Cointegration Analysis: An International Enterprise

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1 Introduction

Cointegration analysis is truly an international enterprise, with researchers from most continents and major countries participating. You will, of course, recognize that the very word is Danish, in the same sense as menu is English. Both Søren Johansen and Katarina Juselius have been at the forefront of the international collaboration, making the University of Copenhagen an epicenter of the development. In this review, I will recall the history of the concept and related notions, as this is central to understanding its present position in the econometrician's toolkit. Then I will illustrate the idea with an example (live at the conference) of how we conceive of cointegration in the context of an issue such as inflation, which has been the centre of much economic policy and even more theoretical and empirical analysis.

The example will show that most of the extant theories of inflation have some truth: many effects matter empirically. I think of the price level as basically indeterminate over historical time, and the cumulation of all past inflation. In turn, inflation is the outcome of responses to a multitude of shocks from:

(a) excess demand for goods and services from the private sector leading their prices to rise;
(b) excess demand for factors of production bidding up wages and the price of capital, partly in response to (a);
(c) excess money holdings that stimulate excess demand;
(d) direct shocks from overseas, both those affecting the international exchange rate and hence the prices of imports and exports, as well as imported inflation;
(e) excess government demands (via unfunded deficits);
(f) special factors such as wars, world-wide commodity price shocks, price controls etc.

It will transpire that money creation is not the sole and only cause of inflation in a modern economy, whatever may have been the case in the 15th–18th centuries under commodity money and the start of fiat money. Rather, money is an idle asset, albeit the counterpart to active credit, and can increase or fall considerably without much impact on inflation. As well as illustrating cointegration in action, I will try and describe the implications for economic policy which we draw from our studies, echoing the emphasis in Katarina's talk.

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2 Historical review

A detailed history of econometrics has developed over the last decade and full coverage is provided in Morgan (1990), Qin (1993) and Hendry and Morgan (1995) . Here, we will review the relevant aspects germane to the evolution of the concepts and tools underpinning cointegration analysis.

Hooker (1901) was one of the first economists to examine time-series relationships taking account of what we would now call their non-stationarity, or lack of homogeneity over time. He sought to allow for the difficulties of various causes operating over different time periods, long-run versus short-run; and of the problems of multiple and common causes. The relationship of concern was between the marriage rate and trade. Hooker first detrended the data by taking deviations from a moving average, then studied lagged reactions $1861 - 95$ between changes in trade and changes in the marriage rate (the direction causality is assumed to take). He found the secular relation to be the opposite of that between changes, and ascribed this to common trendlike movements in population and trade. In other words, he viewed the trend-dominated relation as 'spurious'. In fact, he also considered a regime shift due to cheap American wheat flooding the British market during $1876 - 95$. Plus ça change, plus c'est la meme chose.

Yule (1926) formally analyzed the problem of 'nonsense correlations': in economic and social data, extremely high correlations are often found between variables for which there is no ready causal explanation (church marriages and death rates). He rejected the view that the correlation was the result of both variables being related to some third variable (the rise of science) — this is in fact the notion of 'spurious' correlation he defined in Yule (1897). Instead, he decided the correlation was 'nonsense', and arose by a fluke of sampling. In economic data, each observation is closely related both to the one before and after it, and are not random drawings. He analyzed how misleading correlation coefficients calculated from small samples of time-series of variables can be when the data are polynomials in time. As the proportion of the complete cycle sampled varied, the correlation could take on almost any value even for independent series.

He also categorized time series according to their serial correlation properties and undertook (by hand!) a simulation study to show how their correlation coefficients behaved when two unconnected series were: A] are random; B] had random first differences; C] had second differences which are random. Such series are now called integrated of orders zero, one, and two respectively. He found a near normal frequency distribution in case A; an almost uniform distribution (except at the end points) in case B; and a U-shaped distribution in case C. Thus, rejection of the correct hypothesis was almost certain..

The next major step was again a simulation study by Granger and Newbold (1974), re-emphazising the dangers of nonsense regressions in economics, and highlighting that a very good fit yet with significant residual serial correlation was a standard symptom associated with nonsense regressions. In 1980, I achieved some notoriety by showing that cumulative rainfall in the UK provided a better explanation of price inflation than the money stock – the point of my example, however, was to demonstrate sufficient understanding of the problem to create it at will (see Hendry, 1980). Indeed, I argued in Hendry (1993) that econometrics is potentially scientific precisely because alchemy is creatable, detectable and refutable. A complete analysis of the nonsense-regressions problem was presented by Phillips (1986), adopting tools of analysis that were very unfamiliar to econometricians at the time, but since have become standard. That is a common theme throughout this history: complaints about the advanced mathematics used by the frontrunners, which later generations regard as straightforward.

