UNEMPLOYMENT AND THE CAPITAL STOCK: A DYNAMIC STRUCTURAL MODEL OF THE UK SUPPLY SIDE

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ABSTRACT

This paper estimates a consistent supply side model of the UK economy, where the production structure is modelled using a dynamic flexible functional form. We derive consistent factor demands, output price and wage equations and estimate them on aggregate data , testing, then imposing all of the cross equation restrictions implied by theory. By estimating the unrestricted production set for a sufficiently general production structure we are able to consider the appropriate cross equation restrictions to ensure that equilibrium unemployment is independent of the capital stock and technological progress in the long run. We argue that there is little empirical support for the restrictions with respect to the level of the capital stock, and show that in general the natural rate of unemployment is a function of factor shares. An increase in the cost of capital for example,, will therefore increase equilibrium unemployment. In so far as such an increase cannot be permanent, its effects are shown to be highly persistent in the presence of real inertia.

Keywords: Dynamic factor demands, Unemployment, Capital Constraints, Wages.

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CONTENTS

1 INTRODUCTION

Unemployment has been one of Europe's most persistent problems over the last two decades, rising to over 11% for the EC on average. Furthermore, with the emphasis on fiscal consolidation in Europe, it seems likely to remain high for the foreseeable future. Various explanations and policy prescriptions have been advanced in that time, all with various degrees of empirical validation but all with limited success. Throughout this period the European economy has continued to grow by 2% per year on average[1]. Yet high levels of socially destructive unemployment persists. Much of the emphasis has been on the labour market; for example, examining the role played by trade unions, the unemployment benefit regime or the tax incentives for effort. The recent OECD Jobs Study (OECD, 1994) was almost exclusively labour market orientated in the policies it put forward to tackle high unemployment in Europe. Very much with the North American model in mind, the OECD advocated reform of benefit entitlements (with the duration of benefits limited to six months), and greater flexibility in wages and non-labour costs by reducing employers' taxes and minimum wages. Now in the late 1990s many of these labour market-supply side explanations are beginning to look unconvincing in the face of continued high unemployment. In the UK for example, unions are much weaker, membership has fallen significantly, but unemployment remains high. Equally, pinning an argument on the benefit regime would suggest that equilibrium unemployment would have fallen in the 1980s.[2]

Traditionally, the natural rate hypothesis has ruled out capital as a possible cause of persistent unemployment for what largely amount to statistical reasons: capital has risen for many centuries while unemployment, although sometimes rising to very high levels, has remained essentially untrended. In this paper we argue that a distinction can be drawn between rising levels of income, associated with trend increases in productivity and changes in the demand for labour that arise from shifts in the level of capital shock. We argue that, at any point in time, the latter may represent a locus of capital-labour ratios consistent with a range of non-inflationary unemployment rates. The implication being that increases in the demand for labour, warranted by increases in the capital stock may give rise to changes in employment, that do not necessarily lead to increased wage demands by driving unemployment below the natural rate[3].

Section 2 reviews the classical arguments that have typically been used to rule out the capital stock as a possible cause of equilibrium unemployment. We introduce the concepts of neutrality and super-neutrality of unemployment to the capital stock as described by Manning (1992), arguing that the stylised facts are in fact only consistent with neutrality. We consider, in section 3, a model of the UK supply based on a flexible functional form that is sufficiently general to enable us to distinguish the restrictions required for both types of neutrality. A dynamic version of this model is then estimated jointly as a system. This increases the efficiency of our estimates and enables is to employ all the cross equation restrictions implied by economic theory. In this way we believe we take a significant step to overcoming the problem of identification in non-linear systems discussed in Greenslade, et. al (1999). We find that we are able to accept the restrictions required for neutrality - essentially ensuring that the system has a steady state but argue that the non linear and time varying restriction for super neutrality is highly unlikely to be fulfilled given the behaviour of wages we report in section 6. In these circumstances it is shown that changes in capital accumulation when combined with insider behaviour in the labour market and lead to changes in equilibrium unemployment.

2. UNEMPLOYMENT AND GROWTH

Economists have some very strong theoretical priors about long run labour market behaviour. These can be expressed in shorthand as the idea that unemployment cannot be trended over time. In other words, as economists we believe that the Luddites were wrong; advancing technological change that enables firms to produce the same output but with fewer people, does not lead to lower and lower levels of employment for the economy as a whole. This proposition is clearly supported by the data over very long periods of time. In figure 1 for example, unemployment is untrended over a very long time horizon, while on the other hand our economy's productive potential (figure 2) has persistently risen .

Put another way, in mature industrial economies, this growth in output has typically been achieved with a broadly stable population. Per capita income has therefore grown enormously. This could not have been achieved without technical progress, otherwise diminishing returns would have made it impossible to maintain per capita growth for so long just by accumulating more capital per worker. Our models of the economy therefore have to allow technology to improve over time. More than this however, the neoclassical economists of the 1950s and 1960s noted that as well as being positive, per capita growth rates do not tend to diminish over time (Kaldor, 1963). If we take as a stylised empirical fact the observation that per capita growth rates approach a constant in the long run, then this implies that the economy tends towards a steady state dynamic equilibrium.[4] Taken together, the requirement to have a constant growth rate in the long run and to have neutrality of unemployment to growth requires that the technical progress is biased in a very specific way. In particular it requires technical progress to be labour augmenting or Harrod neutral, for the economy as a whole, over very long periods of time.[5]

A similar argument applies to the idea that there may be a relationship between unemployment and the capital stock. Bean (1989) probably puts it the most succinctly;

