quah and Vahey (1995) adopted a similar procedure to separate core inflation from the joint movement of output and inflation. In our model, we can estimate both the NAIRU and core inflation, because inflation and unemployment are uncorrelated to each other in the long run (i.e. the NAIRU and core inflation are uncorrelated to each other). When the unemployment rate tends to its long run rate, inflation is also close to core inflation. So we can calculate the NAIRU from one disturbance and core inflation from the other.

With our definition and the identifying restrictions, the following characteristics of the NAIRU are obtained by using the U.S. data: first, the NAIRU falls from 6.8 per cent before 1997 to 4 per cent after in the latter part of the 1990s. The reason for this fall can be found in the fundamental changes of the labour market relating to the NAIRU disturbance; and second, the change of the NAIRU accounts for only 6 per cent and 21 per cent of variation of inflation and the unemployment rate in the long run, respectively. This suggests that demand side factors are more important at business cycle frequencies.

The rest of the paper is organised as follows. In Section 2, we show how to identify the model. In Section 3, we analyse the economic interpretation behind our identification and assumptions. We discuss the estimation procedure and present our results in Section 4; Then Section 5 concludes.

2. Identification

Our structural model assumes that the unemployment rate is composed of two parts. One part is the NAIRU. The other is the gap between the NAIRU and the actual unemployment rate. Accordingly, the shocks causing the fluctuations of the unemployment rate are separated into two kinds of disturbances - the kind of disturbances that affect the NAIRU ("NAIRU disturbance") and the kind that affect only the unemployment gap ("gap disturbance"). As the NAIRU is determined by the characteristics of the labour market, such as market imperfections, the cost of gathering information about job vacancies, labour availabilities and so on, the NAIRU disturbance is similar to the aggregate supply shock as in Blanchard & Quah (1989). Similarly, gap disturbance is the equivalence of their aggregate demand shock, (e.g. monetary and fiscal policy shocks).

These two disturbances were first used to identify trend output in a VAR model of output and unemployment by Blanchard & Quah (1989). In our paper, we use them to measure the NAIRU and core inflation. Although the purpose is different from Blanchard's paper, the methods in both papers are same. After separating the two disturbances, we can estimate the NAIRU by setting the gap disturbance to be zero, i.e. the estimated NAIRU is accumulated by the effects of the NAIRU disturbance.

The NAIRU disturbance and the gap disturbance are distinguished by their long run effects on inflation. This is the key identifying assumption of the paper. We assume that the NAIRU disturbance has no long run effect on inflation.[1] The gap disturbance may or may not have significant long run effect on inflation. Both disturbances are assumed to be uncorrelated at all leads and lags. The fact that the NAIRU disturbance does not affect inflation in the long run does not stop it from affecting inflation in the short run.

Using the notation X=($\Delta\pi$, u)' and $\varepsilon = (\varepsilon_N, \varepsilon_G)$ ', where π and u denote inflation and the unemployment rate; and ε_N and ε_G denote the NAIRU and gap disturbance respectively. Write X as the following:

$$
\begin{aligned}
X(t) &= C(0)\varepsilon(t) + C(1)\varepsilon(t-1) + ... \\
&= \sum_{j=0}^{\infty} C(j)\varepsilon(t-j) \qquad\qquad Var(\varepsilon) = I \qquad\qquad (1)
\end{aligned}
$$

Equation (1) is our structural model written in VMA form. This equation expresses $\Delta\pi$ and u as distributed lags of the two structural disturbances ε_N and ε_G. Coefficient C (j) is the matrix of impulse response functions of the disturbances. It gives the effect of shocks in period t on the variables in period t+j.

There are three points we need to explain in this equation. First, due to the assumption that the NAIRU and gap disturbances are uncorrelated at all leads and lags, their variance-covariance matrix is diagonal; and for convenience, the disturbances are normalized so that var (ε_1)=var (ε_2)=1. Second, our structural model cannot be estimated directly, because there is no data for two disturbances. What we are going to do is recover model (1) from the VMA form of a VAR model. But a prerequisite for transforming VMA from VAR is that all the endogenous variables are stationary. That is why we use the first difference of π instead of π itself, since π tends to be I (1). Third, constant, time trend and other exogenous variables can be included into our model. Specially, we put some supply shock variables (import price and unit labour cost) into the model. To remove them from the model would result in unusual fluctuations of the estimated NAIRU. We control those supply shock variables so as to better understand the movement of the NAIRU. This coincides with most economists' definition of the NAIRU and is standard in the literature.