Nonsense regressions are the obverse of cointegration. And in an important sense, economists have been speaking cointegration for decades, but like prose, did not know they were doing so. (Of course, in opposition to prose, there is poetry. One of my colleagues often refers to his work becoming poetry when the mathematics refuses to solve, and large intuitive jumps are required in the argument, so I found the following poster for him! Since this festival is one of culture, in the broad, poetry seemed admissible). Even at its earliest stages, empirical econometric research sought to find sustainable relationships between variables. Researchers knew many economic times-series variables trended over time, and like |Hooker, often made careful adjustments for such factors as population growth, changes in the price level, and so on. Since they usually worked with the logarithms of data (to ensure positive outcomes and constant elasticities), they thereby implicitly assumed constant ratios between trending variables.

Klein (1953) devoted a complete chapter of his well-known textbook to the great ratios of economics: Consumption to income; capital to output; wage share in national income; the real rate of interest and the real exchange rate (purchasing power parity); etc. We will look at some of these shortly.

When I commenced econometrics in the mid-1960s, all this was standard fare, and naturally influenced how we formalized our models. For example, Sargan (1964) was a key precursor that we all studied carefully, embodying a close link between static-equilibrium economic theory and dynamic empirical models, where past disequilibria in levels determined current changes, specifically real wages affecting wage inflation. Long-run equilibria were explicitly economic theoretic, with short-run dynamics guided by optimization theory (such as Holt, Modigliani, Muth and Simon, 1960) and data analysis. The resulting equations were explicitly formulated as growth rates related to levels, embedding the time-series approach (which analyzed differenced-data only, since levels were non-stationary) in an econometric system which nevertheless had a levels long-run solution.

In the late 1960s and early 1970s, there was a somewhat acrimonious debate between time-series analysts and econometricians, ostensibly about model forms, but really about modelling methods (see Box and Jenkins, 1976, Cooper, 1972, and Naylor, Seaks and Wichern, 1972, for example). At the time, I for one thought static-equilibrium economic theory was powerful enough to delineate how the non-stationary levels of economic variables would be related, and merely asserted that ratios induced stationarity, arguing that ‘there are ways to achieve stationarity other than blanket differencing’ (see Hendry and Anderson, 1977). Our model of Building Society behaviour embodied an equilibrium-correction mechanism (ECM) between mortgage and deposit levels determining changes in lending until convergence. However, we were unaware of the important effects which the inherent non-stationarity in the original levels variables might entail for the distributions of many of our estimators and tests. The formal naming of ECM (as error-correction mechanism) occurred in Davidson, Hendry, Srba and Yeo (1978), and led to a further round in the debate (see Granger and Newbold, 1977, Hendry, 1977). However, the war was almost at a close, as the formal idea of cointegration was introduced by Clive Granger in 1980-81 (see e.g., Granger, 1981), irrevocably linking the two approaches with the proof that ECM and cointegration were isomorphic (two names for the same thing) in the Granger representation theorem (see e.g., Engle and Granger, 1987).

Over same period, evidence was accruing that many economic time series were better construed as having unit-root non-stationarity than being stationary (see e.g., Nelson and Plosser, 1982). Thus, the theory of testing for unit roots, and analysing such series began to flourish: see among many others, Dickey and Fuller (1979, 1981), Hall and Heyde (1980), Stock (1987), Phillips (1986, 1987a, 1987b, 1988), Park and Phillips (1988, 1989), Phillips and Perron (1988), Chan and Wei (1988), Banerjee and Hendry (1992), Banerjee, Dolado, Galbraith and Hendry (1993), and Hendry (1995). The new tools introduced thereby have transformed the mathematics of econometrics, but some derivations have become easier (see their application to multi-step forecasting in Clements and Hendry, 1996), even if the newer approach seems daunting at first acquaintance. The analyses of many of the researchers at this university draw on and contribute to such developments: see, inter alia, Johansen (1988), Johansen and Juselius (1990), Osterwald-Lenum (1992), Johansen (1992), and Johansen and Juselius (1992), as well as Johansen (1995) for an extensive treatment.