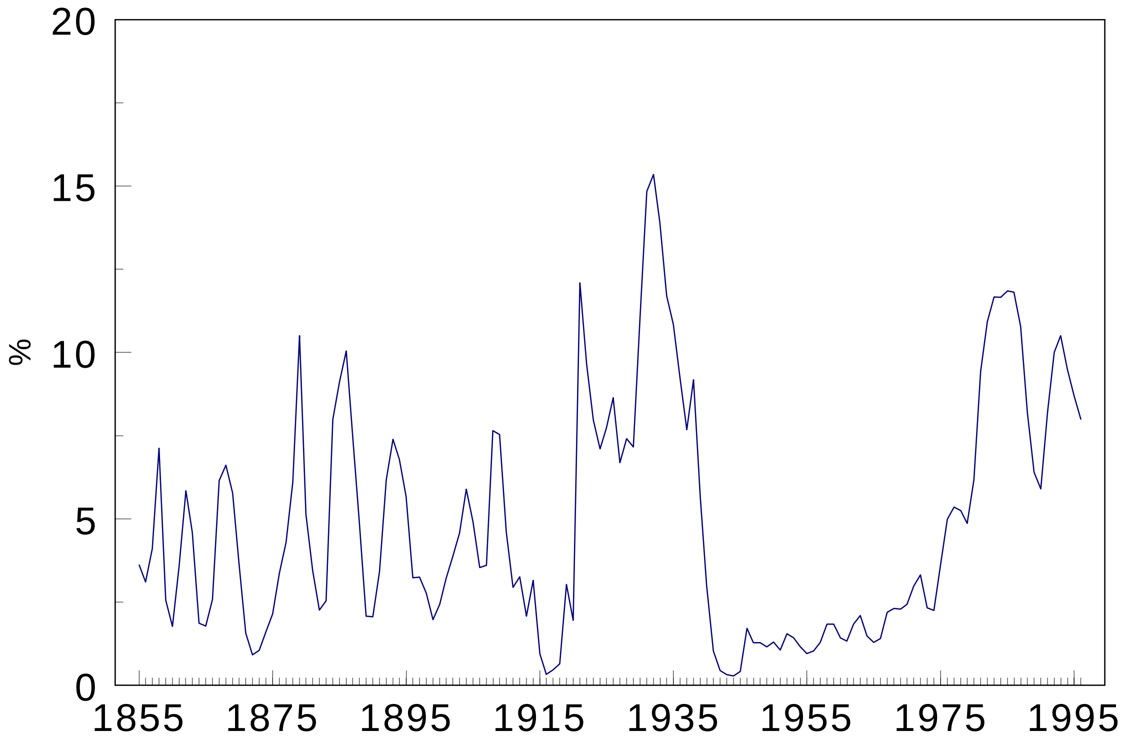

Figure 1: UK Unemployment Rate

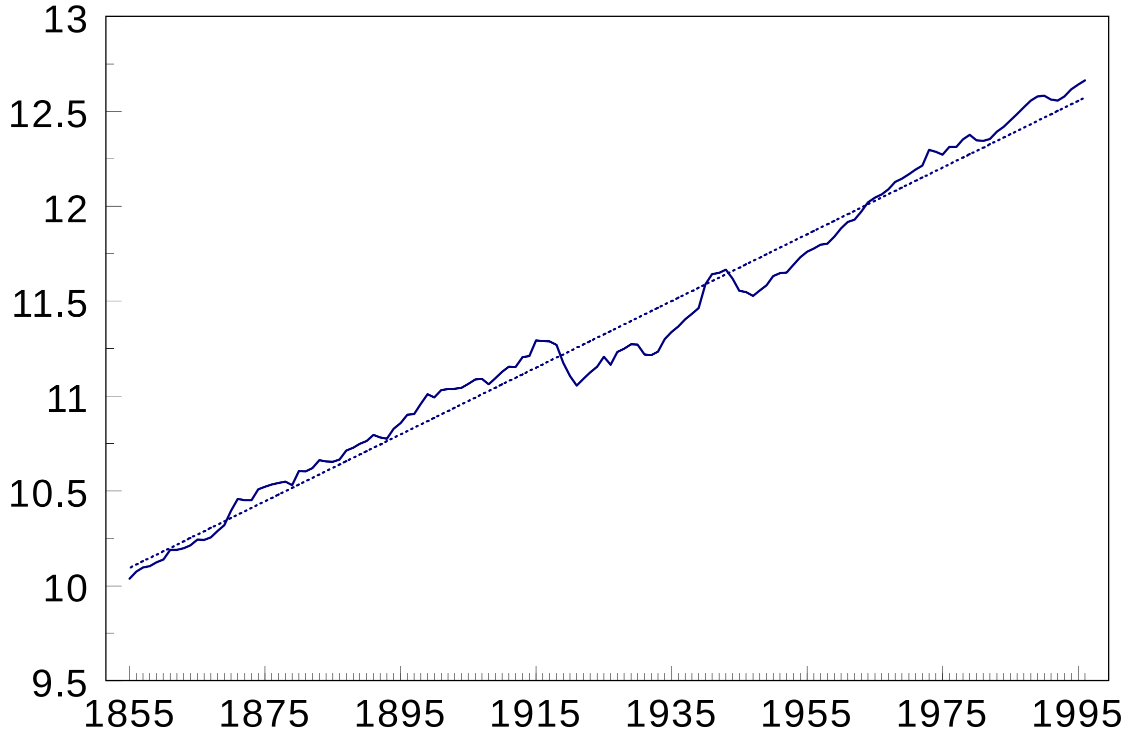

Figure 2: UK Gross Domestic Product and trend - constant prices (log scale)

"capital intensity and productivity have been rising steadily since the Industrial Revolution. Yet the unemployment rate shows no discernible trend; consisting of a few minor wiggles at business cycle frequencies, plus the occasional major change of level. It does not require any formal statistical analysis to confirm that the unemployment rate and capital intensity cannot be related in the long run."

The import of these observations about technical progress and the capital stock means that in the empirical literature suitable cross equations restrictions are usually imposed between the wage, price and employment equations such that neither technical progress or capital accumulation can affect employment determination. This is done to ensure that unemployment is independent of productivity and therefore untrended in long run. This was recognised in the seminal model of unemployment by Layard, Nickell and Jackman in 1991. Their analysis of the supply side can be summarized in the following wage-price system:

$$p - w = \beta_0 + \beta_1 u - \beta_2 \Delta^2 p - \beta_3 (k - l) \qquad \textbf{(1)}$$

$$w - p = \gamma_0 + \gamma_1 u - \gamma_2 \Delta^2 p - \gamma_3 (k - l) + z_w \qquad \textbf{(2)}$$

where (k - l) is the capital-labour ratio, (their proxy for productivity) and u is the unemployment rate . Solving (1) and (2) simultaneously and setting $\Delta^2 p = 0$, and $\beta_3 = \gamma_3$, we can derive an expression of the unemployment rate consistent with stable inflation. Thus the Non-Accelerating Inflation Rate of Unemployment, or NAIRU is given by:

$$u^* = \frac{(\beta_0 + \gamma_0) + z_w}{\beta_1 + \gamma_1} \qquad \textbf{(3)}$$

Such models place all the onus of adjustment on the labour market, requiring wages to adjust to clear the market. Any unemployment that continues to exist in equilibrium is therefore due to structural factors that influence the relative bargaining strengths of employer and worker, such as trade unions or high levels of unemployment benefit. However, as Manning (1992) points out, the imposition of the restriction $\beta_3 = \gamma_3$ amounts to what he describes as "super-neutrality" of the equilibrium unemployment rate with respect to productivity, such that "unemployment is independent of the entire time path of capital accumulation and productivity growth" (p.5). This restriction is therefore "much stronger than the original neutrality proposition, which was that in an economy experiencing steady-state growth, the unemployment rate should be constant."

The problem arises because in the steady state the capital-labour ratio will grow in line with technological progress, and hence $k - l$ can be used as a proxy for productivity. However, it is clear if one considers the underlying production function that technological progress is not the only source of output growth. Increases in output can also arise from increases in intensity for factor inputs for a given level of technology. These changes in factor intensity will be reflected in changes in the factor shares of output. The problem with a Cobb-Douglas specification is that factor shares are constant. A more general functional form will allow factor shares to vary. We should then be able to discriminate between increases in output that arise from technological progress and increases that arise from increased factor intensity. In this paper we argue that by modelling the unrestricted production set we are able to separate the restrictions we require for a steady state (ie. Harrod neutral progress) from those restrictions that imply 'super-neutrality'. This requires modelling the economy in a more general framework than the Cobb-Douglas case. In particular, we allow the elasticity of substitution between factors to be freely determined using a four factor translog cost function.

It is then an open question as to just what wages respond to. For unemployment to still be independent of capital accumulation, and therefore of investment, would require a very particular sympathetic (to use Bean's terminology) adjustment of wages to factors that influenced the level of the capital stock, such as the cost of capital. We argue here however, that the evidence appears to be that at the aggregate level at least, wages respond to productivity regardless of the source of that productivity. This would suggest that wages are unlikely to respond in the required sympathetic way. But again, with a more general functional form we can separately identify the restrictions on the wage equation that are required for the required sympathetic response of wages for unemployment to be independent of the determinants of the capital stock. Below we argue that the restrictions for super-neutrality are highly unlikely to be fulfilled. In this case the long run equilibrium, or natural rate will be a function of the level of the capital stock (or more specifically the determinants of the relative factor inputs such as the relative factor prices)[6]. The remainder of this chapter examines these arguments empirically. The next section introduces a consistent set of factor demands based around a flexible production technology and considers what restriction would be required on wage behaviour to retain the classical independence of unemployment from demand side factors. The remaining sections estimate the model on UK data and present model simulations to underscore the arguments being made here.

