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Abstract - This paper examines business cycle features of UK GDP sectors with regard to trends, cycles and growth. The empirical study adopts the Kalman filter to decompose these GDP sectors into trend and cycle components. The general model of this study encompasses a number of alternative specifications about trend growth, therefore accommodating diverse views on growth. There is reasonable support in the results for a mean-reverting stochastic growth model for the UK economy. The characteristics in trends and cycles of UK GDP sectors are discussed, focusing on their similarities and differences around business cycles.

JEL No: E32, C50

Key words: business cycles, trend, cycle, growth, mean-reverting, decomposition, Kalman filter

1. Introduction

This paper examines three business cycle elements of cycles, trends, and growth in UK GDP sectors. It decomposes sectoral output into cycles and trends and pays attention to growth, adopting a state space method executed through the Kalman filter. Most business cycle studies on trend-cycle decomposition of GDP follow the tradition of Clark (1987) where the growth rate is specified as a pure random walk, implying that the time series in concern is $I(2)$. Though, together with a stationary cycle component, the specification indicates the recognition of the fact that GDP is usually less persistent than a pure integral random walk. The decomposition procedure is the kind of the Kalman filter named after Kalman (1960). Recently the research has become more sophisticated and advanced technically, e.g., in Kim and Nelson (1999), but the construction elements have not been fundamentally amended. In this paper we propose alternative specifications for modeling output growth, which are featured by mean-reversion in

the growth rate for the stochastic trend. A pure random walk allows the growth rate to wander and reach any point, leading to a theoretically unjustifiable proposition. Although we are less critical to the nature of the growth rate in empirical research, alternative specifications of the growth rate must be tendered and the validity of the restrictions imposed on each of the alternatives be tested. With such modeling framework, the present paper possesses inclusiveness and simplicity in statistical formulation. The econometric models in this study are the simplest and most straightforward in the state space executed by the Kalman filter, clearly demonstrating the components and state transition mechanism in economic activity. Moreover, the specification of growth in the general model can easily reduce to two different growth formulations via imposing relevant restrictions. So the study accommodates diverse beliefs about growth paths. In theory and strictly speaking, the results of model estimation are valid only if the data set is infinite in time, which obviously cannot be met in any empirical investigation. Therefore, what we analyze are indeed in a short stretch within the infinite time; or put it another way, an instant in history. In this respect, the term “permanent” is not in the strict sense, allowing various results, some of which appearing to contradict conventional knowledge, to be made possible in empirical studies. From the viewpoint of usefulness and policy effectiveness, explanations and implications obtained from various models, even if they are controversial, can be acceptable.

The present paper is not only motivated by the above theoretical and methodological considerations in search for improved understanding of output growth and fluctuations. Empirically, there are much less business cycle studies conducted at sectoral levels that are also almost confined to US data. It is an obvious fact that the US economy is to a great extent larger than most other economies in the world. Subtler are the implications in output data characteristics and, subsequently, business cycle features. Many typical economies of the UK size involve lesser aggregation in output data than the US economy, and may behave rather

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3 differently due to this difference in the degree of aggregation. Previous research by Engle (1984)
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5 amongst others suggests that aggregation results in correlation even if the individual series are
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7 not correlated, implying that the larger the size of an economy, the higher is the degree of
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9 exaggeration of the cycle component in output data. This problem of aggregation is relevant to
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11 the studies using aggregate output data as against those using sectoral data too, as the cycle
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13 component may be exaggerated in aggregate output data. Moreover, Long and Plosser (1987)
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15 suggest that the contribution of common shocks to the co-movement between sectors will appear
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17 to be greater than their true contribution; therefore the role of common or aggregate shocks may
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19 be over-estimated. All these point to the necessity of empirical business cycle research using
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21 non-US data and at sectoral levels, as carried out by the present paper.
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27 Although the notion of business cycles started to attract attention from economists and
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29 governments alike in as early as the first half of the 20th century, in their search for an
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31 understanding of the patterns in economic activity and a possible therapy for mitigating the
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33 damage caused by severe economic downturns, a century's endeavor has not rendered great
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35 fruition. It seems that modern regulatory frameworks remain as fragile, futile and above all,
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37 primitive, as a century ago in tackling credit crisis; the fear of recession in business cycles
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39 remains as strong as ever; and the peril of credit crisis in severe business cycle downturns
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41 remains as real as in Marx's time and his analysis at the time. Hence go on the search and
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43 research. Recent empirical studies on business cycles with a sectors focus include Caporale
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45 (1997), Peel and Speight (1998), Wang et al (1999), Wang (2000) and Dibeh (2001), among
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47 others. Caporale (1997) modifies a linear real business cycle model to allow for disaggregate
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49 factors in the generation of macroeconomic fluctuations, and then makes attempts to determine
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51 the relative importance of aggregate and sectoral shocks by performing principal components
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53 analysis on the residuals from a VAR of output growth rates in 19 UK industrial sectors.
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55 Investigating shock persistence in property and related sectors, it has been revealed by Wang
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(2000) that shocks from the housing market have the largest effect on the persistence in commercial property, followed by the services sector, production sector and construction. Conversely, shocks in property company shares, i.e. the stock market investment in property, have relatively small effects on the persistence in commercial property. These findings indicate business cycle evolution patterns, especially in economic downturns, which the world economy experiences in the last few years of the first decade in the new millennium. They also point to the likely triggering of recessions. Based on Hilferding's theory of disproportionality in capital accumulation in a two-sector economy, Dibeh (2001) develops a Marxian model of the business cycle. The disproportionality arises from the existence of time delays in production generated by the differential capital intensity in the two sectors. The time delays produce an asymmetric price structure that causes overproduction and crisis. Numerical simulations show that the model produces an economy-wide business cycle phenomenon and various dynamics ranging from monotonic convergence to explosive oscillations. Analyzing UK quarterly GDP deflator and 29 sectoral deflators from the first quarter in 1963 to the fourth quarter in 1994, Wang et al (1999) find that variability between sectors cause uncertainty in economic aggregates, which may identify business cycle evolution. Peel and Speight (1998) employ a joint model of bilinearity unconditional mean and generalized-autoregressive-conditional heteroscedasticity to test for the presence of non-linearities in UK and US industrial and sectoral production growth rates. They find bilinearity unconditional mean to be present in US industrial production and manufacturing, and significant conditional variance asymmetries in the majority of series considered such that conditional variance is higher during recessions and stronger in the more cyclically sensitive durable consumer goods sectors. More recently, Sensier (2003) investigates the movement of manufacturing inventories and production over the business cycle, Jenkins and Tsoukis (2000) attempt to identify and map out the effects of innovations in the money supply, employment, output, wages and prices, while Wu (2003) examines the importance of various macroeconomic

shocks in explaining the movement of the term structure of nominal bond yields in the post-war USA and the channels through which such macro-shocks influence the yield curve.

The rest of the paper is organized as follows. Section 2 introduces the model and provides an analysis of business cycles features with regard to growth, trends and cycles, while the technical aspects of the model's state space representation and estimation are provided in the appendix. Section 3 presents the empirical results of this study and discusses the findings and their implications. Finally, Section 4 concludes.

2. Modeling of growth, trends, and cycles

The review of recent research on business cycles in the previous section has pointed out the importance of decomposition of business cycles data, though the approaches and the theoretical guidelines vary from one study to another. The essence is to capture the crucial features of the business cycle and its components and shed light on the issues such as output growth, fluctuations, and their patterns of persistence and durability. To this end, model specifications utilized in this study are introduced in 2.1, followed by analysis and groupings of business cycle features with regard to growth, trends and cycles in 2.2.

2.1. Model specifications

Unlike most previous studies reviewed earlier where the growth rate is a pure random walk, the model in this example has a stochastic growth rate that can be stationary or non-stationary depending on the value of γ in equation (3). Specifically, if γ is smaller than but close to one, the growth rate is persistent in its behavior. The model is as follows:

$$Y_t = T_t + C_t \quad (1)$$

$$T_t = T_{t-1} + g_{t-1} + u_t \quad (2)$$

$$g_t = gc + \lambda g_{t-1} + w_t \quad (3)$$

$$C_t = \varphi_1 C_{t-1} + \varphi_2 C_{t-2} + v_t \quad (4)$$

where Y_t is log sectoral or aggregate GDP; T_t is its trend component follows a random walk with a stochastic drift or growth rate which is an autoregressive process; and C_t is the cycle component. To stick to the simplicity principle, we model C_t as an AR(2) process which is the most parsimonious to generate oscillatory cycles. Equation (3) collapses to the Clark growth equation when restrictions $gc = 0$ and $\lambda = 1$ are imposed. There are other reasonable assumptions. If λ is set to be zero, then the growth rate is constant over time when w_t is zero as well¹. So, in the empirical inquiries, there are three modes of growth, when two sets of restrictions are imposed against the general form of equation (3). According to Watson (1986) and Clark (1987), the two innovations in the trend and the cycle, u_t and v_t , are specified as independent processes, and innovation in growth, w_t , is further assumed to be uncorrelated to u_t and v_t . Blanchard and Quah (1989) and King et al (1991) also follow this tradition in structural decompositions, while Beveridge and Nelson (1981) assume that the innovations from the trend component and the cycle component are perfectly correlated.