3 UK inflation

We will now use PcGive (see Hendry and Doornik, 1996) to examine the various cointegration relationships potentially relevant to the UK inflation process over the past century. The data set was developed by Friedman and Schwartz (1982) for the UK over 1872–1975, on money (M), prices (P_{uk}), interest rates (the Treasury bill rate Rs_{uk}, and the bond rate Rl_{uk}), output (Y), population (*Pop*).[1] We will also use some of the related US data in Friedman and Schwartz (1982), namely prices (P_{us}) and short-term interest rates (Rs_{us}), as well as the \$/£ exchange rate (E). We have since added the national debt (N), and based on Attfield, Demery and Duck (1995), extended the data to 1993. Finally, Shadman-Mehta (1995) kindly provided the updated UK labour market data to 1990, based on Phillips (1958), comprising unemployment (U), wages (W) and productivity (π). Capital letters denote the original variable, and lower case letters the corresponding logarithm (so $m = \log M$).

First, we graph the log of the UK price level, as measured by an index of the prices of goods and services entering National Income.[2] Despite the huge changes witnessed in the nominal price level since 1872, several features are instantly manifest in fig. 1a: the apparent era of no inflation pre World War I; the rapid rise in prices during World War I, with approximately 20% changes, then the sharp fall around 1920; the slow decline in the interwar period, followed by a fast rise till the late 1960s, then a veritable explosion till 1980 and a distinctly slower rise since. The overall range is impressive: a factor of more than 50 fold over the century and a quarter (4 fold in logs).

US prices in fig. 1b are similar to UK: their correlation seems high, confirmed by copying the US price graph into the UK graph. The UK suffered less deflation in the early 1930s, and more inflation since then, increasingly so later in the sample. The vertical difference between the two lines is the relative price $P_{ukus} = P_{uk}/P_{us}$, a natural variable for economic analysis, albeit in units of £/\$ so depending on the exchange rate. At this stage we cannot tell if the relation is a dreaded nonsense one, or a substantive cointegration connection, but can see from fig. 1c that the relative price moved much less than either absolute price.

The exchange rate, in units of \$ per £, has fallen considerably (roughly 75%), along a similar time path to P_{ukus}, as seen by adding it to fig. 1c. These together suggest there was even less movement in the underlying real exchange rate, or purchasing-power parity $e_r = e - p_{usuk}$. This measure is independent of currency units, and plotting it yields fig. 1d. The variation is greatly reduced relative to the price levels, with a range of about 0.6 (i.e., 60%), and at the end of this century, e_r is close to the value in 1872. This huge reduction in the variability is certainly consistent with cointegration, and with some economic theories of real exchange rate behaviour. Even so, viewed as the exchange rate, substantial and persistent deviations are clear, going 20% above and almost 40% below the initial value: imagine the effect of the latter on the cost of your foreign holiday. The mechanism here is all too obvious: an inflationary shock, from whatever source, worsens competitiveness, drives down the nominal exchange rate to restore the trade balance, and permanently locks in the past inflation.

Relative interest rate levels affect output and international differentials affect capital movements and hence E. The level of the short-run interest rate, Rs_{uk} in fig. 2a, fluctuated around 3% till after

[1] Hendry and Ericsson (1991) record some caveats about these data, as well as a critique of their previous analysis.
[2] Graphs are lettered notionally as a, b, d, c clockwise from the top left.

