Modelling British Industrial Production, 1700-1992

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Abstract: The paper presents results on the persistence of British industrial production using the Cochrane (1988) measure, based upon the spectral density at zero frequency, and an extended version of the Crafts-Harley (1992) data set. Utilising results on the timing of macroeconomic epochs, consideration is given to the effects of structural breaks on measures of persistence. The results show high persistence during the Industrial Revolution and lower levels of persistence experienced during the twentieth century. The problems of ignoring structural breaks when calculating measures of persistence are highlighted and used to explain the results of some previous studies.

1. Introduction

Measuring trends and cycles lies at the centre of British economic history. Hoffmann's (1955) annual series for the years from 1700, and the revisions of Crafts and Harley (1992) provide a rich resource for the statistical analysis of early British industrialisation. These data can be readily extended for the years to 1992 by splicing with the estimates of Lomax (1959) and the CSO, to provide an unrivalled long-run industrial production series. This paper investigates the existence of discontinuities in British industrial growth, particularly by using measures of persistence to identify industrial epochs. To pre-empt, we argue that there was a British industrial revolution around the period 1780-1851, and that World War One (WW1) and the oil price shocks around 1973 delineate distinct industrial eras.

Following Nelson and Plosser (1982), considerable evidence has accumulated that output time series for most countries typically contain a unit root or are difference stationary (DS). The possibility that output innovations might *persist indefinitely* (an implication of DS), contrasts sharply with the traditional trend stationary (TS) models where cycles are transitory. Thus Crafts, Leybourne and Mills, hereafter CLM (1989), have questioned the historiography of the British industrial revolution by identifying the existence of a unit root in industrial production for the period 1700-1913, and arguing that industrial growth evolved as a stochastic process. Their results denying a sharp discontinuity in industrial growth around 1780 run counter to the views of Hoffmann (1955), Deane and Cole (1962), Rostow (1960), and Hausman and Watts (1980).

Modelling industrial production as a DS process offers interesting new perspectives on British industrialisation, but does give rise to some concerns. Most importantly interpreting time series data as either TS or DS, and by implication transitory or infinitely persistent, may be extreme. Measuring the level of persistence, however, see Cochrane (1988), Durlauf (1989), Leung (1992), and Pesaran *et al.* (1993), might lead to a more realistic characterisation of historical data. Secondly, Perron (1989) and Rappoport and Reichlin (1989), show that if the true time series process has changes in trend mean, Dickey-Fuller (1981), type tests will reject the true TS model in favour of unit root. Issues of structural discontinuity figure prominently in historical literature, for example those associated with the industrial revolution or the impact of wars in the twentieth century. The likelihood of discontinuities adds weight to Newbold and Agiakloglou's (1991) call for investigating sub-periods of the industrial production era.

The case for separately investigating segments of industrial production during the period 1700 to 1992 appears compelling. Newbold and Agiakloglou (1991) have noted the unit root for the logarithm of output that CLM (1989) report for 1700-1913 disappears on first differencing, pointing to a constant rate of growth. For the complete sample 1700-1992 we are also unable to reject the DS null, but find no strong evidence of a unit root in first differenced data. Portraying British industrial growth as constant since 1700 would run counter to the richness of the historical record, and highlights the need to investigate distinct industrial epochs. The approach taken here firstly involves unit root tests both for sub-periods within the years 1700-1913 and for longer periods using Perron (1989) and Zivot and Andrews (1992) type extensions to the Dickey-Fuller (1981) strategy to investigate possible discontinuities. These results point to periods when output persistence was either high (infinite) or low (zero). However, the testing procedures allow for a quantitative distinction to be made between a DS and TS characterisation of the series. Secondly, we utilise a measure of persistence due to Cochrane (1988), which derives from the spectral density at zero frequency, to refine the patterns of persistence shown by the unit root tests. Further, we compare its properties with alternative measures based upon low order ARMA models which acts as a partial resolution of the debate between CLM (1989) and Newbold and Agiakloglou (1991). These results form the basis for characterising the record of British industrial growth since 1700.

2. Statistical methodology

One of the first ways used to *infer* persistence was based upon tests which categorise univariate series as either TS or DS. In particular, the class of model most commonly used to describe temporary, i.e. non-persistent, deviations about a trend is:

$$y_t = a + bt + u_t \qquad (1)$$

where y_t is the natural logarithm of industrial production, bt describes the trend and u_t is a stationary invertible autoregressive moving average (ARMA) process. The process is stationary in levels or trend stationary, (TS). The simplest class of model which captures permanent, i.e. persistent, fluctuations is the random walk with drift

$$y_t = \mu_t + y_{t-1} + \varepsilon_t \qquad (2)$$

The random walk is non stationary in levels, but stationary when differenced, i.e. difference stationary, (DS).