The key identifying assumption – in the long run, the NAIRU disturbance has no effect on inflation is shown in our model as following:

$$\sum_{j=0}^{\infty} C_{11}(j) = 0 \tag{2}$$

where C_{11} is the upper left element of the matrix C. To see why this is the case, note in the long run, if inflation is to be unaffected by the NAIRU disturbance, *inflation* must return to its original value after shocks. In another word, the increase of inflation must be positive first and negative afterwards (or negative first, then positive). So the cumulated effects of the NAIRU disturbance on the *change of inflation* must equal to zero. We impose no other restrictions on the model. So the long run impact of the gap disturbance and the short run effect of both disturbances are free to be determined by the data.

Now let's proceed to estimate and recover the model. The VAR model we are going to estimate is

$$X(t) = A(L)X(t-1) + e(t)$$

where L is the polynomials in lag operator. By the Wold Representation Theorem, we can invert the stationary VAR model (Vector Auto Regression) into VMA form (Vector Moving Average).

$$\begin{aligned} X(t) &= e_t + B(1)e_{t-1} + B(2)e_{t-2} + \ldots \\ &= e_t + \sum_{j=1}^{\infty} B(j)e(t-j) \qquad Var(e) = \Omega \end{aligned} \tag{3}$$

[1] The economic interpretation behind of these restrictions will be discussed in section 3.

Equation (1) is the model we need while equation (3) is the model we are able to estimate. So next we need to recover the structural disturbances ε from VAR residuals e.

Now take one-step ahead forecast for the endogenous variables of (1) and (3): ($\Delta\pi$, u). The forecast errors should be equal, because (1) and (3) have the same endogenous variables. By doing so, we can get a relationship between ε and e:

$$e = C(0)\varepsilon, \tag{4}$$

so that
$$C(j) = B(j)C(0) \tag{5}$$

and
$$C(0)C(0)' = \Omega$$

These expressions relating the structural disturbances to the VAR residuals allow the recovery of ε if C (0) is unique. From (4) we get $C(0)C(0)' = \Omega$ which gives three equations in the four unknowns matrix C(0). In order to identify C(0) (and hence ε), we need the fourth restriction. This comes from the long run restriction on the NAIRU disturbance given by equation (2). In order to impose this restriction on the VAR, we first rewrite the VMA replacing e by ε using (4). Then the coefficient of NAIRU disturbance ε_N should be equal to zero according to the restriction (2). Thus the fourth condition is:

$$\sum_{j=0}^{\infty}[(B(j)C(0)]_{11} = 0 \tag{6}$$

With four conditions, we can solve for C (0). The rest of the coefficients can be easily solved using equation (5). Finally, the NAIRU can be obtained by setting ε_G equal to zero, as shown in equation (7).

Similarly, core inflation should be calculated by setting ε_N equal to zero as in (8). This is the case because we assumed that the NAIRU disturbance has no long run effect on inflation. Therefore, in the long run, inflation is caused only by the gap disturbance. The long run inflation rate is exactly core inflation.

$$U_{NAIRU} = \sum_{0}^{\infty} C_{21}\varepsilon_{Nt} \tag{7}$$

$$\pi_{core} = \sum_{0}^{\infty} C_{12}\varepsilon_{Gt} \tag{8}$$

3. Interpretation

The condition that the NAIRU disturbance has no effect on inflation in the long run is the key to identifying the whole model. It reflects the definition of the NAIRU – the component of the actual unemployment rate that is uncorrelated with inflation in the long run. This definition of the NAIRU is different from those of other papers on the feedback between inflation and the unemployment rate. The theoretical background for this definition is still the augmented Phillips Curve. Specifically, the reason why there is a short-term trade off between inflation and the unemployment rate is the existence of nominal rigidities. However, we assume that nominal rigidity cannot last forever. Eventually, there must be some day that the nominal wage keeps pace with the change of inflation. In that time, the unemployment rate will return to its long run rate – NAIRU regardless of the rate of inflation.

