Measuring Excess Demand and its Impact on Inflation

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December 14, 2004

Abstract

Inflation is fundamental to UK macroeconomic policy given that it is the sole target of monetary policy. However, there is no clear consensus on its determination, with a plethora of competing theories. Hendry (2001) argues that there is no single cause of inflation. This paper analyses quarterly UK inflation from 1966-2002 based on this premise. The use of a general to specific framework in which all extant theories of inflation are captured in the general unrestricted model ensures that there are no a priori restrictions on the possible determinants of inflation. Excess demand pressures play a fundamental role in the determination of inflation but they are notoriously difficult to measure and hence a detailed derivation of the output gap is undertaken as a central explanatory variable. We derive a dominant congruent model of inflation within a single equation dynamic framework that encompasses all relevant theories and is a good representation of the data.

1 Introduction

Inflation is fundamental to macroeconomic policy given that it is the sole target of monetary policy in the UK. Whilst its importance in economic policy is undisputed, there are a plethora of theories regarding its determination. We aim to develop a dominant congruent model of inflation within a dynamic single equation framework that encompasses all relevant theories of inflation. To do this we undertake an in depth analysis of excess demand pressures as they play a fundamental role in macroeconomic policy and are a key determinant of inflation. We then develop a model of quarterly UK inflation from 1966q3-2002q2 that is a good representation of the data and refutes the 'single cause' explanation of inflation.

The output gap, as a proxy for excess demand for goods and services, is widely used but is notoriously difficult to measure due to it being a latent variable. An estimate of the output gap is derived using the standard production function approach and an alternative method is proposed, modelling the production function within a dynamic framework in which total factor productivity is modelled as a random walk with drift. Furthermore, as all measures of a latent variable will contain measurement error, the output gap can be analysed within the classical signal extraction framework in which a principal components analysis can extract the signal relative to the measurement error for a range of output gap measures.

Equipped with a satisfactory measure of the output gap, a congruent model of quarterly UK inflation is developed based on excess demands from all sectors of the economy captured by equilibrium correction terms. It is clear that most extant theories of inflation play a role in its determination including unit labour costs, exchange rates, foreign prices, interest rates, money and the excess demand for goods and labour. We go on to test whether there is a generic 'business cycle' factor driving inflation but evidence is limited.

*I am indebted to David Hendry for advice and helpful suggestions and to Neil Shephard, Sonja Keller, Carlos Santos and Christopher Bowdler for insightful comments. Financial support from the Economic and Social Research Council is gratefully acknowledged.

A business cycle component does not negate the individual variables included, although it does increase explanatory power. The lack of interpretability and non-robustness to changes in the information set limit the use of a broad cyclical factor.

The structure of the paper is as follows. Section 2 discusses measurement of the output gap, proposing a dynamic production function approach and assessing the use of principal components analysis to derive a reliable estimate of excess demand. Section 3 discusses the data series to be analysed. Section 4 presents the model of quarterly UK inflation and section 5 assesses whether there is a generic business cycle component to inflation. Finally section 6 concludes.

2 Excess demand for goods and services

Excess demand for goods and services is a key determinant of inflation and the output gap, as a proxy for excess demand, plays a central role in inflation models. As the output gap is a latent variable measurement is difficult. The literature on measuring the output gap is diverse with no clear consensus on how to proceed. Methods of determining the output gap fall into 2 categories, univariate statistical procedures and more theoretical multivariate methods. The univariate statistical procedures include a linear trend or segmented linear trend, a moving average filter, a Hodrick Prescott filter, a cubic spline, a kernel smoother, a Beveridge Nelson filter, band pass filters and univariate unobserved components models. These methods essentially detrend output by smoothing through actual output to give a 'trend output' series. Multivariate methods include common factor models, structural VARs, real business cycle models and the production function method. This paper focuses on the production function approach, deriving an estimate of the output gap from a dynamic production function in which unobserved total factor productivity is modelled as a random walk with drift.

2.1 Static production function

Assuming a Cobb-Douglas technology with constant returns to scale, an elasticity of substitution equal to unity and Hicks-neutral productivity, the production function is given as:

$$y_t = A_t N_t^{\alpha} K_t^{1-\alpha}, \tag{1}$$

where N_t is labour input, K_t is capital input, A_t is total factor productivity (TFP), or the efficiency with which both capital and labour are used to produce output, and α is the elasticity of output with respect to labour $(0 < \alpha < 1)$. N_t comprises employment, L_t, and the number of paid hours worked per employee, H_t. We assume the normal number of working weeks in a year has remained relatively constant over the period. Employment is broken down into three determinants:

$$l_t = wpop_t + pr_t + er_t, \tag{2}$$

where $wpop_t$ is the population of working age, pr_t is the participation rate and er_t is the employment rate.[1] Labour input should theoretically be adjusted for labour quality and so any changes to labour quality will be picked up in the residual. l_t is recorded in figure 1, panel a, along with trend employment. H_t would be approximated by the difference between average overtime hours and average undertime hours, but as the impact of short-time is negligible hours can be calculated as:

$$h_t \approx \ln\left(\overline{H}_t\left(1 + OH_t\right)\right), \tag{3}$$

where $\overline{H}_t$ is the normal number of hours worked per week and OH_t is the number of overtime hours worked per week. $\overline{H}_t$ declined from 39 hours in 1965 to 32 hours in 2002. The implied fall in output is offset by an

[1] Lower cases represent logs.

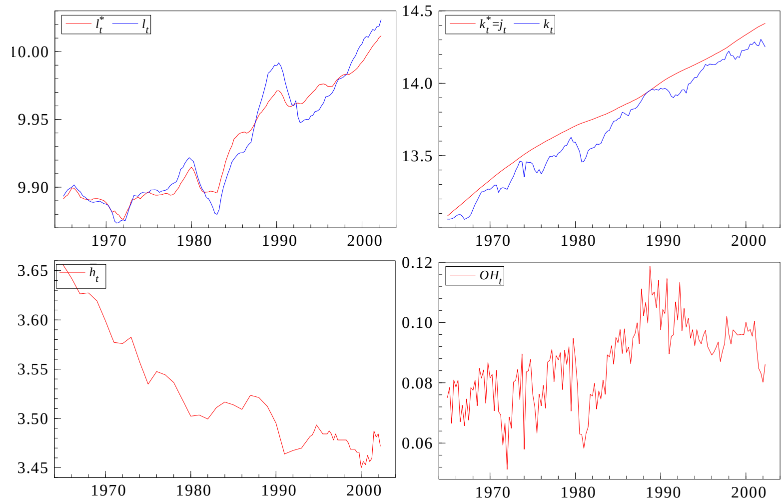

Figure 1: Employment; capital stock and utilization of capital; number of hours worked; number of overtime hours.

increase in efficiency that will be captured in A_t. Average hours are adjusted for a zero mean. h_t and OH_t are recorded in figure 1, panels c and d respectively. Muellbauer (1984) finds that data on average hours provides a good approximation to labour utilization.

Capital input, K_t, is measured by the net capital stock excluding the dwellings sector, J_t. This is a wealth measure of capital, which weights different types of capital by their asset prices. The ideal measure would be capital services, which measures the flow of productive input from capital. In order to move from this theoretical concept to the available data, an assumption that capital services are proportional to the asset value measure of capital stock must be made. There is some debate as to whether J_t should be adjusted for the degree of capacity utilization, $U_{c,t}$, but we find the utilization variable substantially reduces the procyclicality of the residual:[2]

$$k_t = j_t + U_{c,t}. \tag{4}$$

k_t and j_t are recorded in figure 1, panel b. The capacity utilization measure is constructed in the basis of a CBI survey in which firms report whether they are operating below normal capacity levels. Full capacity is assumed to use approximately 91% of the total capital stock available. The data applies to manufacturing output. As services have increased dramatically over the period of estimation and the relationship between utilization rates for manufacturing and services is ambiguous, the utilization measure may be a poor approximation. A shortage of data on capacity utilization levels in the service sector prevents a more rigorous, disaggregated measure being derived.

In order to calculate potential output, we need estimates of the latent variables, potential capital, labour and TFP (denoted by superscript *). For capital input, we assume that capital is always operating at full capacity, hence $U_{c,t} = 0$ and $k^* = j$. Even though net investment per annum is very volatile it is such a small fraction of net capital stock as to have a very limited impact on the stock of capital.

The working population is assumed to be at trend. Most movements in the working population are thought of as being long-run or permanent changes caused by, for example, a change in pensions provisions,

[2]If capital is thought of as simply being an overhead, a capacity utilization variable may not add much information. However, if respondents to the survey are referring to a much broader measure of capacity than labour inputs alone, a separate capacity measure should be included. We find enough variation between the two measures to recommend using both adjustments in the production function approach.

changes in the age of retirement or an increase in the number of women who work. There may be a small cyclical component to the working population, e.g., in the climate of a recession some members may choose to remove themselves from the working population pool by retiring early or choosing not to search for a job, but we shall assume that this effect is negligible. The trend employment rate is derived from the trend unemployment rate, which is used as a proxy for the NAIRU. This is calculated using the unobserved components (UC) method of decomposition based on a stochastic level and cycle. To estimate the trend participation rate, the total number in employment is smoothed using a Hodrick Prescott filter and the level of unemployment is derived from the trend unemployment rate. These are then divided by the actual working population to result in the potential participation rate. $\overline{H}$ is assumed to pick up long-run trends only. Any cyclical fluctuations will not be captured in $\overline{H}$ due to labour hoarding. Also, overtime hours are assumed to be 0, therefore $h_t^* = \overline{h}_t$.

