Persistence of Shocks and their Sources in a Multisectoral Model of UK Output Growth*

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The extent to which the effects of shocks to the economy persist over time has been the subject of extensive investigation over the past few years. Following the seminal paper by Nelson and Plosser (1982), it has now become a widely held view that aggregate output is best represented by a first-difference stationary process, rather than by a stationary process around a deterministic trend. This has the important implication that macroeconomic shocks can have effects on output levels which continue into the indefinite future; an isolated recessionary shock may cause output growth to be only temporarily lower than usual, but this would be reflected by a time path for the level of output which is permanently lower than what it would have been in the absence of the shock. The size of the long run response of output to a unit shock, known as the persistence of shocks to output, is an empirical issue, and several studies have now been conducted to estimate the persistence measure for the real gross national product in the United States and elsewhere.[1] The evidence presented in these papers is mixed and inconclusive however, largely reflecting the difficulties involved in determining the long run properties of the output series from the relatively short data set available over the post war period. In a recent paper, Pesaran et al. (1991) (PPL), we advocated the use of sectoral output data in order to bring extra information to bear on the analysis of persistence at the aggregate level. In that paper, we noted that the information contained in the relationships between sectoral growth rates, and in the correlations that exist between innovations in output growths of different sectors can be fruitfully utilised to obtain a more reliable estimate of the persistence measure for aggregate output using a multisectoral model of output growths than can be obtained through a univariate model. We presented empirical support for this approach by analysing output growth in the United States using data disaggregated according to a ten sector classification. The point estimate of the aggregate persistence measure based on this disaggregated model was 0.67, with a standard error of 0.072. This estimate is somewhat lower, and is considerably more precisely estimated, than the estimate based on the aggregate univariate models.

The proposed disaggregated framework of PPL also allows us to decompose the persistence of shocks to aggregate or sectoral outputs into those generated by particular 'macro' shocks and those generated by 'other', possibly sector- specific, shocks. In the PPL paper, we focused on the persistence effect of 'monetary' shocks, finding these to be statistically significant although relatively unimportant in their

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[1] See, for example, Campbell and Mankiw (1987, 1989), Harvey (1985), Clark (1987), Watson (1986), Cochrane (1988), Christiano and Eichenbaum (1989), Shapiro and Watson (1988), Evans (1989), Blanchard and Quah (1989), Demery and Duck (1990), and Mills (1991).

contribution to the overall persistence measure.[2] In fact, under certain identifying assumptions, this advantage of the disaggregated model could be further exploited, so that the contribution to aggregate persistence of various sources of shocks can be identified and assessed. Of course, 'macro' shocks of different kinds are unlikely to be independent of each other, as innovations in one sphere engender unanticipated changes elsewhere (e.g. governments may react to an unexpected rise in oil prices, say, by engaging in an unexpectedly expansionary monetary policy). In such a case we might wish to measure both the direct long run effect of a shock to a particular macro variable, obtained in the absence of any shocks occurring elsewhere, and the overall long run effect of the shock on the economy, taking into account the feedbacks that have been present historically amongst the different types of shocks in the economy. In this paper, we aim to develop the multisectoral framework set out in PPL further, focusing in particular on the relative contribution of shocks generated from different sources to the overall measure of persistence. In Section I, we develop a multisectoral model in which the effects of different shocks to output in different sectors can be analysed explicitly, and discuss the measurement of persistence effects of the different types of shocks in such a model. In Section II, this framework is applied in an analysis of output growth in the UK economy disaggregated by eight industrial sectors. Estimates of persistence of shocks in each sector and for the economy as a whole are presented, using quarterly data covering the period 1960q1-1989q4. Four types of macro shocks are considered; innovations in money supply growth, in stock returns, in exchange rates, and in oil prices. This is by no means a comprehensive list of all possible sources of macro shocks relevant to the United Kingdom, but represents some of the more interesting ones. Moreover, this provides a first step in the direction away from the univariate approach of Campbell and Mankiw (i987, I989) towards a more behavioural approach to time series modelling of the persistence of shocks in macroeconomics. In so doing, the empirical work suggests which of the shocks are the more important sources of cyclical fluctuations in- sectoral and aggregate outputs, and this may be of practical relevance to policymakers.[3]

I Measuring the persistence effects of different types of shocks in a multisectoral model

Let $\mathbf{y}_t$ be an m x 1 vector of sectoral outputs, and suppose that $\mathbf{y}_t$ can be represented by a first-difference stationary linear process. Then a general multisectoral model of output growths may be written as:

$$\Delta\mathbf{y}_t = \boldsymbol{\alpha} + \mathbf{D}(L)\boldsymbol{\nu}_t + \mathbf{A}(L)\boldsymbol{\epsilon}_t, \tag{1}$$

where $\boldsymbol{\alpha}$ is an m x 1 vector of constants representing sector-specific mean growth rates, $\boldsymbol{\nu}_t$ is a p x 1 vector of innovations in macroeconomic variables $\mathbf{x}_t$, and $\boldsymbol{\epsilon}_t$ is an m x 1 vector of sector-specific innovations with mean zero and the covariance matrix $\boldsymbol{\Sigma} = (\sigma_{ij})$. $\mathbf{A}(L)$ and $\mathbf{D}(L)$ are matrix polynomials of the form

$$\mathbf{A}(L) = \sum_{i=0}^{\infty} \mathbf{A}_i L^i, \quad \mathbf{D}(L) = \sum_{i=0}^{\infty} \mathbf{D}_i L^i \tag{1b}$$

