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THE INTER-RELATIONSHIP BETWEEN MONETARY POLICY AND ENDOGENOUS TECHNICAL PROGRESS

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ABSTRACT

This paper....

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CONTENTS

1 INTRODUCTION

Recently there has been an increasing concern with the interaction between economic policy generally and the long term growth trend in the economy. An example is Blackburn (1999) who argues that if there are important aspects to endogenaity in the growth process then active stabilisation policy can reduce long term growth. Other important contributions in this area include Aghion and Saint-Paul(1993), Cabellero and Hammour(1994) Dellas(1991), Hall(1991), Martin and Rogers(1997) and Ramey and Ramey(1991). While there has been some attempt to investigate the empirical relevance of these effects both the theoretical analysis and the empirical work has been conducted in a way which is far removed from the actual policy debate on economic stabilisation. Often, for example, the inter-relationship between monetary policy (particularly interest rates) and technical progress is obscured as the models are solved for a long run equilibrium in which interest rates are uniquely determined(see for example Grossman and Helpman(1991)). Although there is an interaction between technical progress and monetary policy in these models this is obscured in the final solution presented.

The aim of this paper is to carry out an empirical investigation of the inter-relationship between technical progress and the tools of monetary policy. We believe this is of vital importance to the medium term policy debate as if such effects are empirically relevant then they may set up a serious conflict between the short term stabilisation effects of monetary policy and its long term implications for economic growth. For example, if high interest rates were to actually reduce the rate of technical progress in the economy this would lead to medium term supply side constraints which would both reduce the level of output in the economy and actually make it more difficult to control inflation in the future.

Traditional Real Business Cycle models assume that the evolution of technology is exogenous to the system, thereby implying that the demand-side disturbances such as policy shocks have no impact on productivity. However, in modern endogenous growth models, technology depends on the current state of the economy. The endogenous response of technology to the current state of the economy differ markedly between models and depends, essentially, on the mechanism responsible for generating the technological progress. In models in the tradition of Arrow (1962), where technology improvements are driven by a ``learning by doing'' process, the relationship between the state of the economy and productivity growth, tends to be positive. In models in the tradition of Schumpeter (1942), where monopoly profit maximising firms intentionally invest in R\&D, this relationship tends to be negative. The aim of this paper is to find out which of the two conflicting views is compatible with the observed data and, consequently, to assess the effect of monetary policy on total factor productivity (TFP).

Ideally we would wish to do this by estimating a complete supply side for the economy and investigating the determinants of the growth trends within the economy. However we have spent considerable time investigating such an approach and have found that an econometrically adequate description of the supply side actually needs to be extremely complex and within this framework it is not possible to detect significant effects on long term TFP within the relatively short data sets available. We therefore explore a two stage procedure here; first we present a detailed model of the supply side of the UK economy which is based on exogenous technical progress in the long run. This model is constructed as a system of non-linear equilibrium correction equations which include both long run cointegrating relationships and short run dynamics. We then take the `residuals= from the long run supply side equations and focus on these as a measure of changing technical progress. In effect we are treating these residuals as measures of the conventional Solow residual and therefore as measures of the unobserved component in TFP growth. (In an appendix we argue for why we believe that this is a good measure of the endogenous aspect of technical Progress). In the second stage we then build an unobserved component model using the Kalman Filter to estimate the endogenous aspect of technical progress as a function of a set of conventional exogenous variables from the empirical growth literature (such as private investment in education) and a monetary policy indicator (given by the real interest rate).

The paper is organised as follows. Section 2 reviews the existing literature, Section 3 describes the empirical analysis and results and Section 4 concludes.