The calculation of trend a_t depends on the assumptions made regarding the nature of TFP growth. The decision as to which method is appropriate for detrending a_t depends crucially on whether technical innovations are thought to be random shocks due to a burst of new ideas or whether ideas diffuse gradually as learning is slowly accumulated. One may expect productivity shocks to take their time feeding through as the learning process, along with research and development, occurs. Also, shocks that are specific to sectors are likely to only impact gradually in the aggregate. Hence, a plausible trend would be smooth but would also allow for random productivity shocks. a_t will pick up efficiency gains in the quality of capital and labour. We use a UC model to detrend a_t based on a smooth trend.

The resulting output gap is given in figure 2, panel a. The positive mean gap of 0.0002 is negligible. The 1980s recession is estimated to be a lot deeper than the 1990s recession, reaching a magnitude of 3.6% compared to 2.0% of output in the early 1990s. This may be due to the sharp drop in normal hours at the beginning of the 1990s that is unlikely to be offset by increasing productivity due to efficiency gains, causing lower potential output and reducing the size of the negative gap. Panel b records annual actual and annual trend output growth. There is some divergence at the end of sample. The rise in potential output and the corresponding fall in the gap after 2000 may be driven by the rise in normal hours, which is reversing the previous trend. Panel c records a_t and the smoothed estimate based on a UC model with fixed level and stochastic slope. The lack of cyclicality in TFP shows that the utilization rates have accounted for business cycle fluctuations. Panel d records the estimated gap against the HP gap measure and shows that whilst there is some consensus between the two measures there are periods in which the estimates diverge significantly.

2.2 Dynamic production function

The production function (PF) is a static and cointegrating concept. Hence, the standard growth accounting framework should be sufficient. However, the presence of substantial measurement errors in K, N and A imply that a stable relationship may be difficult to identify. Haavelmo (1944) highlights the problem of measurement errors by distinguishing between the latent variables identified in economic theory, their correctly measured empirical counterparts and the actual data available which contains substantial measurement error. For example, in the case of capital, theory tells us that we need a measure of the flow of capital services in the economy, whereas our data is a measure of the capital stock which contains errors due to the assumptions made about depreciation, scrapping, aggregation etc. Some method of allowance for measurement error is required. To do this we analyse the PF in a log-linear dynamic setting, which enables us to find a stable solution for potential output. This approach has the added advantage of setting the PF in the long-run context. Firms do not produce to the PF constraint on a short-run basis. The magnitude and volatility of inventories highlights this fact. In the short-run, firms tend to produce to inventory or order and then sell from these. However, in the long-run the PF constraints will bite, so a dynamic model that allows for adjustments over the short and medium term is appropriate.

The dynamic PF model is set in the single equation framework with a time varying regression intercept

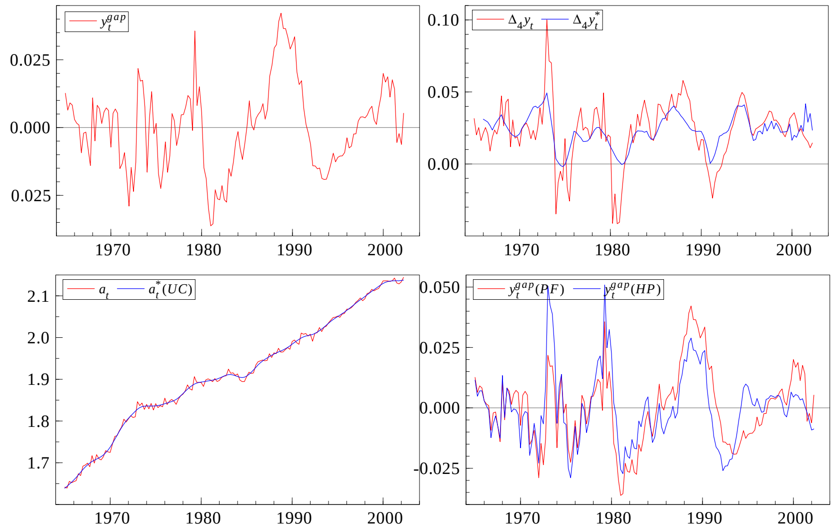

Figure 2: The static production function output gap, output growth and TFP.

that captures unobserved TFP and is augmented by I(0) cyclical factors. The long-run solution, proxying potential output, will be based on the static PF model:

$$y_t^* = \Psi_t + \gamma_1 k_t + \gamma_2 n_t, \tag{5}$$

where Ψ_t is a local level with drift intercept term capturing a_t. We assume that a single equation analysis of Δy_t is valid. This requires that n_t, and k_t are weakly exogenous for y_t. Given an ADL(1,1) model:

$$\begin{aligned} y_t &= \psi a_t + \beta_1 y_{t-1} + \beta_2 k_t + \beta_3 k_{t-1} + \beta_4 n_t + \beta_5 n_{t-1} \\ &\quad + \boldsymbol{\delta}' \,(\text{cyclical factors}) + \varepsilon_t, \qquad \varepsilon_t \sim \text{NID}\left[0, \sigma_\varepsilon^2\right] \end{aligned} \tag{6}$$

we can estimate the model in ECM form:

$$\begin{aligned} \Delta y_t &= \psi a_t + \beta_2 \Delta k_t + \beta_4 \Delta n_t + (\beta_1 - 1)\left[y_{t-1} - \kappa_1 k_{t-1} - \kappa_2 n_{t-1}\right] \\ &\quad + \delta_1 \Delta oh_{t-i} + \delta_2 \Delta U_{c,t-i} + \delta_3 \Delta invent_{t-i} + \varepsilon_t, \end{aligned} \tag{7}$$

where $\kappa_1 = \frac{\beta_2+\beta_3}{1-\beta_1}$ and $\kappa_2 = \frac{\beta_4+\beta_5}{1-\beta_1}$. The cyclical factors include the change in overtime hours, Δoh, change in capacity utilization, ΔU_c, and change in inventories, $\Delta invent$. The time varying intercept evolves according to the transition equation:

$$a_t = a_{t-1} + \mu + \eta_t, \qquad \eta_t \sim \text{NID}\left[0, \sigma_\eta^2\right] \tag{8}$$

We assume σ_ε^2 and σ_η^2 are independently distributed. The model is written in state space form and is estimated using the Kalman Filter. Equation (7) is generalized to allow for a broader dynamic structure, which is identified using a general to specific modelling strategy. The use of the time varying trend, modelled as a random walk with drift, allows for permanent shifts in TFP. This will robustify the coefficient estimates against the effects of any structural change. The time varying trend will proxy advances in human capital, including knowledge accumulation, experience and educational improvements. Human capital is captured by the process of cohort arrival and departure in the labour force. Those departing from the workforce tend

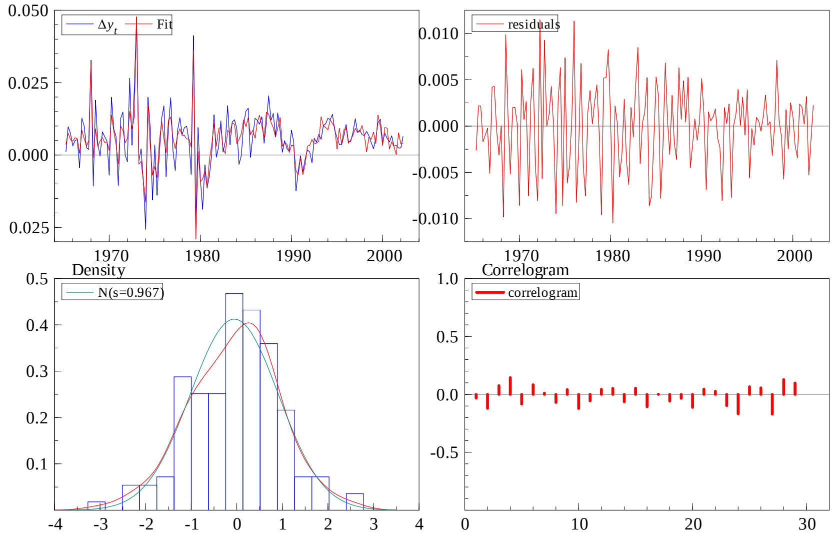

Figure 3: Actual and fitted output growth and the model diagnostics.

to be due to retirements and have a lot of experience but were educated a long time ago whereas new arrivals have a recent education but a lack of experience. Aggregating across all individuals, given that workers are at different stages in their lifecycles, implies a smooth growth in the effective labour force. Also, the effect of human capital using physical capital stock which embodies technological progress will be well captured by a random walk with positive drift.