Write equations (1) – (4) in the state space form, the observation equation is:

$$Y_t = \begin{bmatrix} 1 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} T_t \\ C_t \\ C_{t-1} \\ g_t \end{bmatrix} \quad (5)$$

The state equation is:

¹ When λ is set to zero, w_t is not identifiable from u_t .

$$\begin{bmatrix} T_{t+1} \\ C_{t+1} \\ C_t \\ g_{t+1} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & \varphi_1 & \varphi_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \lambda \end{bmatrix} \begin{bmatrix} T_t \\ C_t \\ C_{t-1} \\ g_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ gc \end{bmatrix} + \begin{bmatrix} v_{t+1} \\ u_{t+1} \\ 0 \\ w_{t+1} \end{bmatrix} \quad (6)$$

The construction elements of the model are:

$$\begin{aligned} y_t &= Y_t, \quad \xi_t' = [T_t \quad C_t \quad C_{t-1} \quad g_t], \quad x_t' = [0 \quad 0 \quad 0 \quad gc] \\ H &= [1 \quad 1 \quad 0 \quad 0], \quad F = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & \varphi_1 & \varphi_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \lambda \end{bmatrix}, \quad A = 0, \quad B = 1 \\ \mu_t &= 0, \quad v_t' = [u_t \quad v_t \quad 0 \quad w_t] \\ Q &= \begin{bmatrix} \sigma_u^2 & 0 & 0 & 0 \\ 0 & \sigma_v^2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma_w^2 \end{bmatrix}, \quad R = 0 \end{aligned}$$

The model will be estimated using the Kalman filter algorithms, and the empirical results will be reported and analyzed in the next section.

2.2. Analysis of business cycle features

Now let us discuss some general ideas about the behavior of output series in relation to the parameters in the model, and analyze business cycle features with regard to trends, cycles and growth. σ_u and σ_v , the standard deviation of the trend component and that of the cycle component, measure the contribution of trends and cycles and indicate their relative importance in the stochastic process. There is no stochastics in cycles when σ_v is zero and there are no cycles when φ_1 and φ_2 are zero. If σ_w , the standard deviation of the growth rate, and λ are zero, the time series collapses to a constant growth rate case. When $\lambda < 1$ the time series is I(1) and when $\lambda = 1$, i.e., a random walk growth rate is assumed, the time series is I(2). Therefore, the

relative importance and size of σ_u , σ_v , and σ_w , together with φ_1 and φ_2 , demonstrate the behavior of GDP series. To demonstrate and summarize the behavior of sectoral output with the above parameters in the model, we propose the following groupings of business cycle features, with Table 1 summarizing these groupings.

Overall fluctuations indicate the relative contributions of the cycle vis-à-vis the trend measured in standard deviations, and total fluctuations in the cycle and the trend. It consists of the sum of the standard deviations of the cycle and the trend, and the ratio of the standard deviation of the cycle to that of the trend. The first element measures the total fluctuations in the output series. The standard deviation in growth, σ_w , also constitutes part of the standard deviation in the trend, which is $\sigma_w/(1-\lambda^2)^{0.5}$, so total volatility in the trend is $[\sigma_u^2 + \sigma_w^2/(1-\lambda^2)]^{0.5}$. The second element explains the relative contributions of the cycle and the trend and adjusts the total fluctuations according to the relative importance of the cycle. The larger the ratio of the standard deviation of the cycle to that of the trend, the larger the contribution of the cycle, and the larger is the indicator of overall fluctuations.

Durability of cycles is the sum of the two cycle equation coefficients φ_1 and φ_2 . When the sum of φ_1 and φ_2 , which is confined by $(-1, 1)$, is large, the effect of a shock to the cycle, though will eventually disappear, would be long-lasting and the process of mean-reversion takes place slowly.

There are three indicators for growth features. *Persistence of shocks to growth* is measured by $1/(1-\lambda)$, the cumulative effect by a unit shock². *Impact of shocks to growth*³ has two

² Notice the shock is to the growth rate so its effect on the level of output is cumulative.

³ Much of the empirical business cycle literature regards technology shocks as those of long-run effects that can be either positive or negative. Few argue, for technological progress, they can only be positive. We assume the former, considering technical advancement as well as technical obsolescence. Evidence of obsolete techniques and their (persistent) effects on the sector and the economy can be easily found, e.g., the British Rail Track, and the British car manufacturing industry. The decline and eventual disappearance of the car manufacturing industry in Britain is in essence a technology problem, it is not due to a strong sterling, nor high costs of labour; if low efficiency is to be blamed, it has its roots in technology (political issues are beyond the consideration

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elements: σ_w that gives a measure for the size of shocks and the immediate impact, and $\sigma_w/(1-\lambda)$, shock size adjusted cumulative effect on trend levels. *Average growth rate*, $gc/(1-\lambda)$, is the average or stationary mean of the growth rate in the whole period.

{Table 1 about here}

In the general model, Model 0, the average growth rate is measured by $gc/(1-\lambda)$. In Model 1 where restrictions $gc=0$ and $\lambda=1$ are imposed, the growth rate is a random walk and no stationary mean value exists for the growth rate. In Model 2, the mean value of the growth rate is simply gc . We regard the specifications of Model 0 and Model 2 as being more justifiable. Because the growth rate is stationary in Model 0 and Model 2, and it is non-stationary in Model 1. In Model 0, the growth rate, either expected or realized, is time-varying. Although it will be subject to empirical verification, we favor the specification of Model 0, because changes in growth are usually the result of technological progress, the impact of which will be realized gradually over some time⁴.

3. Empirical results and discussions

The data used in this study are UK sectoral and aggregate GDP, starting in the first quarter, 1955 and ending in the first quarter, 2002, seasonally adjusted at the 1995 constant price. In addition to the aggregate GDP, the seven main sectors used in the study are: Agriculture, Forestry and

of this paper). One can immediately sense these when visiting the factories if s/he is not science-illiterate. Technical obsolescence comes in two forms, absolute and comparative. The case of the British railways is the former where some parts of the system are simply beyond normal usage and will continue to be so for a considerable period. The British car manufacturing industry is the latter; any technical progress elsewhere that is not to be realized, matched or surpassed in Britain leads to technical obsolescence in the British car manufacturing industry.

⁴ Lippi, and Reichlin (1994) suggest a diffusion process of higher order moving averages for technological changes featured by growth in the trend. The AR(1) process, as we adopt in the study for trend growth, can approximate higher order MA and is parsimonious, and the experience tells us that the use of a parsimonious model is not only simpler, but also more effective.

Fishing (A&B); Manufacturing (D); Electricity, Gas and Water Supply (E); Construction (F); Distribution, Hotels, Catering and Repairs (G&H); Transport, Storage and Communication (I); and Services (J-Q, including business services and finance, and government and other services). The Mining and Quarrying sector (C) is excluded, as its weight in UK GDP is minimal and has been declining over decades; and more importantly, its change has been mainly influenced by unconventional economic forces and other factors.

The estimation results are reported in Table 2. Graphs for the aggregate GDP are plotted in Figure 1 and those for sectors are drawn in Figure 2 to Figure 8, with the top, middle and bottom panels for output and trend, cycle, and growth respectively. We concentrate the analysis on the more recent period, which people can recall vividly. The decline in the British economy appeared to have eased since the 1980s and, in the last twenty years since then, people have witnessed a rather large-scale cycle and hoped to iron out or alleviate the next. Starting in the early 1980s at the trough of the previous recession, the British economy, measured in aggregate GDP, climbed up steadily to last for almost one decade. The economic boom climaxed towards the end of 1989 shortly before the economy endured one of the most severe recessions in its modern history, undergone especially phenomenally in property market and stock market collapses. The recovery did not take place until two years later and the economy has been running smoothly since 1994, with reasonable GDP growth accompanied by (sometimes exceptionally) low inflation and an interest rate converging to the lower interest levels in the US and the rest of the EU.