where the $\mathbf{A}_i$'s and $\mathbf{D}_i$'s are m x m and m x p matrices of fixed coefficients, $\mathbf{A}_0 = \mathbf{I}_m$, and the (i, j)th element of $\mathbf{A}(L)$ is denoted by the lag polynomials $a_{ij}(L)$. The vector of innovations $\boldsymbol{\nu}_t$ are defined by

$$\mathbf{x}_t = \boldsymbol{\Gamma}\mathbf{z}_t + \boldsymbol{\nu}_t$$

where $\boldsymbol{\Gamma}$ is a p x k matrix of fixed coefficients, and $\mathbf{z}_t$ is a k x 1 vector of predetermined variables. This formulation is fairly general and includes the vector autoregressive specification as a special case. The innovations $\boldsymbol{\nu}_t$ are assumed to be white noise processes with mean zero and the constant covariance matrix $\boldsymbol{\Psi} = (\psi_{ij})$. These innovations correspond to macroeconomic shocks such as unexpected changes in oil prices, money supply or exchange rates. The sector-specific innovations, $\boldsymbol{\epsilon}_t$, represent the residual variability in $\Delta\mathbf{y}_t$ not associated with the p identified macroeconomic shocks, $\boldsymbol{\nu}_t$. In order to ensure that the equation system (1) is identified we assume that $\boldsymbol{\nu}_t$ and $\boldsymbol{\epsilon}_t$ are uncorrelated.[4]

[2] The factor analysis of sectoral output growths carried out in Long and Plosser (1987) gives results for the United States which are in line with those in PPL. However, Long and Plosser do not consider the decomposition of macro shocks into its various components.

[3] In view of the difficulties involved in obtaining precise measures of the long run properties of a series on the basis of relatively short data sets, throughout the present work, we give estimates of the standard errors for the various persistence measures, which should serve as an indicator of the degree of uncertainty that surrounds the interpretation of the results.

[4] On this, see section 3.3 in PPL.

The system described by (1) provides time series representations of output growth over m sectors, where each sector is subject to p identified 'macro' shocks and a residual, possibly sector-specific, shock. The aggregate level of output, Y_t, is defined by

$$Y_t = \mathbf{w}'\mathbf{y}_t \tag{2}$$

where $\mathbf{w} = (w_1, \cdots, w_m)'$ is an m x 1 vector of fixed positive weights.[5] Under the multisectoral model, (1), aggregate output growth can be written as

$$\Delta\mathbf{Y}_t = \mathbf{w}'\boldsymbol{\alpha} + \mathbf{w}'\mathbf{D}(L)\boldsymbol{\nu}_t + \mathbf{w}'\mathbf{A}(L)\boldsymbol{\epsilon}_t. \tag{3}$$

Notice that even for simple specifications of univariate sectoral output growths, (3) can have a very high order ARMA representation. This in itself provides *a priori* rationale for the use of disaggregated data in the analysis of aggregate persistence, since with relatively short time series available, the estimation of high order ARMA processes for aggregate output growth may not be desirable or even feasible (see PPL for further discussion). Various statistics have been suggested in the literature as measures of persistence in univariate models, although, as is shown in PPL, all of these alternative measures are based on the spectral density function of $\Delta\mathbf{Y}_t$, evaluated at zero frequency, $f_{\Delta Y}(0)$, and differ only in the way they are scaled. The persistence measure for aggregate output, P_Y, in the multisectoral model, (1a), is based on the spectral density of $\Delta Y_t = \mathbf{w}'\mathbf{y}_t$ at zero frequency scaled by the conditional variance of ΔY_t as follows:

$$P_Y^2 = \frac{2\pi f_{\Delta Y}(0)}{\mathrm{V}(\Delta Y_t|\boldsymbol{\Omega}_{t-1})} = \frac{\mathbf{w}'\mathbf{D}(1)\boldsymbol{\Psi}\mathbf{D}(1)'\mathbf{w} + \mathbf{w}'\mathbf{A}(1)\boldsymbol{\Sigma}\mathbf{A}(1)'\mathbf{w}}{\mathrm{V}(\Delta Y_t|\boldsymbol{\Omega}_{t-1})}, \tag{4}$$

where $\mathrm{V}(\Delta Y_t|\boldsymbol{\Omega}_{t-1}) = \mathbf{w}'\mathbf{D}(0)\boldsymbol{\Psi}\mathbf{D}(0)'\mathbf{w} + \mathbf{w}'\boldsymbol{\Sigma}\mathbf{w}$.[6] This measure can be decomposed into a component due to the identified macroeconomic shocks, P_S, and a component due to 'other shocks', P_O, as follows:

$$P_Y^2 = \lambda P_S^2 + (1-\lambda)P_O^2 \tag{5}$$

where

$$P_S^2 = \frac{\mathbf{w}'\mathbf{D}(1)\boldsymbol{\Psi}\mathbf{D}(1)'\mathbf{w}}{\mathbf{w}'\mathbf{D}(0)\boldsymbol{\Psi}\mathbf{D}(0)'\mathbf{w}}, \quad P_O^2 = \frac{\mathbf{w}'\mathbf{A}(1)\boldsymbol{\Sigma}\mathbf{A}(1)'\mathbf{w}}{\mathbf{w}'\mathbf{A}(0)\boldsymbol{\Sigma}\mathbf{A}(0)'\mathbf{w}}, \quad \lambda = \frac{\mathbf{w}'\mathbf{D}(0)\boldsymbol{\Psi}\mathbf{D}(0)'\mathbf{w}}{\mathbf{w}'\mathbf{D}(0)\boldsymbol{\Psi}\mathbf{D}(0)'\mathbf{w} + \mathbf{w}'\mathbf{A}(0)\boldsymbol{\Sigma}\mathbf{A}(0)'\mathbf{w}}.$$