It has become common practice to discriminate between DS and TS processes and hence *infer* persistence or otherwise, by using the augmented Dickey-Fuller unit root tests see Dickey and Fuller (1981). The usual form of the test treats DS as the null hypothesis and involves estimation of a model like:

$$y_t = \mu + \rho y_{t-1} + \beta t + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + \upsilon_t \qquad (3)$$

where υ_t is assumed to be serially uncorrelated and the null hypothesis of DS implies H_0: $\rho = 1$, $\beta = 0$. This is the approach pioneered by Nelson and Plosser (1982) and followed on numerous occasions. Perron (1989) demonstrated how breaks in the series can lead to biased results (in favour of DS) and Zivot and Andrews (1992) consider the issue of endogenous versus exogenous breaks. The main differences in the testing procedure raised by Perron (1989) and Zivot and Andrews (1992), involves the addition of various dummy variables to (3) to capture changes in the intercept and/or time trend and the use of recursive estimation methods, i.e.,

$$y_t = \mu + \rho y_{t-1} + \beta t + \gamma DT + \theta DU + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + \upsilon_t \qquad (4)$$

where DU=1 if t>TB, 0 otherwise and DT = t if t>TB and 0 otherwise and TB refers to the time of the break. Tests of the null hypothesis of DS still involve H_0: $\rho = 1$, $\beta = 0$ although critical values are now given in Perron (1989) for exogenous breaks or Zivot and Andrews (1992) for endogenous breaks.

However, the distinction between a DS and TS process and hence the inference on absolute or no persistence, is extreme. Campbell and Mankiw (1987) and Cochrane (1988) emphasise this fact and consider some measure of the *persistence* of shocks, i.e. how much does a one-unit shock to industrial production affect forecasts into the future? Furthermore, Cochrane (1988) demonstrates how any DS process can be represented as the sum of a stationary and random walk component where the issue of persistence revolves around the *size of the random walk element*. In particular assume industrial production is a linear DS process i.e.,

$$\Delta y_t = (1 - L) y_t = \mu + A(L)\varepsilon_t = \mu + \sum_{j=0}^{\infty} a_j \varepsilon_{t-j} \qquad (5)$$

Utilising the Beveridge and Nelson (1981) decomposition, let

$$y_t = z_t + c_t \qquad (6)$$

where

$$z_t = \mu + z_{t-1} + \left(\sum_{j=0}^{\infty} a_j\right)\varepsilon_t$$

$$-c_t = \left(\sum_{j=1}^{\infty} a_j\right)\varepsilon_t + \left(\sum_{j=2}^{\infty} a_j\right)\varepsilon_{t-1} + \left(\sum_{j=3}^{\infty} a_j\right)\varepsilon_{t-2} + \ldots$$

and z_t is to be considered the permanent and c_t, the temporary component of y_t. Long-term forecasts of y_t are unaffected by c_t, the temporary component.

Cochrane (1988) considers the innovation variance of the random walk component as a natural measure of the importance of the random walk element. He gives two equivalent formulations of this measure. From (6) and (3) the variance of the random walk element $\sigma^2_{\Delta z}$ is given by:

$$\sigma^2_{\Delta z} = \left(\sum_{j=0}^{\infty} a_j\right)^2 \sigma^2_\varepsilon = A(1)\sigma^2_\varepsilon \qquad (7)$$

Equivalently, $\sigma^2_{\Delta z}$ is equal to the spectral density of Δy_t at frequency zero, i.e.,

$$\sigma^2_{\Delta z} = \left(\sum_{j=0}^{\infty} a_j\right)^2 \sigma^2_\varepsilon = S_{\Delta y}\left(e^{-i0}\right)\sigma^2_\varepsilon \qquad (8)$$

which can be estimated by the Bartlett estimator. However, as demonstrated by Cochrane (1988), the Bartlett estimator will be biased in small samples where the bias can be corrected by multiplying the estimates by T/(T-k-1), where T is the effective sample size and k the window size.

The Cochrane (1988) approach is only one approach to measures of persistence. Campbell and Mankiw (1987) estimated parsimonious ARMA representations of US GNP and measured the importance of the random walk component by the change in z_t in response to a unit univariate innovation in GNP (or y in the notation of equation (6)). However, Cochrane (1988), highlights several conceptual disadvantages of scaling a persistence measure by the univariate innovations in y_t, see Cochrane (1988), p911 fn 9. Nelson and Plosser (1982) derive a measure related to Campbell and Mankiw (1987) based upon an unobserved components model. However, unlike the Cochrane measure the Nelson and Plosser approach is not invariant to the choice of decomposition. Furthermore, as demonstrated by the Monte Carlo evidence presented in Cochrane (1988), low order ARMA representations typically overestimate the random walk element, even though they pass the usual battery of diagnostic tests. In contrast the "spectral density at frequency zero of first differences captures all the effects of a unit root on the behaviour of a series in finite samples," Cochrane (1988). p. 905. Overall, therefore, the weight of theoretical and Monte Carlo evidence suggests the superiority of the Cochrane measure over alternative approaches and that measure alone will be used to derive the results presented below.