Now we analyze what the models tell us about trends, cycles and growth in UK aggregate GDP. The cycle coefficients φ_1 and φ_2 are 0.6222 and 0.2021 (the latter is only close to being marginally significant), so the cycle is modestly durable and persistent. The effect of a shock to the cycle will eventually fade away but it will take time. The standard deviation of the cycle, σ_v , is $0.8390e^{-2}$; the standard deviation of the trend, σ_u , is not significant but the standard

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deviation in growth, σ_w , is $0.3341e^{-2}$, the contribution of which to the standard deviation in the trend is $\sigma_w/(1-\lambda^2)^{0.5} = 0.4571e^{-2}$. Overall, the standard deviation of the cycle is about two times larger than that in the trend, indicating the cycle is the main source of the stochastic fluctuation in UK GDP⁵. The average quarterly growth rate over the whole period is $gc/(1-\lambda) = 0.1932e^{-2}/(1-0.6825)\approx 0.61\%$, or 2.4% annually. With λ being 0.6825, the growth rate is persistent (notice the different scales of the vertical axis for trend, cycle and growth), which appears to coincide with a diffusion process in technical changes. Tests on restrictions confirm that the general model, Model 0, is the best to fit UK GDP data. Model 1, where the growth rate is a random walk, performs worst and is rejected on the ground of a significant LR statistic at the 5% level; while the LR test fails to reject the constant growth rate model, Model 2. The three graphs in Figure 1 exhibit the trend, cycle and growth reasonably well. Panel (b) clearly demonstrates UK business cycle features and panel (c) shows a stochastic growth rate that is persistent but mean-reverting (appears to reject Model 2 also).

{Table 2 about here}

Having inspected UK aggregate GDP and gained a broad view of the British economy, we carry on to scrutinize sectoral output, with reference to Table 2 and Figures 2-8. While on average the standard deviation of the cycle is about two times larger than that in the trend (incorporating growth), as found in the aggregate GDP, the contribution of trends and cycles differ across borders. Industry E, Electricity, Gas and Water Supply, shows the largest cyclical fluctuations with its standard deviation ($0.3743e^{-1}$) being more than 6.6 times larger than that in the trend [$\sigma_w/(1-\lambda^2)^{0.5} = 0.5685e^{-2}$ as the contribution of growth uncertainty to the standard deviation in the trend equation, and a very small insignificant σ_u ignored], whereas industry D, Manufacturing, has the largest relative contribution from the trend, and the standard deviation of the cycle ($0.1083e^{-1}$) is smaller than that contributed by the trend overall [$0.7176e^{-2}$ for σ_u plus

⁵ The fluctuation in the fitted AR(2) equation is non-stochastic.

$\sigma_w/(1-\lambda^2)^{0.5} = 0.1180e^{-1}$ from growth]. Sharp falls of output in sector E in 1985 reflect the fact of the world oil price collapse in that time. Industry I, Transport, Storage and Communication, is next to manufacturing to have the second largest contribution from the trend component [$0.6257e^{-2}$ for σ_u and $\sigma_w/(1-\lambda^2)^{0.5} = 0.5496e^{-2}$ from growth]; and the contribution from the trend and that from the cycle (σ_v is $0.1159e^{-1}$) are of comparable importance. On the other hand, industry F, Construction, is next to the energy sector (Electricity, Gas and Water Supply) to have considerably large contribution from the cycle, with the standard deviation in the cycle ($0.2622e^{-1}$) being 4.5 times larger than that in the trend ($0.5931e^{-2}$). The behavior of the services sector J-Q is rather different. Some problems may arise from the data; in the first 15 years period it exhibits deterministic seasonal cycles. This may have affected parameter estimation, though the model is able to pick the deterministic cycle in the data. Given the results shown in the table, fluctuations in the services sector, both in the trend and the cycle, are much smaller and smoother compared with all other sectors in the economy. Furthermore, it is the only sector to have a much smaller contribution from the cycle ($\sigma_v = 0.1866e^{-2}$), either in absolute terms in comparison with all other sectors, or in relative terms in relation to its own trend ($\sigma_u = 0.4892e^{-2}$). These results and findings indicate that the energy sector (Electricity, Gas and Water Supply) and the construction sector are mostly subject to cyclical fluctuations, though a considerable part of fluctuations in the energy sector could be seasonal rather than business cycles, and caused by a volatile world oil price. On the other hand, the services sector (including government services) is the least vulnerable to suffer business cycles. We provide an indicative rank of the sectors, viewed purely from the trend-cycle standpoint of this section, which considers the relative contributions of the cycle and the trend, and takes into account the overall fluctuations in the time series. We place similar sectors in one category, as it is not helpful to be too trivial. Ranked from low to high with reference to fluctuations, they are: (1) Services; (2) Distribution, Hotels,

Catering and Repairs; Transport, Storage and Communication; Manufacturing; (3) Agriculture, Forestry and Fishing; (4) Construction; Electricity, Gas and Water Supply.

We then inspect the durability of cycles across sectors. This, as discussed earlier, is measured by the sum of the two cycle coefficients ϕ_1 and ϕ_2 . We have reasonably found high durability or persistence of cycles in the Construction sector (0.9741) and the Transport, Storage and Communication sector (0.9731), and low durability or little persistence in the Services sector ($\phi_2 = -0.8590$, ϕ_1 is a small insignificant number 0.09104). But cycles in the sector of Distribution, Hotels, Catering and Repairs also appear to be highly durable (0.9797). The lowest durable cycles are found in industry E, Electricity, Gas and Water Supply (0.5528); and cycles are modestly persistent in industry D, Manufacturing (0.8168) and industry A&B, Agriculture, Forestry and Fishing (0.8637). These three sectors A&B, D and E also have a positive ϕ_1 and negative ϕ_2 , indicating there would be more alternations in their cyclical fluctuations. These sectors constitute production sectors also, with A&B being agricultural production and D and E being industrial production while the mining sector is excluded.

In the above, the main consideration is the relative contribution of the trend and the cycle. Now we turn to the important issue of growth. The size of shocks to growth in Industry D, the manufacturing industry, is by far the largest ($0.9885e^{-2}$). Although the shocks are not highly persistent in terms of the unit cumulative effect [$1/(1-\lambda)=2.2026$], its shock size adjusted cumulative effect [$\sigma_w/(1-\lambda) = 0.2177e^{-1}$] is also the largest. In other sectors where shocks to growth are of considerable consequence are Industry E, Electricity, Gas and Water Supply, with the size of shocks being $0.3396e^{-2}$ and shock size adjusted cumulative effect being $0.1715e^{-1}$; Industry I, Transport, Storage and Communication with $0.3434e^{-2}$ for the size of shocks and $0.1567e^{-1}$ for shock size adjusted cumulative effect; and Industry G&H, Distribution, Hotels, Catering and Repairs with $0.4161e^{-2}$ for the size of shocks and $0.1515e^{-1}$ for shock size adjusted cumulative effect. In industry F, Construction, the size of shocks is large but insignificant, so the

role of shocks to growth is not clear from viewing the results. With sector A&B, Agriculture, Forestry and Fishing and sector J-Q, Services, the size of shocks to growth is much smaller and insignificant. There might be some data problems in the service sector of which we have been aware. With regard to average growth rates measured in $gc/(1-\lambda)$, the highest growth sectors are found to be Electricity, Gas and Water Supply (3.3% annually) and Transport, Storage and Communication (3.2% annually); and Manufacturing (1.3% annually) is only second to Agriculture, Forestry and Fishing (1.2% annually) to be the lowest. In the middle, we find the broadly defined services, sectors G&H (2.1% annually) and J-Q (2.5% annually). We summarize these business cycle features by sector in Table 3. Sectors with similar features under each of the business cycle aspects are grouped into one category and painted with the same color.

{Table 3 about here}

Finally we examine model specifications. All the restrictions are tested against the general model for the sectors as well as the aggregate GDP. The likelihood ratio test, as reported in Table 2, rejects Model 1, the random walk growth rate model, in all seven sectors and the aggregate GDP, and two of the rejections are at the high level of 1% and two at the modest level of 5%. On the other hand, restrictions imposed on Model 2, the constant growth rate model, are rejected only in three out of eight cases, none at a high level of significance. So there is reasonable support in the results for the general model, and the rejection of the random walk growth rate model is overwhelming. While the growth rate is best specified as being time-varying and mean-reverting, tests on the restrictions also indicate that the time-changing component may be fairly negligible. From human beings' perspective, this suggests that people believe the growth rate may change but are less confident in how it changes.

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4. Conclusions

In this paper we have examined the behavior of UK GDP sectors through decomposing the time series data into trend and cycle components using the Kalman filter. Unlike previous business cycle exercises, we determine the characteristics of trend growth empirically. That is, the trend growth rate in this paper is not pre-specified as either stationary as most researchers would insist, or a random walk as in Clark (1987) and a few more recent studies, e.g., Kim and Nelson (1999). The general model of this study encompasses a number of alternative specifications about trend growth, therefore accommodating diverse views on growth.

There is reasonable support in the results for the general model, and the rejection of the random walk growth rate model is overwhelming across UK GDP sectors. The growth rate is best specified as being mean-reverting and time-varying, though it is not materially different from a constant. This is sound, taking into account the economic behavior of output growth over an indefinite time horizon, a setting for the theory as well as for model estimation.