3. AN AGGREGATE PRODUCTION STRUCTURE FOR THE UK ECONOMY

3.1 The Long Run Structural Model

We think of the supply side in terms of a representative, imperfectly competitive firm, operating in a small open economy with five aggregate commodities; goods (Y), capital (K), labour (L), fuels (F) and non-fuels (M)[7]. Fuels and non-fuels are essentially assumed to be raw materials whose price is set exogenously. We assume there is a market for labour and capital which determines their respective prices, although in so far as the cost of capital is influenced by interest rates this too is exogenous, set by an inflation targeting authority. Additionally, we assume there is disembodied exogenous technical progress (t). The imperfectly competitive firm decides its required input volume, taking factor prices as given, to produce an expected level of output, given the current state of technology. It then sets price on the basis of a markup over marginal costs, which in turn determines the real value of factor incomes. This then determines actual demand, through the demand side of the economy.

For our empirical specification, we assume that the cost function can be approximated by a second order translog cost function. The translog is a flexible functional form which can be interpreted as a second-order approximation to any arbitrary cost function (see Denny and Fuss, 1977). It has enough parameters to allow us to estimate empirically an unrestricted set of elasticities of substitution, between the different factors of production. We therefore are not constrained to restrict all of the elasticities of substitution to be unity a priori, as with the Cobb-Douglas production function.

We therefore write the equilibrium cost function as:

$$
\begin{aligned}
\ln C = \; & \alpha_0 \\
+ \; & \alpha_y \ln y \\
+ \; & \alpha_t \, t \\
+ \; & \sum_{i=1}^{n} \alpha_i \ln p_i \\
+ \; & \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} \ln p_i \, p_j \\
+ \; & \sum_{i=1}^{n} \alpha_{iy} \ln y \ln p_i \\
+ \; & \sum_{i=1}^{n} \alpha_{it} \, t \ln p_i \\
+ \; & \alpha_{yt} \, t \ln y \\
+ \; & \frac{1}{2} \alpha_{yy} (\ln y)^2 \\
+ \; & \frac{1}{2} \alpha_{tt} \, t^2
\end{aligned}
\qquad \textbf{(4)}
$$

where p_i is the ith input price, C is the equilibrium total cost, y is output, t is a time trend.

By Sheppard's lemma, differentiating the long run cost function with respect to each of the factor input prices generates the firm's long run cost minimising factor demands. If we differentiate $\ln C$ with respect to $\ln p_i$ we obtain the following system of input share equations:

$$S^{*_i} = \alpha_i + \sum_{j=n}^{n} \alpha_{ij} \ln p_j + \alpha_{iy} \ln y + \alpha_{it} \, t \qquad \textbf{(5)}$$

where $S_i^* = \dfrac{p_i \, X_i}{\sum_{j=1}^{n} p_j \, X_j}$ and X_i is the quantity demanded of input i.

A number of specific restrictions can then be tested for and imposed on this general model.

1. If the shares are to **sum to one**, the following parameter restrictions must hold. This also

ensures **linearly homogeneity in factor prices**.

$$\sum_{i=n}^{n} \alpha_i = 1$$
$$\sum_{j=n}^{n} \alpha_{ij} = 0 \qquad \textbf{(7)}$$
$$\sum_{i=n}^{n} \alpha_{iy} = 0$$

2. Equally we require **symmetry** for the translog to be viewed as a quadratic approximation to an arbitrary cost function[8] (Denny and Fuss, 1997). Thus the cross partial derivatives must be equal. This requires:

$$\alpha_{ij} = \alpha_{ji}, \qquad i \neq j \qquad \textbf{(8)}$$

These two restrictions are be imposed, but the following restrictions are tested for:

3. Additionally, the cost function will be **linearly homogeneous in output** if:

$$\alpha_y = 1$$
$$\alpha_{yy} = 0 \qquad \textbf{(9)}$$
$$\alpha_{yt} = 0$$

4. The homogeneous translog cost function will be **homothetic** if

$$\alpha_{iy} = 0 \qquad for\ all\ i, \qquad \textbf{(10)}$$

5. Finally, **labour augmenting technical progress** requires the following restrictions between the coefficients on the price of labour and the coefficients on the rate of growth of technology, *v*:

$$\alpha_t = \alpha_l\ v$$
$$\alpha_{it} = \alpha_{li}\ v$$
$$\alpha_{yt} = \alpha_{ly}\ v \qquad \textbf{(11)}$$
$$\alpha_{tt} = \alpha_l\ v$$

Turning to the dynamic specification of our model; it is well known that firms cannot adjust factors instantaneously. In the case of the capital stock for example, instantaneous adjustment would imply that discrete changes in the economic environment (such as changes in interest rates) produce infinite rates of investment or disinvestment (Romer, 1996). We therefore assume firms face costs of adjusting the volumes of factor inputs. Following Hall and Nixon (1999), we assume firms face costs of adjusting the actual level of factor input. The firm's objective function is then:[9]

$$L^{*} = (S_t - S_t^{*})^{/} \; C_1 \; (S_t - S_t^{*}) \quad + \quad \Delta\ln(x)^{/} \; C_2 \; \Delta\ln(x) \qquad \textbf{(12)}$$

which will give rise to general factor demand functions which have the following general form (where for simplicity we assume C is diagonal):

$$\Delta\ln(x)_{i,\,t} = \gamma_{i,\,t}.\Delta\ln(x)_{i,\,t-1} + \beta_i \left(\frac{p_{i,\,t-1}.x_{i,\,t-1}}{C(p_{i,\,t-1},\, Y_{i,\,t-1})} - S^{*}_{i,\,t-1} \right) \qquad \textbf{(13)}$$

This suggests that we should estimate the dynamic factor demands as an unnormalised, non-linear system, together with the long run cost function. Before reporting our estimation results we move to consider a consistent model of wage behaviour and in particular to identify to restrictions between the factor demands and wages that are required for neutrality and super neutrality.

4. A CONSISTENT MODEL OF WAGE DETERMINATION

The following is a typical statement of the "right to manage" bargaining framework, see for example Manning (1993). This is deliberate because we wish to concentrate on the innovation of extending the model to the capital stock. Although this model of wage determination is based around a union bargaining model, we believe the model has wider scope than simply the allocation of rents between an employer and a trade union. Pencavel (1985) for example, argued that a bargaining scenario is intrinsic to any situation where firm specific skills are important. Thus the firm's profits can be thought of as a 'cake' to be divided up, where the share that workers receive is a function of their bargaining power and the strength of their negotiating position. This amounts to an argument that in the long run wages must be related to some measure of underlying productivity or profitability.