We do not restrict the permanent effects of gap disturbance on inflation. Furthermore, we say nothing about the permanent effects of both shocks on the unemployment rate. This is because inflation is usually considered as a non-stationary variable and the unemployment rate is treated as a stationary variable (see below). If the NAIRU disturbance has no long-run effect on inflation, the gap disturbance should have. Similarly, since the unemployment rate is stationary, none of the disturbance should have an effect on the unemployment rate in the long run. But we do not impose either of those restrictions because we would like to let data reveal these properties.

Nor do we restrict the short run effect of both disturbances on inflation and the unemployment rate. Following a shock, should inflation and the unemployment rate rise or fall? How long should it take them to return to their original level? We leave these questions to the data. Whether or not the results are reasonable will indicate the validity of our identification.

There may be doubts regarding the assumption that two structural disturbances are uncorrelated. That both disturbances are uncorrelated at all leads and lags does not mean we restrict the channel through which NAIRU and gap disturbances affect inflation and the unemployment rate. The fluctuations of inflation and the unemployment rate can be caused either by the NAIRU disturbance or by the gap disturbance.

Finally note a limitation of this analysis. Obviously, there are many real world shocks. We group them as the NAIRU and gap disturbance depending on whether or not they affect inflation permanently. However, the permanent effects of some shocks on inflation are not clear. For example, we usually consider the productivity shock as the NAIRU disturbance. But the part it played in the double decline of inflation and unemployment at the end of 1990s is still an open question. The long run effect of it on inflation becomes doubtful. Blanchard and Quah (1989) mentioned this particular ambiguity in their paper, and presented a sufficient and necessary condition to deal with it.[2] However, that sufficient and necessary condition is hardly reached in the reality. We will identify more disturbances in Zhao (2005) in order to test the stability of this model.

4. Estimation and Results

We estimate the model using the U.S. annual data over the period of 1960 to 2000. First, we test for a unit root in inflation and the unemployment rate in order to guarantee the variables getting into the basic VAR model are all stationary. The Augmented Dickey Fuller test for the hypothesis that inflation and the unemployment rate have unit root shows that we cannot reject the null for inflation at any significant level.[3] In contrast, for the unemployment rate, we can reject the null at 5 per cent significant level. But the unemployment rate can be treated as a stationary variable at a 10 per cent significant level.[4] Therefore, we

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[2] Correct identification is possible if and only if the individual distributed lag responses in inflation growth and unemployment are sufficiently similar across the different NAIRU disturbances, and across the different supply disturbances.

[3] Augmented Dicky Fuller test with two lags.

[4] P-values of the ADF test with 2 lags on inflation, the change of inflation and the unemployment rate are 0.86895, 0.01362 and 0.08836. All the tests include constant, but the unemployment test include time trend and time trend square additionally. Time trend is shown significantly positive in the unemployment rate test equation, which implies that the unemployment rate tends to infinity as time goes on. But time trend square has negative coefficient. This means that the unemployment rate will fall after reaches its maximum value. The weak evidence for the stationary unemployment

put the first difference of inflation and the level of unemployment rate in the VAR.

The second step is to choose the optimal lag length for the variables in the VAR model. This task can be performed by the likelihood ratio test. Assuming lag five is the maximum lag length, we test the hypothesis that four lags are appropriate over five lags. If the hypothesis is not rejected, we continue to test whether three lags are appropriate over four lags and so on until the optimal lag length is found. Here lag four is the optimal lag length.[5]

Finally, the basic VAR model includes some exogenous variables. They are constant, time trend, time trend square and supply shock variables (the change of import price and the change of unit labour cost). Controlling the supply shock variables should help eliminate the noise from the model.

4.1. The NAIRU

As mentioned in the previous section, the NAIRU can be constructed as the time path of the unemployment rate that would exist in the absence of gap disturbance. The estimated NAIRU has been shown in Figure 1.[6] The NAIRU rises and falls slightly following the fluctuations of the actual unemployment rate. The relative high-frequency movement of the NAIRU in the figure verifies the implication of the time-varying NAIRU. Moreover, the NAIRU values shift between 6 per cent and 8 per cent before 1995. It is not a particular wide range compared with the literature. For example, most estimated NAIRUs in Gordon (1997) stay within a band from 5.5 per cent to 7 per cent.

