# Modelling UK Inflation, 1875–1991

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**Abstract**

UK inflation has varied greatly in response to many economic policy and exchange-rate regime shifts, two world wars and two oil crises, as well as legislative and technological changes. Inflation is modelled as responding to excess demands from all sectors of the economy: goods and services, factors of production, money, financial assets, foreign exchange, and government deficits. Equilibrium-correction terms are developed for each of these over the sample. Indicator variables and commodity prices capture turbulent years. Variables representative of most theories of inflation matter empirically, yielding an eclectic model inconsistent with any 'single cause' explanation.

## 1 Introduction

Denis Sargan (1964, 1980) built quarterly, post-war models of UK price and wage inflation which focused on their interaction and their relation to unemployment. His findings were not only of substantive importance, the modelling methodology that Denis introduced has transformed empirical econometric research. As a contribution to his memorial volume, this paper also models UK inflation, using annual data over a century and a quarter, building on the approaches that Denis pioneered.

Inflation is a major focus of economic policy worldwide. Yet there is a plethora of theories of its determination. The approach here treats inflation as responding to excess demands from all sectors of the economy, so includes variables representative of most extant theories, namely labour costs, foreign prices, exchange rates, and interest rates, as well as excess demands for money, debt, goods, and labour. The empirical model reveals that many of these potential determinants matter, rebutting all 'single-cause' explanations. Of equal importance, some determinants do not matter empirically. Historical contingencies, primarily the major wars and oil crises, also play a substantial role in addition to the economic influences.

Section 2 discusses the data series to be analyzed, considers some important measurement issues, describes the treatment of turbulent events, and compares three alternative measures of inflation. Next, section 3 develops the empirical measures of the five main excess-demand feedback relations. Section 4 presents the model of UK inflation over 1875–1991, investigates its properties, draws some implications for economic policy, and notes the effects of deleting the individual-year indicators. Finally, section 5 concludes. All the empirical analyses and graphics use *PcGive* (see Hendry and Doornik, 1996a) and *PcGets* (see Doornik, 1998, and Hendry and Krolzig, 1999).

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# 2 Measurement issues

## 2.1 Data series

The data set is annual for the UK over 1865–1991, and was derived from a number of sources, detailed in the appendix. The main series are constant-price GDP (denoted $Y$); prices ($P$, the implicit deflator of $Y$); nominal broad money ($M$); interest rates (Treasury-bill rate $R_s$, bond rate $R_l$, and an opportunity-cost measure, $R_n$, defined in Ericsson, Hendry and Prestwich, 1998); nominal national debt ($N$); employment ($L$), unemployment ($U$) and working population ($Wpop$); real capital stock ($K$); nominal wages ($W$); normal hours ($H$); external prices ($P_e$); and a nominal effective exchange rate ($E$). Since the focus is on modelling inflation, two other price measures, namely the implicit deflator of net national income ($P_{nni}$), and a consumer price index ($P_{cpi}$) were also analyzed. Other variables are constructed from this base set. Capital letters denote the original variables, and lower-case letters the corresponding logarithms (so $y = \log Y$). The estimation sample period is usually 1875–1991 after creating lags, although the time series for $W$ and $P_{cpi}$ end in 1990.

## 2.2 Measurement errors

To merit empirical modelling, data must measure the variables of interest with reasonable accuracy. However, given the long historical period investigated here, there must be substantial errors of measurement, both conceptual and numerical, in most of these time series. Indeed, many of the relevant components were not recorded at the time. Our working assumptions are that: (a) the levels data are integrated once ($\mathsf{I}(1)$) with superimposed major breaks, so 'look' like $\mathsf{I}(2)$ series; and (b) measurements thereof have $\mathsf{I}(1)$ deviations from the desired theoretical counterparts. Consequently, inflation is treated as $\mathsf{I}(0)$ with breaks, but measured with an $\mathsf{I}(0)$ error. Such a conjecture is consistent with the effects of revisions on post-war quarterly inflation time series (see Hendry, 1995, ch.14). Mis-measurement in such non-stationary processes both induces non-constancy in derived econometric models, and suggests it may be hard to obtain cointegration (see Nowak, 1991).

Despite these difficulties, four arguments suggest it is worth modelling the available data. First, the price level has increased *sixty fold* over the sample, and annual inflation has varied from $+25\%$ to almost $-20\%$, which will swamp most $\mathsf{I}(0)$ measurement-error effects. Secondly, even in non-stationary processes, appropriate formulations can still produce constant-parameter equations (called extended constancy in Hendry, 1996): for example, a price index using time-varying weights can deliver constancy even though all its components would enter a model non-constantly. Thirdly, previous analyses of related long historical time series yielded insights into money demand (see, e.g., Ericsson *et al.*, 1998). Finally, since inflation remains a central policy concern, yet there is a multiplicity of theoretical explanations, all sources of empirical evidence need to be carefully explored. Nevertheless, the measurement caveats must be borne in mind when interpreting the reported models.

## 2.3 Turbulent periods

Notwithstanding the plethora of economic variables included here, earlier research revealed an abundance of 'outliers' (residuals larger than $3\widehat{\sigma}$ in absolute value: see Hendry, 2000). Such a finding is not surprising for a sample spanning a century and a quarter, which witnessed many policy regime shifts, two world wars and two oil crises, as well as major legislative and technological changes. Individual-year indicators were added for all the turbulent periods, namely the main wars and their after effects (1900–01, 1914–22 and 1939–46), the breakdown of Bretton Woods and the two oil crises (1970–71, 1973–75, 1979–80), as well as different intercepts pre and post 1945 (denoted $I_{2,t}$); preliminary analysis also revealed a switch of about 4% between 1880–81which otherwise induced a significant ARCH test. All indicators are zero other than in the years noted.

The following descriptive statistics summarize the impacts of the main indicators on the mean and standard deviation (SD) of $\Delta p$:

| | Unconditional | $-$War dummies | $-$Oil dummies | pre-1945 | post-1945 |
|---|---|---|---|---|---|
| Mean | $0.031$ | $0.026$ | $0.018$ | $0.000$ | $0.053$ |
| SD | $0.059$ | $0.048$ | $0.037$ | $0.022$ | $0.030$ |

Thus, mean annual UK inflation was 1.8% in the absence of war and oil-crisis effects. However, that camouflages a vast disparity pre and post 1945, as the last two columns show (both exclude turbulent years). High and persistent inflation only appears after the Second World War: including the 'oil crisis' years, the post-1945 mean and SD are 0.066 and 0.046 respectively. As a baseline for judging fit, regressing $\Delta p_t$ on all the indicators yields $\widehat{\sigma} = 2.5\%$.

Since indicators correct for both innovation and additive 'outliers', they summarize deviations unaccounted for by economic variables (see Salkever, 1976). In static models, adding an indicator is equivalent to deleting the corresponding observation, with the degrees of freedom appropriately adjusted. In dynamic models, indicators have more complicated effects (see Doornik, Hendry and Nielsen, 1998), but when economic variables really matter, their effects should not be removed by indicators. Conversely, indicators can reduce chance correlations from matching blips. However, clusters of zero residuals can distort test statistics, so the initial unrestricted indicators were combined into an overall index $I_d$ to minimize such effects (see section 4.1).

### 2.4 Measuring UK inflation

There are three time series of price indices, denoted $p$, $p_{nni}$ and $p_{cpi}$ above. The first is analyzed here, the second by Hendry (2000), and the third by Shadman-Mehta (1995). These measure different commodity bundles, and seem to have different timing (mid-year versus end-year), reflected by the main discrepancies occurring at major structural breaks, particularly the First World War and its aftermath. Nevertheless, if these three series do not mutually cointegrate, they cannot be cointegrated with the same determinants – yet most theories claim to explain 'inflation' without precisely specifying the relevant measure. Consequently, we first examine their cointegration properties.

Figure 1, panel a, records the log-price levels (adjusted to be zero in 1985), with inflation rates in panel b, and the differentials $(p - p_{nni})$ and $(p - p_{cpi})$ in panels c and d.[1] Although the levels and annual inflation rates look similar, the differentials reveal substantial departures, with means of 0.12% and 0.51%, and standard deviations of 1.3% and 2.9% respectively. It is surprising that the CPI measure increased least, given known tax changes.

In a 3-variable VAR with 4 lags, an unrestricted constant, no trend, and unrestricted indicators for each year 1914–1922 inclusive (to remove the main outliers), weak cointegration can be obtained as shown in table 1. The table reports the log-likelihoods ($\ell$), Johansen eigenvalues ($\mu$: see Johansen, 1995), trace tests (Tr($r$) for hypothesis $\mathsf{H}(r)$ of $r$ cointegrating relations), estimated cointegrating vector ($\widehat{\beta}'$) and associated feedback coefficients ($\widehat{\alpha}$: standard errors in parentheses shown when one cointegrating vector is imposed). There is at most one cointegration relation (rather than two), involving all three prices and influencing all three. However, it is fragile (e.g., adding a trend leads to the loss of cointegration).

[1]Graph panels are lettered notionally as a, b, c, ..., row by row.