We assume wages (w) are therefore set to maximise a weighted average of the union's utility and firm's profits. The Nash bargain is then:

$$w_t = argmax \quad U_t^{\chi} \, \Pi_t^{1-\chi} \tag{14}$$

Where U is union's utility, Π is firm's profits and χ represents the relative power of the union in the bargain. A typical form for the union's utility function to take is

$$U = N_t^{\phi} \, (V_t - V_t^{a}) \tag{15}$$

Where V_t is the value of employment and V_t^a is some measure of the value of alternatives elsewhere in the economy. ϕ represents the union preferences for employment relative to wages. With this form of utility function the union therefore cares about both wage and employment levels. Substituting equation (15) into equation (14) and taking logs, we have

$$\ln w_t = \psi \, \chi \, \ln N_t + \chi \, \ln (V_t - V_t^{a}) + (1-\chi) \, \ln \Pi_t \tag{16}$$

Differentiating with respect to log wages gives:

$$\Omega_w = \psi \chi \frac{\delta \ln N_t}{\delta \ln w_t} + \chi \frac{\delta \ln (V_t - V_t^a)}{\delta \ln w_t} + (1-\chi) \frac{\delta \ln \Pi_t}{\delta \ln w_t} = 0 \qquad \textbf{(17)}$$

which after some rearrangement can be written as:

$$W_t = \mu (V_t - V_t^a) \quad \textit{where} \quad \mu = \psi \varepsilon_{NW\,t} + \frac{(1-\chi)}{\chi} \varepsilon_{\Pi W\,t} \qquad \textbf{(18)}$$

where ϵ_{NW} and $\epsilon_{\Pi W}$ are the elasticity of employment and profits with respect to the wage.

Thus the first term, the elasticity of employment with respect to the wage, is included because the union are explicitly concerned about employment levels. It is not immediately clear why a union should be concerned about employment in the steady state. We also have in mind the situation where individual skilled workers are able to bargain over their wage but clearly have little influence over employment. We therefore set this term to zero.

Following Manning (1993), defining the value functions in a standard way, leads to a relationship for real wages of the following form:

$$\frac{W_t}{P_t} = \frac{\mu_t(1-\eta)}{\mu(1-\eta) - [1-d_t(1+g)(s_t-q_t)]} \cdot \frac{B_t}{P_t} \qquad \textbf{(19)}$$

Finally, by making plausible assumptions about the relationship between unemployment and the transition probabilities q and s, ie. that job quitters have probability of staying unemployed of γs, we can rearrange (19) to derive what down Manning (1993) describes as a structural wage equation:

$$U_t = \frac{\mu \gamma(1-R) + d_t - (1+qd)(1-\gamma q)}{(1+d_t q)\gamma q} \qquad \textbf{(20)}$$

where R is the replacement ratio R=B/W.

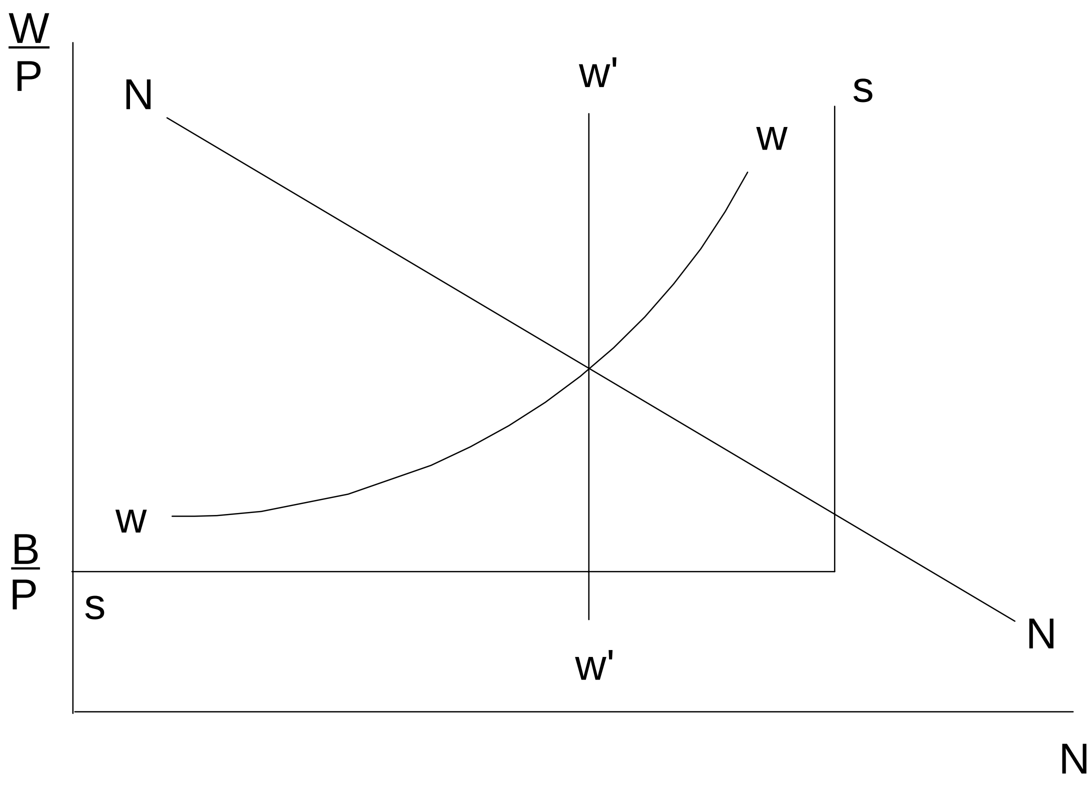

Figure 3: The determination of equilibrium unemployment

To borrow the nomenclature in Manning (1995), our original wage setting schedule, as given by (19), can be drawn as WW in Figure 3. However, on the assumption that benefits are indexed to the level of wages, ie. replacing B/W by the replacement ratio, we can eliminate wage from our wage equation to obtain the structural unemployment equation (18). Thus the WW curve is completely inelastic as represented by W'W'. This gives us the equilibrium unemployment rate as determined by the wage setting relationship alone, that is as a function of union bargaining power, the replacement ratio, the job competitiveness of the unemployed and μ.

As Manning points out, $\epsilon_{\Pi W}$ will be a constant for the Cobb-Douglas case, leading to an exogenous μ_t depending only on union power. Thus the assumption of Cobb-Douglas in addition to the cross equation restrictions between the wage equation and the price-employment schedule lead to the imposition of super-neutrality of unemployment with respect to any of the determinants of productivity, such as the level of capital stock. But this is not the case for a more general functional form. We now therefore derive the structural determinants of μ_t consistent with our supply side. This in turn will lead us to four alternative but inter-related possible specifications for wage equations, relating wages to productivity, costs, profits, and individual components of the cost function, respectively.

We first derive an expression for the elasticity of wages with respect to profits so that we can substitute for μ_t[10]. The profit function for the imperfectly competitive firm is therefore;

$$\Pi = P(Y) \, . \, Y - C(P_i \, , \, Y) \tag{21}$$

where $C(P_i,Y)$ is the unrestricted cost function. Then from the envelope condition we have:

$$\frac{\delta \Pi}{\delta W} = - N \tag{22}$$

The elasticity of profits with respect to the wage is therefore:

$$\epsilon_{\Pi W} = - \frac{\delta \, \ln \Pi}{\delta \, \ln W} = - \frac{\delta \Pi}{\delta W} \, . \, \frac{W}{\Pi} = \frac{W.N}{P.Y - C(P_i \, , \, Y)} \tag{23}$$

Which if we divide through by total costs gives:

$$\epsilon_{\Pi W} = \frac{S_L}{\Psi} \qquad where \qquad \Psi = \frac{P.Y - C(P_i \, ,Y)}{C(P_i \, ,Y)} \tag{24}$$

where Ψ, the difference between revenue and costs as a percentage of costs is the profit rate. Given the homogeneity of the cost function in the long run, this is equivalent to the markup on marginal costs. [11]

Log linearising the structural wage equation (20) and substituting for μ_t, we derive a wage equation from the factor share.

$$\ln W_t = \ln \, C(P_i \, ,Y) - \ln N_t + a_0 + a_1 \ln U_t + a_2 \ln \psi_t + a_3 \ln \chi + a_4 \ln R_t \tag{25}$$

A little inspection indicates the wage equation can be expressed in one of three equivalent ways:

1. One that uses the cost to employment ratio as above in (25).
2. If we appeal to duality theory we can replace this term with productivity, ie. Y/N
3. A third is to use the envelope condition (22) to derive an expression for wages in terms of nominal profits per employee (where in this instance the markup term Ψ is included in profits.) Thus we see the broad equivalence between wages equations based on profits (see for example the argument made by Carruth and Oswald, 1989), and wage equations based around productivity (see Hall, 1986).