In Figure 1, the business cycle is measured by an expansion and a contraction of the unemployment gap.[7] The first business cycle of the U.S. starts from 1975 and ends in 1985. The NAIRUs in this period all have a high value, but

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rate is also shown in Evans (1989). But they use Monte Carlo study to derive a very significant test result that the unemployment rate is a I(0) process, even without time trend.

[5] The optimal lag length is 4 by the likelihood ratio test. The test statistic is 10.439 for the hypothesis that 3 lags are appropriate over 4 lags. The critical value at 5% significant level is 9.488.

[6] The NAIRU in Figure 1 starts from 1976 because we take 10 lags for the NAIRU disturbance to calculate the NAIRU. Together with 4 lags in the VAR model, 14 NAIRU observations are lost.

[7] We add NBER recessions for reference, which are shown by the shaded area in Figure 1. However, NBER recession is measured by the fall of real GDP. The unemployment rate is a lagging indicator compared with GDP. We can see from the figure that when NBER recession happens, the unemployment gap is turning to be positive.

they remain relatively stable. According to the identification, the fluctuations of the NAIRU curve can be regarded as the impact of the NAIRU disturbance on the market, while the expansion of the unemployment gap represents the movement pattern of the gap disturbance. As shown in the figure, the expansion and contraction of the unemployment gap are much bigger than the change of the NAIRU, which indicates that the economic boom at the end of 1970s and the following economic recession at the beginning of 1980s are attributed to the impacts of the gap disturbance. This result is consistent with most of studies on the NAIRU. It is well known that OPEC reduced the production of oil in the beginning of 1970s and 1980s. The dramatic rise of oil price, which should be captured by our supply shock variables, leads to a fall the economic recession in each period. The economic boom happened between two oil price shocks is a short recovery of the U.S. economy. This result benefits a lot from the inclusion of supply shock variables into our model. By doing so, the NAIRU keeps stable in this period.

The second business cycle takes place during the period of 1986 to 1993. The NAIRU *falls* by 0.7 per cent in the boom period and meanwhile the unemployment gap shows a decrease of the same amount. Similarly, during the recession period, both the NAIRU and the unemployment gap *rise* 0.7 per cent. This raises a problem in distinguishing the reason for the economic fluctuations from 1986 to 1993. Were the fluctuations caused by the NAIRU disturbance or the gap disturbance? Many people assume that it was the aggregate demand shock (here represented by gap disturbance), especially considering the expansionary fiscal policy of the period. However, we cannot ignore the obvious shift of the NAIRU shown in the figure. This implies that there might be some structural changes of the labour market in late 1980s.

In the economic boom at the end of 1990s, low unemployment co-existed with low inflation. As shown in the figure, the NAIRU falls from 7 percent in 1993 to 3 per cent in 2000, whereas the unemployment gap changes only slightly. The change in the unemployment gap is only 1/7 as much as the change in the NAIRU. Apparently, the structural change of the labour market related to the NAIRU disturbance occupies the dominant position in this economic boom. What particular structural changes lead the NAIRU to fall at the end of 1990s is beyond the scope of this paper but could be an interesting topic for further research.

We show the NAIRU in figure 2 with 95 per cent confidence interval. The standard error bands in the figure are obtained by using Monte Carlo study with 1,000 replications.[8] The problem of uncertainty about the NAIRU still exists in our paper. The distance between the error bands ranges from 1.6 per cent to 2 per cent, then increases to 2.5 per cent in the last three estimation years. Comparing with the Staiger et al. (1997), univariate Phillips Curve derived a pair of standard error bands for the NAIRU with the distance of 2.6 per cent. From the simple bivariate model (Laubach, 2001), the gap between two bands is about 2.3 per cent. The comparison of the standard error bands shows the NAIRU is estimated more precisely by our model.