2. THEORY

Unlike early Real Business Cycle models, in modern (endogenous) growth theory models productivity changes endogenously, as a response to the current state of the economy. Endogenous growth models focus on the following type of production function with labour augmenting technological process:

$$Y(t) = F[K(t), A(K(t))L(t)]$$

where Y(t) is the output flow, L(t) is the labour input and A(.) is the state of technology depending on K(t). For Arrow (1962) K(t) is physical capital and firms contribute inadvertently to a public pool of knowledge (a ``learning by doing'' process) represented by A(K(t)). For Romer (1986) K is knowledge (i.e there is a certain amount of resources intentionally devoted to knowledge accumulation). In Roemer, investment in R&D occur outside the profit sector, whereas in Grossman-Helpmann (1991) it is assumed that firms devote resources to knowledge accumulation in order to capture a stream of monopoly profits. The latter are models developed along Schumpeterian lines, where there is a mechanism of ``creative destruction'' (Schumpeter (1942)). Since the firm which invest in R\&D cannot fully appropriate the technology innovation benefits, knowledge spillover effects occur and growth is sustainable.

The endogenous response of technology changes to the variation in the current state of the economy differ markedly between models and depends essentially on the mechanism responsible for generating the technological progress. In a class of models (Aghion-Saint-Paul (1993) among the others) in line with a Schumpeterian approach, the relationship tends to be negative. Productivity improving activities (such as training and reorganisation) may be seen as taking place currently at the expenses of directly productive activities (manufacturing). Since the return to the latter is lower in recession then in booms, firms have an incentive to devote relatively more resources to improving productivity during bad times. This ``opportunity cost'' effect may be supplemented by a ``cleaning-up'' effect (Caballero-Hammour (1994)), whereby downturns serve the purpose of eliminating inefficient business. In another class of models in line with the Arrowian approach, where the mechanism is learning by doing, the relationship tends to be positive (Martin-Rogers (1995) among the others). Productivity improving activities may be seen as contributing to current production. This is the case when the acquisition of knowledge and skills depends positively on the amount of factors (labour and capital) employed in manufacturing. Since factor employment varies pro-cyclically, recessions are now events which have negative effects on future productivity. In the light of the discussion above, the effects of a deflationary macroeconomic policies, such as monetary policy, on TFP and long-run economic growth are ambiguous and we need to appeal to the empirical evidence.

3. THE ECONOMETRIC MODEL

In this section we adopt a two stage procedure in order to test for the relevance of the effect of various endogenous feedbacks onto TFP. In section 3.1 we present a description of our model of the supply side of the UK economy. In section 4 we extract the long run residuals of this model as a measure of the solow residual and build an unobserved component model to measure the endogenous aspect of TFP growth and to test for the important determining factors.

3.1 An Aggregate Production Structure for the UK

We model the supply side of the UK economy in terms of a representative, imperfectly competitive firm, operating in a small open economy with five aggregate commodities; goods, capital, labour, fuels and non-fuels. Fuels and non-fuels are essentially assumed to be limitless raw materials whose price is set exogenously but maybe imported. 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. 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.

Suppressing the time subscript for clarity, aggregating across firms and imposing symmetry, we consider the imperfectly competitive firm=s optimisation problem as

$$\min TCOST = C\,(P_K\,, P_L\,, P_E\,, P_M\,, Y, t)$$

where there are four inputs to production; capital (K), labour (L), energy (E) and imported materials (M) and where P_i is the corresponding factor price, and Y is expected demand. Additionally, we assume disembodied exogenous technical progress (t). By virtue of Sheppard=s Lemma, differentiating the cost function with respect to each of the factor prices gives the conditional factor demands

$$x_i = \frac{\partial c}{\partial p_i} = c'_{p_i}(\ p_i\,, y, t)$$

Turning to our empirical specification, we assume that the cost function can be approximated by 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 introduce Harrod neutral technical progress by considering labour as being measured in efficiency units. Essentially we pre-multiply L in the production function by an index of technology $A(t)$, which in the simplest case we take to be an exponential time trend, ie. $L = e^{vt}L_a$, where L_a is actual labour input. Thus the production function takes the form $Y = F(\underline{X}, L.A(t))$, where $\underline{X}$ is a vector of other factors (see Uzawa, 1961). Output therefore grows over time in the same way as if the labour input was increasing, hence technical progress is Alabour augmenting≅. In the cost function case an analogous procedure would be to pre-multiplying the price of labour P_L. We therefore write the general equilibrium translog cost function in the form:

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

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:

$$S_i^* = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ln p_j + \alpha_{iy} \ln y + \alpha_{it} t$$

where $$S_{ij}^* = \frac{p_i X_i}{\sum_{j=1}^{n} p_j X_j}$$

and X_i is the quantity demanded of input I.

A number of specific restrictions can then be tested for or imposed on this general model. Restrictions 1 and 2 described below are imposed on the model to ensure some degree of coherence; the remaining restrictions 3, 4 and 5 however are tested.

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

linearly homogeneity in factor prices.

$$\sum_{i=1}^{n} a_i = 1$$

$$\sum_{j=1}^{n} a_{ij} = 0$$

$$\sum_{i=1}^{n} a_{iy} = 0$$

2. Equally we require symmetry for the translog to be viewed as a quadratic approximation to an arbitrary cost function[1] (Denny and Fuss, 1997). Thus the cross partial derivatives must be equal. This requires:

$$a_{ij} = a_{ji}, \qquad i \neq j$$

$$a_y = 1$$

$$a_{yy} = 0$$

$$a_{yt} = 0$$

$$a_{iy} = 0 \qquad for\ all\ i,$$

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

4 The homogeneous translog cost function will be homothetic if

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:

$$a_t = a_l v$$

$$a_{it} = a_{li} v$$

$$a_{yt} = a_{ly} v$$

$$a_{tt} = a_l v$$

These restrictions enable us to factor together all the time trend terms with the price of labour, ie for I =

L, $P_L = e^{-vt}$. P_{LA}, where P_{LA} is the actual nominal price of labour. Without these restrictions, differentiating the translog cost function (3) with respect to t gives the factor bias of technical progress, for given factor prices and output:

$$\frac{dC}{dt} = \boldsymbol{a}_t + \sum_{i=n}^{n} \boldsymbol{a}_{it} \ln\ p_i + \boldsymbol{a}_{yt} \ln\ y + \boldsymbol{a}_{tt}\, t$$

3.2 Dynamic Adjustment in The Presence of Adjustment Costs

We assume that firms are unable to adjust their factor volumes instantaneously because of the presence of adjustment costs, where the cost incurred may be direct costs incurred such as construction or training costs, or else profit foregone incurred by producing a less that optimal scale. These adjustments costs themselves are likely to vary between factors, with capital the most costly to adjust. This in turn is likely to be reflected in different speeds of adjustment. Following the suggestion of Hall and Nixon (1999), we specify the firm=s objective function in terms of changes in factor volumes. If we assume firms face costs (C_2) when adjusting the volumes of factor inputs (x) in addition to an opportunity cost (C_1) for not producing at optimal factor shares, S* (ie. for producing with factor proportions that are not consistent with their long run optimal cost function). The firm=s objective function would then be:

$$L^* = (Z_{i,t} - S^*_{i,t-1})' C_1 (Z_{i,t} - S^*_{i,t-1}) + \Delta \ln(x)_{i',t}\, C_2\, \Delta \ln(x)_{i,t}$$

where Z is the actual factor proportion relative to optimal costs (ie. $\frac{P_{i,t} X_{i,t}}{C^*_{t-1}}$). The first order conditions will then give rise to general factor demand functions which have the following general form (where for simplicity we assume C is diagonal):

$$\Delta \ln(x)_{i,t} = g_{i,t} . \Delta \ln(x)_{i,t-1} + b_i \left(\frac{p_{i,t-1} \cdot x_{i,t-1}}{C(p_{i,t-1}, Y_{i,t-1})} - S^*_{i,t-1} \right)$$

Where in general the dynamic factor demands are estimated as an unnormalised, non-linear system. 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.