Moreover, the component due to the macroeconomic shocks can be further decomposed:

$$P_S^2 = \sum_{j=1}^{p} \mu_j^2 (P_{Sj}^2 + P_{SXj}) \tag{6}$$

where

$$P_{Sj}^2 = \frac{\mathbf{w}'\mathbf{d}_j(1)\psi_{jj}\mathbf{d}_j(1)'\mathbf{w}}{\mathbf{w}'\mathbf{d}_j(0)\psi_{jj}\mathbf{d}_j(0)'\mathbf{w}}, \quad P_{SXj} = \frac{\sum_{k=1,k\neq j}^{p} \mathbf{w}'\mathbf{d}_j(1)\psi_{jk}\mathbf{d}_k(1)'\mathbf{w}}{\mathbf{w}'\mathbf{d}_j(0)\psi_{jj}\mathbf{d}_j(0)'\mathbf{w}}, \quad \mu_j^2 = \frac{\mathbf{w}'\mathbf{d}_j(0)\psi_{jj}\mathbf{d}_j(0)'\mathbf{w}}{\mathbf{w}'\mathbf{D}(0)\boldsymbol{\Psi}\mathbf{D}(0)'\mathbf{w}}.$$

In the above expressions, $\mathbf{d}_j(L)$ denotes the jth column of the matrix $\mathbf{D}(L)$; $\mathbf{d}_j(0)$ measures the immediate impacts of the jth shock on the m sectoral output growths, while $\mathbf{d}_j(1)$ measures its long run effects. The components $P_{Sj}, j = 1, \cdots, p$ provide p measures of persistence due to the *direct* effects of shocks to each of the p identified macroeconomic variables assuming all the other shocks are set to zero, and their contribution to P_S is determined by the relative size of the shocks, as represented by the weights μ_j. The *overall* long run impact of the jth shock on Y_t go beyond the direct effects, and include also the interaction terms, P_{SXj} These terms capture the effect of correlations that exist between different shocks on the overall persistence measure. For any macroeconomic shock, comparison of the

[5] In the empirical analysis, we set $\mathbf{w} = (1, 1, \cdots, 1)'$, and hence use the sum of the logs of the sectoral outputs as the measure of 'aggregate output'. This measure differs from the log of the sum of sectoral outputs used in the literature, but in our work we find that the two measures follow each other very closely and have very similar autocorrelation functions.

[6] In the univariate case where the sources of shocks are not explicitly identified, we can write $\Delta Y_t = \alpha + a(L)u_t$, where α is a scalar constant, $a(L)$ is a polynomial in the lag operator, and u_t are mean zero, serially uncorrelated shocks with common variance σ_u^2. Here, (4) collapses to

$$P_Y^2 = \frac{2\pi f_{\Delta Y}(0)}{\mathrm{V}(\Delta Y_t|\boldsymbol{\Omega}_{t-1})} = \frac{\sigma_u^2 a^2(1)}{\sigma_u^2} = a^2(1)$$

which is the measure of persistence popularised by Campbell and Mankiw (1987).

direct persistence measure, P_{Sj}, and the overall measure, $(P_{Sj} + P_{SXj})$, provides an indication of the extent to which the persistence effects of the jth shock, ν_{jt}, are offset or compounded by associated shocks in other macroeconomic variables.

If we are interested not only in persistence of shocks at the aggregate level, but also in the long term effects of shocks on output of a particular sector, then in place of (4), we can consider the matrix of cross-sectoral persistence measures, $\mathbf{P}$, with its *(i, j)*th element given by

$$P_{ij} = \frac{\mathbf{e}_i'\mathbf{D}(1)\mathbf{\Psi}\mathbf{D}(1)'\mathbf{e}_j + \mathbf{e}_i'\mathbf{A}(1)\mathbf{\Sigma}\mathbf{A}(1)'\mathbf{e}_j}{\mathbf{e}_j'\mathbf{D}(0)\mathbf{\Psi}\mathbf{D}(0)'\mathbf{e}_j + \mathbf{e}_j'\mathbf{\Sigma}\mathbf{e}_j} \tag{7}$$

and $\mathbf{e}_i$ is a selection vector with unity on its ith element and zeros elsewhere. These provide measures of the long-term effects of shocks in sector j on the level of output in sector i. Sector-specific measures of persistence can be obtained from the diagonal elements of $\mathbf{P}$, and these can be decomposed as in (5) and (6), replacing $\mathbf{w}$ with $\mathbf{e}_i$ for sector i. The relationship between the cross-sectoral persistence measures and the aggregate persistence measure, P_y, is in general a complicated one, and is affected by the cointegrating properties of the sectoral output series (see PPL for more details).

II Empirical results; an analysis of sectoral output growth in the UK economy

In this section we apply the multisectoral framework developed above to an analysis of output growths across eight industrial sectors of the UK economy using quarterly data over the period 1960q1-1989q2. The eight sectors cover the whole of UK industrial production, and correspond closely to the main divisions of the 1980 Standard Industrial Classification. The macroeconomic shocks that we investigate explicitly in the analysis include unexpected changes in (nominal) oil prices, in stock returns, in exchange rates, and in the money stock (detailed definitions of the measurement of these series, and further information on the sectoral classification employed, are provided in the Data Appendix of Lee et al. (1991). Of course, other macroeconomic aggregates could be included, but we believe these four types of shock represent some of the more interesting ones in the case of the United Kingdom.