4.2. The Phillips Curves

After deriving the NAIRU, we can use the gap disturbance to identify core inflation using equation (7). The relationship between the NAIRU and core inflation forms a framework of the long run Phillips Curve. The rest of unemployment (i.e. unemployment gap) and inflation (i.e. non-core inflation) describe the movement along a short run Phillips Curve. Both Phillips Curves are shown in Figure 3.

The trade-off between inflation and the unemployment rate is very obvious in the short run Phillips Curve diagram. But if looking at some particular years, the points after 1985 are all gathered within a limited space, by which the trade-off is hardly recognisable. The long run Phillips Curve is close to a vertical line during the period of 1975 to 1985. After tracing out a circle from 1986 to 1995, it shifts back to a low level in the last three years. The average value of the NAIRU before 1997 is 6.8 per cent, and then it falls to 4 per cent afterwards. Overall, These two diagrams clearly outline the movement of inflation and the unemployment rate that is very close to the typical textbook model.

[8] We take the variance-covariance matrix of the error terms from the VAR model. Then select randomly 1,000 series of artificial error terms with the same distribution. We replace the true error terms in the VAR model by the artificial terms one by one, and apply the decomposition technique

4.3. Impulse Response Function (IRF)

Plotting the impulse response function is a practical way to visually represent the behaviour of inflation and the unemployment rate in response to the various shocks and this tests the plausibility of our identification. The impulse response function is the coefficient of the disturbances of the structural model. All the impulse response functions in our paper are calculated from one per cent increase of the disturbance and the increase of the disturbance can be understood to have a positive effect to the economy. Thus, no matter which disturbance rises by one per cent, the unemployment rate should be reduced initially. Figure 4 shows our impulse response functions.[9]

Inflation IRF to one per cent increase of the NAIRU disturbance: In response to a shock that reduces unemployment, inflation falls by 0.4 percent points in the beginning. It keeps growing afterwards until reaches to the maximum three years later. Then, as imposed by identification, it eventually returns to its original level in the long run. The fall of inflation in the beginning can be considered as the evidence of nominal price rigidity. The increase of the actual inflation rate would be postponed response to the initial shock due to the reason that agents fail to take into account the unexpected inflationary pressure when they make contracts.

Inflation IRF to one per cent increase of the gap disturbance: The gap disturbance has permanent effect on inflation. After an increase of the gap shock, inflation goes up by 0.8 percentage points. This effect reaches the maximum in the first year. Then inflation eventually falls to a stable level three years later but the one that is higher than the initial level. This inflation IRF result is consistent with the similar monetary policy studies. Christiano et al. (1999) summarizes different structural VAR models and shows that monetary policy has effect on price over a period of 12 quarters or 40 months.

Unemployment rate IRF to one per cent increase of the NAIRU disturbance: The unemployment rate falls by 0.36 percentage points at the

as described in the identification section. We will get 1,000 NAIRUs. The standard deviation are calculated from these 1,000 NAIRUs generates the standard error band.

[9] The standard error bands are obtained by using Monte Carlo study with 1,000 replications, the details of which has been described in the NAIRU sub-section.

beginning, and then returns to its original level after three years.[10] Comparing with the gap disturbance, the NAIRU disturbance has less effect on the unemployment rate. The NAIRU is more stable.

Unemployment rate IRF to one per cent increase of the gap disturbance: The unemployment rate falls by 0.7 percentage points immediately. It takes the unemployment rate more than 4 years to recover itself. We can see clearly from the figure that the fluctuations of the unemployment rate caused by the gap disturbance are bigger than those caused by the NAIRU disturbance. This implies that the movement of the unemployment rate is mainly attributed to the gap disturbance. However, the fact that none of the disturbance affects the unemployment rate in the long run supports our unit root test that the unemployment rate is stationary.

In summary, we imposed a restriction on the effect of the NAIRU disturbance on inflation. Although we did not restrict other effects of the NAIRU and gap disturbance, their effects are plausible. This suggests that our identification is plausible and conforms to standard view of the Phillips Curve.