**Table 1** Cointegration analysis of three price measures: 1875 to 1990.

$$\left[\begin{array}{ccccc} r & 0 & 1 & 2 & 3 \\ \ell & 1416.0 & 1430.3 & 1434.4 & 1434.5 \\ \mu & - & 0.219 & 0.067 & 0.003 \end{array}\right]$$

$$\left[\begin{array}{cccc} \mathsf{H}(r) & r=0 & r\leq 1 & r\leq 2 \\ \mathrm{Tr}(r) & 37.1^{**} & 8.4 & 0.4 \end{array}\right]$$

$$\left[\begin{array}{cccc} \widehat{\boldsymbol{\beta}}' & p & p_{nni} & p_{cpi} \\ & 1 & -1.20\ (0.03) & 0.20\ (0.04) \\ \widehat{\boldsymbol{\alpha}} & p & p_{nni} & p_{cpi} \\ & -0.63\ (0.13) & -0.44\ (0.13) & -0.45\ (0.19) \end{array}\right]$$

$^{*}$ and $^{**}$ denote significance at the 5% and 1% levels respectively.

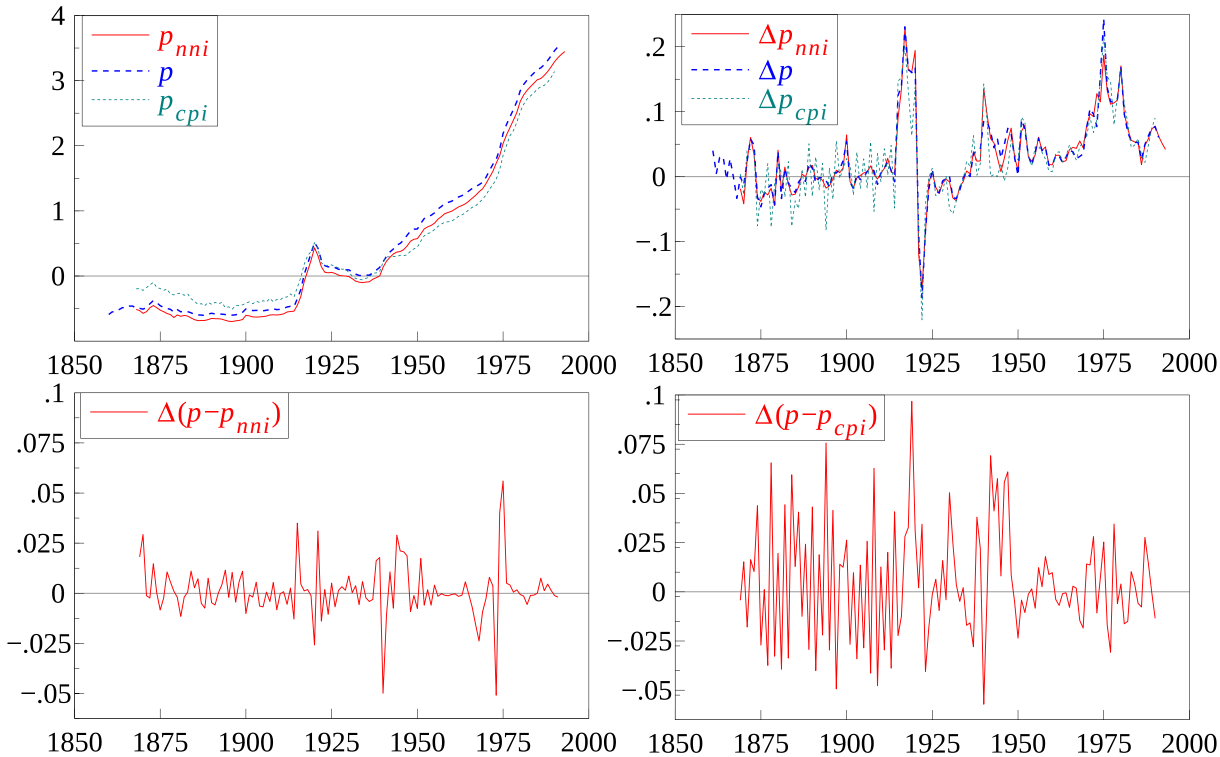


**Figure 1** Three measures of UK prices and inflation, and their differentials.

Single-equation analyses also suggest that neither $p$ and $p_{nni}$, nor $p$ and $p_{cpi}$, cointegrate with unit coefficients, based on first-order autoregressive-distributed lag relations (AD(1,1)) using the *PcGive* unit-root test $\mathrm{t}_{ur}$ (see Banerjee, Dolado and Mestre, 1998, and Ericsson and MacKinnon, 1999). Thus, the same 'single-variable' explanation of inflation could not work for all three measures, and empirical models of any one series need not be appropriate for others. Finally, the residual standard errors from this VAR provide an order-of-magnitude estimate of how well econometric equations might fit, namely, around $\widehat{\sigma} = 2.5\%$. This is similar to the value in section 2.3, and while higher than $\widehat{\sigma} = 1.7\%$ from conditional AD(1,1) equations, suggests a good fit for the model reported in section 4.1.

# 3 Feedback relations

To determine which of the many excess-demand measures is relevant empirically, all must be constructed. We first discuss the relevant theories, then the empirical measures incorporated in the inflation model.

Many UK studies treat the labour market as the primary source of inflation, either from excess demand for labour, or competition between employers and employees over the profit share. Salient UK contributions include Phillips (1958, 1962), Dicks-Mireaux and Dow (1959), Sargan (1964, 1980), Godley and Nordhaus (1972), Nickell (1990), and Layard, Nickell and Jackman (1991). The basic theory-model usually comprises equations for the markup of prices over costs (often measured by unit labour costs and import prices), wage determination, and import prices, which depend on unemployment, productivity, commodity prices, taxes, exchange rates, special factors (such as UK oil resources), and lags. The resulting policy emphasis is often associated with the 'natural rate of unemployment' (see e.g., Friedman, 1977), or the related NAIRU. In summarizing the implications for UK inflation over 1969–85, Rowlatt (1988) concluded that primary-commodity prices and import prices were the main short-run influences, whereas domestic forces had a relatively small influence, apart from the labour market. Wage-price dynamics are important in numerous studies of other economies (see, e.g., de Brouwer and Ericsson, 1998, and Banerjee and Russell, 2000, for Australia).

However, factor demands are derived from final demands, so the latter seem likely to be the direct determinants of inflation, perhaps intermediated by factor markets bidding up wages and the prices of capital goods. Even in models with price-setting firms where wage inflation is a 'cost-push' (passing on factor-cost increases in higher final-goods prices: see Dicks-Mireaux and Dow, 1959), adequate final demand is required to sustain the process. Unemployment (perhaps in relation to vacancies) is one demand measure used, but other choices include capacity utilization and measures of the output 'gap'.

We now describe the cointegration relationships potentially relevant to the UK inflation process, commencing with excess demands for goods and services; then money, interest rates and debt; world prices, exchange rates, and unit labour costs; concluding with labour-market pressures. Because of the many structural breaks over the sample period and the high dimensionality of the information set, a multivariate cointegration analysis proved infeasible. Consequently, each relation is analyzed separately, interpretable as one equation from an implicit (non-linear) VAR, sometimes conditional on contemporaneous variables (such as world prices). Related analyses involving disequilibria from several sectors include Rowlatt (1988), Surrey (1989), Juselius (1992), and Metin (1995). The specifications here also draw on earlier research reported in Hendry and Ericsson (1986), Hendry and Doornik (1996b), and Hendry (2000).

## 3.1 Excess demand for goods and services

Perhaps the most venerable theory of inflation, discussed by Hume (1758), is that excess final demands determine inflation – final-demand prices rise to 'ration' goods to those most willing to pay – although Hume also discussed impacts on factor markets. Many current models are variants thereof: see, for example, the system in McCallum (2000), where the deviation of output from its 'natural rate' and expected future inflation determine current inflation. As McCallum emphasizes, money plays no role in his system; output deviations are determined by the real interest rate and government expenditure, and the nominal interest rate by a Taylor (1993) rule.

The output 'gap' plays a central role in macroeconomic policy analysis, but being a latent variable, is hard to measure. Deviations from a linear trend become mis-leading if trend-growth changes (as pre and post World War II), whereas spline measures fail if cyclical properties alter (as in the great depression). Moreover, 'goodness-of-fit' based estimates are inappropriate when substantial and prolonged deviations occur. The present approach uses deviations from a measure of potential capacity (*cap*), allowing for secular changes in the rate of (non-embodied) technical progress.