Each of these formulations suggests that wages respond purely to changes in productivity, arising from whatever source. This property arises by virtue of the “insider” model we have adopted for wage determination. The implication is that a change in productivity that arises from increased factor intensity will still be captured by wage bargainers, other things, particularly bargaining power, being constant at the expense of employment opportunities for outsiders. In the next section we present what we believe is the compelling econometric evidence that this is exactly how wages are determined. For it to be otherwise would require very particular restriction on the wage equation that essentially distinguishes between technological progress and changes in factor prices (that produces changes in factor intensities). This is discussed in an appendix and future work will test such restrictions explicitly but *a priori*, we see no theoretical justification for such a complex non linear relationship. In the absence of such sympathetic adjustments in wages the unemployment schedule W’W’ will be a function of factor shares. Thus an increase in the cost of capital will shift the W’W’ schedule to the right decreasing equilibrium unemployment, if labour and capital are substitutes. Unemployment is therefore a positive function of the labour share, other things being equal.

In reality we feel that the sympathetic adjustment in wages is more likely to come through some of the other parameters, such as union bargaining power, that we have so far held constant. In so far as such restrictions would require institutional changes in the real world, they are likely to be very slow to come about. This suggests that high levels of equilibrium unemployment, stemming from deficient employment demand may persist for very long periods of time.

5. ESTIMATION RESULTS

We now attempt to estimate the dynamic cost function and system of dynamic factor shares discussed in section 3. Since the system is non-linear in factor prices and because we want to estimate a very specific adjustment mechanism we are not able to employ standard the Johansen technique (see Johansen 1988, 1991). Instead we estimate the system jointly using fully information maximum likelihood (FIML). The approach we take is also an example of the ideas discussed in Greenslade et. al. (1999) in that we impose a high degree of structure on the data and estimate a very particular conditional system. We do this because in a small sample we are not confident of correctly being able to identify the cointegrating vectors that correspond to the particular model we are attempting to estimate. We do however consider the cointegrating properties of our system by estimating the long run equations separately and testing for cointegration in a rather heuristic fashion using standard Augmented Dickey Fuller tests. This can be thought of as the first stage of the Engle-Granger procedure but generalised to a full system. We do not report tests for the order of integration of the data or problems associated with cointegration in non-linear systems as these we extensively discussed in earlier work (Allen 1997). But, in summary we treat all the variables of interest, prices, costs and output, as I(1). The shares themselves for example, can also be shown to be I(1) after an appropriate logit transformation. Allen (1997) also considers the implications of the non-linear nature of the system for cointegration and we do not repeat his discussion here. We apply our restrictions to the model in three stages, homogeneity, homotheticity and then Harrod neutrality, testing for continued cointegration at each stage. Having gauged the cointegrating properties of the system we then jointly estimate the full set of dynamic equations including the coefficients on levels. Ideally, we would like to test the validity of our restrictions via conventional likelihood ratio tests in the dynamic model.

Table 1 reports cointegration tests on each equation in the system, as we successively impose the three groups of restrictions on the system estimated jointly. We find that in order to achieve cointegration we are required to extend our theoretical model to include two further variables. In particular, to apply linear homogeneity with respect to output requires the addition of capacity utilisation as a variable in our system. This finding mirrors the arguments made in the real business cycle literature about the need to measure capital services accurately (see for example Burnside, Eichenbaum and Rebelo, 1995). Clearly, it is utilised factors that go into the production function so this result is hardly surprising. In principle it would be possible to adjust the data for factor volumes employed (most easily labour could be multiplied by hours, for example). However, hours data is only available for manufacturing and in any case this series has been recently discontinued. We therefore include capacity utilisation in our system as an extra regressor. This implies the addition of six extra terms to the cost function; *cu*, $p_i.cu$, for I=1 to 4, and *cu.t*, with the appropriate cross equation restrictions between them.

The second extension stems from the observation that our measure of fuel input shows a marked drop at the start of the 1980s. This seems to reflect a fundamental asymmetry of response, possibly associated with irreversibility of investment or permanent technical change. Thus the long fall in real fuel prices over the 1980s has not resulted in a return to the same level of fuel use for a given level of output. Rather the price hike of the 1970s appears to have produced a permanent increase in fuel efficiency. To capture this effect, we additionally include a cumulated real fuel price as well as the the share of manufacturing in GDP, as a two further dummies in our system. This again implies the addition of a further six terms and two more restrictions for each dummy.

The results from the ADF tests on the residuals from each equation on the system, indicate that we can restrict our model to be consistent with economic theory and still maintain cointegration. Thus imposing linear homogeneity, homotheticity and Harrod neutrality improve the cointegration properties of the system without increasing the standard error of the regressions markedly. Turning to the dynamic model shown in table 4, we are able to estimate the full non-linear system with error correction in factor shares. All of the error correction terms are significant and the system is well specified, passing diagnostic tests for autocorrelation and hetroskedelasticity. In terms of individual coefficients, we find that the necessary concavity conditions are global and that the estimated Allen elasticities are consistent with previous studies. The elasticity of substitution between capital and labour is 0.42 which is broadly in line with a wide average of studies (see Rowthorn, 1996 for a survey).

Table 1a: Cointegration tests on Unrestricted Levels System

	ADF(n)	(n)	SSR	SE	LogL
TCOST	4.61 [.028]	(0)	.01064	.00912	2110
SL	6.44 [.000]	(3)	.00218	.00413	
SK	4.93 [.011]	(3)	.00345	.00519	
SF	5.01 [.008]	(0)	.00065	.00225	

Table 1b: Cointegration tests when linear homogeneity with respect to output is imposed

	ADF(n)	(n)	SSR	SE	LogL
TCOST	4.71 [.021]	(0)	.01608	.0112	2065
SL	5.81 [.000]	(1)	.00231	.00425	
SK	4.73 [.019]	(1)	.00467	.00604	
SF	5.57 [.001]	(0)	.00064	.00224	

Table 1c: Cointegration tests when homotheticity is imposed

	ADF(n)	(n)	SSR	SE	LogL
TCOST	5.52 [.001]	(0)	.0329	.0160	2033
SL	6.43 [.000]	(3)	.00214	.00409	
SK	5.12 [.005]	(3)	.00338	.00514	
SF	4.35 [.057]	(0)	.00071	.00236	

Table 1d: Cointegration tests when Harrod Neutral Technical Progress is imposed

	ADF(n)	(n)	SSR	SE	LogL
TCOST	4.41 [.049]	(0)	.05090	.0214	1940
SL	4.96 [.009]	(0)	.00327	.00505	
SK	5.03 [.007]	(3)	.00340	.00515	
SF	5.17 [.004]	(0)	.00071	.00236	

Notes: ADF tests of order n are reported for residuals on each equation, where n is the minium lag required to remove serial correlation from the ADF regression. Cointegration probability values are for 6 regressors and are for guidance only.