4.4. Variance Decomposition

If we use our structural model to do inflation and unemployment forecast, the variances of forecast error are determined by the NAIRU and gap disturbances. A variance decomposition separates the effects of two disturbances on the variation of inflation and the unemployment rate and demonstrates which is bigger and whether the effect diminishes over time. Table 1 gives the result of variance decomposition. The total variation of inflation or the unemployment rate is assumed to be 100 per cent. The proportion of the variation that the NAIRU disturbance accounts for is shown in the table with the rest being due to the gap disturbance (not reported). Again, Two standard errors in the parentheses are obtained from 1,000 Monte Carlo replications.

The NAIRU disturbance has very little effect on the variation of inflation. The variations that it can explain are less than 10 per cent of the total. The contribution of it to the unemployment rate variation increases, but it is still

[10] Regarding the speed of adjustment of the unemployment rate to the NAIRU disturbance and the gap disturbance, Blanchard & Quah (1989) found a similar result.

unimportant. Furthermore, this situation is unchanged over the whole sample period. The reason for this would be related to the stability of the NAIRU. So most fluctuations of inflation and the unemployment rate are attribute to the gap disturbance. However, the large standard error bands on both NAIRU and gap disturbance implies that the effects of both disturbances on the variance of inflation and the unemployment rate would be imprecise.

5. Conclusion

We proposed a structural VAR approach to estimate the NAIRU. The NAIRU is defined as the component of the actual unemployment rate that is uncorrelated to inflation in the long run. This definition is different from the traditional one in that it allows for the feedback between inflation and the unemployment rate. Another advantage of this approach is that both the NAIRU and core inflation can be estimated simultaneously. Our estimate of the NAIRU is based on the following assumptions: there are two uncorrelated disturbances that can be distinguished by their effects on inflation in the long run. The first disturbance has no long run effect on inflation, while the second one may have. The estimated NAIRU corresponds to the first disturbance and core inflation corresponds to the second one.

We conclude that, within the limit of our research data, the business cycle of the U.S. from 1975 to 1985 is attributable to the impact of the gap disturbance. The sharp increase of oil price in that time is the source of this shock. The business cycle during the period of 1986 to 1993 is caused by both NAIRU and gap disturbance. Policy shocks and the structural change of the labour market both play a role.

In contrast, the NAIRU disturbance occupies the dominant position in the economic boom at the end of 1990s. The NAIRU falls dramatically during this period. Our results show that the NAIRU shifts back from around 6.8 per cent before 1997 to 4 per cent afterwards. Impulse response function confirms the assumptions on the NAIRU and gap disturbance so that it gives support to our identification.

This paper provides some insight into the movement of the NAIRU. But further work is needed. Firstly, the model can be extended by identifying more supply shocks: NAIRU shock and other supply shocks, because some supply shocks may be correlated with unemployment and inflation. As discussed in Ball & Mankiw (2002), dealing with the identification problem for the supply shock in a more satisfactory way would be helpful to increase the precision of estimating the NAIRU. Secondly, our estimation result shows that the NAIRU apparently falls in the second half of the 1990s. It would be interesting to explore the source of the labour market that caused the fall of the NAIRU during this period. Productivity has been attractive due to its extraordinary performance since late 1990s. Gordon (2003) explores the context, causes and implications of the recent productivity growth. It would be to particularly examine the effect of productivity on the NAIRU. In Zhao (2005), we examine precisely this effect.

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Table 1

Variance Decomposition of Inflation and The Unemployment Rate.

Percentage of Variance Due to The NAIRU Disturbance

Horizon (year)	Inflation	Unemployment Rate
1	6.39	18.44
	(0, 13.51)	(0, 37.44)
2	7.46	20.06
	(0, 15.6)	(0.62, 39.5)
3	9.74	19.96
	(0, 24.98)	(0, 41.68)
4	8.18	20.84
	(0, 22.32)	(0, 42.84)
5	7.56	21.97
	(0, 22.94)	(0, 45.37)
6	7.05	21.14
	(0, 23.07)	(0, 44.72)
7	6.67	20.31
	(0, 22.05)	(0, 43.97)
8	6.46	20.27
	(0, 21.66)	(0, 43.83)
9	6.29	20.54
	(0, 21.19)	(0,44.16)

Figure 1. The Unemployment Rate and The NAIRU

(NBER recessions shaded)