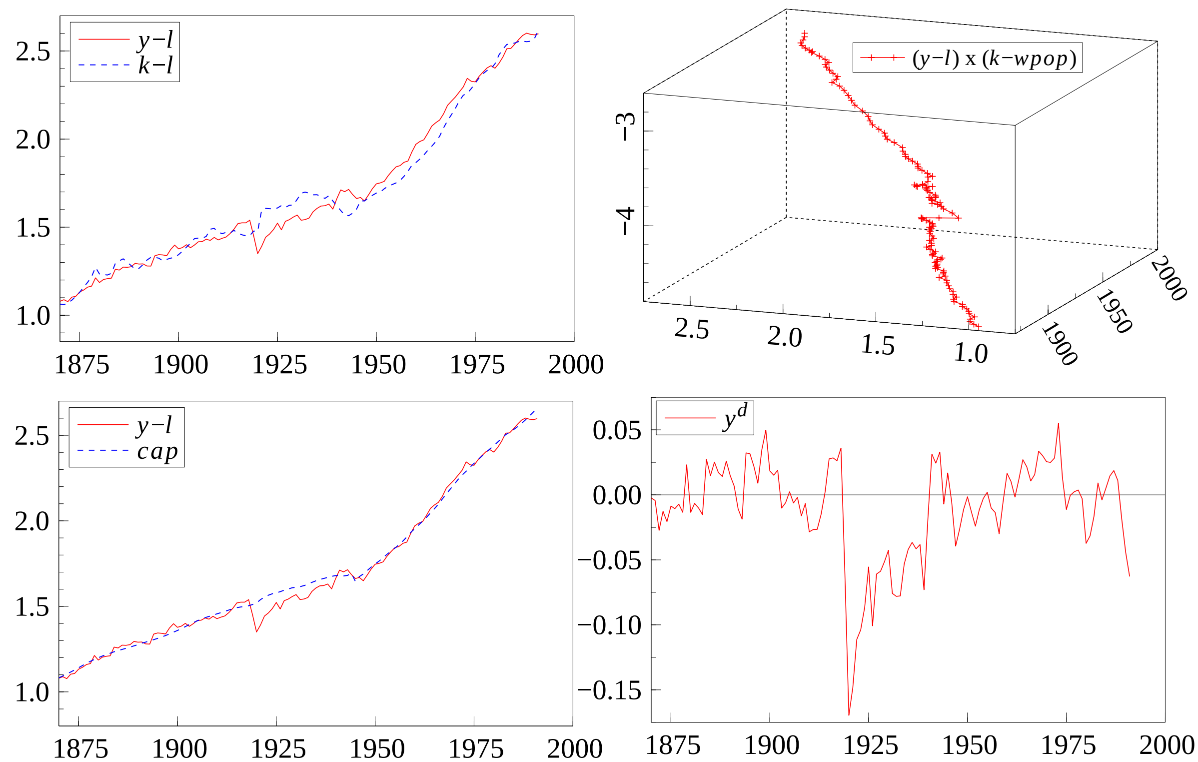


**Figure 2** Output, capital stock, capacity, and excess demand.

The time series of real GDP per worker $(y-l)$ is shown in fig. 2a, together with capital per employee $(k-l)$. Their trend rates of growth are similar, and seem to have been increasing, with a sharp fall in GDP during 1918–21. The concomitant rise in $(k-l)$ was mainly due to the jump in unemployment, so *cap* is computed using $(k-wpop)$. As the 3-D plot in fig. 2b reveals, the 'production-function' points essentially lie in a 2-dimensional subspace, so it is difficult to disentangle the impact of technical progress. Consequently, the coefficient on capital was set at 0.36 (consistent with that on unit labour costs in (4) below), and the impact of technical progress estimated by regressing $((y-l_t)-0.36\,(k_t-wpop_t))$ on a constant and linear trend, separately for the periods 1875–1918, and post-1945. The inter-war values were interpolated from the former equation, leading to:

$$cap_t \doteq \begin{cases} 2.650 + 0.0052t + 0.36\,(k_t - wpop_t) & 1870-1944 \\ 1.875 + 0.0135t + 0.36\,(k_t - wpop_t) & 1945-1991. \end{cases}$$

These relations are similar to the separate unrestricted static regressions of $(y-l)$ on $(k-wpop)$, constant and trend over 1867–1918 and 1945–1991 respectively. Figure 2c graphs $(y-l_t)$ and $cap_t$, and fig. 2d shows $y^d_t = y_t - l_t - cap_t$, which defines excess demand. The resulting 'booms and depressions' seem to match the historical record reasonably.

### 3.2 Money, interest rates and debt

A second major strand of the inflation literature emphasizes the role of money creation (see Cagan, 1956), sometimes viewing money as the 'sole and only cause of inflation' (see Friedman and Schwartz, 1982). Certainly, in the 15th–18th centuries, gold discoveries and currency debasements lowered the purchasing power of the numeraire in terms of other goods and services, so induced inflationary episodes. Under fiat money, however, causation is less clear-cut: unfunded government deficits are both a source of money creation and associated with inflation, but they induce final-demand pressures which are directly inflationary (see Metin, 1995). In models of inflation derived from the 'quantity theory', the money-demand equation is 'inverted' to solve for the price level, treating nominal money as 'exogenous' (see Friedman, 1956). Although there are technical and empirical drawbacks to this last approach (discussed in Hendry and Ericsson, 1991, Ericsson and Irons, 1994, and Hendry, 2000), it is obviously important to test the impact of excess money holdings on inflation.

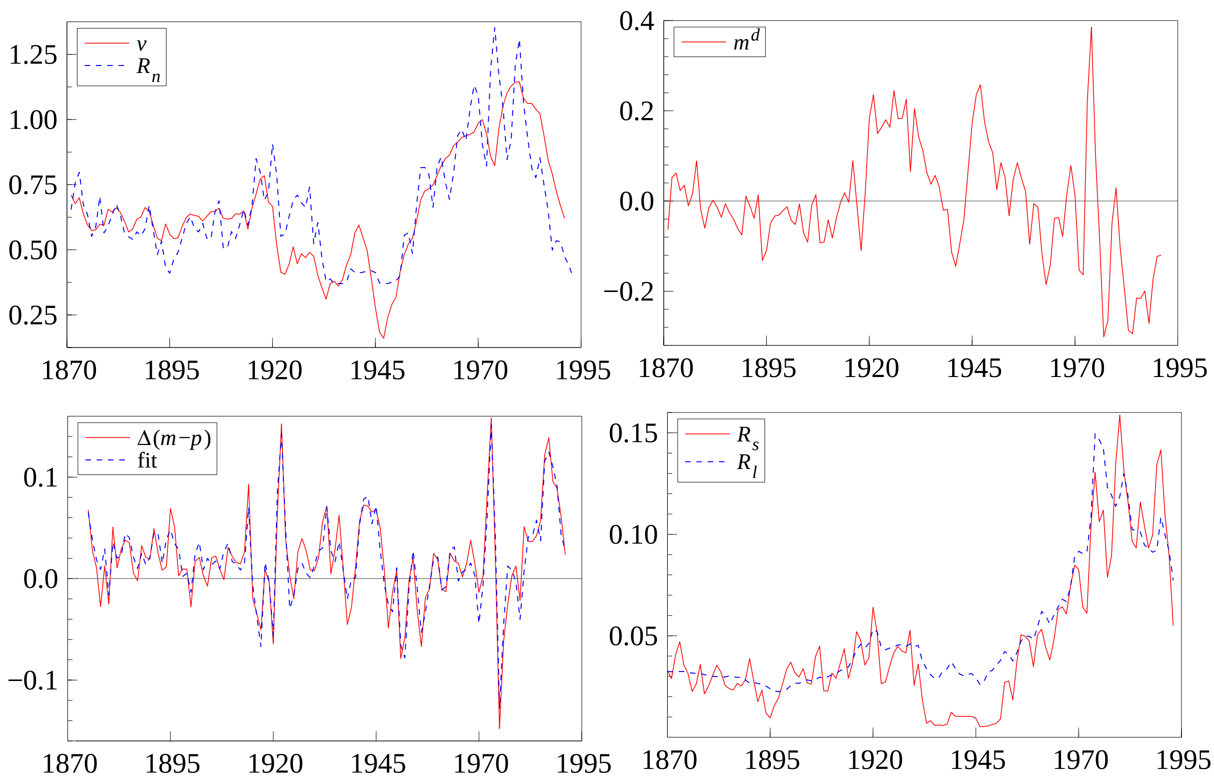


**Figure 3** Velocity, money demand, and interest rates.

Figure 3a records the log velocity of broad money ($v_t = p_t + y_t - m_t$) and the opportunity-cost measure $R_{n,t}$. Much of the observed behaviour seems to be portfolio adjustment. The cointegration relation and resulting dynamic money-demand model in Ericsson *et al.* (1998) were re-estimated using the present data set, and could be closely reproduced. An AD(2,0) delivered an excess-demand relation with $\mathrm{t}_{ur} = -4.12^{**}$ which is close to their static regression:

$$m^d = (m - p - y) + 7.3R_n + 0.38, \tag{1}$$

and is shown in fig. 3b. The dynamic model is similar to that in Ericsson *et al.* (1998), but only the linear feedback is significant with these price and income measures: fig. 3c shows the actual and fitted values.[2]

[2]Tests of whether its 'inverse' explains inflation are presented in Hendry (2000), and demonstrate that it does not.

Long-term and short-term interest rates moved together over most of the sample (see fig. 3d), with $R_{l,t}$ acting like a moving average of $R_{s,t}$. However, there is a prolonged departure from the late 1920s to the mid 1950s when $R_{s,t}$ fell to 0.5%, before both rise sharply with the epoch of high inflation. The 'short-long spread' $s_t = R_{s,t} - R_{l,t}$ shown in fig. 4a seems I(0), but heteroscedastic.