The resulting model is given by:

$$\begin{aligned}\Delta y_t &= \underset{(1.90)}{1.103}a_t + \underset{(0.0013)}{0.002}\,\mu - \underset{(0.06)}{0.413}y_{t-1} + \underset{(0.05)}{0.098}k_{t-1} + \underset{(0.11)}{0.302}n_{t-1} \\ &\quad + \underset{(0.25)}{0.555}\Delta n_t + \underset{(0.007)}{0.031}\Delta invent_t + \underset{(0.05)}{0.156}\Delta U_{c,t} \\ &\quad + \underset{(0.006)}{0.027}I_{68:1} + \underset{(0.006)}{0.035}I_{73:1} + \underset{(0.01)}{0.027}D_{79:2} \\ LL &= 695.054,\ \widehat{\sigma} = 0.664\%,\ \chi^2_{DH}(2) = 1.347,\ Q_{BL}(11,10) = 12.088. \end{aligned} \tag{9}$$

The model represents a good fit given the simplicity of the model, with an equation standard error, $\widehat{\sigma}$, of 0.66%. The goodness of fit, R^2_d, is 0.776 and the model passes all diagnostics. $\chi^2_{DH}(2)$ is a test of normality on the residuals based on the Bowman-Shenton statistic with a correction of Doornik and Hansen (1994). The Box-Ljung statistic, $Q_{BL}(11,10)$, tests the hypothesis that the residuals are uncorrelated up to the 11th order. It is distributed as a $\chi^2(10)$ under the null. Tests for heteroskedasticity, serial correlation at the 1st and 11th lag and the Durbin-Watson test are also satisfactory. Figure 3 records the actual and fitted values along with the diagnostics.

The model has an adjustment coefficient of 0.41, implying that two fifths of the disequilibrium at $t-1$ is removed in the following quarter. The current dated adjustment in k was insignificant (up to 6 lags of Δk were included in the GUM) and so all adjustment to capital takes place in the error correction term. The adjustment term on Δn_t is large. In period t, firms will not only consider whether they were in equilibrium last period but also whether there is a change in labour input in the current period and so current decisions have a direct impact on Δy. Overtime hours are not significant. A convex investment adjustment cost was also included, $\left[\frac{a}{2}I_t^2/K_t\right]$, but was found to be insignificant. As the adjustment to equilibrium for k should be captured in the ECM this is not surprising. Other factors that may impact upon output growth in the short-run such as real interest rates and real exchange rates were included in the GUM but these were also found to be insignificant.

$D_{79:2}$ is a blip dummy taking the values 1 in 1979q2 and -1 in 1979q3 and hence integrates to an impulse dummy which does not enter into the long-run solution. With regard to the impulse dummies, $I_{68:1}$ and $I_{73:1}$, whilst they are highly significant, their coefficients are reasonably small. A simple plot of output shows the impulses not to be persistent and we conclude that the indicators are capturing one-off shocks or outliers and should not enter the long-run solution as level shifts. They are not included as blip dummies because the counteracting residuals do not occur in the immediate quarter following the positive shock but over the following year and summing the negative residuals over the following 4 quarters removes the majority of the shock. The time varying trend will capture the persistent shocks to output.

Equation (9) suggests that we can impose a restriction of constant returns to scale. Reparameterising the model results in equation (10).

$$\begin{aligned} \Delta (y-n)_t &= \underset{(0.557)}{0.975} a_t + \underset{(0.0004)}{0.001} \mu - \underset{(0.061)}{0.375} (y-n)_{t-1} + \underset{(0.049)}{0.112} (k-n)_{t-1} + \\ & +\underset{(0.007)}{0.027} \Delta invent_t + \underset{(0.053)}{0.137} \Delta U_{c,t} + \underset{(0.007)}{0.025} I_{68:1} + \underset{(0.007)}{0.030} I_{73:1} + \underset{(0.005)}{0.027} D_{79:2} \\ LL &= 682.332,\ \widehat{\sigma} = 0.70\%,\ \chi^2_{DH}(2) = 4.016,\ Q_{BL}(11,10) = 5.095. \end{aligned} \tag{10}$$

The model passes all diagnostics and the equation standard error is only marginally increased to 0.7%. By estimating the model in terms of output and capital per capita, the estimated coefficients on n_{t-1} and Δn_t become insignificant. The parameters are relatively stable when imposing the restriction and the drift of 0.1% is now significant. Figure 4, panel a records the estimated local level, proxying TFP. It clearly shows the productivity slowdown in the 1970s, the increase in the second half of the 1980s and the 'new economy' productivity increases of the late 1990s, although this does tail off considerably from 2000. TFP enters the short-run dynamic model with a near unit coefficient resulting in growth of approximately 20% over the period of estimation. Note that the long-run solution determines the total growth in TFP over the period. The q-ratio, determined as the ratio of the variance of the unobserved component to the variance of the model residuals, is 0.14. Panel b records a_t estimated from equations (9) and (10), denoted $a_t(Dyn1)$ and $a_t(Dyn2)$ respectively. Whilst both models pick up a similar trend, the drift in the unrestricted model is slightly larger, with TFP growing by approximately 26% over the period if the constant returns to scale assumption in not imposed.

The long-run solution is given as:

$$y_t^* = 0.3k_t + 0.7n_t + 2.6a_t. \tag{11}$$

Figure 4, panel c records the long-run solution, which proxies potential output, against actual output. The trend tracks actual output quite closely resulting in a small output gap, recorded in panel d. Whilst the gaps in the 1970s match those of the static PF gap, the late 1980s boom and early 1990s recession are estimated to be much smaller in the dynamic setting. The shocks in the 1970s are quite clearly attributable to short-run shocks and so are not picked up in the long-run trend, whereas the local level component estimates a slowdown in productivity between 1988 and 1992 that is not picked up in the residual based estimation of TFP to the same extent. The static residual based estimation of TFP estimates growth of approximately 50% over the period. With a coefficient of 2.6 in the long-run solution, TFP growth is approximately 53% in the dynamic model, which is comparable. Output growth between 1965 and 2002 is approximately 130% and so TFP growth accounts for about two fifths of output growth over the period. This is difficult to compare with capital and labour as the growth rates depend on how much technical progress is captured by capital and labour. 40% does seem very plausible though, given that there have been large increases in labour participation over the period of estimation.

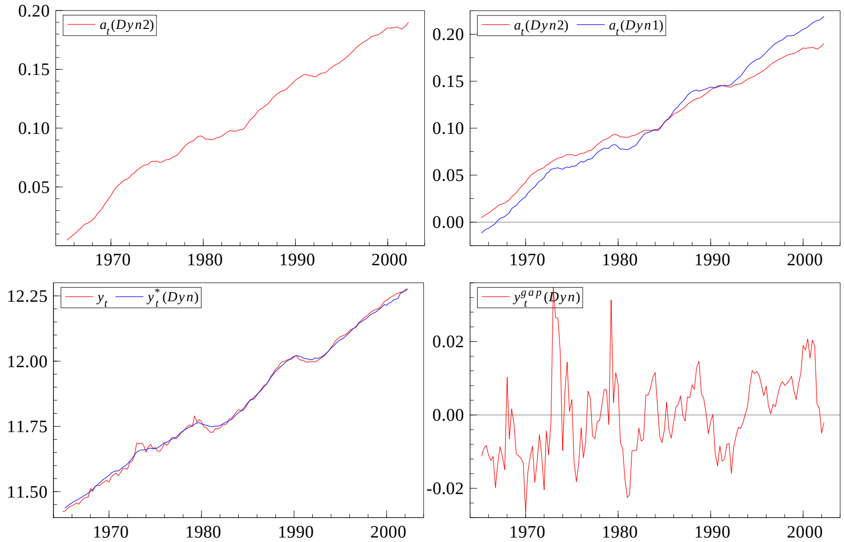

Figure 4: TFP, trend output and the output gap estimated by the dynamic model with time varying intercept.

2.3 A composite measure of excess demand

As the output gap is a latent variable and numerous estimates of the gap can be derived from various methods there is a classical signal extraction problem. For each method, the estimated output gap is a combination of the true gap plus some error:

$$\widehat{y}_{i,t}^{gap} = y_t^{gap} + e_{i,t}, \quad e_{i,t} \sim \mathrm{N}(0, \sigma_{e_i}^2). \tag{12}$$

We can use the method of principal components (PC), which essentially forms a weighted average of the individual measures, to extract the signal relative to the errors. The signal to noise ratio will be given by $\sigma_{\widehat{y}_i}^2 / \sigma_{e_i}^2$. The PC technique enables the reduction of data by finding linear combinations of the variables that contain most information. Hence, we can compile a measure of the output gap by assembling all measures of the gap into a vector and taking a linear combination with weights determined by maximizing the canonical correlations between variates. The first PC is defined as a composite measure of excess demand.

We undertake a PC analysis based on 10 output gap measures. These include a segmented linear trend (with break in 1980), the 4$^{\text{th}}$ difference filter, the Hodrick Prescott filter, a cubic spline (with bandwidth 12), the kernel smoother (with bandwidth 12), a moving average with lag of 32 adjusted for 0 mean, an unobserved components model, a measure of excess demand for goods and services based on Hendry (2001), the static production function output gap and the dynamic production function output gap.[3] The first PC is taken as our composite measure of the gap as this accounts for 68% of the variation. This is recorded in figure 8, panel d and is the estimate of the output gap that is used in the inflation analysis in section 4.