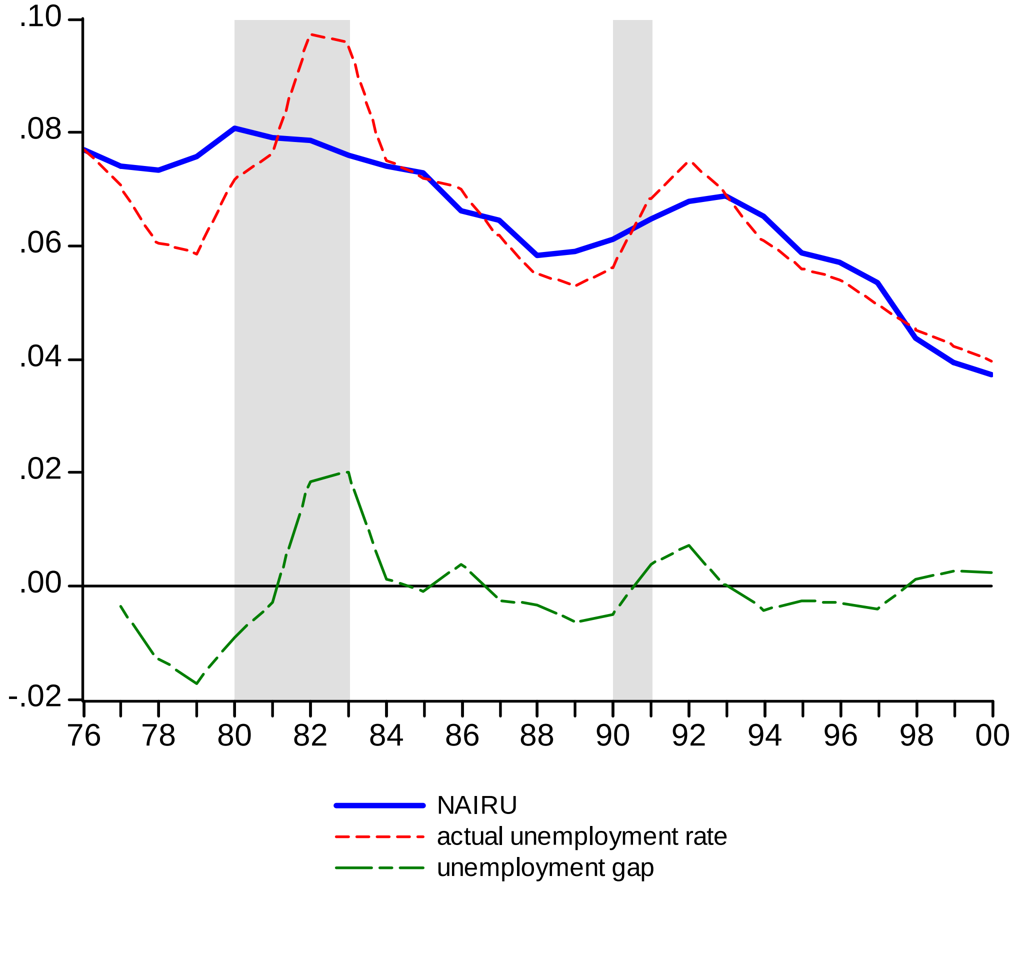

Figure 2. The NAIRU with Standard Error Bands

(within 95 % confidence interval)