Figures 4b and c show the ratio of debt to income $(n_t - p_t - y_t)$, and the change in nominal debt respectively $(\Delta n_t)$. A dynamic model of $n_t$ was developed to derive an excess-demand relation over 1875 to 1991, leading to the solution:

$$n^d_t = n_t - p_t - y_t + 40 s_t + 0.46, \tag{2}$$

shown in fig. 4d. Here, $(n_t - p_t - y)_t$ and $s_t$ cointegrate weakly, and yield a measure of excess demand for debt that has enormous variability. Since most debt creation has been to finance wars – so non-economic considerations dominated supply – (2) seems reasonable. The greatest (non-war) excess supply appears during the mid 1970s despite a favourable spread, matching the conjunction of large peace-time deficits and high inflation.[3]

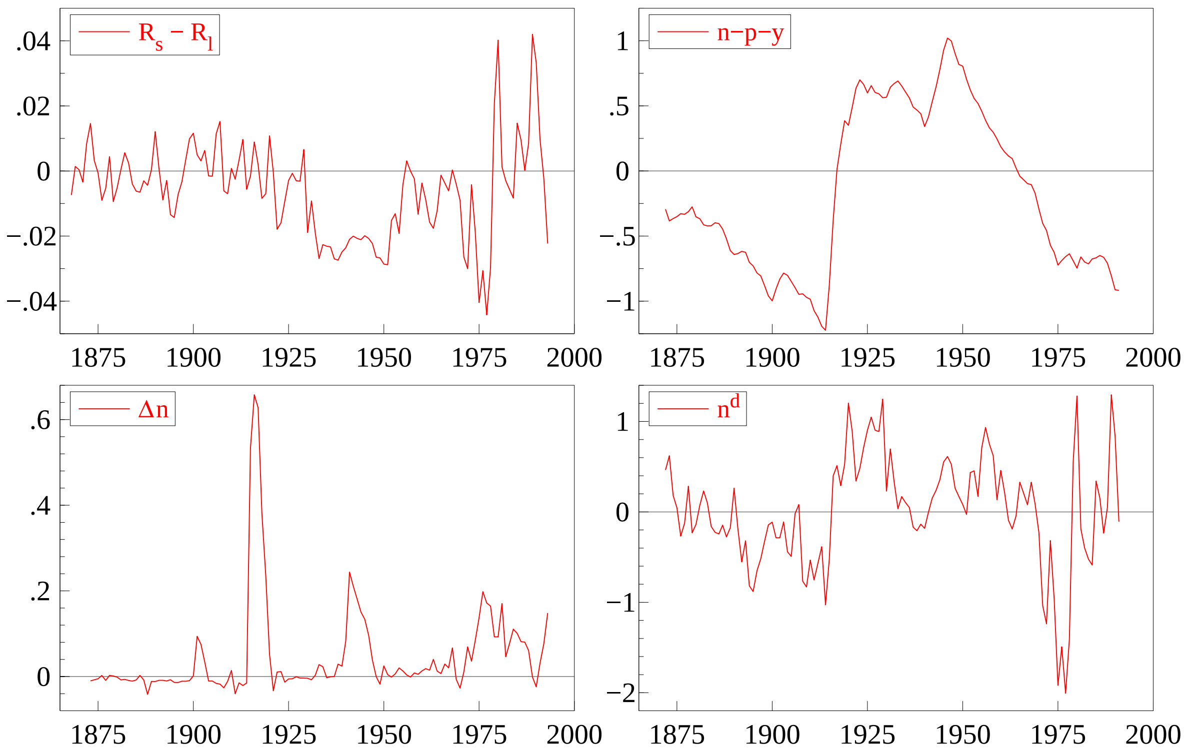


**Figure 4** Interest rate spread, National Debt, and excess demand for debt.

### 3.3 World prices and exchange rates

Purchasing-power parity (PPP) theories have existed for several centuries, as has knowledge of the inflationary consequences of devaluations, linked to notions of imported inflation ('pass-through'). Sterling's collapse is central to many explanations for the UK's inflation behaviour in the 1970s (partly summarized in Hendry, 1981).

Let $p_{£,t} = p_{e,t} - e_t$ denote world prices in sterling. Figures 5a and b respectively show the graphs for $p_t$ and $p_{£,t}$; and $\Delta p_t$ and $\Delta p_{£,t}$: the match is reasonable for levels, but relatively low for the latter

[3]Note that debt is not valued at market prices.

pair (the 'spikes' in $\Delta p_{\pounds,t}$ occur at domestic or foreign devaluations). World price inflation measured by currency-of-origin, $\Delta p_{e,t}$, and shown in fig. 5c, reveals that UK inflation was only persistently faster after the oil crises (however, a measured fall in $p_{e,t}$ of almost 5% in 1986 seems dubious). Given the different world environments, economic policies, and endowments of the UK's trading partners, the inflation track records till the mid 1970s are surprisingly similar, particularly as the UK is often viewed as 'inflation prone': presumably, the Gold Standard and Bretton Woods helped ensure such a match.

The real exchange rate (setting the sample mean to zero):

$$e_{r,t} = p_t - p_{\pounds,t} + 0.52, \qquad (3)$$

is shown in fig. 5d. At the end of the 20$^{th}$ century, $e_{r,t}$ was close to its value in 1872 – consistent with cointegration, and with some economic theories of real exchange-rate behaviour – and is I(0) as judged by a Dickey–Fuller test (Dickey and Fuller, 1979, 1981). Even so, substantial and persistent deviations are clear, going 20% above and 20% below the initial value, for prolonged periods.

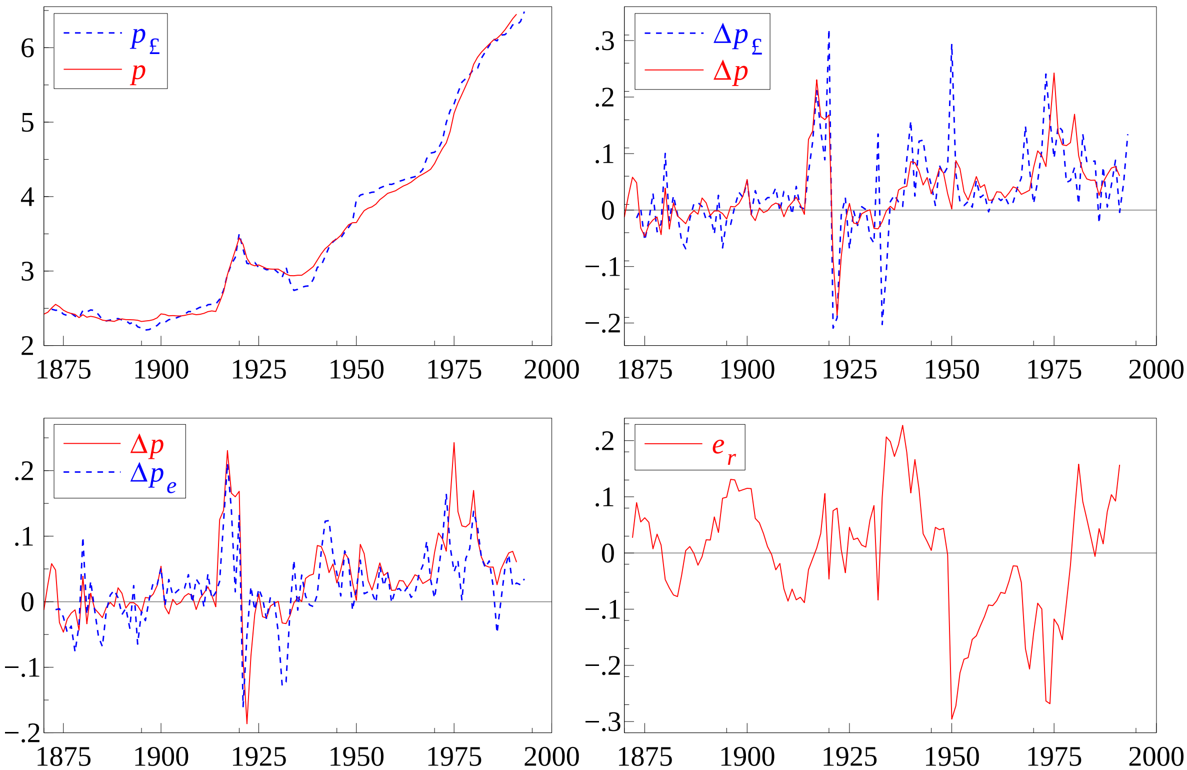


**Figure 5** UK prices with world prices in £ and domestic currencies, their inflation rates, and the real exchange rate.