Overall, the results indicate that the Services sector is least to subject to business cycle fluctuations, and that the energy sector of Electricity, Gas and Water Supply and the Construction sector are most vulnerable to suffer cyclical fluctuations, though a considerable part of fluctuations in the energy sector could be seasonal rather than business cycles, and caused by a volatile world oil price. With regard to durability of cycles, the Services sector again exhibits low durability or little persistence in cycles; while the Construction sector, the Transport, Storage and Communication sector and the Distribution, Hotels, Catering and Repairs sector appear to be on the other end of the spectrum.

The largest impact of shocks to growth is reasonably found in the Manufacturing sector, a technology intensive and sensitive sector, which is followed by the Electricity, Gas and Water Supply sector, the Transport, Storage and Communication sector and the Distribution, Hotels,

Catering and Repairs sector. While in the Construction sector, the role of shocks to growth is not clear according to the results. Although shocks to growth are important to the Manufacturing industry, it is one the lowest growing sectors in the UK economy, in contrast to the other two capital and machinery intensive sectors, the Electricity, Gas and Water Supply sector, and the Transport, Storage and Communication sector, with the latter topping the UK growth league in the period. The difference may arise from the fact that the latter two sectors are utility oriented and the large parts of them are non-tradable, especially when the end user is concerned; while in the former, a considerable element can easily move across the borders.

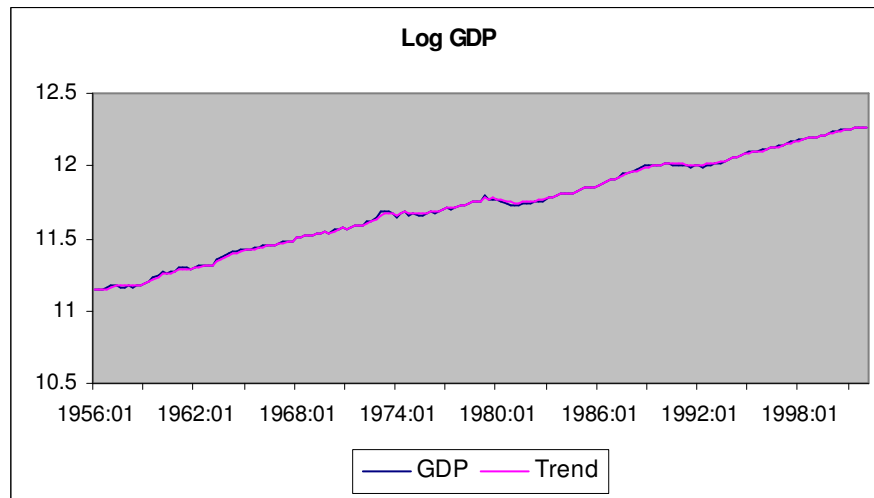
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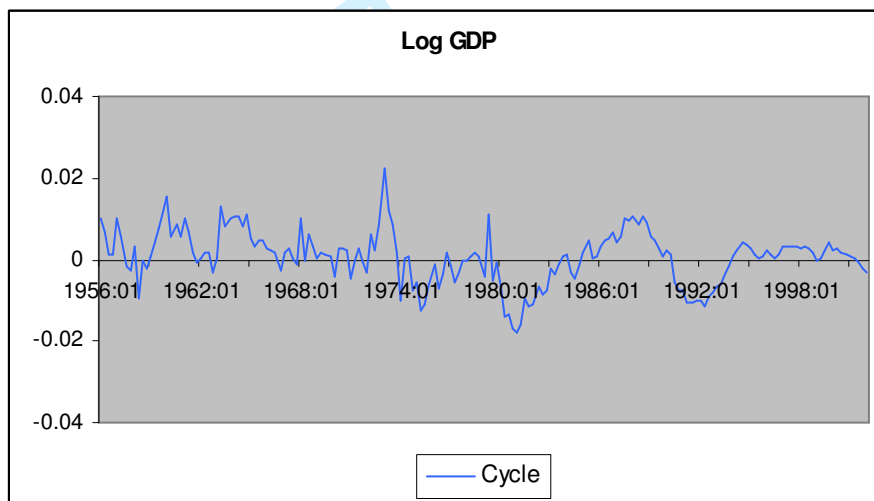
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Figure 1. GDP Aggregate

(a)



(b)



(c)

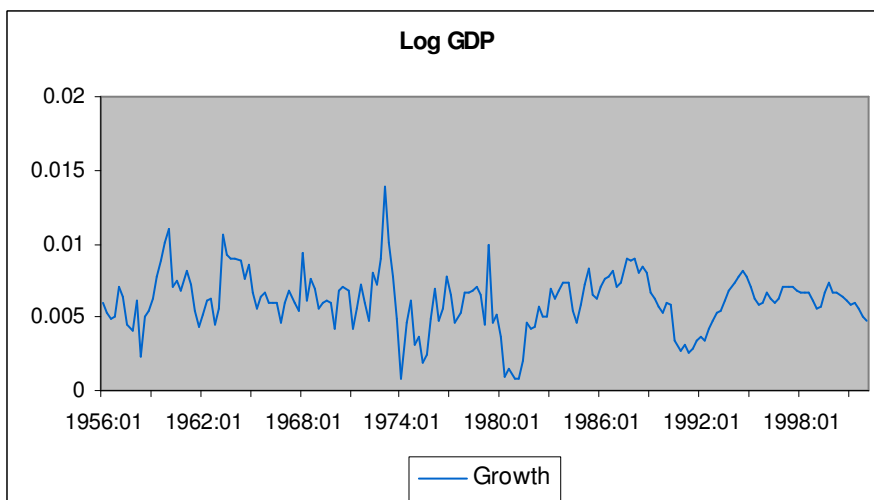
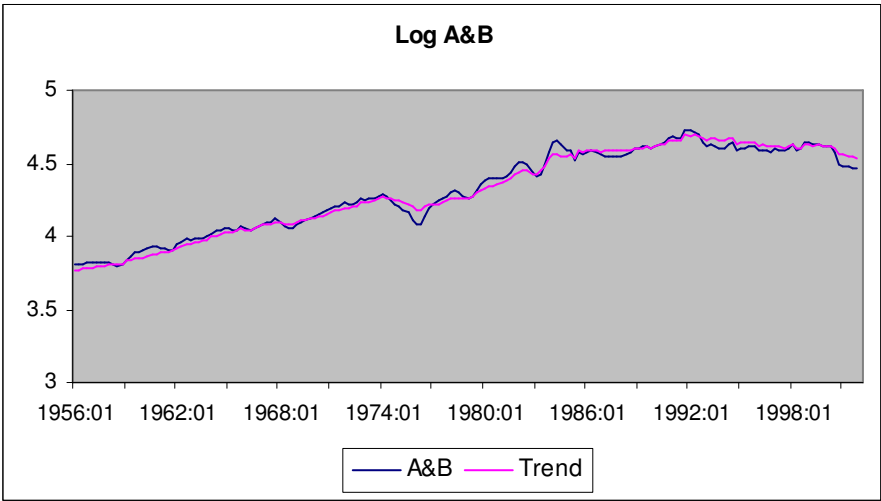
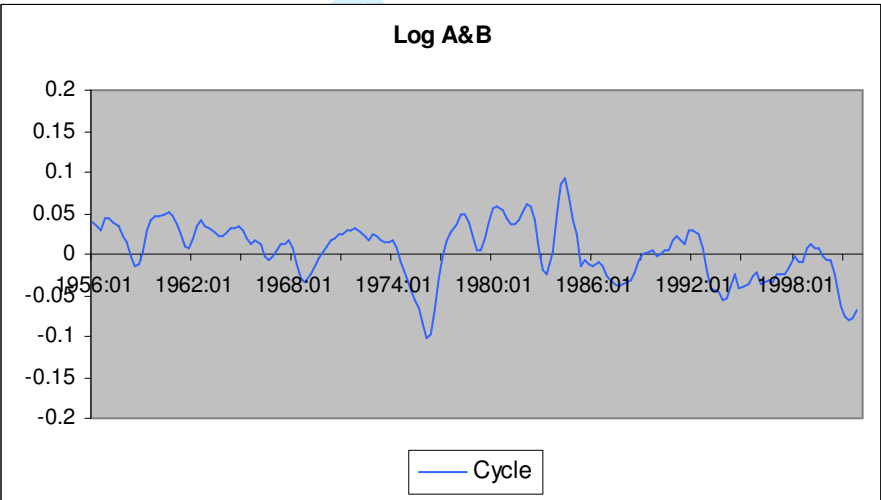


Figure 2. Agriculture, Forestry and Fishing (A&B)

(a)



(b)



(c)