Table 2: Log likelihood Ratio tests of the restrictions on the dynamic System

	Log likelihood	Chi Sq	(n)	p (value)
Unrestricted	1762			
Homogeneity	1760	4.34	(3)	0.226
Homotheticity	1754	10.67	(4)	0.031
Harrod Neutrality	1746	15.44	(9)	.0799
All restrictions		30.45	(16)	.0159

Table 3a: Long Run Allen Elasticities of Substitution[12]

	Labour	Capital	Fuel	Non-Fuel
Labour	-0.133	0.461	-0.479	0.366
Capital		-0.832	1.902	-2.511
Fuel			-6.876	3.5146
Non Fuel				-0.332

Table 3b: Long run Price Elasticities

	Labour	Capital	Fuel	Non-Fuel
Labour	-0.089	0.075	-0.027	0.041
Capital	0.215	-0.136	0.112	-0.284
Fuel	-0.183	0.278	-0.396	0.397
Non Fuel	0.379	-0.413	0.173	-0.038

Table 4: Levels and Dynamic Estimates of Main Coefficients

66q2 - 96q4	Static Model		Dynamic Model	
FIML:	Estimate	t-statistic	Estimate	t-statistic
A0	-3.161	-.250	-0.46543	-.091175
A1	.5528	9.19	-.212794	-.987472
A2	.5417	73.74	1.24868	30.9058
A3	.0640	-34.5	-.063788	-3.94799
A11	.1690	32.21	.163842	4.18784
A12	-.0587	-32.71	-.145369	-5.22424
A13	-.0531	-36.27	-.845225E-03	-.258361
A22	.1118	59.79	.165077	5.31508
A23	.0092	-12.10	-.010561	-3.98151
A33	.0311	41.98	.018169	2.89945
V	-.0048	-62.90	-.005578E-02	18.5859
B0			.538740E-02	1.85901
B1			-.221817	-2.93514
B2			-.491001E-02	2.38615
B3			-4.39729	2.62236
B4			-3.14291	2.21445
ΔN_{-1}			.323493	4.03552
ΔN_{-2}			.165658	2.17369
ΔK_{-4}			.486817	7.0986
ΔF_{-1}			-.299425	-4.15931
ΔF_{-1}			-261300	-3.62754
ΔM_{-1}			-.217297	2.88183

Notes: where *Ai j* are the production coefficients, where 1=labour (N), 2=capital (K), 3=fuels (F), and 4=non-fuels (M).

6. A COINTEGRATING VECTOR FOR WAGES AND PRODUCTIVITY

The reduced form wage equations derived in section 4 posit a relation between real wages, productivity and a number of variables that might effect the relative strength of each party to the wage bargain. We also argued there that it is possible to substitute further for the cost (or production) function and derive a model of wages in terms of a target real wage in which it would be possible to identify the restrictions required between the wage equation and the system of factor demands for unemployment to be independent of the capital stock. neutrality.

A number of authors, particularly Manning (1993) and Lee and Pesaran (1993) have commented on the difficulty in identifying a suitable restricted wage equation. One possible approach for tackling this question would be to attempt to model the first order conditions to the union's bargaining problem directly (see for example Henry and Lee, 1996). However, we take to view that the identification problem is something of a misnomer. One can recast the argument of Manning as in a systems context as essentially saying that the long run solution of the wage-price-employment system is of reduced rank. In other words, in the terminology of Davidson and Hall (1991), there exists a target relationship between wages, prices and employment that corresponds to a single cointegrating vector. In a dynamic context there is no reason why wages, prices and employment cannot adjust towards to same target relationship. The most obvious possibility is therefore to jointly estimate the wage and price equations with the system of factor demands. This would have the added advantage of achieving identification through the use of appropriate non-linear restrictions rather than through simple exclusion restrictions.

However, this is rather more than we need to do to establish the presence of non-neutralities and is in itself far from trivial. The restriction we require for simple neutrality is merely that wages be related to productivity with a unit coefficient in the long run. We therefore focus on identifying this 'target relationship' in a standard Johansen framework. To demonstrate the simulation properties of our model, which we do in the next section we then go on to estimate a dynamic model based on this cointegrating vector.

Table 5: Cointegrating regression for wages with productivity

LWW=	OLS 65q1 96q4	OLS 66q1 96q4	OLS 66q1 96q4	Johansen 66q1 96q4	Johansen 67q1 96q4	Johansen 67q1 96q4
Constant	-4.963 (0.227)	-5.208 (0.256)	-1.0767 (.57605)			
LPC	1.0875 (.0177)	1.0743 (0.019)	1.0690 (0.0131)	1 (imposed)	1 (imposed)	1 (imposed)
LPROD	0.9459 (.0634)	1.0369 (0.077)	0.9484 (0.0540)	1.1223	.99593	1.0018
LU	-.06155 (.01022)	-0.0426 (0.013	-.01461 (.0087)	.017178	-0.0597	-.03130
LMTUR		-.13952 (0.047)	-.10117 (0.0308)		.59555	.37534
LPFIT			-.01461 (0.0033)			0.0020
DF	2.649 [4.19]	2.972 [4.53]	4.539 [4.84]			
ADF(4)	3.346 [4.19]	2.906 [4.53]	3.848 [4.85]			
H_O r = 0 H_A r =1				39.2 [20.9]	26.7 [27.0]	37.8 [33.4]
H_O r <1 H_A r = 2				10.4 [14.1]	22.4 [20.9]	27.3 [27.0]

Notes: 1. Dependant Variable is the log of wedge adjusted wage (LWW)
2. A unit coefficient on prices was tested for and accepted on the Johansen estimates. This is therefore imposed in the results reported here. .
3. LPC is log consumer prices, LPROD is log productivity, LU is log unemployment rate, LMTUR is proportion of unemployed, unemployed for more than 26 weeks and LPFIT is the profit rate as defined in equation (34).
4. VAR length in Johansen = 4 (minium required to avoid mis-specification).

Cointegration tests for wages from both first stage Engle-Granger and a Johansen VAR are reported in table 5. There is clear evidence of at least one cointegrating vector between real wages and productivity, and very possibly two. We find it useful to include the proportion of long term unemployment in the total unemployment count, as an extra regressor (see also Westaway 1996). A number of authors attribute this to hysteresis stemming from the depreciation of human capital associated with long term unemployment (Blanchard and Summers 1986). The inclusion of long term unemployment is not strictly necessary to achieve cointegration but the parameter estimates from the Johansen regression that does, are much more appealing theoretically.

Table 6 reports estimates of dynamic regressions for wages on the basis of the Cointegrating vector reported above. Again the long run parameters point to a clear relationship between wages, prices and productivity with unit coefficients, although the unemployment term and the error correction coefficients are small but still significant. Finally, the equation readily supports dynamic homogeneity; this last finding can be interpreted as suggesting that wages are set on the basis of expectations of inflation, rather than the price level, which seems reasonable.