### 3.4 Unit labour costs

Many theories of price determination treat firms as price setters and volume takers in imperfectly competitive goods markets (see e.g., Bårdsen, Fisher and Nymoen, 1998, who find similar results to (4) below for Norway). The markup, $\pi$, is given by:[4]

$$\pi_t = p_t - \alpha c_t - (1 - \alpha)\, p_{\pounds,t},$$

[4]Under Cobb-Douglas technology, with which section 3.1 was consistent, profit would depend on prices less a weighted average of labour and capital costs, but we currently lack data on the latter.

where $c_t = w_t + l_t - y_t$ denotes nominal unit labour costs. Figure 6a plots $c_t$ and $p_t$, and fig. 6b shows $\Delta c_t$ and $\Delta p_t$: there is a close match in both levels and differences, with $\Delta c_t$ being more volatile, particularly around major wars. Real unit labour costs, $c_t - p_t$, shown in fig. 6c, are very persistent, but seem non-integrated, as they provide a highly-significant feedback ($t_{ur} = -6.6^{**}$) in models of real wage growth (i.e., $\Delta(w_t - p_t)$). Using the weights from the production function, which are close to those of the static regression, suggests:

$$\pi_t = p_t - 0.64c_t - 0.36p_{£,t}. \tag{4}$$

Because prices are indices, there is no natural metric for measuring $\pi_t$, so the mean disequilibrium was set to zero. However, as $c_t - p_t$ was not adjusted for hours, it drifted downwards, inducing an upwards drift in $\pi_t$. The actual variable used, denoted $\pi_t^*$ and plotted in fig. 6d, is discussed in section 4.1 as it is calculated with somewhat different weights, including commodity prices, as well as being corrected for a 0.5% p.a. hours reduction (see equation (5)). Visually, $\pi_t^*$ is relatively steady, apart from sharp fluctuations around the First World War, until the plunge in the early 1970s (share prices fell 70% between 1972–74); although $\pi_t^*$ ends at a low level, it has recently recovered.

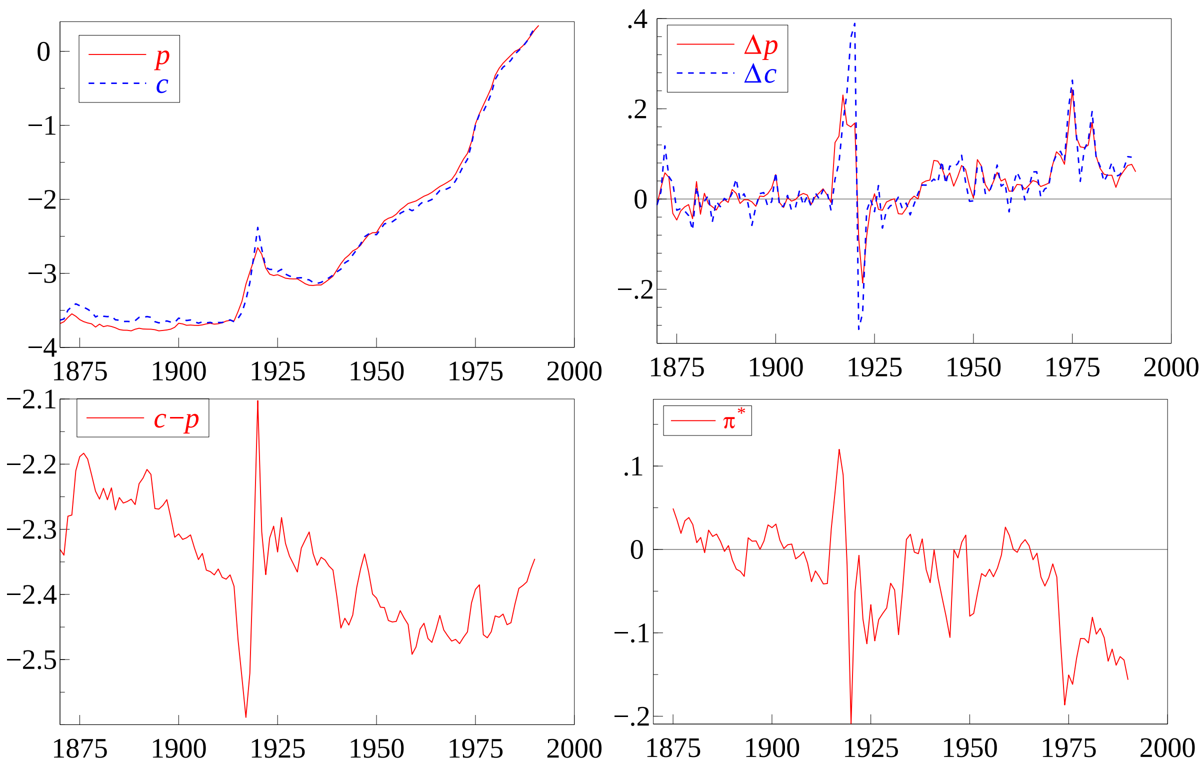


**Figure 6** UK prices with unit labour costs, their inflation rates, real unit labour costs, the markup.

### 3.5 Wages and unemployment

Nominal wages have grown much faster than prices, as shown in fig. 7a, consistent with productivity-adjusted real wages having been relatively constant (fig. 6c above). However, the model of wage inflation delivered no new feedback relations.

The unemployment rate has cycled greatly (fig. 7b), with the interwar period being a major aberration even compared to the high levels of the 1970s and early 1980s. A simple model was postulated to derive disequilibrium unemployment, based on steady-state growth theory, whereby $U_{r,t}$ rises when the real interest rate $(R_{l,t} - \Delta p_t)$ exceeds the real growth rate $(\Delta y_t)$, and falls in the opposite case. Figure 7b records the fitted values from the dynamic model[5] and fig. 7c plots $(R_{l,t} - \Delta p_t - \Delta y_t)$. Since $U_{r,t}$ and $(R_{l,t} - \Delta p_t - \Delta y_t)$ are cointegrated, the derived excess-demand for labour measure, $U_t^d$, is:

$$U_t^d = U_{r,t} - \underset{(0.01)}{0.05} - \underset{(0.24)}{0.77}\,(R_{l,t} - \Delta p_t - \Delta y_t)\,,$$

recorded in fig. 7d. Mean equilibrium unemployment is slightly above the sample mean of $4.8\%$.

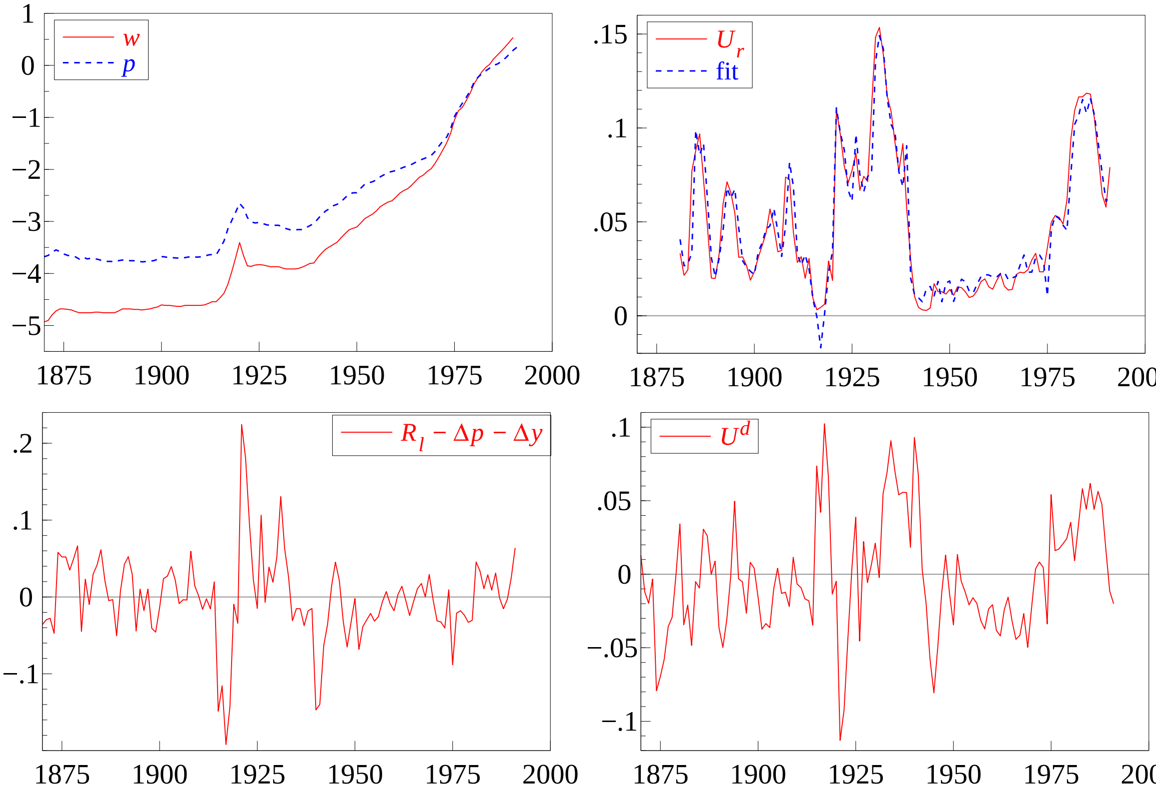


**Figure 7** Wages and prices, unemployment with fitted values, $(R_{l,t} - \Delta p_t - \Delta y_t)$, and excess demand for labour.

### 3.6 Commodity prices

Finally, commodity prices in Sterling ($p_{o,t} = p_{o\$,t} - e_t$) were added to test their direct effects, and see if they accounted for the high inflation around the oil crises. Unfortunately, the commodity price data were missing during the two world wars, so were quadratically interpolated over each period. Thus, the unrestricted indicators described in section 2.3 now play a beneficial role, correcting for any resulting measurement errors *inter alia*.