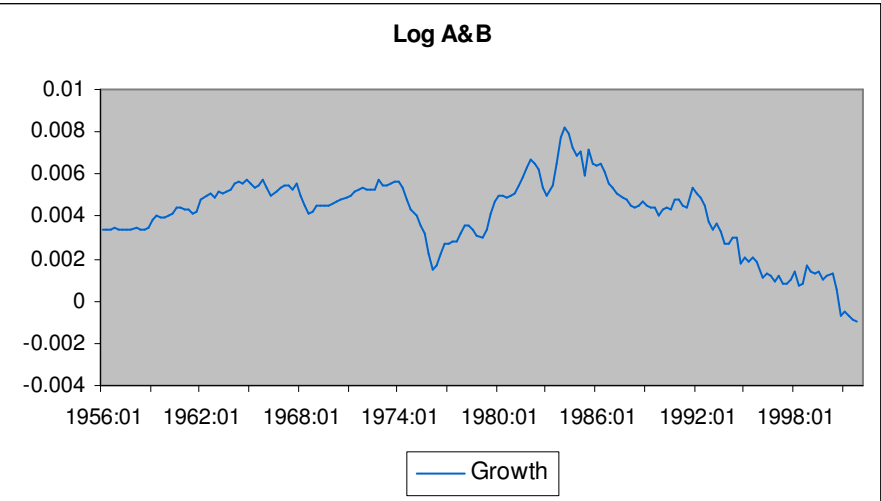
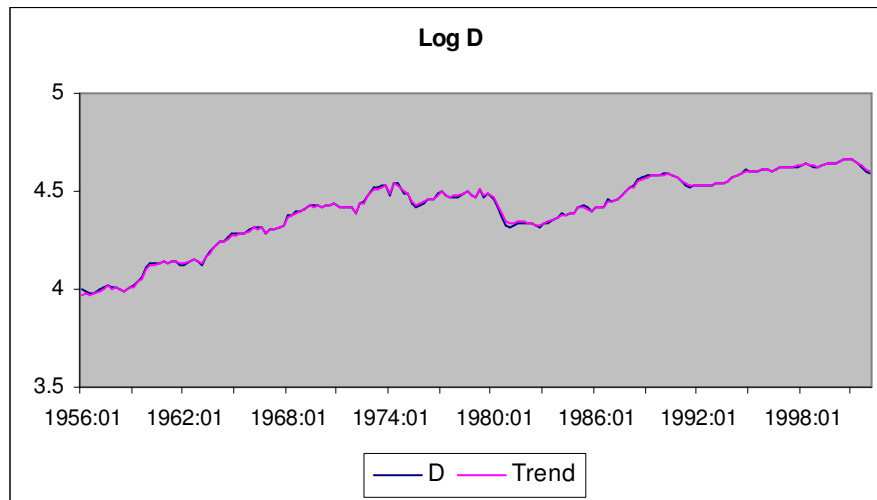
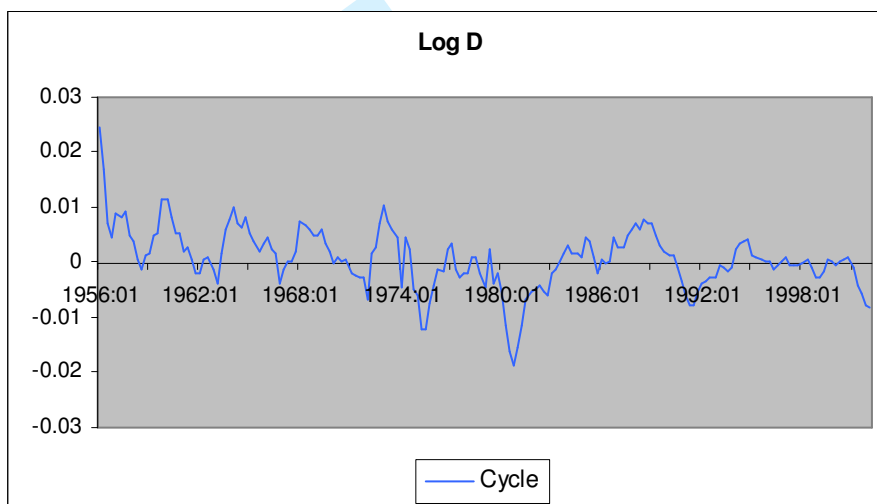


Figure 3. Manufacturing (D)

(a)



(b)



(c)

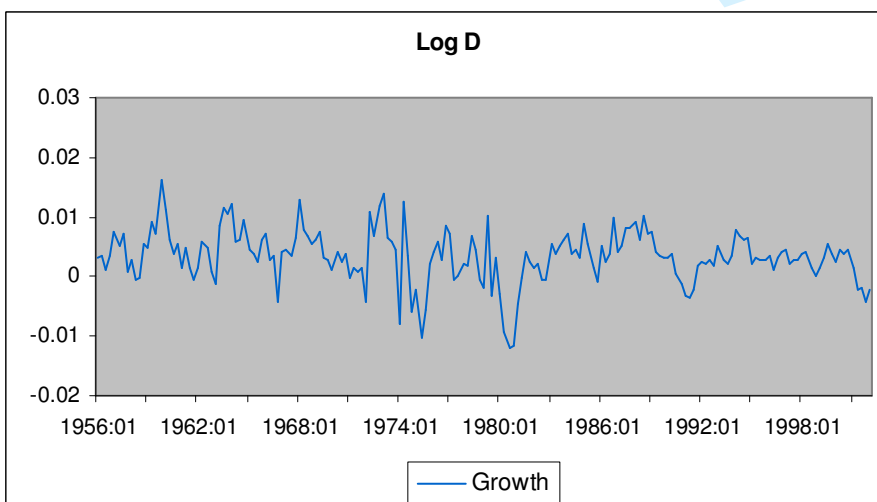
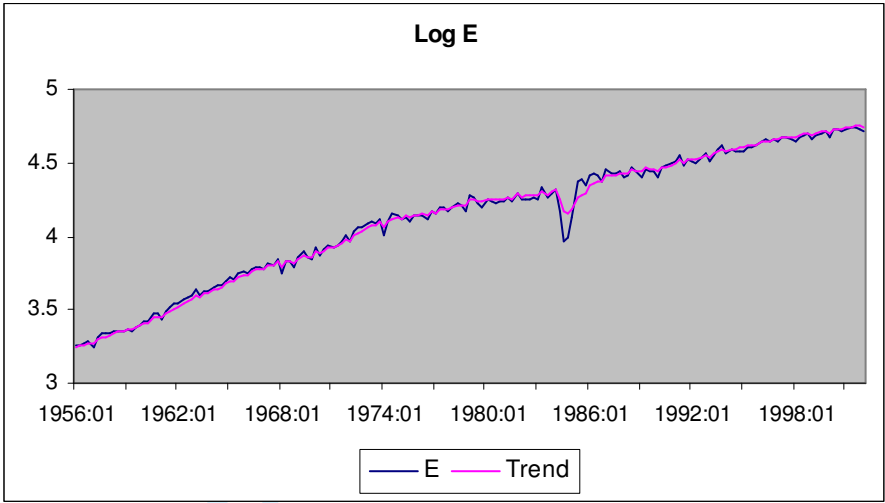
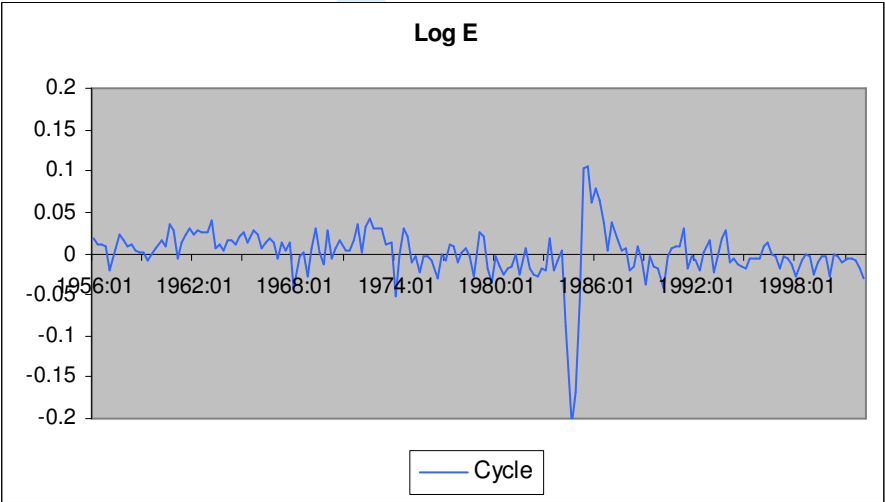


Figure 4. Electricity, Gas and Water Supply (E)

(a)



(b)



(c)