The first stage in the analysis is to obtain an overview of the time series properties of the sectoral output data. Augmented Dickey-Fuller (ADF) statistics for a variety of different lag lengths computed over the sample period do not provide statistically significant evidence in favour of rejecting the unit root hypothesis for the sectoral output series,[7] and this remains true even if we allow for a different trend growth path before and after the first oil shock in 1973q4.[8] Using the ADF procedure, we also tested the hypothesis of a unit root in sectoral output growth rates and found that it was rejected in the case of all the eight sectors. These test results suggest that it is reasonable to proceed with the assumption that sectoral output growth rates are stationary.[9] We also applied the maximum likelihood procedure of Johansen (1988, 1989) to investigate the cointegrating properties of the eight sectoral output series, and found evidence of either one or two cointegrating vectors, depending on whether we used 'trace' or 'maximal eigenvalue' statistics.[10] The relatively small number of cointegrating vectors found indicates that there are a relatively large number of independent sources of shocks to output, thus providing some evidence of the importance of sector-specific shocks in generating cyclical fluctuations.

The ADF results presented above indicate that the multisectoral model described in (1) is an appropriate framework with which to analyse persistence in the UK economy. As a preliminary exercise in obtaining estimates of the persistence measures, however, we consider a simplified version of ((1) in which the macroeconomic shocks are not explicitly identified. Persistence measures are still provided by (5), setting $\lambda = 0$, and interpreting P_O as the overall measure of persistence. In the empirical analysis,

[7] The ADF statistics are based on regressions including an intercept, and lags of various lengths in sectoral and aggregate output growths. The inclusion of the lagged values of aggregate output growth in the ADF regressions for the sectoral output growths does not alter the asymptotic properties of the ADF test, but can improve efficiency by reducing the residual serial correlation which may arise because of the inter-relationships of the output growths in different sectors.

[8] This is the 'changing growth' model of Perron (I989).

[9] A more complete description of the ADF tests carried out, together with the relevant tables summarising the ADF statistics, are given in Lee et al. (1991).

[10] Test statistics based on the maximal eigenvalue of the stochastic matrix suggest that there is precisely one cointegrating vector, while those based on the trace of the stochastic matrix suggest that there are two. These findings were robust to the choice of the specification of the underlying model: similar test results were obtained on the basis of VAR models of order 2, 3, and 4, either allowing for or excluding the possibility of a time trend in, the underlying data generation process. The computation of the Johansen test statistics are carried out on Microfit 3-0. See Pesaran and Pesaran (1991).

we consider the following simplified versions of (1):

$$M_1: \quad \Delta y_{it} = a_i + \sum_{s=1}^{r} c_{s,ii}\Delta y_{i,t-s} + \sum_{j=1,j\neq i}^{r}\sum_{s=1}^{r} c_{s,ij}\Delta y_{j,t-s} + u_{it}, \quad i = 1,\cdots,m$$

$$M_2: \quad \Delta y_{it} = a_i + \sum_{s=1}^{r} c_{s,ii}\Delta y_{i,t-s} + \sum_{s=1}^{r} b_{s,i}\Delta y_{-i,t-s} + u_{it}, \quad i = 1,\cdots,m$$

M_3 : a restricted version of M_2, where variables with coefficients having a t-ratio less than unity (in absolute terms) are excluded from the model

$$M_4: \quad \Delta y_{it} = a_i + i + u_{it}, \quad i = 1,\cdots,m.$$

Model M_1 is an unrestricted VAR, and explains output growth in sector i, Δy_{it}, in terms of lagged output growth in all sectors, including sector i, lagged by up to r quarters. M_2 imposes $rm(m-2)$ restrictions on M_1, and explains Δy_{it} in terms of lagged output growths in sector i and lags in aggregate output growth in the rest of the economy (denoted by $\Delta y_{-i,t,} = \sum_{j=1,j\neq i}^{m}\Delta y_{j,t,}$. Model M_3 imposes further restrictions on M_2 to exclude insignificant variables, and M_4 represents the most simple model considered in which (log) output in each sector is described by a random walk with drift.

The four models were estimated for our eight sectors of the UK economy including up to five lags in sectoral and aggregate output growth, using the Full Information Maximum Likelihood (FIML) method over the period 1961q4- 1989q2. With $m = 8$ and $r = 5$, model M_1 contains 328 parameters, not counting the parameters of the variance covariance matrix. This model is clearly overparameterised and is entertained here as a benchmark. Imposing the 240 restrictions that underlie model M_2 reduces the number of parameters to be estimated to 88. The likelihood ratio statistic for the test of these restrictions is given by 126.03 (277.1) which is well below its 95% critical value given in brackets. The imposition of a further 50 restrictions on model M_2, setting coefficients equal to zero where t-ratios are less than unity in absolute value, cannot be rejected either, since the likelihood ratio statistic for this test is 23.80 (67.50). However, model M_4 is readily rejected against model M_3 as the relevant likelihood ratio statistic is equal to 217.58 (43.77).