## 4 Empirical modelling of UK inflation

The initial model of $\Delta p_t$ included one lag of $y^d$, $m^d$, $n^d$, $U^d$, $e_r$, $c$, $(R_s - R_l)$, $p$, $p_o$, $R_l$, $\Delta p_{e,t}$, $\Delta p$, $\Delta U_r$, $\Delta w$, $\Delta c$, $\Delta m$, $\Delta n$, $\Delta R_s$, $\Delta R_l$, $\Delta p_o$, as well as the contemporaneous value of $\Delta p_{e,t}$, all the indicators noted in section 2.3, and a linear trend (which was demeaned).[6] Most regressors had sample means close to zero (depending on the precise period). The 1% significance level was used for both

[5] The negative fitted value in 1917 could be corrected by modelling the logit of $U_r$

[6] The markup is a linear combination of other included variables; and the non-linear adjustments $\Delta e_t e_{r,t-1}$ and $\Delta e_t e_{r,t-1}^2$ from Hendry (2000) were insignificant in the initial general model, so were excluded.

selection and diagnostic tests. The unrestricted model yielded $\widehat{\sigma} = 1.21\%$ for 52 variables (*SC* $= -7.3$: without indicators, $\widehat{\sigma} = 2.5\%$), and there were no significant mis-specification tests.

### 4.1 Model simplification

The first reduction allocated indicators to dummies for very big, large, and medium outliers (denoted $I_b$, $I_l$ and $I_m$ respectively), using data-based restrictions acceptable at the 5% level. The resulting pattern was reasonably consistent with the historical record, noting indexing of some wages to coal prices during the First World War, price controls during the Second World War, and the mid-1970's 'wage-price' freezes:

$$
\begin{aligned}
I_b &= \begin{cases} 1 & \text{for } 1915,\ 1917,\ 1919 \\ -1 & \text{for } 1921,\ 1922 \end{cases} \\
I_l &= \begin{cases} 1 & \text{for } 1916,\ 1918,\ 1920,\ 1975 \\ -1 & \text{for } 1943,\ 1945,\ 1973 \end{cases} \\
I_m &= \begin{cases} 1 & \text{for } 1880,\ 1900,\ 1939,\ 1940,\ 1970,\ 1971,\ 1980 \\ -1 & \text{for } 1881,\ 1942,\ 1944. \end{cases}
\end{aligned}
$$

That reduction yielded $\mathsf{F}_{\mathsf{red}}(25, 65) = 0.68$ (*SC* $= -8.08$). Since $I_b$, $I_l$ and $I_m$ corresponded to outliers of roughly 12%, 6% and 4%, they were combined into one overall index $I_d$ using weights of 3, 1.5, and 1. Testing that reduction yielded $\mathsf{F}_{\mathsf{red}}(2, 90) = 0.32$ (*SC* $= -8.16$): both simplified models remained congruent.

Next, the trend increase of 0.1% p.a. was interpreted as corresponding to the fall of 0.5% p.a. in normal hours (see the appendix), so was incorporated into unit labour costs $c_t$, which were converted to constant prices, denoted $(c_t - p_t)^*$. Also, $p_{o,t-1}$ was transformed to real terms; then the trend and $p_{t-1}$ could be deleted ($\mathsf{F}_{\mathsf{red}}(2, 92) = 0.47$). Variables with small t-values ($|\mathsf{t}| < 1$) were sequentially eliminated to clarify the specification. Then, $e_{r,t-1}$, $(c - p)^*_{t-1}$ and $(p_o - p)_{t-1}$ were combined to form a 'markup' $\pi^*_t$, based on (4) but incorporating real commodity prices, with weights summing to unity:

$$
\begin{aligned}
\pi^*_t &= 0.25 e_{r,t} - 0.675\,(c-p)^*_t - 0.075\,(p_o - p)_t + 0.11 I_{2,t} + 0.25 \\
&= (p_t - 0.675 c^*_t - 0.25 p_{\pounds,t} - 0.075 p_{o,t}) + 0.11 I_{2,t} + 0.25.
\end{aligned}
\tag{5}
$$

The weights differ from those suggested by the production function (0.64, 0.36, and zero in (4)), but the resulting variable is similar to the initially-calculated markup, other than the trend adjustment for hours. A static regression yielded $p_t = 0.68 c^*_t + 0.23 p_{\pounds,t} + 0.043 p_{o,t} - 0.034 I_{2,t} + 1.42$, so the weights are similar to those in (5) ($\pi^*_t$ dropped sharply in the post-war period when $I_{2,t}$ was not included, so it may capture a shift in the relative shares of labour and capital). Finally, $U^d_{t-1}$, $n^d_{t-1}$ and the intercept were dropped as insignificant at the 1% level ($\mathsf{F}_{\mathsf{red}}(6, 102) = 1.82$), yielding:

$$
\begin{aligned}
\Delta p_t = {} & \underset{(0.032)}{0.180}\, y^d_{t-1} + \underset{(0.028)}{0.187}\, \Delta m_{t-1} - \underset{(0.088)}{0.834}\, (R_{s,t-1} - R_{l,t-1} + 0.006) \\
& + \underset{(0.106)}{0.618}\, \Delta R_{s,t-1} - \underset{(0.024)}{0.186}\, \pi^*_{t-1} + \underset{(0.025)}{0.265}\, \Delta p_{e,t} \\
& + \underset{(0.002)}{0.038}\, I_{d,t} + \underset{(0.010)}{0.041}\, \Delta p_{o,t-1} + \underset{(0.027)}{0.267}\, \Delta p_{t-1}
\end{aligned}
\tag{6}
$$

$$
\mathsf{R}^2 = 0.975 \quad \widehat{\sigma} = 1.14\% \quad SC = -8.66 \quad V = 0.20 \quad J = 1.26
$$

$$\chi^2_{\mathsf{nd}}(2) = 2.67 \quad \mathsf{F}_{\mathsf{ar}}(4,104) = 0.20 \quad \mathsf{F}_{\mathsf{arch}}(2,104) = 2.14 \quad \mathsf{F}_{\mathsf{reset}}(1,107) = 0.27$$
$$\mathsf{F}_{\mathsf{het}}(18,89) = 1.03 \quad \mathsf{F}_{\mathsf{Chow}}(10,98) = 1.71 \quad \mathsf{F}_{\mathsf{red}}(42,65) = 0.72 \quad T = 1875\text{–}1991.$$

In (6), $\mathsf{R}^2$ is the squared multiple correlation, $\widehat{\sigma}$ is the residual standard deviation, coefficient standard errors are shown in parentheses, *V* and *J* are the variance-change and joint parameter-constancy tests from Hansen (1992), and *SC* is the Schwarz criterion (see Schwarz, 1978). The diagnostic tests are of the form $\mathsf{F}_{\mathsf{j}}(k, T-l)$ which denotes an approximate $\mathsf{F}$-test against the alternative hypothesis $\mathsf{j}$ for: $k^{th}$-order serial correlation ($\mathsf{F}_{\mathsf{ar}}$: see Godfrey, 1978), $k^{th}$-order autoregressive conditional heteroscedasticity ($\mathsf{F}_{\mathsf{arch}}$: see Engle, 1982), heteroscedasticity ($\mathsf{F}_{\mathsf{het}}$: see White, 1980); the RESET test ($\mathsf{F}_{\mathsf{reset}}$: see Ramsey, 1969); parameter constancy ($\mathsf{F}_{\mathsf{Chow}}$: see Chow, 1960) over $k^{th}$ periods; and a chi-square test for normality ($\chi^2_{\mathsf{nd}}(2)$: see Doornik and Hansen, 1994). The residual standard error of $1.14\%$ is close that for the model of $\Delta p_{nni,t}$ in Hendry (2000). All the diagnostic and constancy tests are insignificant in (6), also matching Hendry (2000).[7] Re-estimation of (6) using only post-1945 data delivers similar estimates (other than a smaller coefficient on $y^d_{t-1}$).

Most of the potential explanatory influences are still represented in (6), either as disequilibrium corrections or as growth rates, and will now be discussed in the same order as in section 3.

### 4.2 Model interpretation

Excess demands for goods and services have an 18% effect on inflation, so were an important source of inflation throughout. As in Hendry (2000), ‘excess money causes inflation’ receives minimal support, although broad-money growth has an impact of 19%. Excess debt had a small effect, but was insignificant at 1%. The short-long interest-rate spread has a marked impact, lowering inflation when short rates exceeded long, adjusted for the mean spread of $-0.006$. As the monetary authorities control the short rate, and the long rate is a proxy for the cost of capital, such an effect is plausible. The positive effect from the change in short rates is hard to rationalize, and would have a counterproductive effect in the initial stages of monetary policy. Unit labour costs and real exchange rates enter very significantly through the combined term $\pi^*_{t-1}$, also with a 19% effect, so higher real exchange rates reduce inflation, whereas higher unit labour costs or higher commodity prices raise it (compare Banerjee, Cockerell and Russell, 2000). World inflation affects the UK contemporaneously with a coefficient of more than a quarter, and is the most significant economic variable. Excess unemployment was only significant at 5%, but the formulation of $U^d$ seems an improvement over an earlier measure. The special-effects indicator is the most significant regressor, revealing that a substantial component of historical inflation is not accounted for by the economic variables. The coefficient of $I_{2,t}$ suggests inflation was 2.0% p.a. lower post-war than might have been anticipated from the measured feedbacks. Commodity-price changes matter in addition to any effects captured by world prices, but do not ‘explain’ all the large inflation shocks. Finally, the coefficient of a quarter on lagged inflation suggets relatively little inertia, and confirms that the equation cannot be expressed purely as a ‘surprise’ model for $\Delta^2 p_t$. The intercept was insignificant, so there is no evidence for ‘autonomous’ inflation.