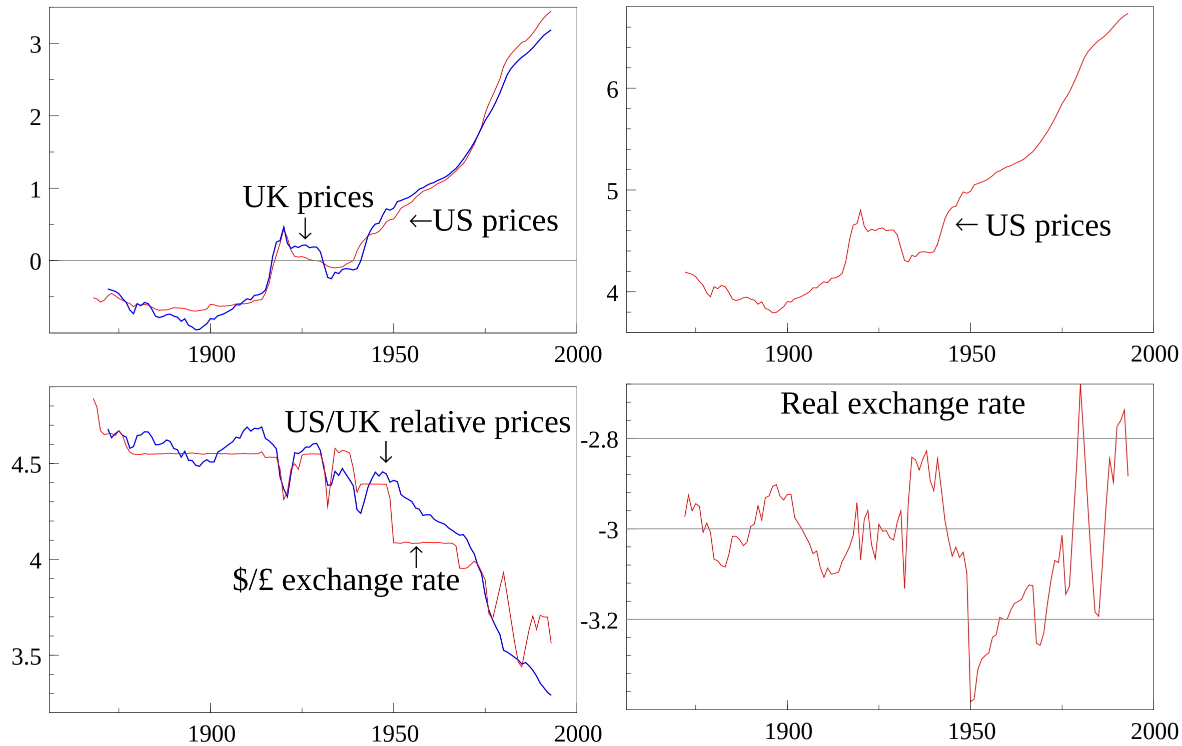

Figure 1 UK and US prices and the real exchange rate.

World War I, then fell to 0.5% where it stayed till 1950, then rose to unprecedented levels of 15% in the inflations of the 1970s, before reverting to more 'normal' levels in the early 1990s. The epoch also began with $Rs_{us} > Rs_{uk}$ but ended with the reverse (also see fig. 2a). Plotting the relative interest rates together with the relative price level, namely p_{ukus} versus Rs_{ukus}, shows that when the UK inflated faster than the US, the interest differential moved against it from favourable in the 1880s to unfavourable by the 1990s (fig. 2b). The two countries had closely similar inflation experiences till the 1960s, and only thereafter did the UK inflate considerably faster (fig. 2c). Thus, differential inflation fluctuated around zero for most of the sample (fig. 2d), and only became noticeably positive in the last part. Overall, there is less evidence of cointegration for interest rates, even though one would be surprised by systematic long-run departures.

We remarked earlier on the role of excess demand for goods and services in determining inflation, so we now consider national output. This has trended over the sample (fig. 3a), with a sharp fall in 1918–19 not recouped till post World War II. The trend rate has been relatively constant, possibly with a shift in the mean around 1920. The deviations from an overall linear trend are interesting – see fig. 3b – suggesting a large 'disequilibrium' in the 1920s and 30s, only removed late in the sample. Given the severity of the post World War I shock to output and prices, it is unclear if the deviation series is stationary or not, but we will treat it as such.

National debt N has altered markedly as well, with the step changes due to world wars very apparent; fig. 3c shows the ratio of national debt to national income N/PY; and fig. 3d the log changes in nominal debt, where the huge impact of 1914–18 is manifest. Even so, despite governments running deficits since 1945, N/PY has fallen steadily in the post war period due to the inflation seen earlier. Once again, the end point is close to that at the start, despite enormous movements in between. That aspect favours