Table 6: Dynamic Wage Equations based on Labour Productivity

ΔLW =	65q2 96q4	65q2 96q4	65q2 96q4	65q2 96q4
ΔLW_{-1}	.45537 (.0861)	.50940 (.0740)	.49836 (.0724)	.43489 (.0723)
ΔLW_{-4}	.17104 (.0811)	.21978 (.0811)	.21153 (.0703)	.22217 (.0676)
ΔLPC	.07030 (.1015)			
ΔLPC_{-1}	.19337 (.1027)	.23572 (.0931)	.25111 (.0905)	.27037 (.0931)
ECM term	-.0822 (.0339)	-.09141 (.03268)	-.07820 (.02740)	-.07195 (.02371)
LWW_{-1}	1	1	1	1
Constant	-2.0981 (.3480)	-2.1994 (.24047)	-2.1787 (.27684)	-2.0584 (.22902)
LPC_{-1}	1.0496 (.0664)	1.0472 (.0558)	1	1
$LPROD_{-1}$	.86611 (.2890)	.95971 (.1902)	1.0824 (.1324)	1
$LPROFIT_{-1}$	.01013 (.0217)			
LU_{-1}	-.09408 (.0497)	-.09291 (.0432)	-.08289 (.0462)	-.0771 (.0474)
$LMTUR_{-1}$	.42858 (.2995)	.31608 (.2119)	.36362 (.24903)	.43157 (.2266)
Chi - Sq (1)			.71222 [.399]	.38710 [.534]
Regression SE	.008623	.008574	.008574	.008253
Serial correla'n	6.2091 [.184]	7.4836 [.112]	7.4836 [.112]	5.9837 [.200]
Functional form	7.1664 [.007]	8.7037 [.003]	8.7037 [.003]	3.2287 [.072]
Normality	.83380 [.659]	2.2247 [.329]	2.2247 [.329]	1.2878 [.525]
Heterosced	4.2671 [.039]	2.7670 [.096]	2.7670 [.096]	.82332 [.364]

Notes 1. LW is the log of the nominal wage and LWW is the wedge adjusted wage.
2. Standard errors on brackets

7 EQUILIBRIUM UNEMPLOYMENT AND CAPITAL FORMATION

This section reports the simulation properties of the entire supply side system, the cost function, factor demands, and wages. These are combined with a simple marginal cost price equation (discussed in Nixon; 1998). Finally, we close the model with a reduced from IS-LM equation of the form

$$y = \sigma_1 x + \sigma_2 (m - p) \qquad \textbf{(26)}$$

where x is fiscal policy, m is the nominal money stock and p is the gross output price deflator. Taken together our system of equations define an equilibrium (or natural) unemployment rate, which will be a function of relative factor prices[13].

Figure 4 reports the effect of a 10% increase in the money supply to illustrate the neutrality properties of the system. The model eventually settles down to a new equilibrium where the price level is 10% higher but output and employment are unaltered. However, it takes more than the whole simulation period (60 years) for the equilibrium to be restored. This is the result of the small coefficient on unemployment in the wage equation, which in the absence of a policy response and all the factors affecting relative bargaining strength, is the only feedback equilibrating the system. When this coefficient is doubled the response time is nearly halved (see the second line on figure 4) but still remains very long. We believe this is an example of real inertia; ie. that the equilibrating mechanism of unemployment on real wages is just very weak. Dynamic adjustment is protracted because changes in relative factor prices continue to propagate through the system as capital accumulates. The final simulation considers what happens if there is an increase in the real cost of capital. This is shown in figure 5, which shows the proportionate change in the unemployment from base following an increase in the real interest rate. Employment rises at first as the system substitutes for the cheaper factor but in the long run employment falls since output is a function of the real increase rate. Equilibrium unemployment is therefore a function of the real interest rate. Thus this simulation is equivalent to a leftward shift of the aggregate supply curve; a new stable inflation equilibrium is established a higher level of unemployment.

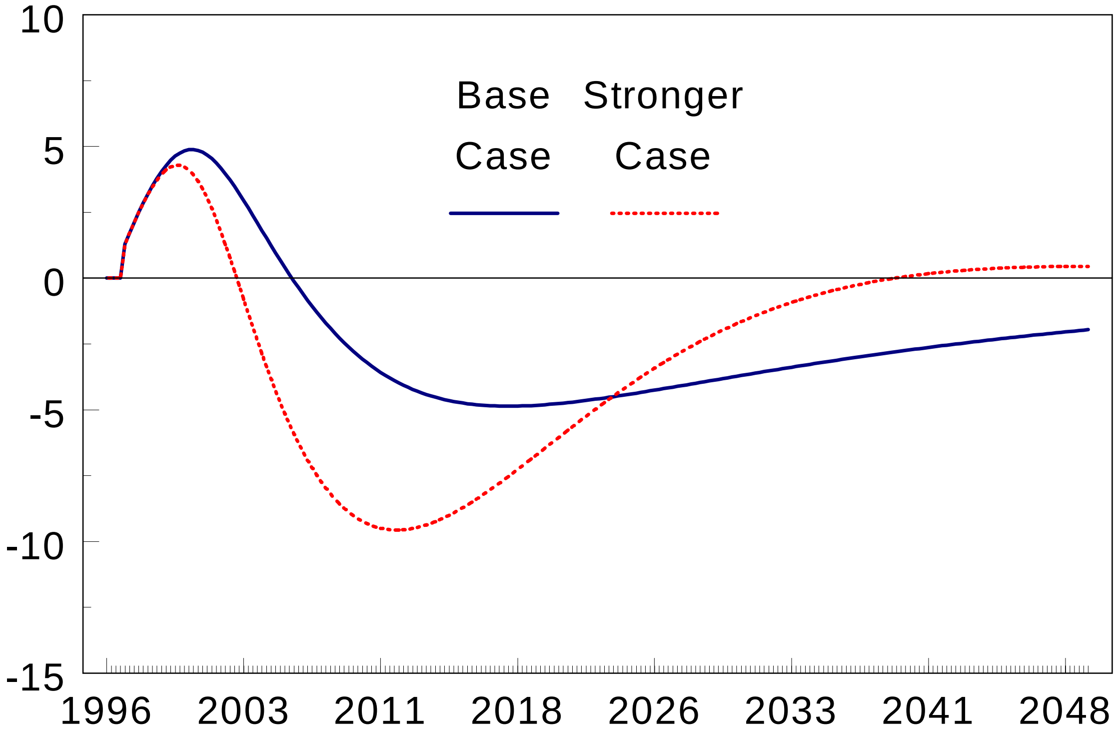

Figure 4: Employment - % deviation from base after a 10% increase in the money stock.