4. ESTIMATING THE CONSISTENT DEMAND SYSTEM

We now attempt to estimate the dynamic cost function and system of dynamic factor shares discussed in the previous. 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 full 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 theoretical 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 factor demands 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 are extensively discussed in (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 therefore reports cointegration tests as we successively impose the three groups of restrictions on the system estimated jointly but purely in levels terms. We find that in order to achieve cointegration we are required to extend our theoretical structure to include two additional variables. Perhaps most importantly, to apply linear homogeneity with respect to output requires that we take account of changes in capacity utilisation. This finding mirrors some 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. Instead we take the expedient of 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.

In a similar vein, 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 share of manufacturing in GDP, as a two further regressors in our system. This again implies the addition of a further six terms and two more restrictions for each variable.

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.

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 SF	5.12 [.005] 4.35 [.057]	(3) .00338 (0) .00071	.00514 .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.

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 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. A closer inspection of the residuals of the fully restricted cost function suggests that there is clearly a systematic pattern to the residuals (see figure 4). Thus in contrast to Darby and Wren-Lewis (1992) we do not appear to be able to explain costs solely on the basis of factor inputs, substitution between factors, capacity utilisation and a deterministic trend. Given the pattern of residuals; low in the 1970s, high in the 1980s, we take this to be evidence of time varying technical progress (or possibly endogenous scrapping). Later work in our research programme will return to this.

Turning to the dynamic model shown in table 2, 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). Finally, our estimate of technical progress is for growth of around 2.3% per year.

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 3: Levels and Dynamic Estimates of Main Coefficients

66q2 - 96q4	Static Model		Dynamic Model	
FIML:	Estimate	t-statistic	Estimate	t-statistic
A0	-2.604	-57.74	-0.46543	-.091175
A1	.4393	3.167	-.212794	-.987472
A2	.6959	65.71	1.24868	30.9058
A3	-.0289	-4.533	-.063788	-3.94799
A11	.1673	32.39	.163842	4.18784
A12	-.1075	-46.19	-.145369	-5.22424
A13	-.0462	-23.77	-.845225E-03	-.258361
A22	.1364	54.52	.165077	5.31508
A23	.0092	-10.47	-.010561	-3.98151
A33	.0436	40.66	.018169	2.89945
V	-.00435	-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).

Table 4: Individual Equation Diagnostics

	R^2	S.E.	Q (1)	Q (2)	Q (3)	Q (4)	Arch (1)
COSTS	.1251	.0234	.154	.190	.688	8.51	.154
EMP	.5225	.00338	.708	1.67	2.66	2.86	4.61
KP	.0943	.01333	.885	1.10	1.25	6.41	.107
VFUEL	.3275	.0250	.004	.063	4.72	5.48	1.75
VNF	.1328	.0347	.194	.198	.283	3.67	.801

Notes Q(n) is Box-Pierce portmanteau test, distributed $\chi^2(n)$
Arch (1) is Q(1) performed on the squares of the residuals

Table 5a: Long Run Allen Elasticities of Substitution

	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 5b: 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

	Labour	Capital	Fuel	Non-Fuel
Non Fuel	0.379	-0.413	0.173	-0.038

Notes: Elasticities are evaluated at sample means.