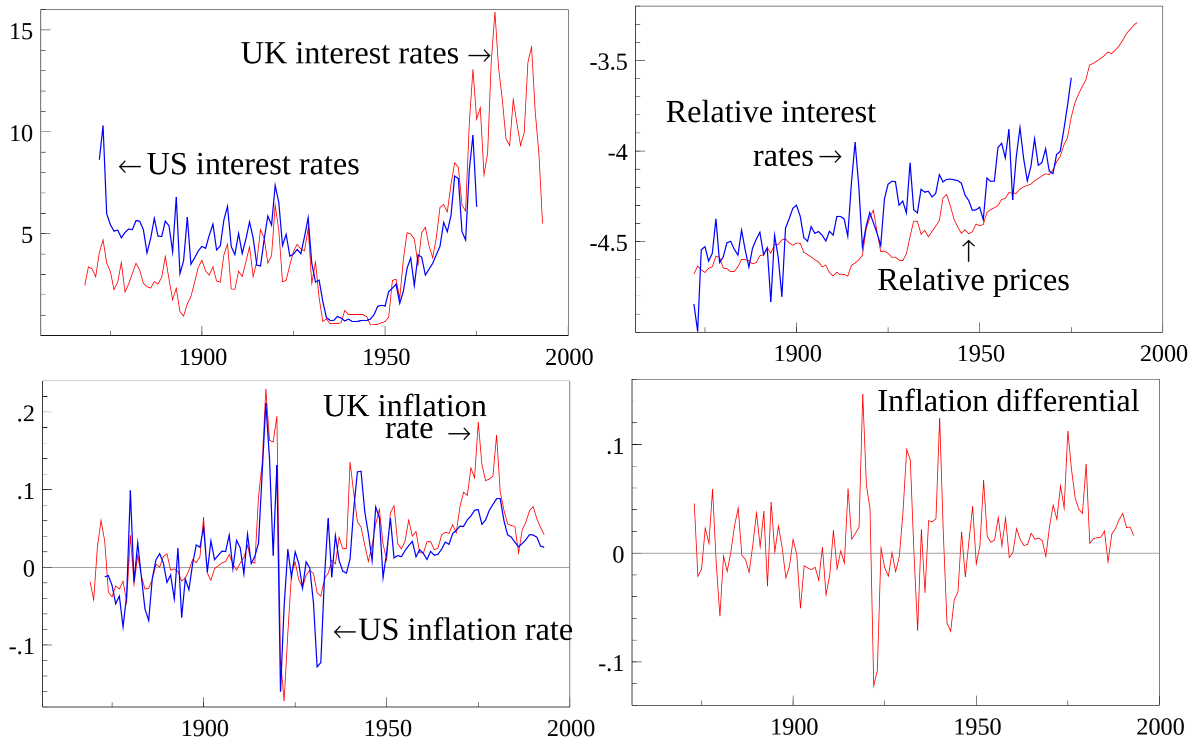

Figure 2 UK and US interest rates and inflation.

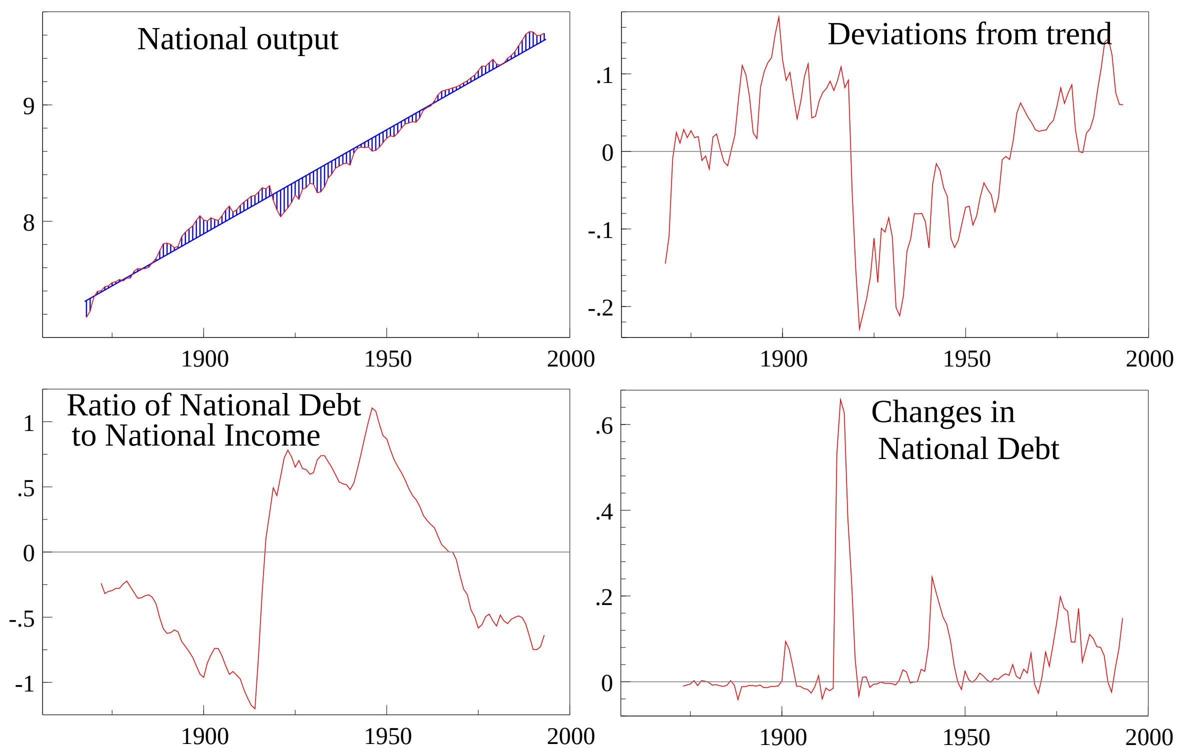

Figure 3 UK output, trend deviation and national debt.

cointegration between debt and income; the contrary evidence is the systematic and prolonged nature of the departures from constancy.