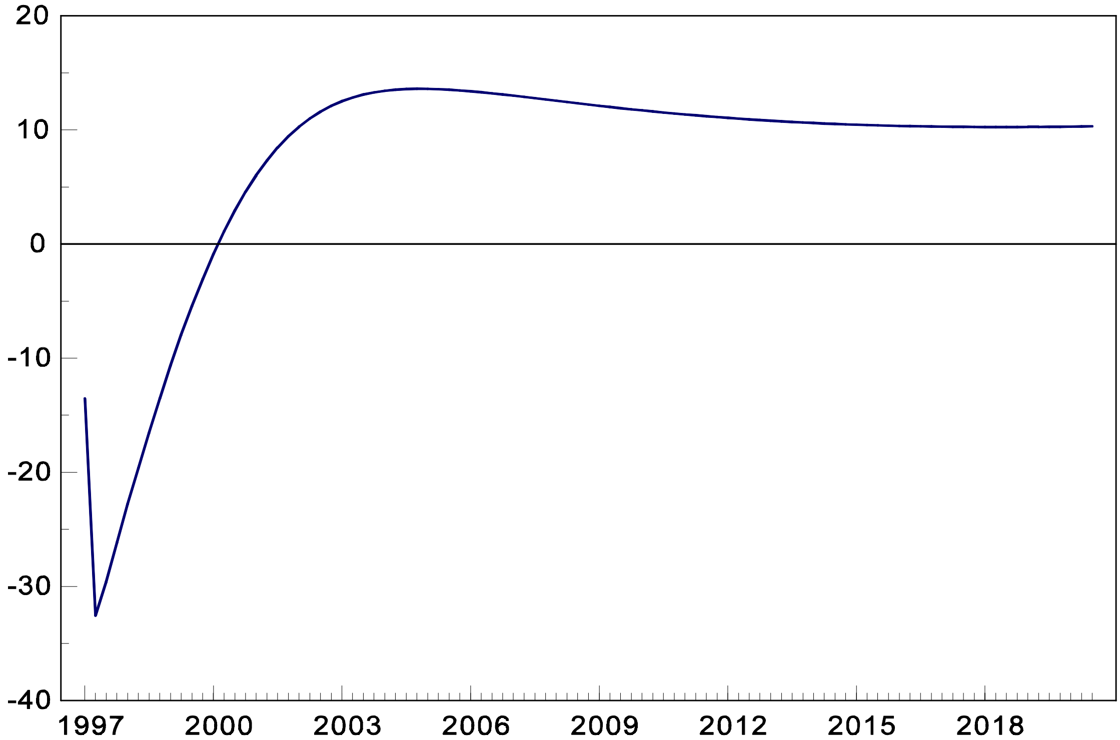

Figure 5: Unemployment rate - % deviation from base after a 1% increase in the real cost of capital

8. CONCLUSION

In this paper we have estimated a consistent aggregate production structure for the supply side of the UK economy incorporating a consistent to dynamic factor demands. We have paid particular attention to the restrictions required to ensure our system has a steady state solution and those restrictions required for a classical dichotomy between real and nominal values. By estimating the unrestricted production set and using a flexible functional form for technology, we are able to make a distinction between those restrictions required for a steady state and those required for the neutrality of unemployment to the capital stock. We we are able to estimate a full dynamic model for the aggregate UK supply side that is theoretically consistent and has desirable economic properties. In particular the model has an identified steady state, with a constant equilibrium unemployment rate. Moreover the classical dichotomy is shown to hold, with an increase in the money stock eventually reflected in a proportionate change in the price level, while output and employment are unchanged. The model has sensible non unit elasticities of substitution, where the concavity requirements (for negative own price elasticities of demand) are met and is dynamically stable. The model therefore converges to a steady state growth path.

With respect to capital stock neutrality, we have argued that the restrictions required for 'super-neutrality' will in general be non-linear combinations of the factor shares, which will themselves change over time. It is our view that the imposition of super neutrality is overly restrictive and not at all appropriate over sort of sample periods we are typically dealing with. If this is the case then in general equilibrium unemployment (ie. the Natural Rate of Unemployment) will depend on the factor share. Finally, in the context of a full system equilibrium, we show that in the absence of such cross equation restrictions, an increase in the real cost of capital, which leads to a reduced capital stock will increase equilibrium unemployment.

FOOTNOTES

1. Estimates taken from Crafts and Toniolo (1996), 1973-92, GDP for the 12 counties; Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and the United Kingdom.

2. Coulton and Cromb (1994) for example note;

   "*a common feature is a decline in the replacement ratio since the early 1980s. This would appear to suggest that benefits cannot readily explain much of the increase in unemployment during the early 1980s.*" (p.19)

3. Similar ideas have recently been advanced by Blanchard (1998) and Malley and Moutos (1999).

4 Of course a cursory glance at figure 2 indicates that the trend growth rate of GDP has been anything but constant. Part of this will be growth in labour supply, part of it will be catch up after a period of capital destruction such as a war (see Crafts and Toniolo, 1996 for a discussion of European growth after the second world war). There then may still be residual changes in trend growth which are central importance and may be explanations of unemployment in their own right. This is something we wish investigate in future, for the time being however we believe it is important construct a model that has interpretable steady state properties before we consider altering the trend growth rate.

5. A proof of this proposition can be found in Barro and Xala-I-Martin (1995), pp. 54-55.

6. This is discussed in more detail in Allen and Nixon, 1997, who provide analytical solutions for a general supply side model

7. We chose a four factor production technology because it is important to allow for the large increases in commodity prices that have been experienced from time to time over the last 30 years. In the case of oil prices for example, these have had a very significant effect on the demand for labour.

8. As an exact functional form, the translog cannot adequately represent a separable technology as a flexible second-order approximation. The set of constraints required for weak separability impose strong restrictions on either the micro aggregation functions or the macro function (see Diewert, 1976 for a general discussion of aggregation, while Blackorby et.al discuss the restrictions). In order to avoid these restrictions, the weaker notion of a second-order approximation at a point has been adopted. It is not clear that this loss is trivial since the behaviour of the approximation away from the point of approximation will depend on the data set.

9. We can obviously extend the model to allow for higher order adjustment costs to give rise to more lags or intertemporal optimisation to give rise to rational expectations effects.

10. We are grateful to Alan Manning for providing the derivations behind the relationships in his 1993 EJ paper, to which this section is obviously related.

11. Since this term will appear in the wage equation but not in the labour demand schedule, the W’W’ schedule will also be shifted by changes in the profit rate.

12. Elasticities are evaluated at sample means.

13. An analytical discussion of this model is considered in Allen and Nixon (1997).

APPENDIX 1 : RESTRICTIONS ON WAGES FOR SUPER-NEUTRALITY

To identify the sources of productivity we can substitute for costs in the wage equation using the full translog cost function. This will give us a wage equation in terms of factor prices and technology:

$$\ln W_t = \gamma_i \ln P_i - vt - \ln N_t + a_0 + a_1 \ln U_t + a_2 \ln \psi_t + a_3 \ln \chi + a_4 \ln R_t \quad \textbf{(27)}$$

where Pi are the individual factor prices, v is the rate of technical progress and γi are coefficients on the individual factor prices. For unemployment to be independent of capital accumulation, there has to be (in Bean's 1989 terminology) a sympathetic adjustment in wages to offset this effect. One possibility is the imposition of suitable cross equation restriction between the γ's of our wage equation and the parameters of the cost function. However, these will themselves be non-linear functions that vary over time, again with factor shares.

To demonstrate this, consider the Allen cross price elasticity of demand for labour with respect to an alternative factor price P_F:

$$\eta_{LF} = \frac{dN}{dP_F} \cdot \frac{P_F}{N} \quad \textbf{(28)}$$

and the own price elasticity of labour is

$$\eta_{LL} = \frac{dN}{dP_L} \cdot \frac{P_L}{N} \quad \textbf{(29)}$$

Then for equilibrium unemployment rate to be independent of factor prices requires an offsetting adjustment in wages such that employment is constant. Equating dN in equations (28) and (29);

$$\eta_{LL}\ dP_L \cdot \frac{N}{P_L} = dN = \eta_{NF}\ dP_F \cdot \frac{N}{P_F} \quad \textbf{(30)}$$

which rearranging gives:

$$\frac{dP_L}{P_L} = \frac{\eta_{LF}}{\eta_{LL}} \cdot \frac{dP_F}{P_F} \qquad \textbf{(31)}$$

Substituting from for the elasticities in terms of the factor share gives:

$$\frac{dP_L}{P_L} = \frac{S_F \ . \ \sigma_{LF}}{S_L \ . \ \sigma_{LL}} \cdot \frac{dP_F}{P_F} \qquad \textbf{(32)}$$

where we can substitute further using the expression in appendix 1 to get an expression in terms of parameters of the cost function and factor shares. This will therefore be the required restriction on the γ's, such that

$$\gamma_F = \frac{S_F \ . \ \sigma_{LF}}{S_L \ . \ \sigma_{LL}} \qquad \textbf{(33)}$$

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