Figure 8 records the fitted and actual values, the scaled residuals, their correlogram, density and histogram: the tracking is close. Next, fig. 9 plots the recursive coefficient estimates and 1-step residuals with $\pm 2$ standard errors. Most coefficients are constant, with some upward drift in that of $\Delta p_{t-1}$, and perhaps unmodelled changes around the First World War and the onset of the Great Depression. All the

[7] Although most variables are in common, re-fitting the earlier specification to the present data (using $I_b$, $I_l$ and $I_m$) yielded $\widehat{\sigma} = 1.62\%$ with few significant regressors, and some significant diagnostics, consistent with the lack of cointegration between the two price measures.

1-step and break-point constancy tests are insignificant, and 1-step forecasts over the final decade lay within ±2 forecast standard errors.

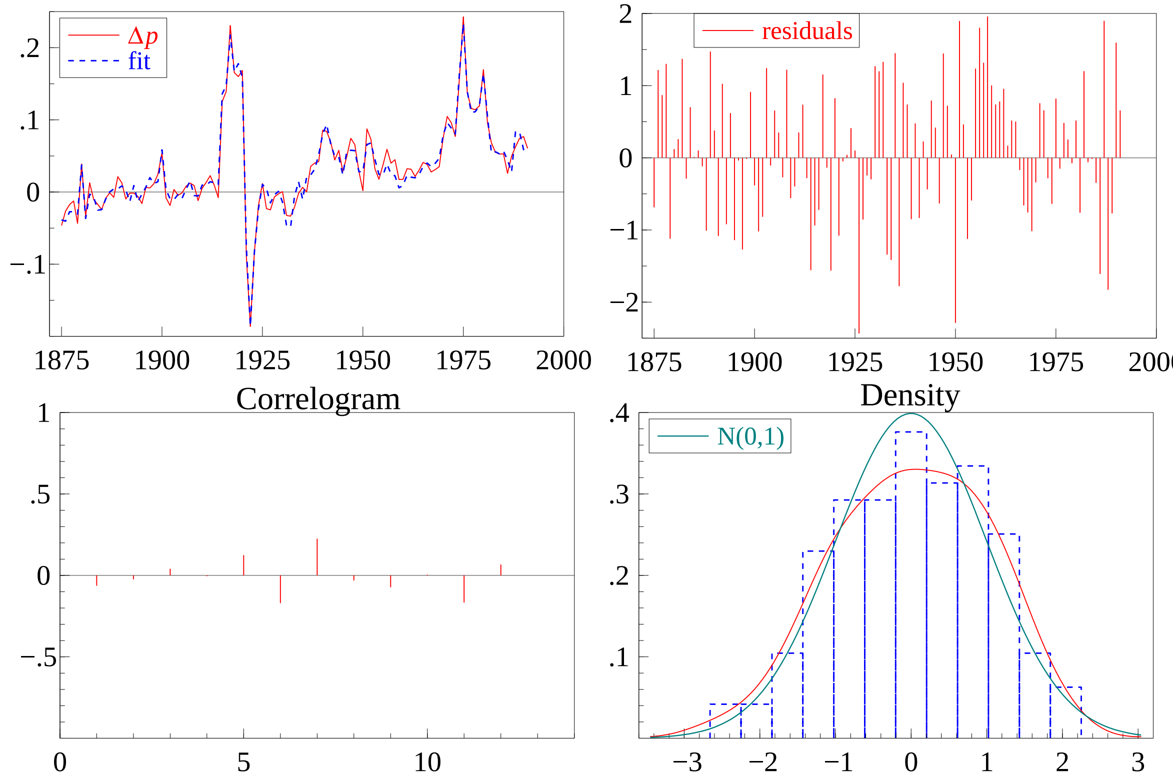


**Figure 8** Inflation model fit, residuals, their correlogram and density.

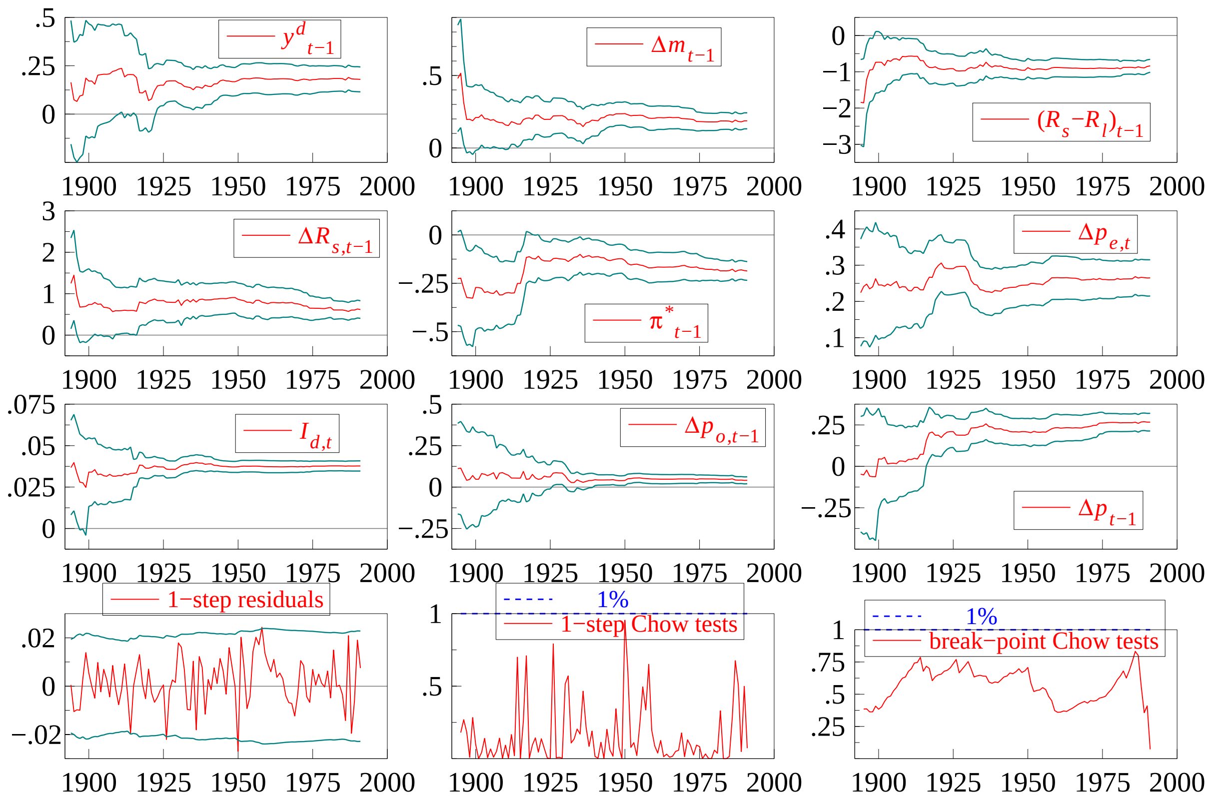


**Figure 9** Inflation model recursive coefficients with ±2SE, 1-step residuals, and constancy tests.

### 4.3 Checking the selection

Given the recent advances in computer automation of model selection (see Hoover and Perez, 1999, and Krolzig and Hendry, 2000), *PcGets* was used to check the simplification. Expressing the general model in terms of $\pi^*_{t-1}$ with the indicators restricted to $I_d$, *PcGets* also selected (6) using 1% significance levels.