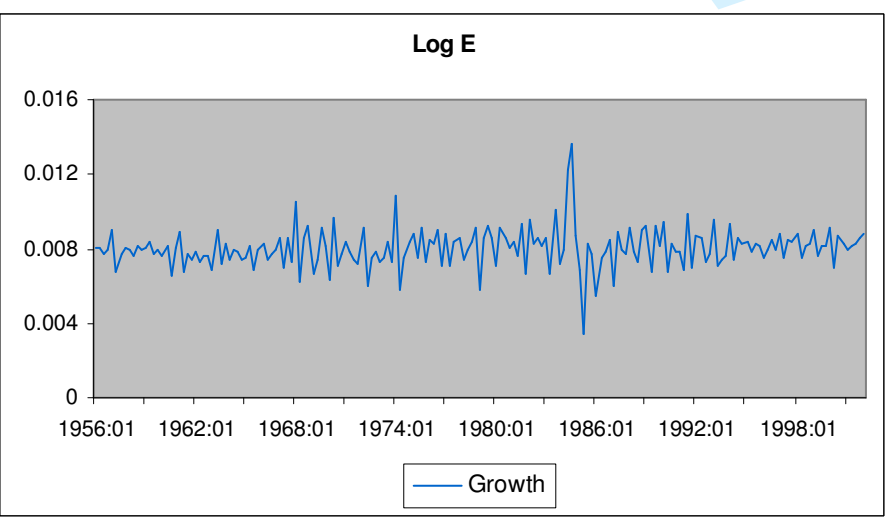
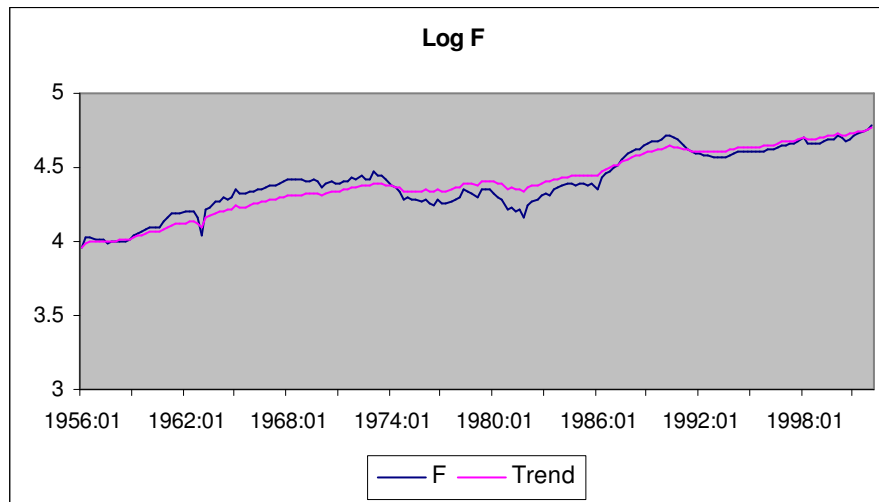
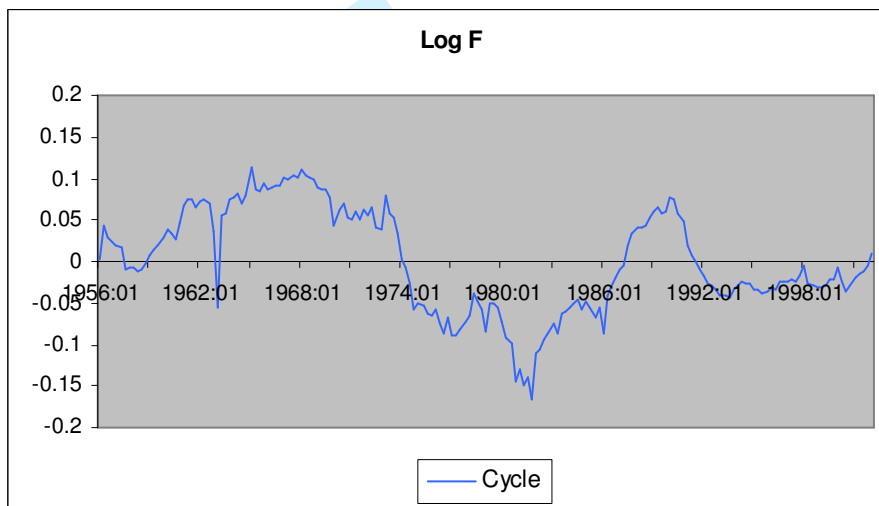


Figure 5. Construction (F)

(a)



(b)



(c)

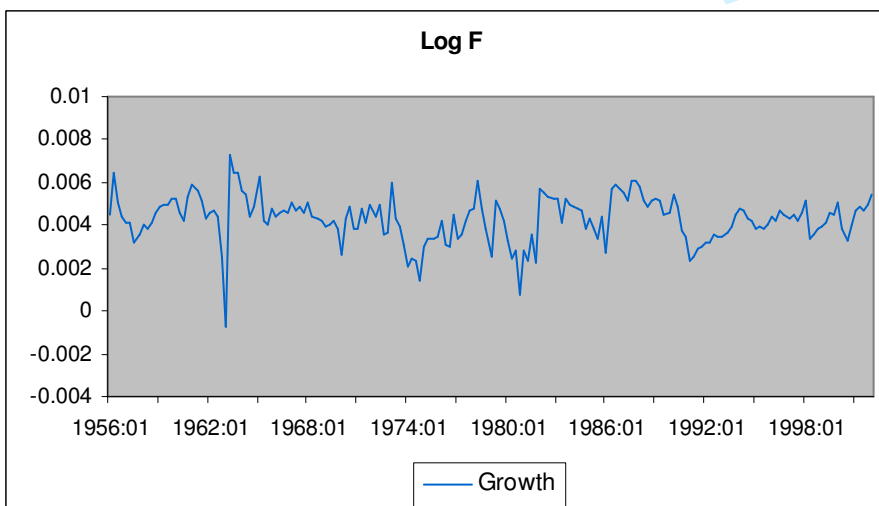
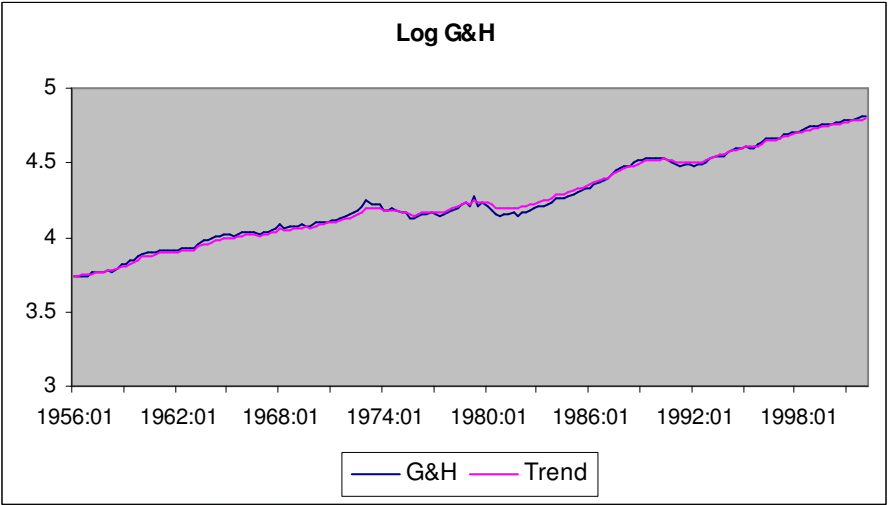
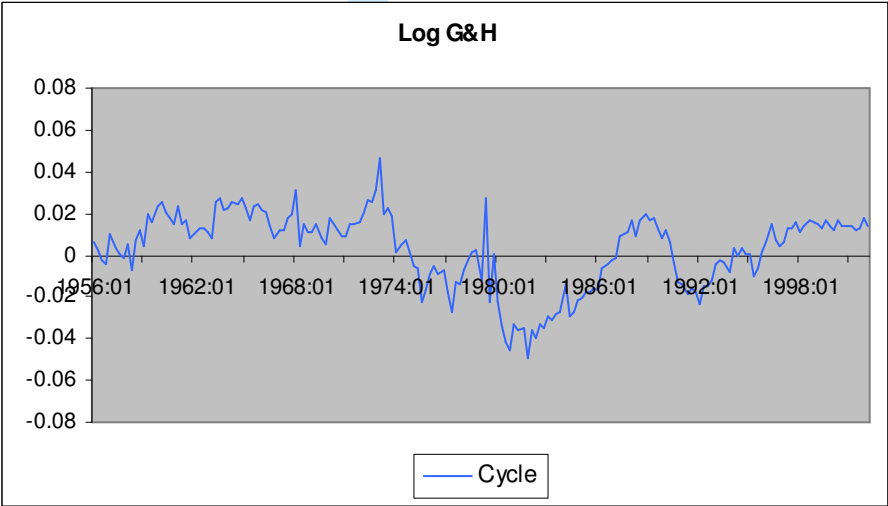


Figure 6. Distribution Hotels, Catering and Repairs (G&H)

(a)



(b)



(c)