Money variables have behaved in a similar manner to debt, as fig. 4a shows for the log inverse velocity of broad money ($v = m - p - y$). There was large rise in money per unit income in the 1920s, and a fall in the 1960s returning to near the ratio of the 1870s. The main difference from debt is the large increase in money relative to income in the 1980s, associated with the financial innovation of that period, particularly the increasing level of own interest rates, and the percentage of money that earned interest. This last is a portfolio adjustment and severs any putative link of money causing inflation. Indeed, we can see from fig. 4b that the link is nowhere very strong: there was large negative inflation in the early 1920s with no corresponding drop in money growth; and large money growth in the 1980s without much inflation. The cross plot in fig. 4c confirms that the relation is neither close nor proportional (the regression line lies well below 45^o). Finally, different measures of money have behaved differently: fig. 4d contrasts broad and 'high powered' (the very narrow monetary base), where their ratio has more than doubled.

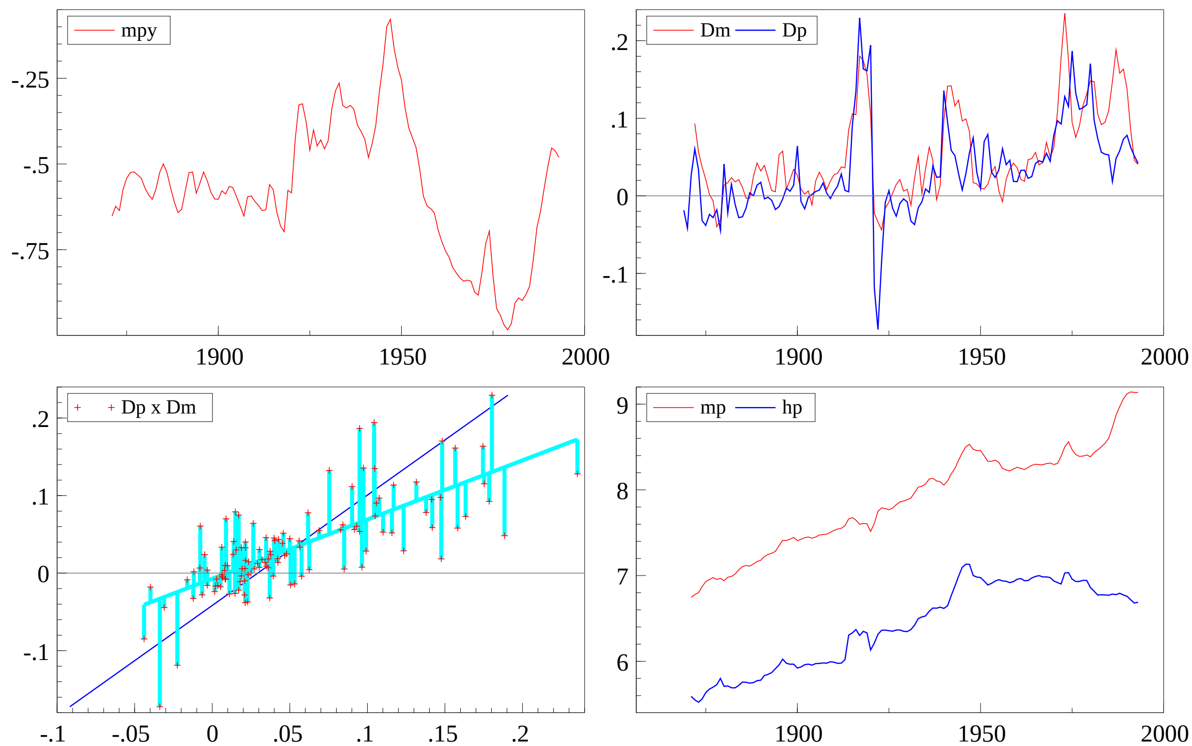

Figure 4 UK money variables.

Wages and prices have grown in line over the century as well (fig. 5a), the former faster than the latter. Thus, real wages (W/P) have risen considerably (fig. 5b), by almost 10 fold. The latter grew roughly proportionately to productivity (fig. 5c), such that productivity-adjusted real wages (the share of labour income in total income) have been more nearly constant (fig. 5d). Once more we see the possibility of cointegration, linking variables over prolonged periods during which their levels have altered hugely. We have not adjusted for participation changes, which may explain the slight trend in the variable plotted.