[3] Hendry (2001) estimates excess demand for goods and services as:

$$\begin{aligned} cap_t &= \beta_0 + \beta_1 t + \alpha\,(kpe)_t \\ y_t^{gap} &= ype_t - cap_t \end{aligned}$$

where kpe = capital per worker and ype = output per worker.

3 Data

The data set consists of quarterly data for the UK over 1965q1-2002q2 and was derived from a number of sources detailed in the appendix. All data are seasonally adjusted and lower cases represent logarithms. The difference operator, Δ_i, is defined as $\left(1 - L^i\right)$ where L is the lag operator. The estimation sample extends from 1966q3-2002q2.

The order of integration of price level data has been discussed extensively in the literature. Hendry (2001) concludes that the price level is I(1) but contains deterministic shifts which give the impression that the series is I(2). Dickey-Fuller tests are rarely conclusive due to their low power and results differ across countries and time periods. However, the DF test statistics for the implicit GDP deflator suggest that the price level is I(2) and the inflation rate is I(1).[4] This implies that we have two forms of cointegration. Firstly, the price measures cointegrate to I(1) and secondly, the I(1) cointegrating price measures drive fluctuations in the inflation rate, yielding a polynomially cointegrating relation. This will give a long-run solution for the price level and a long-run solution for the inflation rate based on relative prices. Whilst the model is estimated in I(1) space, I(0) demand side variables drive the short-run fluctuations. Note that many studies examine the consumer price deflator or the net national income deflator as opposed to the GDP deflator. Hendry (2001) finds that these series do not mutually cointegrate and so empirical models are specific to the price measure used.

Figure 5 records the quarterly growth rates of ppi, wpi, $import$ and c^* in panels a to d respectively. Δppi follows price inflation fairly closely but both $\Delta import$ and Δwpi are much more volatile than inflation. Unit labour costs for the whole economy, c, are scaled for the gradual decline in the average number of hours worked per week. If a more disaggregated approach were undertaken, c_t should also control for the effects of self-employment and for the slower evolvement of wage-price linkages in the public sector but data limitations prevent a disaggregated analysis.

$\Delta rent$ is recorded in figure 6, panel a. Housing market volatility has increased substantially since the late 1980s boom and subsequent recession. The extent of the oil price shocks can be captured by $(oil - p)$ in panel b (scaled for zero mean). Real unit labour costs $(c^* - p)$ are recorded in panel c and the mark-up, π^*, derived in equation (18) below, is given in panel d.

The short-long real interest rate spread, $(rrs - rrl)$, is included in the GUM as opposed to the interest rates entering independently. The short rate can be thought of as the control variable and the long rate as a proxy for the cost of capital. Hence, the spread captures the inflationary pressures arising from an increase in the cost of capital relative to the borrowing rate. As the interest rates are annual measures they are scaled to represent quarterly interest rates and are adjusted for a sample mean spread of -0.002, recorded in figure 7, panel a.

Theories of inflation based on purchasing power parity argue that in the long-run exchange rates should adjust to eliminate arbitrage opportunities and hence inflation will be imported via pass-through effects. The $reer$ is derived (setting the sample mean to zero) as:

$$reer_t = p_t - wp_t + 0.02, \qquad (13)$$

where wp_t are world prices in sterling. Figure 7, panel b records $reer$. There are substantial and persistent deviations from PPP over the period, with a range extending from +20% to -30%. Whilst $reer_t$ is judged to be I(0) over very long data sets, the ADF statistics for the period 1965q1-2002q2 find $reer$ to be I(1).

Monetary theories of inflation stem from Friedman's (1956) seminal work on the 'quantity theory' in which money is treated as exogenous, enabling the money demand equation to be inverted in order to solve for the price level. There is a vast literature looking at money causing inflation but Hendry (2000a) finds

[4] ADF test results with constant and trend: $H0 = I(1) : ADF\ \tau = -0.906$, $H0 = I(2) : ADF\ \tau = -2.884$, $H0 = I(3) : ADF\ \tau = -13.82^{**}$.

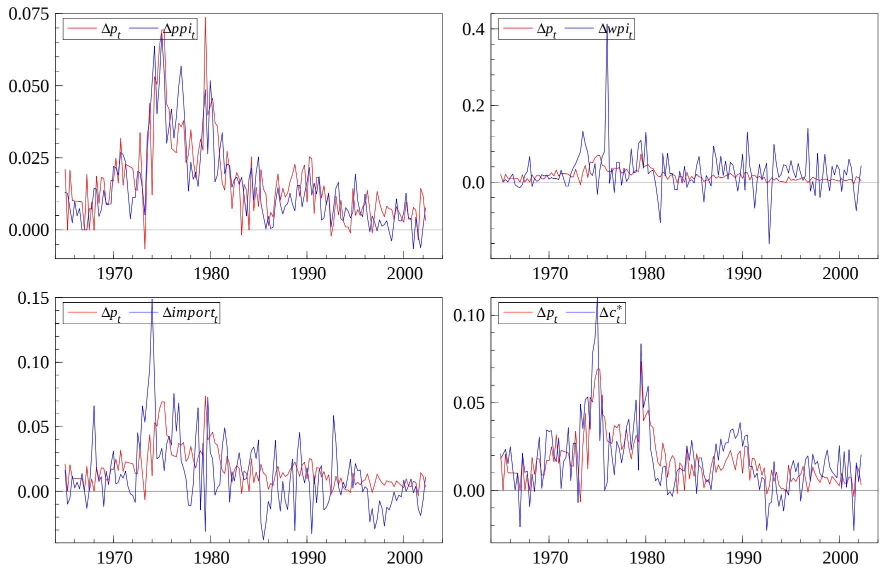

Figure 5: Quarterly growth rates of the producer price index, the wholesale price index, import prices and scaled unit labour costs.

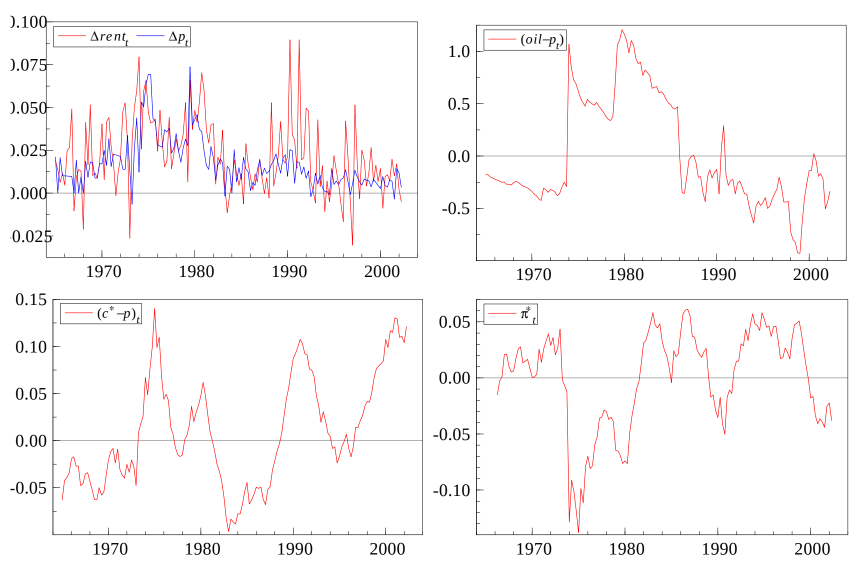

Figure 6: The growth rate of housing rent, oil minus the price level, unit labour costs minus the price level and the markup.

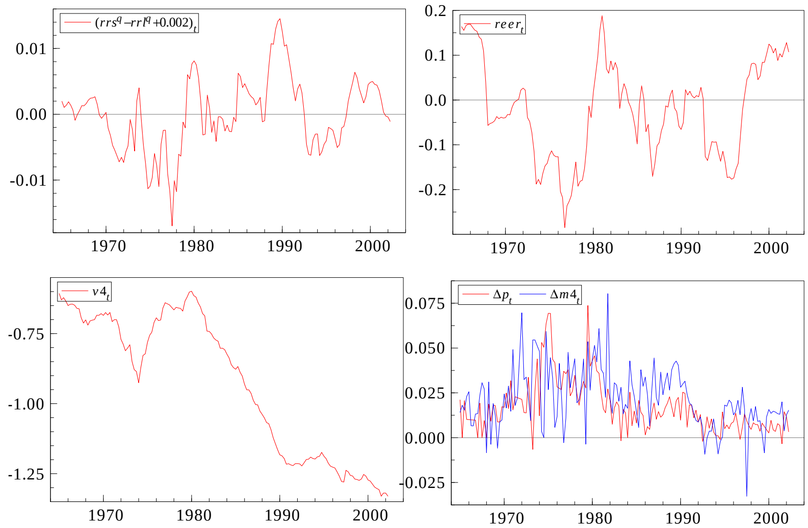

Figure 7: Interest rates, real effective exchange rate, velocity and growth of broad money.

no support for this theory. The growth rate of broad money is included in the general unrestricted model but we do not include an excess demand for money variable. Figure 7 records the velocity of broad money, $v_t = p_t + y_t - m4_t$, in panel c and $\Delta m4$ along with Δp in panel d. The velocity declines sharply over the 1980s when monetarism was operated in the UK via the Medium Term Financial Strategy. The growth rate of broad money tends to exceed price inflation over the 1980s as people transferred their holdings from narrow money to broad money due to the tightening operated.