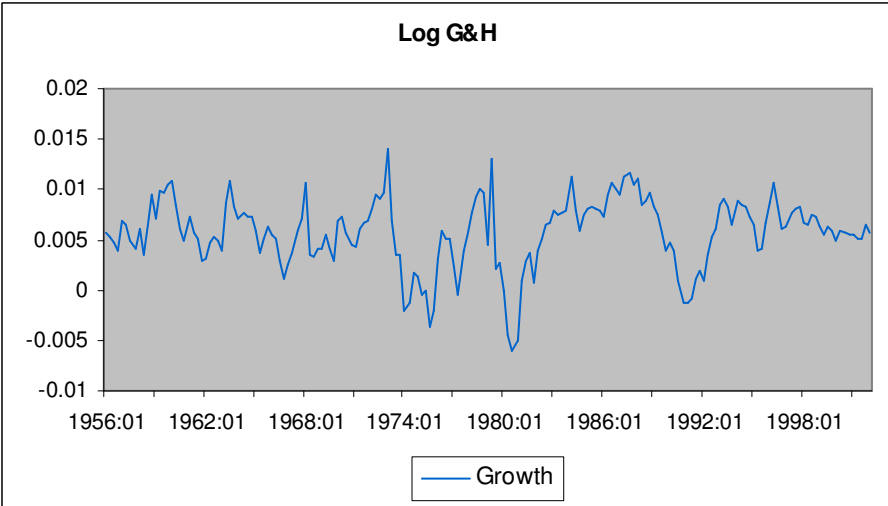
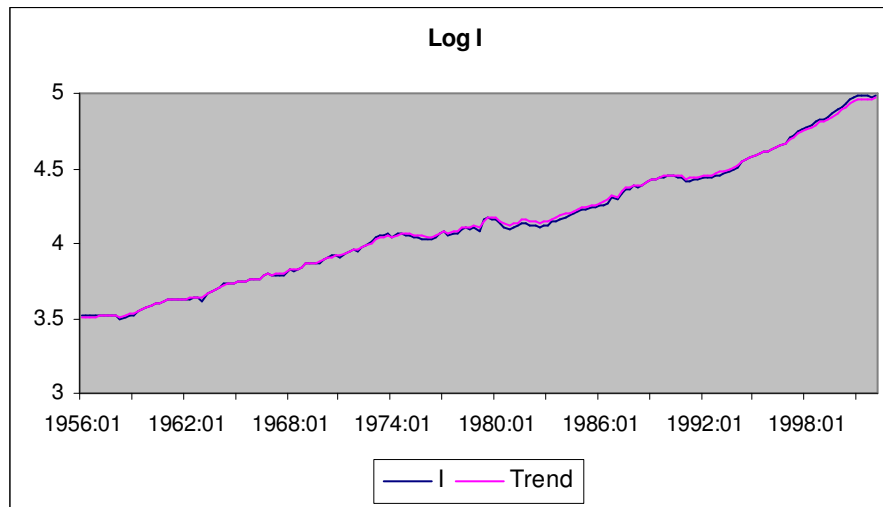
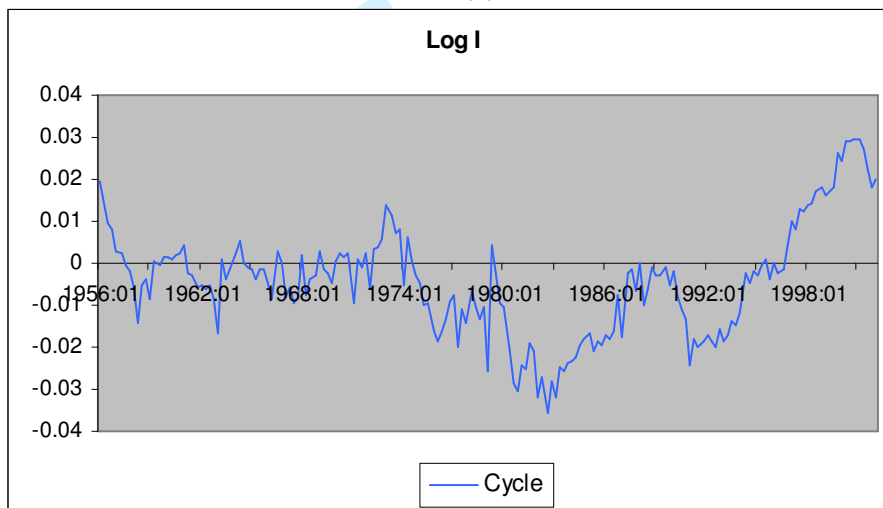


Figure 7. Transport, Storage and Communication (I)

(a)



(b)



(c)

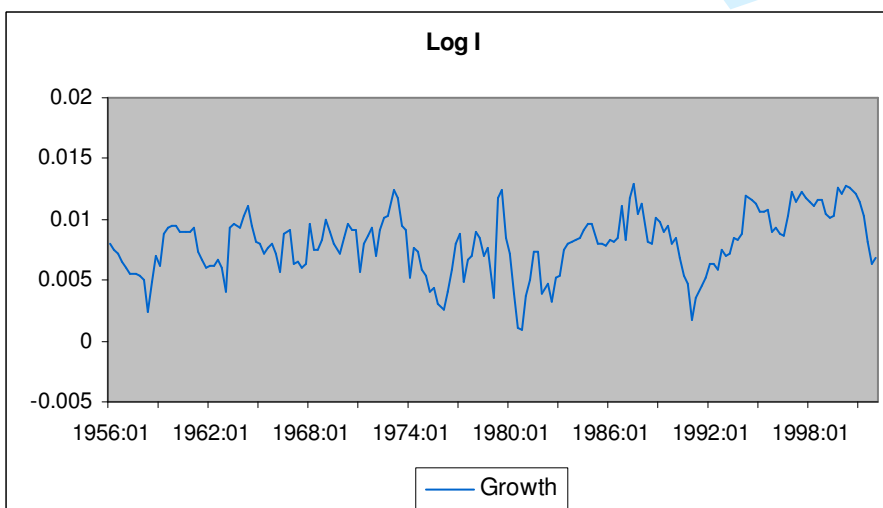
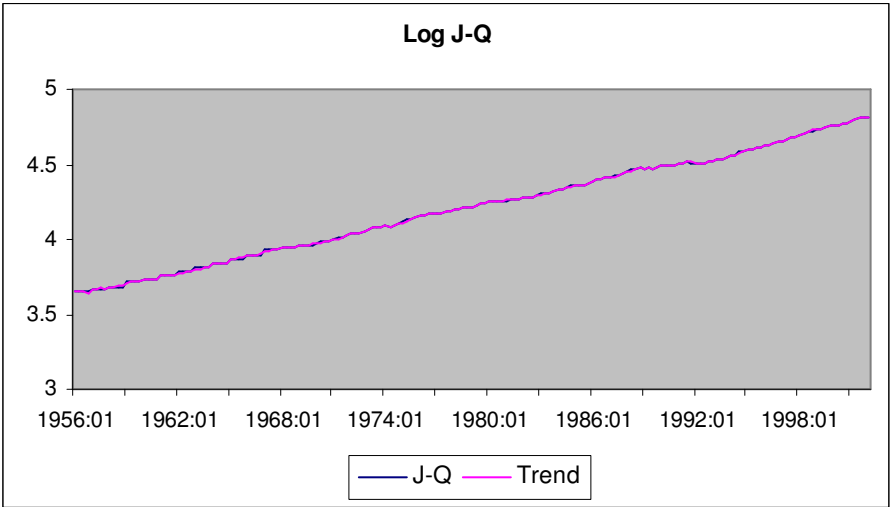
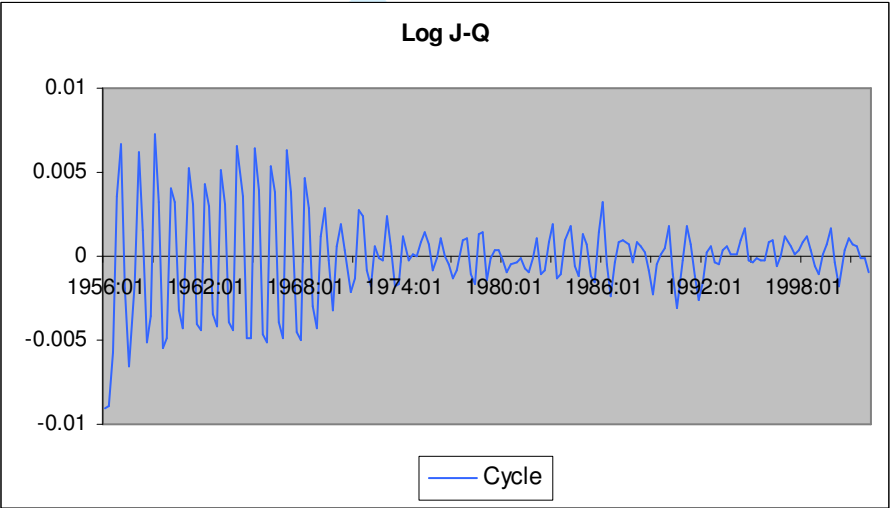