Estimates of sectoral and aggregate persistence measures based on models M_1, M_2 and M_3 are provided in Table 1. As is to be expected, persistence measures based on the more parsimonious models M_2 and M_3 are much more precisely determined than the estimates based on the unrestricted model M_1. The aggregate persistence measure obtained from model M_3 is estimated to be 1.07 (0.11), with the standard error of the estimate given in brackets, which is somewhat lower than that obtained using models M_1 or M_2. The persistence measures obtained from model M_3 show considerable variability across sectors; persistence measures in the Agriculture and Manufacturing sectors (1, 3 and 4) are well in excess of unity, and are also rather larger than those obtained for the Construction and Service sectors (2, 5 to 8).

It is of interest to compare the results obtained from the multisectoral models M_1, M_2 and M_3 with those obtained from a univariate model, and we therefore also calculated persistence measures for aggregate output estimated on the basis of various ARMA models fitted to aggregate output growth over the same sample period. The most general specification considered for the aggregate series was an ARMA(5,4) model, although the maximised values of the log likelihood function obtained for this model and for lower order ARMA processes were very close, indicating that the process for aggregate output may be adequately characterised by a random walk with drift (for which the persistence measure is equal to unity). We have already noted that model M_4, in which output in each sector follows a random walk with drift, is rejected by the data, so that the univariate result is consistent with the multisectoral findings only under particular restrictions on the size of the ARMA coefficients in the sectoral equations and on the correlations between sectoral shocks. There are, however, no *a priori* reasons for the validity of such aggregation restrictions, and consequently, these results raise the possibility of aggregation bias in models estimated at the economy-wide level, suggesting that caution should be exercised in the use of aggregate data.[11] It is noted that the unit measure of persistence associated with the univariate model is lower than that obtained for aggregate output based on the multisectoral model M_3. However, given the estimated standard errors, there is no inconsistency in these results, which are in line with those provided in the literature on persistence of shocks to aggregate output in the United Kingdom.[12]

[11] See Lee et al. (1990a,b) for a more complete discussion of the problems of aggregation bias in the context of linear regression models.

[12] Campbell and Mankiw (1989) report a (bias-corrected) estimate of 0.94 for $a(i)$, based on 60 autocorrelation coefficients

Table 1: Sectoral and Aggregate Persistence Measures

	Models		
Sectors	M_l	M_2	M_3
1. Agriculture	2.53	1.75	1.58
	(1.24)	(0.14)	(0.05)
2. Construction	1.23	0.93	0.96
	(0.43)	(0.04)	(0.01)
3. Durables	2.01	1.28	1.24
	(0.99)	(0.08)	(0.01)
4. Non-durables	1.59	1.16	.22
	(0.59)	(0.06)	(0.01)
5. Transport	1.28	1.06	0.97
	(0.50)	(0.06)	(0.01)
6. Energy	1.45	1.01	0.91
	(0.82)	(0.07)	(0.01)
7. Distribution	1.60	0.97	1.10
	(0.60)	(0.05)	(0.01)
8. Services	1.17	0.93	1.15
	(0.59)	(0.06)	(0.06)
Aggregate output	1.33	1.11	1.07
	(0.42)	(0.29)	(0.11)

Notes: Sectoral persistence measures, P_i, are estimated using (5) setting $\lambda = 0$, and using the selection vector $\mathbf{e}_i$ in place of $\mathbf{w}$. The aggregate persistence measure, P_y, uses $\mathbf{w}$. Bracketed figures are asymptotic standard errors. These are calculated using analytic derivatives. The formulae used are given in Appendix B of PPL.

We now turn our attention to the primary concern of this paper, which is to identify the contribution of different types of shocks to the total persistence measure. The following version of the complete multisectoral model, (1), is therefore considered:

$$\widetilde{M}_2: \quad \Delta y_{it} = a_i + \sum_{s=1}^{r} c_{s,ii}\Delta y_{i,t-s} + \sum_{s=1}^{r} b_{s,i}\Delta y_{-i,t-s} + \sum_{j=1}^{p}\sum_{s=0}^{r} \gamma_{i,js}\nu_{j,t-s} + u_{it}, \quad i = 1, \cdots, 8.$$

The model contains up to four lags of sectoral and aggregate output growth rates, as well as current and four lagged values of the macroeconomic shocks. Model $\widetilde{M}_2$ to be completed with equations for the p types of macroeconomic shocks, $\nu_{jt}(j = i, \cdots, p)$. Here, we consider four types of shocks; namely, (i) unexpected changes in the money supply ('money shocks'), (ii) unexpected changes in excess returns on stocks ('stock market shocks'), (iii) unexpected changes in Sterling exchange rate ('foreign exchange shocks'), and (iv) unexpected changes in nominal oil prices ('oil price shocks'). The specification of the four equations that are used to determine these shocks are shown in Table 2. For each of the four equations, the most general specification that was considered included among the explanatory variables values of the four dependent variables lagged by up to four periods. For the first two of the macro equations, these were further supplemented by (lagged) measures of growth in Governmnent expenditure, and by an unemployment variable U (for the money equation), and by measures of changes in interest rates, of the dividend yield, and of the rate of price inflation for the excess returns equation.[13] (Precise variable definitions are provided in the Data Appendix of Lee et al. (1991)). A specification search was carried out on the OLS estimates of the equations to obtain the specifications chosen in Table 2. This involved dropping those variables whose coefficients had t-values which were less than unity (in absolute value), ensuring that none of the variables thus excluded were jointly significant. The results of Table 2

using data covering the period 1957q1-1986q2; and Mills (1991) reports a value of unity based on annual data over the post-war period.