5. MODELLING THE UNOBSERVED ASPECTS OF ENDOGENOUS TECHNICAL PROGRESS

Given the estimated model from the last section we now extract the long run residuals from the cost function which should contain the missing endogenous technical progress effects and proceed to build an unobserved components model based on these `Solow residuals=. Given the definitions used negative values for this series represent positive values for TFP growth. We now proceed to use the following unobserved component model in state space form (see Hall, Cutherbson, Taylor (1992) and Harvey(1990)):

$$Y(t) = S(t) + v(t)$$

$$S(t) = TS(t-1) + RX(t) + e(t)$$

In the first equation, the measurement equation, Y(t) is the solow residual variable and S(t) is the unobserved state variable which will measure the endogenous growth in TFP and $v_t \sim N(0,\sigma_e^2)$. In the second equation, the transition equation, T is an unknown coefficient, X(t) is a three dimensional vector of explanatory variables, R is a four dimensional vector of unknown coefficients and $e(t) \sim N(0,\sigma_v^2)$. In the transition equation the unobserved component S(t) responds endogenously to changes in the X variables which may include such things as education, R&D or monetary policy variables.

The vector of X variables will include the following; As a proxy for monetary policy, the short term real interest rate RLBR. The ratio of private investment to output, PINV. Private investment in human capital share, PEDC[2].

The model in (1) is estimated by the Kalman filter. In table 1 we report the parameters estimates (t-ratios in parenthesis) for the coefficients of the state variable and of the set of exogenous variables (the subscript indicates the lag order). The Solow residual is stationary (the coefficient for S(t-1)) is less than unity). Given the definition of TFP above, an increase in the real interest rate (a tight monetary policy, has a significant negative effect on productivity, whereas investment in physical and human capital will have a positive effect. Therefore, we find empirical support for the predictions of the learning by doing approach to endogenous growth. In particular, a deflationary monetary policy will decrease the capital and labour inputs employment and this will negatively affect the acquisition of knowledge and skills. There is also evidence of a considerable delayed effect of each exogenous variable on productivity growth.

Table 1

S(t-1)	0.631
	(6.342)
$RLBR_{18}$	0.001
	(2.756)
$PEDC_{20}$	-0.002
	(-3.440)

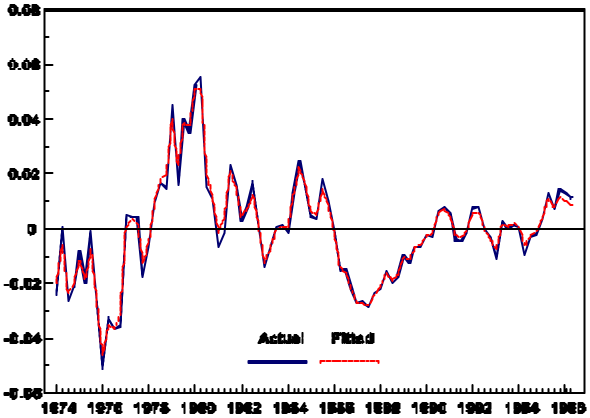
$PINV_{18}$	-0.001
	(-2.120)
intercept	0.060
	(3.006)

The model in (1) is not misspecified: there is evidence of residuals normality (the χ^2 Jacque-Bera test statistic for the null of gaussian errors is 0.03) and the $\chi^2(p)$ (where p is the autocorrelation order) Lyung-Box test gives evidence for no residual autocorrelation (see Table 2).

Table 2

lag	1	2	3	4	5	6	7	8	9	10	11	12
L-B	0.00	0.12	0.39	4.77	5.45	6.89	6.90	8.94	14.5	14.6	16.0	16.2

In Figure 1 the Solow residual and the smoothed estimate for its unobserved component are plotted against time.



6. CONCLUSION

In endogenous growth models productivity growth responds endogenously to the current state of the economy. In this paper an unobserved component model has been used to model the dynamics of the Solow residual. The empirical analysis supports the learning by doing approach to long-run growth, which, through al loss of experience and skills during bad periods, predicts a negative relationship between recession (or any deflationary policy, such as a tight monetary policy) and TFP and, consequently, long-run growth.