There is a substantial literature examining the importance of labour market pressures on inflation. We use a measure of excess demand for unemployment based on Hendry (2001). In this model, unemployment rises when the real interest rate exceeds the real growth rate and vice versa. As the unemployment rate, Ur_t, is recorded as in annual units, we derive excess demand for unemployment based on an annual measure of the real interest rate and growth rate and then scale for a quarterly measure. The resulting model is given as:

$$\begin{aligned}
\Delta Ur_t &= \underset{(0.0004)}{0.001} + \underset{(0.0058)}{0.019}\,\Delta\left(Rl_t - \Delta_4 p_t - \Delta_4 y_t\right) - \underset{(0.0046)}{0.013}\,Ur_{t-1} + \underset{(0.038)}{0.872}\Delta Ur_{t-1} \\
&\quad + \underset{(0.0041)}{0.010}\,\left(Rl_{t-1} - \Delta_4 p_{t-1} - \Delta_4 y_{t-1}\right) - \underset{(0.0014)}{0.006}\,I_{71:1} + \underset{(0.0014)}{0.007}\,I_{71:2} \\
\mathsf{R}^2 &= 0.800\ \ \widehat{\sigma} = 0.132\%\ \ SC = -6.775\ \ \mathsf{F_{ar}}((5,117) = 2.453^{*} \\
\chi^2_{\mathsf{nd}}(2) &= 0.757\ \ \mathsf{F_{arch}}(4,114) = 1.515\ \ \mathsf{F_{reset}}(1,142) = 0.852 \\
\mathsf{F_{het}}(10,132) &= 1.524\ \ \mathsf{F_{Chow}}(18,125) = 0.466\ \ T = 1965q1 - 2002q2.
\end{aligned} \tag{14}$$

The model provides a reasonable fit and passes all diagnostics apart from the AR test at the 5 percent significance.[5] The dummies for the first two periods of 1971 cancel each other out and therefore do not enter into the long-run solution. The long-run solution yields an excess demand for unemployment measure given by:

$$xd(u)_t = Ur_t - 0.05 - 0.55\left(Rl_t - \Delta_4 p_t - \Delta_4 y_t\right). \tag{15}$$

[5] Coefficient standard errors are shown in parentheses. R^2 is the squared multiple correlation, $\widehat{\sigma}$ is the residual standard deviation and SC is the Schwarz criterion. The diagnostic tests are of the form $\mathsf{F_j}\,(k, T-l)$ which denotes an F-test against the alternative hypothesis j for: k^{th}-order serial correlation ($\mathsf{F_{ar}}$), k^{th}-order autoregressive conditional heteroscedasticity ($\mathsf{F_{arch}}$), heteroscedasticity ($\mathsf{F_{het}}$), the RESET test ($\mathsf{F_{reset}}$) and parameter constancy over k periods ($\mathsf{F_{Chow}}$), and finally ($\chi^2_{\mathsf{nd}}\,(2)$) represents a chi-square test for normality.

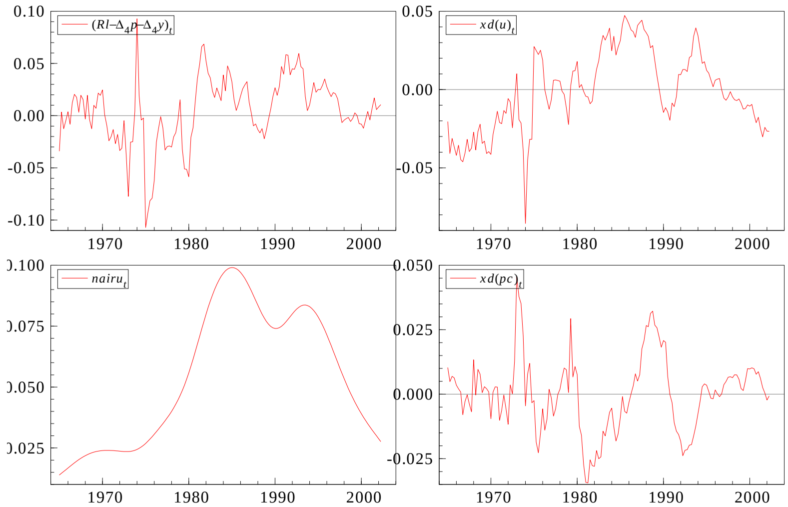

Figure 8: $(Rl_t - \Delta_4 p_t - \Delta_4 y_t)$, excess demand for unemployment, the non-accelerating inflation rate of unemployment and the output gap.

Figure 8 records excess demand for unemployment in panel b which is compared to the NAIRU derived in section 2.1, recorded in panel c. Both measures were tested in the GUM. As a proxy for excess demand for final goods, the Principal Component of the output gap computed in section 2.3 is used, recorded in panel d.

4 Empirical model of UK inflation

Hendry (2001) argues that there is no single-cause explanation of inflation. Therefore, by adopting a general to specific modelling strategy using PcGets, we can test the relevance of all possible causes of inflation. The use of the single equation framework requires weak exogeneity in the regressors. If this is not the case a VE-qCM framework should be used where all variables are modelled explicitly, capturing the variety of channels through which correction to the long-run equilibrium takes place. However, the single equation framework tends to be more robust and enables a broader analysis and so we concentrate on this methodology.

The model of inflation is based on a mark-up model, with excess demand pressures causing short-run cyclical movements in inflation whilst the long-run price level is determined by sectoral price levels including producer prices (ppi), import prices $(import)$, housing rent $(rent)$, wholesale prices (wpi), unit labour costs scaled for the decline in average hours (c^*), oil prices (oil), and national debt (nd). The short-run pressures are captured by the output gap $(xd(pc))$, excess demand for unemployment $(xd(u))$, the growth rate of broad money, $(\Delta m4)$, the short-long real interest rate spread $(rrs - rrl)$, the real effective exchange rate $(reer)$ and asset prices $(assets)$. Some terms are excluded to avoid perfect collinearity and some isomorphic transformations are implemented to limit the parameter space. Also, all t-dated terms in the equilibrium correction model are excluded in an attempt to reduce the possibility of reverse causation bias in the results. If some of the variables were not predetermined a shock may cause a contemporaneous effect on quarterly inflation and other t-dated variables, e.g. an exchange rate shock may impact upon import prices and inflation simultaneously, biasing the results.

The general unrestricted model (GUM), estimated in ECM form, is given as:

$$\begin{aligned}
\Delta p_t &= \beta_0 + \sum_{j=1}^{J-1} \beta_{1,j}\Delta p_{t-j} + \sum_{j=1}^{J-1} \beta_{2,j}\Delta import_{t-j} + \beta_2^* \left(import_{t-J} - p_{t-J}\right) \\
&\quad + \sum_{j=1}^{J-1} \beta_{3,j}\Delta ppi_{t-j} + \beta_3^* \left(ppi_{t-J} - p_{t-J}\right) + \sum_{j=1}^{J-1} \beta_{4,j}\Delta rent_{t-j} \\
&\quad + \beta_4^* \left(rent_{t-J} - p_{t-J}\right) + \sum_{j=1}^{J-1} \beta_{5,j}\Delta wpi_{t-j} + \beta_5^* \left(wpi_{t-J} - p_{t-J}\right) \\
&\quad + \sum_{j=1}^{J-1} \beta_{6,j}\Delta c^*_{t-j} + \beta_6^* \left(c^*_{t-J} - p_{t-J}\right) + \sum_{j=1}^{J-1} \beta_{7,j}\Delta oil_{t-j} + \beta_7^* \left(oil_{t-J} - p_{t-J}\right) \\
&\quad + \sum_{j=1}^{J-1} \beta_{8,j}\Delta nd_{t-j} + \beta_8^* \left(nd_{t-J} - p_{t-J}\right) + f(XD) + \eta D + u_t \\
f(XD) &= \sum_{k=1}^{K} \gamma_{1,k} xd(pc)_{t-k} + \sum_{k=1}^{K} \gamma_{2,k} xd(u)_{t-k} + \sum_{k=1}^{K} \gamma_{3,k} reer_{t-k} \\
&\quad + \sum_{k=1}^{K} \gamma_{4,k} (rrs - rrl)_{t-k} + \sum_{k=1}^{K} \gamma_{5,k} \Delta m4_{t-k} + \sum_{k=1}^{K} \gamma_{8,k} assets_{t-k} \\
u_t &\sim \text{NID}\left(0, \sigma_u^2\right) \qquad (16)
\end{aligned}$$

4.1 Model simplification

The GUM contains 3 lags of all variables excluding t-dated terms. The model is reduced to equation (17) by eliminating variables with insignificant t-values. This was conducted in PcGets using a liberal strategy. The liberal strategy minimizes the chances of omitting relevant variables and is therefore less 'tight' than the conservative strategy which minimizes the chances of retaining irrelevant variables. Both strategies are consistent; as $T \to \infty$ the significance level tends to 0.