[13] These specifications therefore incorporate more behavioural content. The choice of the additional variables included in the money equation is justified in Barro (1977) and Pesaran (1991), while those in the stock returns equation are discussed in Pesaran and Timmerman (1990).

show that the inclusion of the additional behavioural variables in the first two equations is an important exercise, with the estimated coefficients of the additional variables showing significantly, and taking their expected signs.[14] The results also indicate that simple AR representations cannot be improved upon for the exchange rate and the oil price variables. Given that the residuals from these equations are to be employed as expectational errors, it is important that they do not contain a systematic element, and we note that we could not reject the hypothesis of no serial correlation in any of the four equations.

Table 2: Estimates of the Equations used in the Derivation of Macro Shocks

Money supply growth equation

DLM = 0.0246 +0.1108 $DLM(-1)$ +0.11858 $DLM(-2)$ +0.1858 $DLM(-3)$ +0.4879 $DLM(-4)$
(2 747) (1.1335) (2.220) (2-279) (5 967)
+0.0194 $DLG(-1)$ +0.1252 $DLG(-2)$+0.1009 $DLG(-3)$+0.0040 $U(-1)$ $+\widehat{\nu}_{1t}$
(0 302) (2-022) (1.1548) (2 036)

$R^2 = 0.4650$, S.E. equation = 0.01382, LLF = 328.5408, SC = 4.7343

Excess returns equation

ST = -0.1804 -0.0078 $DI(-1)$ +0.0388 $DIVY(-1)$ -1.6704 $PI(-1)$ $+\widehat{\nu}_{2t}$
(4 705) (1.196) (4.388) (2 504)

$R^2 = 0.1678$, S.E. equation = 0.09119, LLF = 110.3585 SC = 4.7743

Exchange rate equation

DER = -0.4465-0.1866 $DER(-1)$ + $\widehat{\nu}_{3t}$
(1.288)(1.977)

$R^2 = 0.0346$, S.E. equation = 3.6174, LLF = -299.2134, SC = 3.4339

Oil price equation

DLP = 0.0154 + 0.4544 $DLP(-1)$ -0.2036 $DLP(-2)$ + $\widehat{\nu}_{4t}$
(1.290) (4.818) (2.127)

$R^2 = 0.1776$, S.E. equation = 0.1242, LLF = 75.5793, SC = 3.7554

Notes: The estimates presented in this table are computed using the OLS method. However, the estimates of the persistence measures reported in Tables 3 and 4 are computed by the joint estimation of the sectoral output growth equations and the macro equations by the FIML method.

DLM refers to changes in the (log) money stock, DLG refers to changes in the (log) real Government final consumption, U refers to the unemployment variable used in Barro (I977), ST refers to excess returns on stocks, DI refers to the change in the rate of interest on 91 day Treasury Bills, $DIVY$ refers to the dividend yield (%), PI refers to the rate of price inflation, DER refers to changes in the logarithm of the Sterling exchange rate, and DLP refers to the changes in the (log) nominal oil prices (See Data Appendix of Lee et al. (1991) for further details).

'(-i)' indicates that the variable is lagged i periods. Figures in brackets are (absolute) t-ratios. LLF is the maximised log likelihood, SC is the Lagrange Multiplier statistic for testing residual serial correlation (cf. $\chi^2(4)$).

Having established the form of the macro equations to be used to identify macroeconomic shocks, the system of equations M_2, with eight equations explaining sectoral output growth plus four equations identifying the different macroeconomic shocks, was estimated jointly by the FIML method.[15] Table 3 provides Wald statistics for tests of two null hypotheses, H_1 and H_2:

$$H_1: \quad \gamma_{i,j0} = \gamma_{i,j1} = \gamma_{i,j2} = \gamma_{i,j3} = \gamma_{i,j4} = 0, \qquad j = 1, \cdots, 4, \quad i = 1, \cdots, 8$$

$$H_2: \quad \sum_{s=0}^{4} \gamma_{i,js} = 0, \qquad j = 1, \cdots, 4, \quad i = 1, \cdots, 8.$$

[14] The insignificance of the interest rate variable in the equation explaining excess returns may be because the variable used does not adequately reflect the most up-to-date information available in the market. A more elaborate investigation of effects of using different interest measures might also be worthwhile. Given the purpose of this paper, these possible further refinements will not be pursued here, however.

[15] The use of the FIML method enables us to avoid the generated regressor problem highlighted in Pagan (1984). See also (Pesaran, 1987, ch. 7).

Under H_1, the macro shocks have no effect on output growths (whether short- run or long-run), while under H_2, macro shocks are allowed to have short run effects, but no long run impact on output growths. Clearly H_1 implies H_2, but not vice versa. Both hypotheses are rejected only in a small number of cases (5 out of 32), although the more restrictive hypothesis, H_1, is rejected in 11 cases. Imposing the restrictions H_1 where they were not rejected,[16] and excluding variables with t-values less than unity in absolute terms, we obtained a new restricted model, $\widetilde{M}_3$.[17] The sectoral and aggregate persistence measures derived on the basis of this model are presented in Table 4. Total sectoral and aggregate persistence measures are given in column (i) of this table, and the decomposition of these totals into the component due to 'macro' shocks and that due to 'other' shocks is given in columns (3) and (2), respectively. The further decomposition of the persistence measure due to the four 'macro' shocks, as defined by equation (6), is given in columns (4) to (8). In terms of the measures of the total persistence of shocks, the results in column (i) of Table 4 are similar to those presented in Table i. Point estimates of the persistence measures for the Agriculture, Services, and the Manufacturing sectors are the largest obtained, although the first two of these are relatively poorly determined. The point estimate of the total persistence measure for aggregate output is o-8833 (0-067), which is lower than that obtained in Table I and is significantly less than unity.