Figure 8. Services (J-Q)

(a)



(b)



(c)

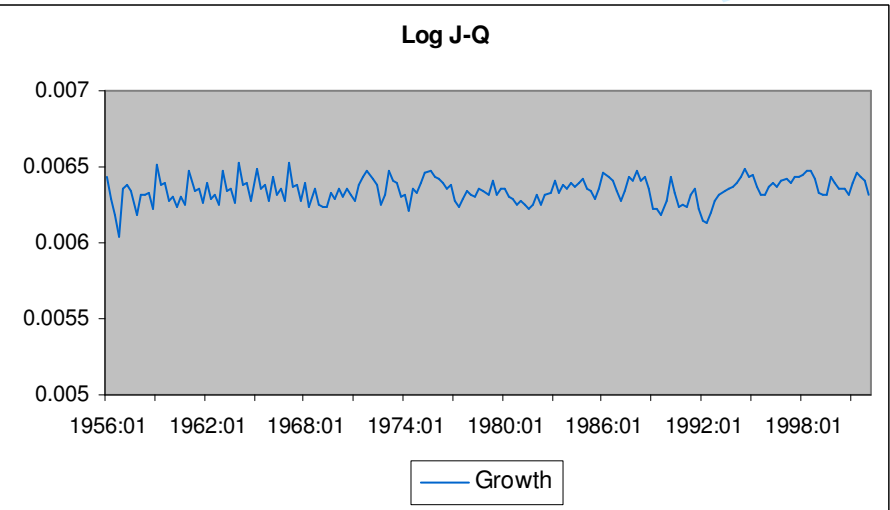


Table 1. Business cycle features: summary

Overall fluctuations	Durability of cycles	Impact of shocks to growth	Persistence of shocks to growth	Average growth rate
$\ln\left(\frac{\sigma_v}{\sigma_{u'}}\right) + (\sigma_v + \sigma_{u'})$	$\phi_1 + \phi_2$	$\sigma_w, \sigma_w/(1-\lambda)$	$1-\lambda$	$gc/(1-\lambda)$

$\sigma_{u'} = [\sigma_u^2 + \sigma_w^2/(1-\lambda^2)]^{0.5}$ is total volatility in the trend, which takes into account of the contribution of the standard deviation of growth.

Overall fluctuations: Relative contributions of the cycle vis-à-vis the trend measured in standard deviations, and total fluctuations in the cycle and the trend. The sum of $\sigma_v + \sigma_{u'}$ is adjusted by

$\ln\left(\frac{\sigma_v}{\sigma_{u'}}\right)$ to account for, or tilt toward, the contribution of the cycle. When $\sigma_v = \sigma_{u'}$, the measure is simply

$\sigma_v + \sigma_{u'}$, when $\sigma_v > \sigma_{u'}$, the measure is greater than $\sigma_v + \sigma_{u'}$, and vice versa.

Durability of cycles: Sum of the two cycle equation coefficients, ϕ_1 and ϕ_2 . The larger the sum, the more durable is the cycle. Cycles are highly durable when $\phi_1 + \phi_2$ is close to being one.

Impact of shocks to growth: Size of shocks to growth and shock size adjusted cumulative effect on trend levels.

Persistence of shocks to growth: Measure of persistence of the effect on the growth rate.

Average growth rate: Average or stationary mean of the growth rate in the whole period.

Table 2. Decomposition of GDP sectors into trend and cycle with a stochastic growth rate using the Kalman filter

	A&B	D	E	F	G&H	I	J-Q	GDP
φ_1	1.4829 [*] (0.1133)	1.0288 [*] (0.3821e ⁻¹)	0.7524 [*] (0.8868e ⁻¹)	0.8608 [*] (0.2181e ⁻¹)	0.7916 [*] (0.5966e ⁻¹)	0.5827 [*] (0.5660e ⁻¹)	0.9104e ⁻¹ (0.8873e ⁻¹)	0.6222 [*] (0.9757e ⁻¹)
φ_2	-0.6192 [*] (0.1018)	-0.2121 [*] (0.4065e ⁻¹)	-0.1996 [‡] (0.1024)	0.1133 [*] (0.1994e ⁻¹)	0.1881 [‡] (0.7931 ⁻¹)	0.3904 [*] (0.5666e ⁻¹)	-0.8590 [*] (0.4655e ⁻¹)	0.2021 [‡] (0.1230)
σ_u	0.7958e ^{-2‡} (0.4229e ⁻²)	0.7176e ^{-2*} (0.5359e ⁻³)	0.2357e ⁻⁴ (0.2143e ⁻¹)	0.5931e ^{-2‡} (0.3239e ⁻²)	0.2787e ⁻² (0.1950e ⁻²)	0.6257e ^{-2*} (0.3650e ⁻³)	0.4892e ^{-2*} (0.6649e ⁻³)	0.1237e ⁻³ (0.4260e ⁻²)
σ_v	0.1861e ^{-1*} (0.1855e ⁻²)	0.1083e ^{-1*} (0.5221e ⁻³)	0.3743e ^{-1*} (0.2496e ⁻²)	0.2622e ^{-1*} (0.6503e ⁻³)	0.1204e ^{-1*} (0.6224e ⁻³)	0.1159e ^{-1*} (0.9448e ⁻³)	0.1866e ^{-2*} (0.2373e ⁻³)	0.8390e ^{-2*} (0.5070e ⁻³)
σ_w	0.6466e ⁻³ (0.4438e ⁻³)	0.9885e ^{-2*} (0.1523e ⁻²)	0.3396e ^{-2*} (0.1249e ⁻²)	0.6216e ⁻² (0.8314e ⁻¹)	0.4161e ^{-2*} (0.6209e ⁻³)	0.3434e ^{-2*} (0.7823e ⁻³)	0.8512e ⁻³ (0.9898e ⁻³)	0.3341e ^{-2*} (0.3311e ⁻³)
Gc	0.6787e ^{-4*} (0.1571e ⁻³)	0.1529e ^{-2*} (0.1396e ⁻³)	0.1619e ^{-2*} (0.3435e ⁻³)	0.2153e ^{-2*} (0.3740e ⁻³)	0.1428e ^{-2†} (0.6304e ⁻³)	0.1761e ^{-2*} (0.7007e ⁻⁴)	0.3441e ^{-2*} (0.2088e ⁻³)	0.1932e ^{-2*} (0.3888e ⁻³)
λ	0.9772 [*] (0.3252e ⁻¹)	0.5460 [*] (0.2792e ⁻¹)	0.8020 [*] (0.3528e ⁻¹)	0.4973 [*] (0.8767e ⁻¹)	0.7253 [*] (0.4451e ⁻¹)	0.7808 [*] (0.8810e ⁻²)	0.4576 [*] (0.7459e ⁻¹)	0.6825 [*] (0.5380e ⁻¹)
General model								
Likelihood Value	618.7923	658.1481	501.4905	575.2099	698.7701	686.6194	845.3897	759.3137
Restrictions: gc=0, λ =1								
Likelihood value	616.2179	652.1676	494.3601	572.7405	695.1590	683.6324	842.2776	756.2246
LR	5.1488 [‡]	11.9610 [*]	13.8384 [*]	4.9388 [‡]	7.2222 [†]	5.9740 [‡]	6.2242 [†]	6.1782 [†]
Restrictions: λ =0, σ_w =0								
Likelihood value	616.9088	656.9255	496.8284	573.9711	696.1267	683.7019	844.8977	757.4017
LR	3.7670	2.4452	8.9018 [†]	2.4776	5.2868 [‡]	5.8350 [‡]	0.9840	3.8240

* significant at the 1% level; † significant at the 5% level; ‡ significant at the 10% level. Standard errors in brackets. LR is the likelihood ratio statistic

Table 3. Business cycle features by sector

Overall fluctuations	Durability of cycles	Impact of shocks to growth	Persistence of shocks to growth	Average growth rate
J-Q	J-Q	J-Q	J-Q	E
G&H	E	A&B	F	I
I	D	F	D	J-Q
D	A&B	G&H	G&H	G&H
A&B	I	I	I	F
F	F	E	E	D
E	G&H	D	A&B	A&B

Overall fluctuations: Relative contributions of the cycle vis-à-vis the trend measured in standard deviations, and total fluctuations in the cycle and the trend. From top to bottom: increasing overall fluctuations.

Durability of cycles: Sum of the two cycle equation coefficients. From top to bottom: increasing durability, short to long.

Impact of shocks to growth: Size of shocks to growth and shock size adjusted cumulative effect on trend levels. From top to bottom: increasing impact, small to large.

Persistence of shocks to growth: Measure of persistence of the effect on the growth rate. From top to bottom: increasing persistence, low to high.

Average growth rate: Average or stationary mean of the growth rate in the whole period. From top to bottom: decreasing growth rate, high to low.