$$\begin{aligned}
\Delta p_t &= \underset{(0.0014)}{0.007} + \underset{(0.062)}{0.185}\Delta p_{t-2} + \underset{(0.020)}{0.092}\left(c^*_{t-1} - p_{t-1}\right) + \underset{(0.035)}{0.082}\Delta m4_{t-7} \\
&\quad + \underset{(0.0015)}{0.010}\left(oil_{t-1} - p_{t-1}\right) + \underset{(0.028)}{0.118}\Delta rent_{t-4} + \underset{(0.038)}{0.117}\Delta c^*_{t-3} + \\
&\quad + \underset{(0.040)}{0.318} xd(pc)_{t-1} - \underset{(0.037)}{0.182} xd(u)_{t-2} - \underset{(0.088)}{0.169}\left(rrs - rrl + 0.002\right)_{t-2} \\
&\quad - \underset{(0.007)}{0.016}\left(reer + 0.02\right)_{t-1} - \underset{(0.007)}{0.044} I_{73:2} + \underset{(0.0066)}{0.025} I_{79:3} \\
\mathsf{R}^2 &= 0.835 \;\; \widehat{\sigma} = 0.625\% \;\; SC = -9.795 \;\; \mathsf{F}_{\mathsf{ar}}(5, 126) = 0.664 \\
\chi^2_{\mathsf{nd}}(2) &= 0.010 \;\; \mathsf{F}_{\mathsf{arch}}(4, 123) = 1.028 \;\; \mathsf{F}_{\mathsf{reset}}(1, 130) = 1.174 \\
\mathsf{F}_{\mathsf{het}}(22, 108) &= 1.216 \;\; \mathsf{F}_{\mathsf{Chow}}(18, 113) = 0.824 \;\; T = 1966q3 - 2002q2. \qquad (17)
\end{aligned}$$

The model contains elements of most theories of inflation and passes all diagnostics. We can undertake yet another model simplification, following Hendry (2001), by forming a mark-up variable, π^*_t. This is determined by combining c^*, oil and $reer$ in an attempt to capture the mark-up of prices over costs.[6] We make the assumptions of long-run linear price homogeneity and the adjustment speeds are the same in response to c^*, oil and $reer$.

$$\begin{aligned}
\pi^*_t &= 0.016 reer_t - 0.092\left(c^* - p\right)_t - 0.010\left(oil - p\right)_t \\
&= p_t - 0.14 wp_t - 0.78 c^*_t - 0.08 oil_t. \qquad (18)
\end{aligned}$$

[6] Profit should actually be a function of capital and labour costs, as in the Cobb-Douglas technology used in Chapter 4.1, with weights summing to 1. However, data on capital costs are limited. The long bond rate was tried as a proxy for the cost of capital but the effect is already being captured in the short-long spread. Hence the weight on c^*_t exceeds the Cobb-Douglas weighting of approximately 0.7, because capital costs are not fully captured.

Unit labour costs feed through to the GDP deflator with a coefficient of 0.78, which is very similar to Nielsen and Bowdler (2003) who find a coefficient of 0.79 when import prices and unit labour costs enter the long-run solution. Bardsen, Fisher and Nymoen (1998) find a larger coefficient of 0.89 but they exclude import prices and the real exchange rate, which will bias the unit labour cost coefficient upwards. Unit labour costs are dominant in determining the price level and this is consistent with Batini, Jackson and Nickell (2000), who find that the labour share (represented by c) is an important leading indicator of UK inflation. The mark-up is adjusted for a zero mean.[7]

Imposing this restriction yielded $F_{Reduct}(2, 131) = 4.35^*$ which is marginally significant. However, the restriction does not impact upon the coefficients substantially as they do not change by more than 1 standard error, other than $xd(u)$ which does not change by more than 2 standard errors, and so the restriction is imposed and the final model is given as:

$$\begin{aligned} \Delta p_t &= \underset{(0.0014)}{0.006} + \underset{(0.061)}{0.223}\Delta p_{t-2} + \underset{(0.028)}{0.124}\Delta rent_{t-4} + \underset{(0.038)}{0.111}\Delta c^*_{t-3} + \\ &\quad + \underset{(0.037)}{0.313} xd(pc)_{t-1} - \underset{(0.026)}{0.128} xd(u)_{t-2} - \underset{(0.022)}{0.141}\pi^*_{t-1} + \underset{(0.034)}{0.103}\Delta m4_{t-7} \\ &\quad - \underset{(0.104)}{0.256}\left(rrs - rrl + 0.002\right)_{t-2} - \underset{(0.007)}{0.045} I_{73:2} + \underset{(0.007)}{0.029} I_{79:3} \end{aligned} \tag{19}$$

$$\begin{aligned} \mathsf{R}^2 &= 0.824 \;\; \widehat{\sigma} = 0.641\% \;\; SC = -9.800 \;\; \mathsf{F}_{\mathsf{ar}}(5, 128) = 0.566 \\ \chi^2_{\mathsf{nd}}(2) &= 0.001 \;\; \mathsf{F}_{\mathsf{arch}}(4, 125) = 0.904 \;\; \mathsf{F}_{\mathsf{reset}}(1, 132) = 3.416 \\ \mathsf{F}_{\mathsf{het}}(18, 114) &= 1.257 \;\; \mathsf{F}_{\mathsf{Chow}}(118, 115) = 0.780 \;\; T = 1966q3 - 2002q2. \end{aligned} \tag{20}$$

The model represents a reasonable fit with a standard error of 0.64%, which is low in view of the turbulence in inflation over the period in question and it passes all diagnostic and constancy tests. The actual and fitted values are recorded in figure 9, along with the scaled residuals, their correlogram and the residual density. Figure 10 records the recursive coefficient estimates and the 1-step residuals with ± 2 standard errors, as well as the 1-step, break-point and forecast Chow tests. The recursive graphics exhibit some evidence of parameter instability, most notably in the spread and $\Delta m4$. As there have been a variety of monetary policy regimes over the period this is not surprising. The 1-step residuals mostly lie within the $\pm$2SE bands, although there does appear to be a slight downward bias over the period. There is some evidence of reduced forecast accuracy post 2000, which can probably be pinpointed as being due to the oil price variable. The large increase in oil prices over 1998 and 1999 has caused an overestimation of quarterly inflation. There is also a large outlier in 1979 in the 1-step Chow test, again probably due to the oil price shock as this is not reflected in an increase in $\widehat{\sigma}_t$. As the model is relatively stable over time despite many regime changes we can conclude that the implications of the Lucas critique are limited.

4.2 Model interpretation

The final model contains variables that represent most theories of inflation. The results for quarterly post-war inflation are essentially very close to those obtained by Hendry (2001) for annual inflation over the period 1875-1991, suggesting that the modelling approach used does explain inflation well. There is a small amount of inflation persistence entering through the second lag of quarterly inflation (including the first lag which is positive but insignificant gives an inertia of 25%). The limited evidence for inflation persistence refutes much of the literature, which has suggested that coefficients of the lagged dependent variable are statistically insignificant from 1. Observed inflation persistence in these models may well be due to second round effects in explanatory variables which are not modelled. There is a small but significant constant, suggesting that there is some autonomous inflation of 0.6%.

[7] As the prices are indices there is no natural metric for measuring π^*_t.

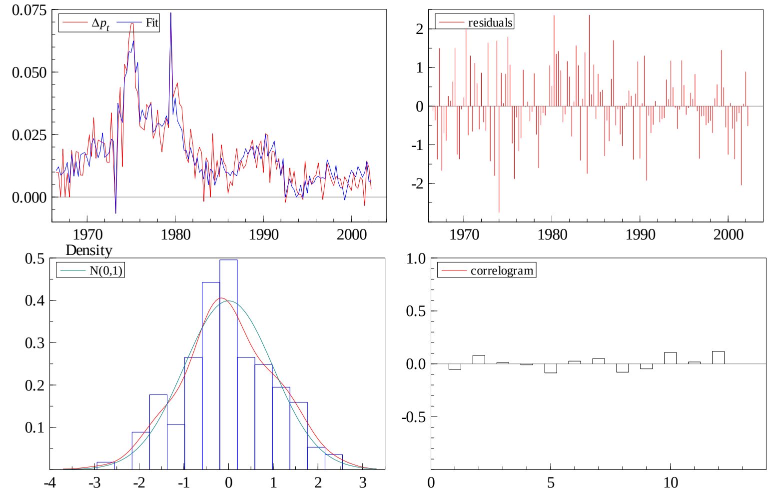

Figure 9: Fitted and actual values of quarterly inflation, the residuals, correlogram and density.