In almost all sectors, the contribution of the 'macro' shocks to total persistence is relatively small. This is clearly reflected in the similar estimates obtained for P_Y and P_O. This seems to be primarily due to the fact that 'macro' shocks over the period under consideration have been small in size as compared with the 'other' shocks, and this is reflected by the small weight given to the macro shocks in the total persistence measure in (5).[18] The exceptions to this observation are the Durable and Non-durable Manufacturing sectors, for which the component due to 'macro' shocks is relatively large and significantly different from zero. Columns (4) to (8) of Table 4 consider the further decomposition of the sectoral and aggregate persistence measures for macroeconomic shocks, and for each type of macroeconomic shock give the contribution of the direct and overall measures of persistence of shocks to P_S, (i.e, $\mu_j P_{Sj}$, $(j = 1, \cdots, 4)$, $\sum_{j=1}^{4} \mu_j^2 P_{SXj}$ respectively, as in (6)). To a large extent, these measures reflect the results of Table 3, with only a small number of measures being significantly different from zero.[19] However, the results indicate that among the four 'macro' shocks, it is the foreign exchange shocks which have the largest persistence effects on aggregate output, primarily exerted through their effect on the Durable and Non-Durable Manufacturing sectors. The contribution of oil price shocks and stock market shocks are smaller, although still significant, while money shocks appear to be the least important in contributing to the persistence measure due to 'macro' shocks.[20]

In every case where more than one type of macroeconomic shock is included in the output equation, the contribution of $\sum_{j=1}^{4} \mu_j^2 P_{SXj}$ is negative, indicating that in general an unanticipated change in one of the macroeconomic variables is associated with offsetting unanticipated changes in the other macro variables such that the overall impact of the shock on the persistence measure is much reduced. As an illustration of this phenomenon, consider the direct and the overall impact of oil price shocks on UK output growth. In practice, it is reasonable to assume that oil price shocks are exogenous to the UK economy, but we cannot rule out the possibility that oil price shocks generate unanticipated movements in other macro variables, namely money supply, exchange rates, etc. In fact, we find the direct long run effects of oil price shocks on aggregate output, denoted by P_{S1}^2 in (6), takes the value of 0. 8812 (0.2487), while the overall measure, given by $(P_{S1}^2 + P_{SX1})$ takes the value of 0.7374 (0.4306). This can be interpreted as providing evidence that the responses of the monetary authorities and the foreign exchange and stock markets serve partially to offset the long run impact of oil price shocks.

The results described above provide some justification for the use of sectoral data not only in the

[16] We did not impose the restriction in H_2 even if the hypothesis was not rejected so as not to eliminate the effects of macroeconomic shocks which may show significantly in a more parsimonious model in which coefficient values are more precisely estimated.

[17] The unrestricted model $\widetilde{M}_2$ contains 250 parameters. Model $\widetilde{M}_3$ is obtained through the imposition of 168 restrictions, and the corresponding likelihood ratio statistic for the joint test of the validity of these restrictions is equal to 160.12, cf. $\chi^2(168)$.

[18] We should recall here that the measures of persistence due to 'other' shocks include the effects of all macroeconomic shocks which are independent of those explicitly accommodated within the analysis, as well as purely sector-specific shocks.

[19] The presence of non-zero persistence measures in Table 4 which have turned out to be not significantly different from zero are generally due to the indirect effect of shocks in other sectors operating through the lagged aggregate output terms included in the model.

[20] In contrast to the United Kingdom, we did find a significant persistence effect due to money shocks in the United States (see PPL). However, it would be interesting to check the robustness of the US results to the explicit inclusion of more macro shocks in the model. This is particularly important in the light of the evidence provided in Hamilton (I983) on the effects of oil price shocks on the US economy.

Table 3: Wald Test Statistics on the Coefficients of the Macroeconomic Shocks

	Oil price shocks		Money shocks		Foreign Exchange shocks		Stock Market shocks	
	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
1. Agriculture	5.33	0.21	10.69*	0.04	2.31	0.98	3.12	2.01
2. Construction	15.39*	13.46*	3.00	0.27	1.54	0.03	4.80	0.11
3. Durable Manufacturing	12.49*	2.89	6.12	0.59	12.44*	6.60*	16.37*	2.38
4. Non-Durable Manufacturing	8.24	2.74	6.55	0.94	13.64*	10.23*	13.35*	7.36*
5. Transport	1.53	0.63	0.72	0.10	0.05	0.00	3.23	1.46
6. Energy	16.29*	1.83	5.89	2.19	12.60*	3.78	2.42	0.09
7. Distribution	11.89*	10.50*	4.02	0.45	3.65	0.25	9.21	1.46
8. Services	8.21	1.56	4.85	0.02	18.64*	1.01	4.38	0.78

Notes: Results relate to model R_3 described in the text. For each of the sectors and macroeconomic shock, Wald statistics are computed for the test of the hypotheses:

$$H_1: \quad \gamma_{i,j0} = \gamma_{i,j1} = \gamma_{i,j2} = \gamma_{i,j3} = \gamma_{i,j4} = 0, \qquad (j = 1, \cdots, 4)$$

$$H_2: \quad \sum_{s=0}^{4} \gamma_{i,js} = 0, \qquad (j = 1, \cdots, 4).$$

Wald statistics for test of H_1, (H_2) are to be compared with the critical values of the chi-squared distribution with five (one) degree(s) of freedom. '*' indicates that the statistic is significant at the 5% level.

analysis of the persistence of shocks to sectoral output levels, but also in the analysis of aggregate persistence. As is the case with the results presented in PPL for the United States, the estimate of the aggregate persistence measure based on the multisectoral model is lower than that obtained from a univariate model, raising the question of whether there is an element of aggregation bias introduced in the aggregate model.[21] However, although the measure of persistence of shocks to aggregate output in the UK based on the multisectoral model is less than the unit value obtained using the univariate models, it is clear that the measure is substantially larger than zero, so that output levels seem to be permanently affected by shocks.