Taking these graphs as a group, we see that the huge variations in the levels of all the basic time series are greatly reduced by working with linear combinations of logarithms (i.e., near constant ratios).

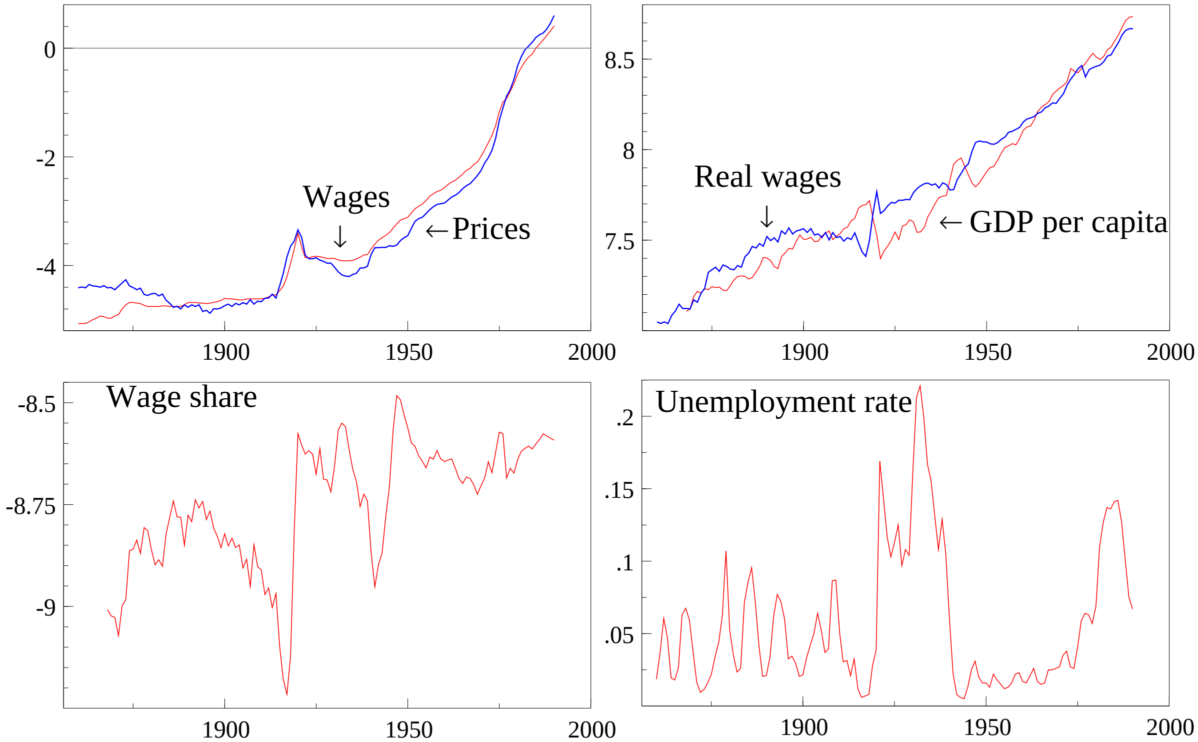

Figure 5 UK real wage and labour share.

The underlying model of inflation is based on Hendry and Ericsson (1986) who built on Frisch (1949), using recent developments in the theory of integrated-cointegrated times series (for an overview, see Banerjee *et al.*, 1993). It also draws on the approach in Johansen and Juselius (1992) and the formulation in Juselius (1992) and Metin (1995). Inflation is deemed to be the resultant of all the forces of excess demand in the various markets noted above, and the empirical evidence accords a role to most of the potential effects. In particular, the evidence explicitly excludes any single factor being the sole explanation, be it money, cost push, demand pull, devaluation or profligate governments. Instead, the deviation of output from trend, purchasing power parity, the ratios of money and national debt to income, the wage share, the unemployment rate, and both long-run and short-run interest rates all matter to some degree, as do lagged rates of change in several of the variables entering cointegration vectors. We have assumed a constant effect from each source, but in practice, the system may operate more like a steam engine, where the valve under most pressure releases first, inducing non-linear effects. Further, a number of episodes are still not explained by the model, especially the high rate of inflation in the first World War, the collapse in 1920–21, rapid inflation in 1940, and the high inflation during the two oil crises of the 1970s. Indicator, or dummy variables, are needed to remove the large residuals of these periods, and reveal that there was 5% additional inflation during 1915–1919, and 10% in 1975 and 1980.