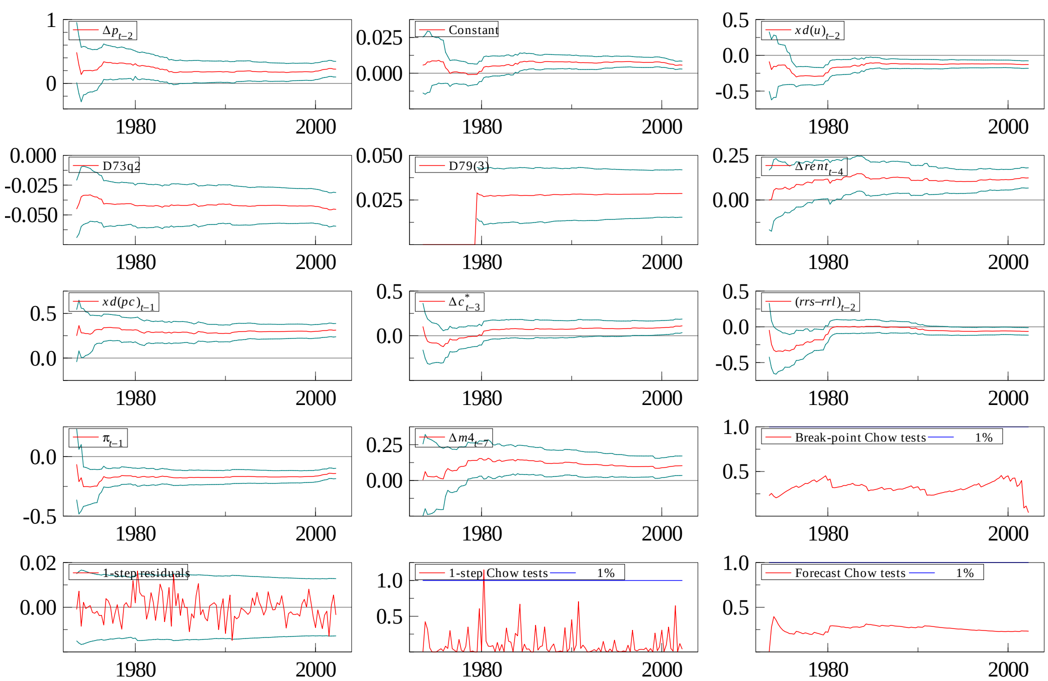

Figure 10: Inflation model recursive coefficients with ±2SE, 1-step residuals and the 1-step Chow test.

The short-long spread has a significant impact upon inflation, which is consistent with the long rate being interpreted as a proxy for the cost of capital. $\Delta m4$ enters significantly but with a long lag which is surprising. As a nominal variable it would be expected to feed though to inflation relatively quickly. However, as broad money includes not only assets used as a medium of exchange but also those used as a temporary store of value, wealth effects may take up to two years to feed through to inflation via potential purchasing power, which would be consistent with a 7 quarter lag.

$\Delta rent$ has a substantial impact of 12%. Rental payment is used as a proxy for the theoretical flow concept of the unit cost of housing. Whilst rents will not control for income effects that arise from the housing market, these will be captured in other demand side variables. The impact occurs with a four quarter lag due to indirect effects. For example, an increase in the cost of housing may reduce labour mobility, increasing wage and price inflation over a longer time horizon. Unit labour costs enter significantly via the mark-up and the growth rate. The mark-up variable is highly significant, with an effect of 14%. Hence, c^* and $reer$ are important determinants of inflation, as well as oil which is highly significant although it has a small coefficient.

Excess demand for unemployment has a significant effect of 13%. Another measure of labour market pressures is the NAIRU. Intuitively, the gap between the level of actual employment and the NAIRU should capture inflationary pressures in the economy. However, replacing $xd(u)$ with $nairu$ led to a significant but smaller impact upon inflation of 6% ($t = -2.24$) dated $t-2$. As with potential output, the NAIRU is a latent variable that is notoriously difficult to measure and hence caution should be applied to these estimates.

The output gap has a substantial effect upon inflation of over 30%, which is highly significant. Replacing the output gap measure by various other measures yields on impact of between 22% and 34%. and all measures enter significantly with 1 lag, indicating that the timing of the transmission of a shock from the gap onto inflation is captured consistently. Excess demand for goods and services is a fundamental explanatory variable for the determination of inflation.

The two impulse dummies are highly significant but with relatively small coefficients. As the impulses are not persistent but are instead capturing one-off shocks or outliers, they should not enter the long-run solution as level shifts. The negative residual in 1973q2 is a one-off outlier due to the negative inflation rate recorded in this quarter and is most likely a measurement error. The 1979q3 dummy is capturing the increase in VAT after the Thatcher election. This is unlikely to be a step increase as the impact will gradually filter through to inflation. Also, as we are modelling the GDP deflator as opposed to the expenditure deflator, we can assume that the dummy does not impact in the long-run via a level shift.

5 A 'business cycle' factor

Evidence presented in section 4 suggests that there is no single cause of inflation. Inflationary pressures arise via many different channels which can be captured in terms of excess demand or supply pressures in different markets. However, it may be argued that inflation is driven by a general business cycle factor that captures these demand and supply pressures. To examine this theory we test whether it is possible to explain inflation by a linear combination of various demand and supply side pressures which should capture all the business cycle characteristics of the data. If, on the other hand, different gap measures have differing impacts on inflation, information will be lost by looking at a general business cycle explanation of inflation as opposed to the models examined in section 4.

We estimate a composite measure of the business cycle based on PC analysis. The theoretical underpinnings lie in the decision as to which variables should be included. Stock and Watson (1998) adopt a very general approach whereby they include 216 variables in the analysis. As the main aim of our analysis is to detect a general structure in the combined variables, a much smaller subset of data is used in order to avoid cluttering with irrelevant variables that may pick up spurious correlations.

	Eigenvalues	Cumulative %
$PC1$	8.994	32.12
$PC2$	4.250	47.30
$PC3$	2.877	57.58
$PC4$	2.647	67.03
$PC5$	1.718	73.16
$PC6$	1.374	78.07
$PC7$	1.216	82.42

Table 1: Estimated eigenvalues for the first seven principal components for inflation.

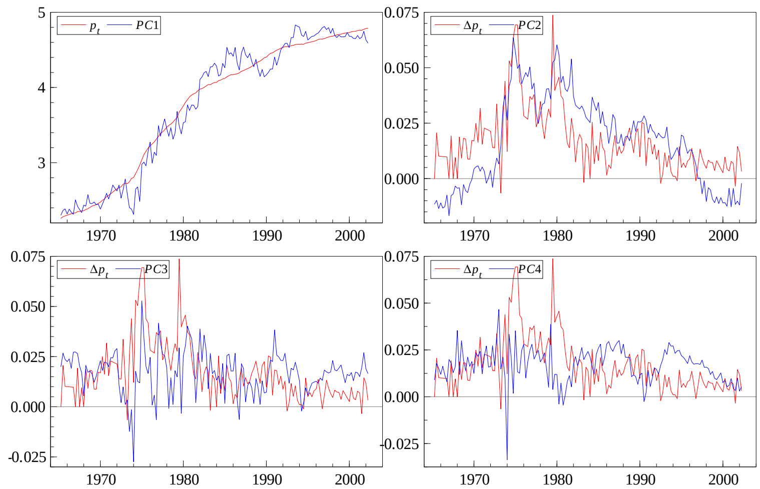

Figure 11: Leading 4 principal components for quarterly inflation.

Table 1 reports the estimated eigenvalues for the first 7 PCs based on the variables: ppi, wpi, c^*, oil, $rent$, nd, $import$, ur, Rs, Rl, $m4$, $reer$, $assets$, $xd(u)$ and $xd(pc)$. Both levels and first differences were included in order to detect trend and cycle components.[8] The variables included were scaled in order to avoid the series with the greatest amplitude in cycle exerting too much pressure on the PC. The normalized variable is given as $x_i^* = \frac{(x_i - \mu_{x_i})}{\sigma_{x_i}}$. By the Kaiser criterion 7 would be retained and the Scree test suggests that 6 or 7 components should be retained.[9]

Figure 11 records the first 4 PCs, scaled by the price level for PC1 and quarterly inflation for PC2, PC3 and PC4. The first component is picking up the trend in the price level, although it is much more volatile, the second component matches inflation reasonably well (ρ= 0.67) and the third and fourth components tend to be picking up innovations in the data.

We can estimate a model of inflation based on these business cycle factors. A general to specific modelling strategy was used and the GUM contained 4 lags of the first 7 principal components, imposing the restriction that the first component enters in differences as opposed to levels, along with lags of the depen-

[8]The first difference of both housing rent and national debt were excluded from the principal component analysis. As the levels of these variables are very smooth, the differences are small and this adversely biases the components. Also, p_{t-1} and Δp_{t-1} are excluded to avoid biasing the results.

[9]The factor loadings for the principal components are available on request.

dent variable. The resulting model is given as:

$$\begin{aligned}
\Delta p_t &= \underset{(0.0011)}{0.009} + \underset{(0.058)}{0.322}\Delta p_{t-2} + \underset{(0.119)}{2.489}\Delta PC_{1,t} + \underset{(0.350)}{2.583}\Delta PC_{1,t-1} \\
&\quad + \underset{(0.123)}{1.385}PC_{2,t} - \underset{(0.135)}{1.236}PC_{2,t-1} + \underset{(0.044)}{0.184}PC_{3,t} - \underset{(0.071)}{0.361}PC_{4,t} \\
&\quad + \underset{(0.070)}{0.234}PC_{4,t-1} + \underset{(0.070)}{0.343}PC_{4,t-2} - \underset{(0.074)}{0.278}PC_{5,t} + \underset{(0.065)}{0.432}PC_{5,t-2} \\
&\quad - \underset{(0.074)}{0.353}PC_{6,t} + \underset{(0.066)}{0.219}PC_{6,t-1} - \underset{(0.007)}{0.031}I_{73:2}. \\
\mathsf{R}^2 &= 0.828 \;\; \widehat{\sigma} = 0.642\% \;\; SC = -9.694 \;\; \mathsf{F}_{\mathsf{ar}}(5,125) = 1.703 \\
\chi^2_{\mathsf{nd}}(2) &= 8.672^* \;\; \mathsf{F}_{\mathsf{arch}}(4,122) = 0.411 \;\; \mathsf{F}_{\mathsf{reset}}(1,129) = 1.496 \\
\mathsf{F}_{\mathsf{het}}(27,102) &= 1.151 \;\; \mathsf{F}_{\mathsf{Chow}}(18,112) = 0.709 \;\; T = 1966q2 - 2002q2.
\end{aligned} \tag{21}$$

The model provides a good fit with a residual standard error of 0.642%, which is comparable to equation (20). The model does fail normality at the 5% significance level, even when the 1973q2 impulse dummy is included. Further restrictions could not be imposed. Whilst the composite measures do explain inflation well, the inability to interpret the model implies that the model is of limited value to policy-makers.