The results also suggest that sectoral analysis is a useful exercise in its own right. Certainly, there are some sectors in which shocks have larger long term effects than in others, and it is clear that certain types of shocks are more significant in some sectors than in others. Moreover, subject to the qualifications elaborated above, the results can be interpreted as providing evidence that sector-specific shocks have a more permanent impact on sectoral and aggregate output than macroeconomic shocks. A partial explanation for the relative unimportance of macro shocks is that a macro shock of one type may result in offsetting macro shocks of another type, and indeed, we found evidence that the persistence effects of an oil price shock are partially offset by the (unanticipated) reactions of the monetary authorities, foreign exchange market, and stock market. However, a large element of the total persistence of shocks was identified to be due to 'other' shocks. The cointegration test results reported in the paper also suggest that there are a relatively large number of independent sources of shocks in the UK economy, and one interpretation of this result is that shocks which are most important in generating persistence effects are the sector-specific ones. This is an important conclusion and deserves further investigation. The sensitivity of the results to the inclusion of other types of macro shocks, the choice of sample period, lag lengths and the level of disaggregation need to be further studied. It would also be interesting to see whether results obtained for the United Kingdom can be replicated for other countries.

[21] It would be interesting to investigate whether the relatively high estimated persistence measures obtained in many countries by Campbell and Mankiw (1989) using univariate models for aggregate output are similarly affected by such aggregation bias, and if so, whether the large variability in measures found across the countries would be reduced by the use of sectoral data.

Table 4: Decomposition of Sectoral and Aggregate Persistence Measures for Macroeconomic Shocks

(FIML estimates, 1961q4-1989q2)

Sectors	(1) Total P_Y	(2) Other P_O	(3) Macro P_S	(4) *DLP* $\mu_1 P_{S1}$	(5) *DLM* $\mu_2 P_{S2}$	(6) *DER* $\mu_3 P_{S3}$	(7) *ST* $\mu_4 P_{S4}$	(8) Interaction $\sum_{j=1}^{4} \mu_j^2 P_{SXj}$
1. Agriculture	1.6107	1.6176	1.1472	0.0000	1.1472	0.0000	0.0000	0.0000
	(0.2453)	(0.2442)	(1.7964)		(1.7964)			
2. Construction	0.9010	0.8097	4.0146	4.0146	0.0000	0.0000	0.0000	0.0000
	(0.0854)	(0.0581)	(3.1310)	(3.1310)				
3. Durables	1.2156	1.0751	3.1429	0.0000	0.0000	2.9701	1.0868	-0.1248
	(0.1353)	(0.1151)	(1.1280)			(1.0021)	(0.8700)	
4. Non-Durables	1.0731	0.8312	4.1267	0.0000	0.0000	3.1920	2.6779	-0.3306
	(0.0943)	(0.0526)	(1.6133)			(1.3099)	(1.2566)	
5. Transport	0.8392	0.8392	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(0.0788)	(0.0788)						
6. Energy	0.8464	0.8586	0.7713	0.4055	0.0172	0.6786	0.1051	-0.0416
	(0.0802)	(0.0671)	(0.4163)	(0.2494)	(0.0347)	(0.4781)	(0.0587)	
7. Distribution	0.7893	0.7916	0.6331	0.3050	0.0276	0.5420	0.1697	-0.0156
	(0.0656)	(0.0641)	(0.4238)	(0.2186)	(0.0569)	(0.3738)	(0.1254)	
8. Services	1.2195	1.2662	0.3663	0.1323	0.0120	0.3411	0.0736	-0.0052
	(0.2644)	(0.2762)	(0.5122)	(0.1054)	(0.0250)	(0.5615)	(0.0576)	
Aggregate	0.8833	0.8062	1.8538	0.8930	0.0808	1.5873	0.4969	-0.1337
output	(0.0671)	(0.0566)	(0.5254)	(0.2530)	(0.1599)	(0.5741)	(0.1988)	

Notes: Results relate to model $\widetilde{M}_3$ described in the text. The number of estimated coefficients, N, is 82. The maximised log-likelihood value, LLF, is 2627.72. Sectoral persistence measures, P_{ii}, are estimated using (7) in the text. The aggregate persistence measure, P_Y, is estimated using (4) in the text. The decomposition of total persistence into P_S and P_O, ie persistence due to 'Macroeconomic' and 'Other' shocks, is described by (5) in the text. The table also shows for each type of macroeconomic shock the contribution of the direct and overall measures of persistence of shocks to P_S as described by (6) in the text, using $\mathbf{w} = (1, \cdots, 1)'$ to obtain the aggregate output persistence measures, and using the selection vector $\mathbf{e}_i$ in place of $\mathbf{w}$ to obtain sectoral persistence measures. Definitions of *DLP*, *DLM*, *DER* and *ST* are provided in the Notes to Table 2.

Bracketed figures are asymptotic standard errors. These are calculated using analytic derivatives. The formulae used are given in Appendix B of PPL.

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