3. Empirical Results

The data used relates to an extended version of CH's estimates of the index of British industrial production, where the extension from 1913 gives a full sample 1700-1992. In a series of papers, Greasley and Oxley (1994 a,b, 1995, 1996) consider structural breaks in the series utilising both the Dickey-Fuller (1981) approach and the extensions of Perron (1989) and Zivot and Andrews (1992). On the basis of their results they identify an alternating TS/DS/TS characterisation of the data for the period 1700-1913 and present a case for dating the British industrial revolution as 1780-1851, see Greasley and Oxley (1994a,b). Furthermore, Greasley and Oxley (1995, 1996) use Perron (1989) and Zivot and Andrews (1992) methods to identify crashes and breaks in the post 1913 data coinciding with World War 1; the post (WW1) decline; a 1973 trend break and a 1979 crash. This leads to an alternating TS/DS/TS characterisation for the whole sample period 1700-1992.

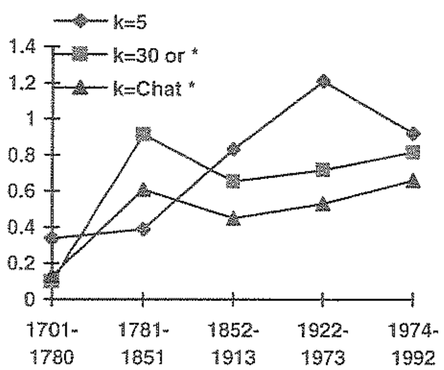
Furthermore, on the basis of ADF test results Greasley and Oxley conclude that the period 1700-1992 comprises several distinct epochs of industrial growth, in particular: *1700-1780; 1781-1851; 1852-1913; 1922-1973* and *1973-1992.* These periods have both quantitative statistical support and a wealthy of economic historiography.

However, as discussed above, the characterisation of the time-series properties of a series as either DS or TS is an extreme one. In contrast, the results presented as Table 1 in the appendix, consider the Cochrane measure of persistence over a number of periods, including Greasley-Oxley epochs. This is crucial as Cochrane (1988) demonstrates that measures of persistence constructed for periods (segments) of differing growth rates, will tend to bias the results in favour of finding *too much persistence.*

If we consider the results presented as Table 1, and limit discussion initially to the column "Chatfield" which gives the Chatfield (1989) $2\sqrt{T}$ criteria for the choice of window width (where T is the effective sample size), a number of features emerge. Firstly, the periods identified by Greasley and Oxley (1994a,b) have markedly different measures of persistence which lend support to their results based upon ADF tests. As can be seen, the persistence measures for Greasley-Oxley epochs (pre-WW1) are respectively 0.132, (1700-1780), 0.607, (1781-1851) and 0.449 (1851-1913) showing that the Industrial Revolution exhibited a marked difference in persistence from the earlier and later periods. Turning to the preferred Cochrane window width of 30, the results are even more pronounced with measures of 0.098, 0.912 and 0.653 for the respective periods..

Using the full sample period 1700-1992 and assuming no breaks in the series implies a high degree of persistence, i.e. 0.712 for the Chatfield rule, or 0.659 for k=30, reflecting the bias raised by Cochrane (1988) in favour of excessive persistence (or in favour of DS). A similar problem arises if the twentieth century is treated as a single epoch. In particular, the results for 1922-1992 imply a degree of persistence close to 1 i.e. 1.058 for k=14 or 1.377 for k=30. However, if the Greasley-Oxley epochs are considered, the pattern of persistence is as presented in Figure 1.

Figure 1
Persistence



*=15 in the case of 1974-1992

For either k=30 or the Chatfield rule, persistence rises during the Industrial Revolution from the very low levels of pre-industrial Britain. It then declines pre-WW1, recovering only slowly to (or approaches, based upon k=30) its Industrial Revolution level. However, some caution need be expressed about the period 1974-1992 given the small sample size. The results based on k=30 or k=Chatfield are qualitatively the same, however, because of the quantitative differences the interpretation differs in important ways. In particular based upon k=30, the Industrial Revolution represents an historical high point in terms of persistence. Twentieth century persistence levels are moderately high and higher than the mid-late nineteenth century, but lower than the period 1780-1851. This result is not as clear-cut based upon k=Chatfield, although it depends crucially upon the small sample results of the period 1974-1992. On these basis, the Industrial Revolution period identified by Greasley and Oxley represents a unique period of high persistence.