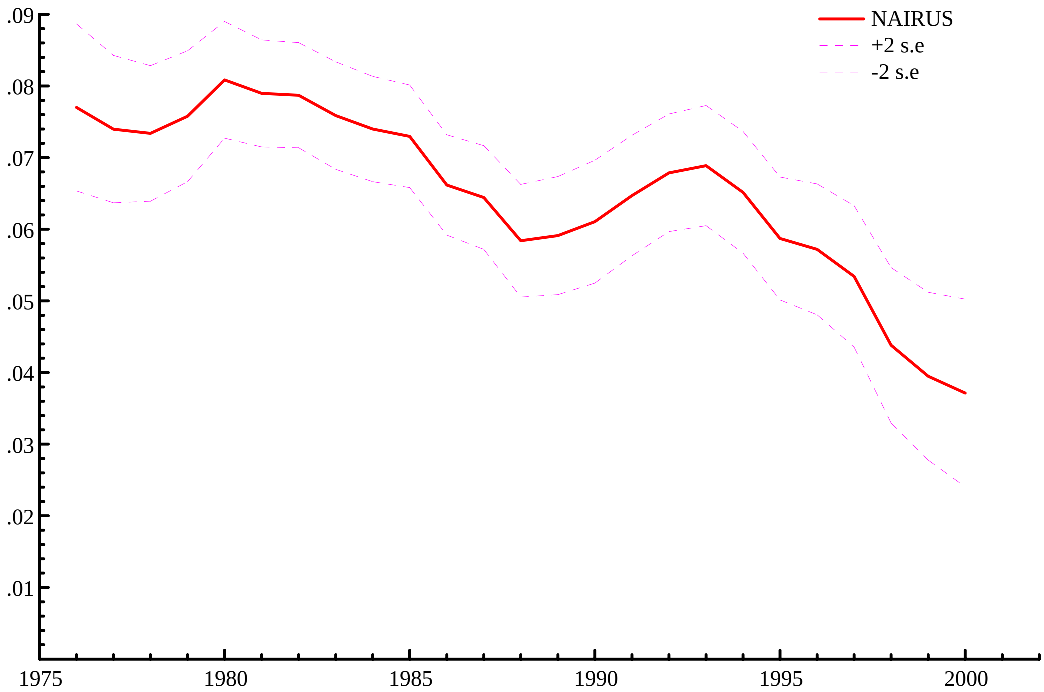

Figure 3. Short Run and Long Run Phillips Curve

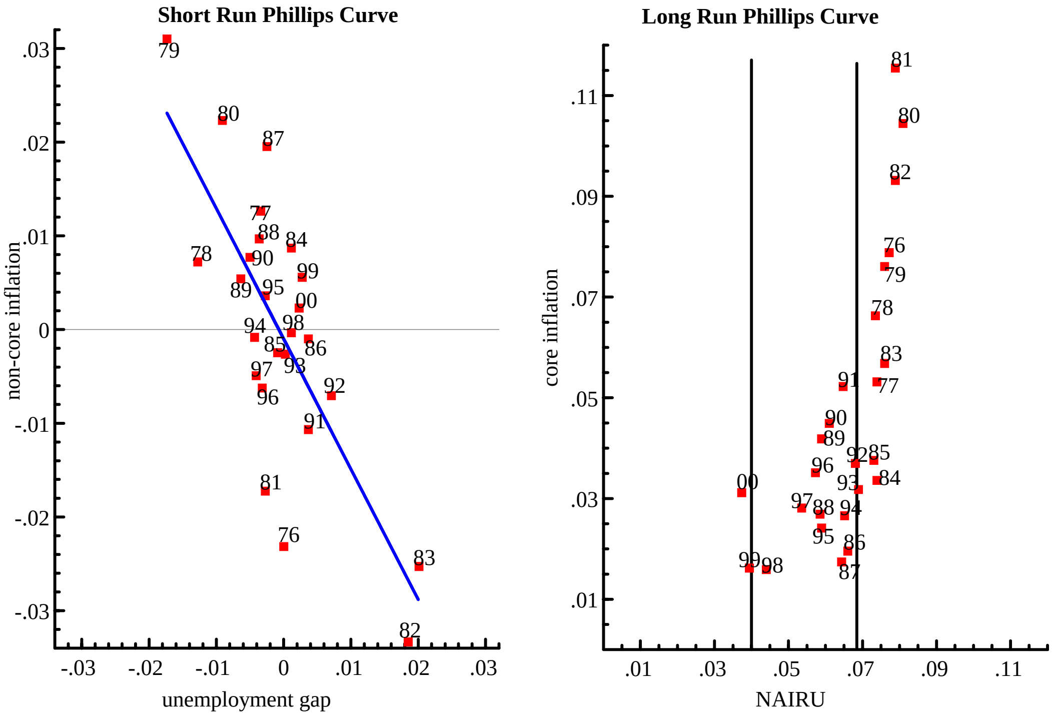

Figure 4. Impulse Response Function