The actual cointegration relationships used in the model are shown in fig. 6a–c, and visually these appear relatively non-trending and low variance compared to the original variables.

The approach of using cointegration to determine equilibria, with the deviations representing disequilibria that influence inflation captures many of the economic analytical ideas about inflation, as well as providing a useful data description. Moreover, it yields several policy implications. First, money was not the main cause of inflation in the 1960s and 70s, and was far from the main influence throughout the entire period. Secondly, excess demand for goods and services always played an important role, and

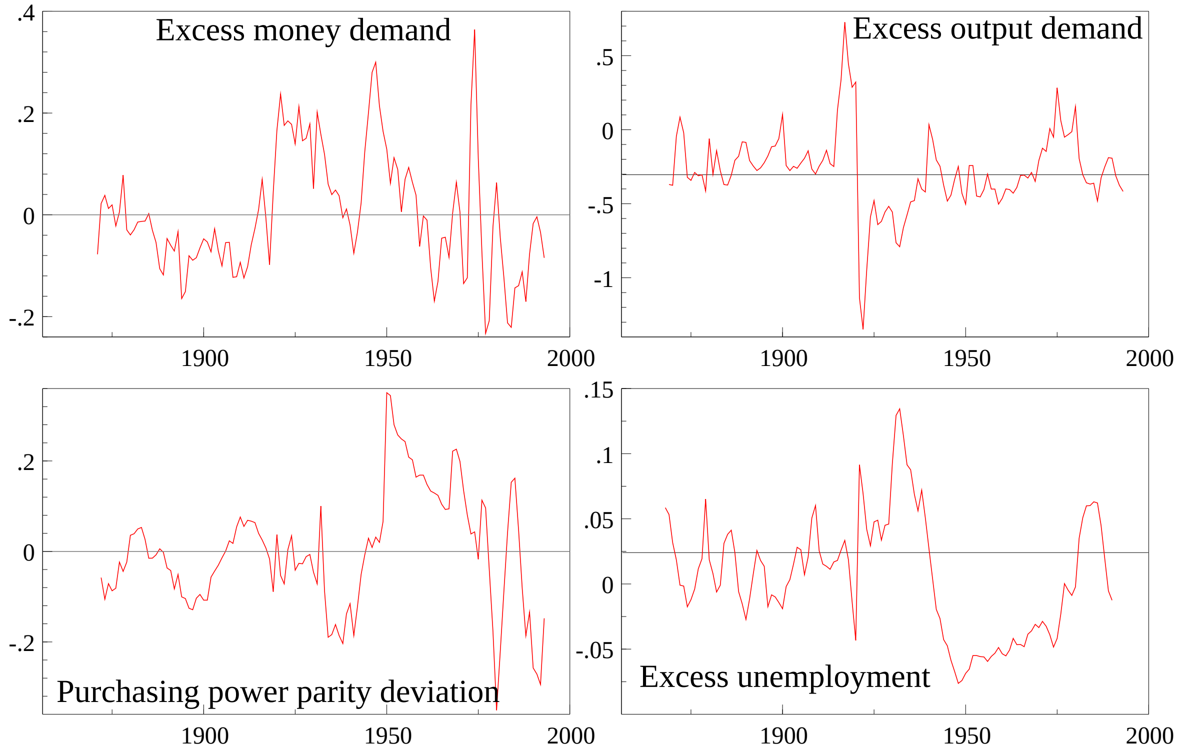

Figure 6 UK cointegration relations.

of course, leaves a major role for interest rates to dampen demand. Thirdly, the real exchange rate is also important, and suggests different implications for inflation if a devaluation helps convergence to purchasing power parity, or induces a divergence therefrom. For example, on leaving the ERM in September 1992, the resulting devaluation was sharp, but little inflation resulted as sterling was overvalued previously, and the economy was in a state of negative excess demand.

4 International dimensions

Similar analyses have been undertaken in many countries by investigators from many others. I hope you now have an intuitive grasp of cointegration, and of our efforts to distinguish sense from nonsense in the welter of high correlations that growing economies generate. We have seen a number of relations that are potentially cointegrated, and noted that the associated long-run relations have a basis in economic analysis. Moreover, new insights can be gleaned into the determinants of inflation, suggesting that policy needs care if badly wrong and costly actions are to be avoided. Positive examples include that policy succeeded when not responding to portfolio shifts in money holdings due to the introduction of interest-bearing assets, and not worrying about post ERM inflation.

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