Apart from providing a measure of persistence, interpretation of the normalised spectral density function gives a measure of the proportion of total variance of the process accounted for by cycles of various lengths, $l=2\pi/\omega$ where ω is the frequency.

Table 2, below, presents estimates of the cycle lengths contributing most to the explanation of the variance of industrial production based upon the Chatfield rule for choosing window width.

Table 2
Cycle lengths, $l=2\pi/\omega$

Years	*k*	*Cycle*
1701-1780	18	2
1781-1851	16	3
1852-1913	16	10
1922-1973	14	15
1974-1992	9	9

k=Chatfield window width

For the period up to 1913 it can be seen how pre- and post-industrial production cyclical elements differ. Short cycles (around 2-3 years), or a low cyclical element to the data, explain most of the variance in output pre-1780. Whereas post 1851 cycles of around 10 years, or a high cyclical element to the series, explain most of the variance in production. The cyclical nature of the Industrial Revolution period is similar to the pre-revolution period - in both cases the data suggests an economy not best classified as cyclical. However, for different reasons. These measures are qualitatively similar (though with a somewhat different interpretation given the methods of analysis) to those presented by CLM where they consider the periods pre-1783, with cycles of around 4 years, and post 1815, with cycles of around 7 years. Plots of the spectrum also indicate the following phenomena. For the periods 1701-1780, 1781-1852, the spectrum tends to rise continuously from low to high frequencies indicating the contribution of short cycles in explaining the variance of output. However, the shape of the spectrum reverses post 1852, including the twentieth century, indicating the contribution of longer cycles. Taking the post 1922 period as a whole suggests that cycles of 14-15 years contribute most to the explanation of output variance. These conform closely to the results of Yeung (1992). However, as with the persistence measure, treating the twentieth century as a single epoch can be misleading.

The amount of variance explained by longer cycles (or a more cyclical characteristic to the data), increases after the Industrial Revolution. However, cycle length appears to decline as persistence appears to increase. It does seem however, that there is strong quantitative and historical evidence in favour of distinct periods of growth, as argued by Greasley and Oxley.

These results with and without assumptions on specific breakpoints, highlight some of the apparent inconsistencies in recent work which implies a uniquely high level of persistence during the twentieth century see for example Leung (1992). Leung in particular treats certain periods as constant trend, i.e. 1914-1990, 1946-1990, when based upon the results for industrial production, distinct breaks in trend occur. The case is particularly apparent when considering his persistence measure of 1.73 (k=30) for the period 1914-1990.

4. Conclusions

In this paper we have argued that the time-series properties of the index of British industrial production have varied over the period 1700-1992. In particular, we argue in favour of a number of distinct macroeconomic epochs characterised by different degrees of persistence. On this basis we argue in favour of a particular epoch, 1780-1851, being considered as the British Industrial Revolution. Furthermore, we argue that the onset of WW1 and its post-war aftermath, and the oil price shocks around 1973 constitute breaks in the series sufficiently distinct as to be able to distinguish qualitatively and quantitatively different periods of economic growth. In particular, the periods or epochs would be delineated as: 1700-1780; 1781-1851; 1852-1913; 1922-1973 and 1974-1992. Comparison of these epochs has yielded a number of patterns of persistence depending on the particular value of k (window size) used. Using low values of k implies an increase in persistence into the twentieth century conforming to the results of for example DeLong and Summers (1988). However, using the more acceptable Chatfield or Cochrane window sizes changes the implications dramatically. Treating the twentieth century as a single epoch exaggerates this tendency further. Here the Industrial Revolution represents an historically high (if not maximum) value of persistence with the twentieth century only aspiring to such levels. However, although the Industrial Revolution and latter twentieth century industrial production persistence may be qualitatively similar (with a period of lower persistence between), the nature of the shocks producing the result seems to be fundamentally different.

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Appendix

Table 1

Cochrane (1988) measure of persistence

	k=5	k=10	k=15	k=20	k=30	Chatfield	k
1701-1992	0.521	0.469	0.465	0.544	0.659	0.712	34
1701-1780	0.340	0.265	0.164	0.135	0.098	0.132	18
1781-1851	0.389	0.464	0.577	0.704	0.912	0.607	16
1852-1913	0.832	0.538	0.497	0.558	0.653	0.449	16
1852-1992	0.807	0.558	0.532	0.622	0.559	0.549	24
1922-1992	1.225	0.975	0.980	1.223	1.377	1.058	16
1922-1973	1.209	0.789	0.593	0.774	0.716	0.531	14
1974-1992	0.918	0.504	0.817	-	-	0.660	8

k denotes the window size for the Bartlett estimator;

a - denotes not calculated. All figures are corrected for small sample bias following Cochrane (1988).