We can examine the impact of the business cycle factors by adding them into the GUM outlined in equation (16) to see if they explain inflation by negating the exogenous variables. The resulting model is given as:

$$\begin{aligned}
\Delta p_t &= \underset{(0.0009)}{0.011} + \underset{(0.026)}{0.071}\Delta rent_{t-4} + \underset{(0.032)}{0.145}\Delta c^*_{t-3} + \underset{(0.042)}{0.236}xd(pc)_{t-1} \\
&\quad - \underset{(0.026)}{0.159}xd(u)_{t-2} - \underset{(-4.64)}{0.100}\pi^*_{t-1} - \underset{(-4.53)}{0.381}(rrs^q - rrl^q + 0.002)_{t-2} \\
&\quad - \underset{(-5.63)}{0.034}I_{73:2} + \underset{(0.0061)}{0.019}I_{79:3} + \underset{(0.198)}{0.462}\Delta PC_{1,t} + \underset{(0.124)}{0.619}PC_{2,t} \\
&\quad - \underset{(0.109)}{0.358}PC_{2,t-1} + \underset{(0.035)}{0.179}PC_{3,t} + \underset{(0.045)}{0.111}PC_{5,t-1}. \\
\mathsf{R}^2 &= 0.878 \;\; \widehat{\sigma} = 0.540\% \;\; SC = -10.063 \;\; \mathsf{F}_{\mathsf{ar}}(5,125) = 0.686 \\
\chi^2_{\mathsf{nd}}(2) &= 0.244 \;\; \mathsf{F}_{\mathsf{arch}}(4,122) = 0.192 \;\; \mathsf{F}_{\mathsf{reset}}(1,129) = 1.382 \\
\mathsf{F}_{\mathsf{het}}(24,105) &= 0.789 \;\; \mathsf{F}_{\mathsf{Chow}}(18,113) = 0.843 \;\; T = 1966q3 - 2002q2.
\end{aligned} \tag{22}$$

The model passes all diagnostics and represents an improvement in fit from equation (20), with a residual standard error of 0.54% as opposed to 0.64%. Thus, the PCs are capturing important information, but not to the extent that they can represent inflation alone. The lagged dependent variable is insignificant, suggesting that there is no inflation persistence but that any observed persistence is actually proxying the long-run determinants of inflation captured by the mark-up and the PCs, which contain many input price levels. Also, the growth rate of broad money is negligible once the PCs enter the model. Their presence does impact upon the coefficients, although whilst most do not change by more than 2 standard errors the constant increases by 4 standard errors to 0.011. The impact of excess demand for goods is reduced but the PCs are probably also capturing these pressures. It is very difficult to interpret any of the coefficients because of the lack of interpretability of the components, which are likely to be picking up effects from many causes of inflation. The PCs do not negate the dummies, suggesting that these are modelling effects that are not captured by the economic variables included.

The evidence does suggest that whilst this data reduction method does capture useful information, it cannot substitute well specified reduced form equations which attempt to model all significant theories of inflation. The single-cause explanation of inflation, in this case represented by what we term general 'business cycle characteristics', is again refuted. The problems of a lack of interpretability and non-robustness to changes in the information set considerably hinder the use of principal component methods.

6 Conclusion

The paper develops a dominant congruent model of quarterly UK inflation from 1966q3-2002q2 that encompasses all relevant theories of inflation and is a good representation of the data. A production function method of estimating the gap is initially undertaken in a static and cointegrating framework. The residual estimate of total factor productivity accords with our priors regarding this latent variable and the lack of cyclicality suggests that efforts to correct for labour hoarding and capacity utilization are successful. Given the presence of substantial and systematic measurement error in the capital stock, potential output is then modelled as the long-run solution to a dynamic model with a time varying intercept that proxies total factor productivity. The dynamic model attributes more of the fluctuations in output to changes in potential output, resulting in a smaller gap. Whilst measures of excess demand do differ there is an element of consensus amongst the various measures. A composite measure of excess demand is extracted, based on the reasoning that if all gap estimates measure the true gap with some error, this should extract the signal relative to the errors. The resulting output gap measure provides a good estimate of the latent variable.

An empirical model of post-war quarterly inflation is then developed, with most extant theories of inflation playing a role in the explanation. The impact of excess demand is found to be substantial, with other key determinants including unit labour costs, exchange rates, foreign prices, interest rates, money and the excess demand for labour. The results concur with those for annual UK inflation over 1875-1991 derived in Hendry (2001) and therefore suggest that the modelling approach used does explain inflation well. Furthermore, a general 'business cycle' explanation of inflation based on principal components analysis is refuted suggesting that the individual channels by which various sectoral pressures feed through to inflation need to be modelled individually.

The empirical results presented suggest that inflation is determined by excess demand and excess supply pressures in the economy and the general to specific framework embodied in PcGets is the most appropriate framework to use when modelling inflation.

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8 Data Appendix

(All data are seasonally adjusted)

Y_t = Gross Domestic Product at constant 1995 prices, £million. [NS, ABMI]

P_t = Implicit deflator of Gross Domestic Product (expenditure) at market prices, (1995=100). [NS, YBGB]

GVA_t = Gross Value Added at basic prices, constant 1995 prices, £million. [NS, ABMM]

$M4_t$ = Nominal broad money stock, £million. [NS, AUYN]

Rs_t = Three-month treasury bill rate. [DS, UKGBILL3]

Rl_t = Yield on 20-year gilts. [DS, UKGBOND]

$REER_t$ = Real Effective Exchange Rate based on relative Unit Labour Costs, (1995=100). [IFS, REUZF...]

W_t = Total compensation of employees, current price, £million. [NS, DTWM]

Z_t = Total gross operating surplus, current price, £million. (Seasonally adjusted using X-11). [NS, ABNF]

$WPOP_t$ = Population aged 16-59/64, ‘000s. [NS, YBTF from 1992. Pre-1992, EPG, DEG, EG]

EMP_t = Total number in employment, aged 16+, ‘000s. [NS, MGRZ from 1992. Pre-1992, EPG, DEG, EG]

$Er_t = EMP_t/WPOP_t$

$U_t = WPOP_t - EMP_t$

$Ur_t = U_t/WPOP_t$

$INACTr_t$ = (Economically Inactive population)/(Population) Both for age 16+, ‘000s [NS, MGSI/MGSL]

$Pr_t = 1 - INACTr_t$

$L_t = WPOP_t \times Er_t \times Pr_t$

H_t = Average actual weekly hours of work (all workers in main & 2nd job). [NS, YBUV from 1992. Pre-1992, EPG, DEG, EG].

OH_t = (Weekly overtime hours per operative on overtime $\times$ fraction of operatives on overtime)/average hours. [EPG, DEG, EG, LMT]

K_t = Net capital stock for the whole economy excluding dwellings sector, £million. [BoE]

I_t = Total gross fixed capital formation, constant price, £million. [NS, NPQT]

$\Delta INVENT_t$ = Changes in inventories, constant 1995 prices. [NS, CAFU]

$U_{c,t}$ = A capacity utilization index based on the CBI index, % working below capacity. [DS, UKCBICAB]

$IMPORT_t$ = Implicit price deflator of imports: (total imports at current prices/total imports at constant prices). [NS, IKBI/IKBL]

PPI_t= Manufacturing output price index, (1995=100) [IFS, 11263...ZF...]

WPI_t = Wholesale price index of materials and fuel purchased by manufacturing industry, (1995=100). [DS, UKPPIMMNF]

C_t = Unit labour cost index for the whole economy, (1995=100). [NS, LNNL]

OIL_t = Petroleum spot price, sterling. [BoE]

ND_t = Public sector net debt, £million. [NS, BKQK]

$ASSET_t$ = FTSE all share index/($GVA \times P$). [DS, UKSHRPRCF]

$RENT_t$ = Actual rentals for housing + Imputed rentals for housing, £million. (Seasonally adjusted using X11). [NS, ADFT+ADFU]

$Is =$ Impulse Dummy equal to unity in period s only

$Ds =$ Blip dummy equal to 1 in period s and -1 in period $s+1$ only.

Sources: [NS] National Statistics database; [IFS] International Financial Statistics Database; [BoE] Bank of England; [DS] Datastream; [EPG] Employment and Productivity Gazette, pre-1971; [DEG] Department of Employment Gazette, 1971-79; [EG] Employment Gazette, 1980-1995; [LMT] Labour Market Trends, 1996-present. Data source codes also in brackets.