### 4.4 An implicit 'Taylor rule'

To affect inflation using interest rates given (6), a government must change either the equilibrium means of the cointegration relations or the spread. An implicit 'Taylor (1993) rule' can be derived by 'solving' for the required level $R^m_s$ of $R_s$ needed to attain a given target. We do so for the function needed to achieve the present Monetary Policy Committee (MPC) steady-state target of 2.5% inflation, denoted $\dot{p}^m$, when lagged inflation is $\dot{p}$, assuming no unanticipated large shocks, so $I_d = 0$, with a benign world environment where $\dot{p}_e = \dot{p}_o = \dot{p}^m$. We also assume no recent interest-rate changes, constant real growth at $\dot{y} = \rho$ (the real rate of interest), and set $R_l = \dot{p} + \rho$, using $\dot{m} = \dot{p} + \dot{y}$ from (1). Substituting these into (6) yields:

$$0.694\dot{p}^m = 0.18y^d - 0.19\pi^* - 0.834\left(R^m_s + 0.006\right) + 1.291\dot{p} + 1.024\rho.$$

While 'inversion' of the inflation equation is invalid, it is convenient to re-normalize on $R^m_s$ which yields the approximation:

$$R^m_s \approx (\rho + \dot{p}) + 0.7\left(\dot{p} - \dot{p}^m\right) + 0.22\left(y^d - \pi^*\right), \tag{7}$$

using $(1.23\rho - 0.006) \simeq \rho$ (which holds for $\rho$ around 0.025), and rounding the coefficients of $\dot{p}$ and $\dot{p}^m$ to their common mean. Inflation remains the endogenous variable in (7), with $R^m_s$ being adjusted to set $\mathsf{E}[\dot{p}] = \dot{p}^m$, given the inflationary pressures from demand and costs. The implication of (7) is that short rates need to be adjusted above $(\rho + \dot{p})$ by 70% of excess inflation, mediated by the excess demand for goods and the markup, similar to the form of control rule derived in Johansen and Juselius (2000). For $\dot{p}^m = \rho = \dot{p} = 0.025$ and $y^d - \pi^* = 0.05$ (5% above capacity), $R^m_s \approx 0.06$, close to the rate during 2000.

### 4.5 Explaining the 'oil-crisis' inflation

To investigate the 'causal' properties of (6) in the face of oil-price shocks, we derive an alternative steady-state solution when there has been constant inflation at the rate $\dot{p}$, and real growth at $\dot{y} = \rho$, but not constraining $(\dot{p}_e, \dot{p}_o)$. Setting $\Delta R_s = 0$, and $\dot{m} = \dot{p} + \dot{y}$ as before:

$$\dot{p} \approx 0.33y^d - 0.34\pi^* + 0.48\dot{p}_e + 0.08\dot{p}_o + 0.34\rho - 1.5\left(s + 0.006\right) + 0.07I_d. \tag{8}$$

Thus, roughly one third of deviations in goods demand, the markup and real-income growth eventually affect inflation, together with almost a half of foreign-price inflation and 8% of commodity price inflation, offset by a large effect from the spread. Using (8), the main sources of the high inflation in 1974–75 following the 'oil-crisis' are:

Inflation contribution

| year | $y^d$ | $\pi^*$ | $\dot{p}_e$ | $\dot{p}_o$ | $\dot{y}$ | $s + 0.006$ | $I_d$ | $\widehat{\dot{p}}$ | $\dot{p}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1974 | 0.018 | 0.011 | 0.078 | 0.038 | 0.024 | 0.003 | 0.00 | 0.17 | 0.16 |
| 1975 | 0.004 | 0.039 | 0.032 | 0.052 | −0.005 | 0.018 | 0.105 | 0.25 | 0.24 |

While dynamic adjustments clearly matter, the match of the equilibrium outcome to the actual shown in the final column is close: external factors ($\dot{p}_e$, $\dot{p}_o$) played a major role with domestic factors relatively more important in 1975, although 10% was then unexplained. Lagged domestic inflation matters less in (6) than in Rowlatt (1988), but the main implication of an external 'trigger' is similar.

The large influence from $s$ prompts the question: could the MPC have stopped this inflation? Using (7) for the data values over 1974–75 to achieve $\dot{p}^m = 0.025$, assuming the other equilibria hold, leads to $R_s^m$ values of 21% and 27% respectively, as against the data values of 10% and 13%, and the largest observed value of 15%. These 'steady-state' calculations suggest positive real rates were needed, so the large negative real interest rates at the time may have exacerbated the inflation.[8]

### 4.6 Impact of the dummies

Dropping $I_{d,t}$ from (6) worsens the fit substantially ($\widehat{\sigma} = 2.9\%$), and the coefficient of $\pi^*_{t-1}$ falls markedly, compensated by an increase in that of $y^d_{t-1}$, but most parameter estimates remain relatively unchanged. As in Hendry (2000), the tracking is still reasonable, although the main peaks and troughs are under-predicted. When *PcGets* was used to select the best simplification from the initial model without indicators, the resulting equation had $\widehat{\sigma} = 2.5\%$. Since the model including $I_{d,t}$ had $\widehat{\sigma} = 1.12\%$, the role of the indicators is not well proxied by any variables in the data set.

## 5 Conclusions

Most theories of inflation provide part of the empirical explanation for UK inflation over the last century and a quarter. The main proximate economic determinants are the excess demand for goods and services, world price inflation, the short-long interest-rate spread, and the markup. Nominal money growth, commodity price inflation, and interest rate changes also matter, but excess money, excess debt, and excess labour demand do not. No 'single-cause' explanation is viable: in particular, neither excess money nor unemployment play a key role. Indicators are needed for many turbulent historical periods, despite commencing with an unrestricted model incorporating most theoretically-suggested factors. Since inflation is found to be I(0) but non-stationary, the price level $p_t$ ($\equiv p_{t-1} + \Delta p_t$) is essentially indeterminate over historical time, even though there is no evidence of 'autonomous' inflation.

Equation (6) is part of an interacting system which has to be understood in detail before 'deep' policy questions can be addressed. Nevertheless, applying the equilibrium solution of the model to account for the first 'oil crisis' revealed a switch between external and domestic driving forces between 1974 and 1975. And solving for the level of the short-term interest rate consistent with the present MPC target of 2.5% p.a. inflation suggested extremely high interest rates would have been necessary at the time.

As ever in empirical research, the results remain tentative, but are consistent with the basic framework that inflation is the resultant of the many excess demands and supplies in the economy.

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[8] However, it is questionable if the assumed steady-state conditions would have held.

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# 6 Appendix: Data definitions

| | | | |
|---|---|---|---|
| $Y_t$ | $=$ | real GDP, £million, 1985 prices | [6], p.836, [9]a (1993) |
| $P_t$ | $=$ | implicit deflator of GDP, (1985=1) | [6], p.836, [9]a (1993) |
| $M_t$ | $=$ | nominal broad money, £million | [1], [2] |
| $R_{s,t}$ | $=$ | three-month treasury bill rate, fraction p.a. | [1], [2] |
| $R_{l,t}$ | $=$ | long term bond interest rate, fraction p.a. | [1], [2] |
| $R_{n,t}$ | $=$ | opportunity-cost of money measure | [3] |
| $N_t$ | $=$ | nominal National Debt, £million | [8] |
| $U_t$ | $=$ | unemployment | [7], [9]c (1993) |
| $Wpop_t$ | $=$ | working population | [7], [9]c (1993) |
| $U_{r,t}$ | $=$ | $U_t/Wpop_t$ (unemployment rate, fraction) | |
| $L_t$ | $=$ | employment (= $Wpop_t - U_t$) | [4], [5] |
| $K_t$ | $=$ | Gross capital stock | [6], p.864, [9]c (1972,1979,1988,1992) |
| $W_t$ | $=$ | wages | [4], [5] |
| $H_t$ | $=$ | normal hours (from 1920) | [6], p.148, [9] |
| $P_{e,t}$ | $=$ | world prices, (1985=1) | [1], [2], [10] |
| $E_t$ | $=$ | annual-average effective exchange rate | [1], [2], [10] |
| $P_{nni,t}$ | $=$ | deflator of net national income, (base 1985) | [1], [2] |
| $P_{cpi,t}$ | $=$ | consumer price index, (1985=1) | [4], [5] |
| $P_{o\$,t}$ | $=$ | commodity price index, $ | [11] |
| $\Delta x_t$ | $=$ | $(x_t - x_{t-1})$ for any variable $x_t$ | – |
| $\Delta^2 x_t$ | $=$ | $\Delta x_t - \Delta x_{t-1}$ | – |
| $I_{rs,t}$ | $=$ | Indicator equal to unity in $19rs$ only | – |

**Sources**

[1] Friedman and Schwartz (1982); [2] Attfield, Demery and Duck (1995); [3] Ericsson *et al.* (1998); [4] Shadman-Mehta (1995) (who cites Sleeman (1981) and Thomas (1984) as sources); [5] Phillips (1958); [6] Mitchell (1988); [7] Feinstein (1972); [8] Bank of England; [9] Bean (taken from (a) *Economic Trends Annual Supplements*, (b) *Annual Abstract of Statistics*, (c) *Department of Employment Gazette* and (d) *National Income and Expenditure*, as well as other sources cited here); [10] Cameron and Muellbauer; [11] UN Statistical Yearbook.

**Notes**

Hendry and Ericsson (1991) record caveats about several of the time series in [1]–[3].

Wage index: hourly wage rates prior to 1946, then weekly wage rates afterwards, so the latter were standardized by dividing by normal hours. However, GDP is an annual flow, and the trend rate of decline of hours is about 0.5% p.a. (based on a drop from 56 to 40 between 1913 and 1990, with an additional increase in paid holidays), so unit labour costs were adjusted accordingly.

CPI: constructed from a cost of living index prior to 1947, then the retail price index.

Exchange rate: annual £/$ rate till 1954, then an annual aggregate of quarterly data on the trade-weighted effective exchange rate, spliced to the £/$ rate in 1955.

World prices: US prices till 1954, then a trade-weighted annual aggregate of quarterly data on the corresponding PPP values, from which the price data were derived and spliced to US prices in 1955.