NOTES

APPENDIX 1. QUANTIFYING TECHNICAL CHANGE

In recent years the empirical quantification of technical change has undergone something of a resurgence: some of this has centred upon the real business cycle literature and the focus there on >productivity shocks=, and some from the growth literature itself. Solow (1957) attempted to quantify technical change by using a constant returns to scale production function. Traditionally, the real business cycle models (beginning with Prescott, 1986) have adopted a similar approach calculating technology as:

$$\log(z) = \log(y) - q\,\log(l) - (1 - q\,)\log(k)$$

where y is output, l is labour supply, k is the capital stock and the empirical measure of the technology shock z, is known as the Solow residual.

The Solow residual attributes to technology any change in output that cannot be explained by changes in factor inputs. Jogenson and Griliches (1967) and Griliches (1996) point out that the Solow residual measures much more than underlying technological change (a fact recognized by Solow himself, 1957, p. 312), picking up among other things variability in capital utilization and labour hoarding as well as any mis-specification. Summers (1986) and Mankiw (1989) reiterate these points in the context of real business cycle models. Hall (1986, 1990) notes that calibrating the parameters of the Cobb-Douglas production function (ie. θ and $1-\theta$) as the shares of labour and of capital in output requires the assumption of perfect competition so that firms are paid their marginal products and factor shares exactly exhaust output. But if firms have market power so that price exceeds marginal cost, factor shares will no longer coincide with these parameters and z will reflect variations in the markup across the business cycle as well as true technology shocks.

Hall (1990) also demonstrates that if there are increasing returns to scale, the Solow residual will move with things other than pure technology shocks.

Jorgenson, Griliches and Hall conclude that the Solow residual captures a great deal beside technology. Hartley (1994) provides evidence that the Solow residual may not reliably capture even genuine technology shocks. The evidence is found in simulated economies constructed using Hansen and Sargent=s (1990) flexible, dynamic linear quadratic equilibrium macro model. This model permits a richer specification of the underlying production technology than is typical of say the real business cycle literature: there are multiple sectors, including intermediate and final goods and parameters representing multiple aspects of the production process. Hartley was able to generate specific series for output, capital and labour based on shocks to specific parts of the production process. Because these were simulations, he could be assured the variability in these series reflected only technology shocks and not market power, labour hoarding, etc. He then calculated Solow residuals from the simulated series and asked whether these accurately reflected the size and direction of the underlying true technology shocks. For a wide range of plausible parameters Hartley found an extremely low correlation between his controlled technology shocks and the calculated Solow residuals. The failure of the Solow residual to capture the underlying process accurately appears to reflect the fact that the Cobb-Douglas production function used to calculate the Solow residual is a poor approximation to the rich production structure of the Hansen and Sargent model: hence the Solow residual largely reflects specification error rather than technical change on a quarter by quarter basis.

The econometric approach we take here enables us to address some of these criticisms - at least partially. First and perhaps most importantly we do not restrict ourselves to a Cobb-Douglas specification but instead employ a flexible functional form (that nests Cobb-Douglas as a special case). This means we can go along way in avoiding the misspecification that results from imposing unit and constant elasticities of substitution between factors. Instead the elasticities are free to be determined by the data. We also extend the model to include four factors, labour, capital, fuels and imported materials where the later include semi-manufactures. The impact of fuel prices for example, has had a particularly important impact on the supply side over the 30 years period we are considering. We also allow for variations in capacity utilisation and hours worked. Finally, we model the dual of the production technology by means of a translog cost function: this enables us to cast the model in terms of imperfect competition and we are then not constraint to assume factor shares that are invariant to changes in the markup. The result is hopefully a well specified description of the production structure that is flexible enough to avoid the worse misspecifications of the normal Solow residual calculation but still parsimonious enough to estimated econometrically on aggregate quarterly data for the UK economy.

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1. 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 behavior of the approximation away from the point of approximation will depend on the data set. Typically, this is not an issue when one is estimating point estimates of the elasticities of substitution but is more problematic when the translog is pressed into time series analysis.

2. To be more specific $PEDC$ is the share of private spending in education to the private sector total spending in educational and cultural activities