Inflation, Relative Price Variability and the Markup:

Evidence from the United States and the United Kingdom[*]

by

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Abstract

This paper links two separate empirical literatures on inflation, relative price variability (*RPV*) and the price-cost markup. Measures constructed from annual and quarterly data for the US and UK are used to examine the nature of the relationships among these variables. The results show that two long-run relationships can be identified from the data: a negative relationship between inflation and the markup and a positive relationship between inflation and *RPV*. We eliminate the possibility that inflation is a proxy for *RPV* in the inflation-markup relationship and show systems estimates to be superior to single-equation estimates.

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1. INTRODUCTION

There is now considerable empirical evidence that there is a negative relationship between inflation and the markup[1]. Two broad explanations of the negative relationship are offered in the literature. The first are the 'demand side' arguments that focus on the role that relative price dispersion has on the level of the markup. In this case, higher inflation leads to higher price dispersion which in turn reduces the markup. The second are the 'supply side' arguments that consider how inflation interacts on the way firms adjust prices and, in the process, how inflation affects the markup.

It is intriguing that in the empirical work examining the veracity of the demand-side explanations the models are estimated using inflation and the markup rather than price dispersion and the markup. Consequently, inflation in these papers is only a proxy for relative price dispersion. If the demand-side arguments and this modelling approach are valid, we should be able to replace inflation with a measure of price dispersion to yield a similar relationship.

This paper attempts to distinguish between these two broad explanations of the inflation-markup relationship by considering the relationship between inflation, price dispersion and the markup simultaneously. In doing so we draw together two separate literatures; one on inflation and price dispersion (as measured by relative price variability, *RPV*) and the other on the markup and inflation[2]. While previous studies were able to establish, independently, the consensus that there is a negative relationship between inflation and the markup and a positive relationship between inflation and *RPV* they were not able to do so in a single unified modelling approach.[3, 4]

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[1]   Richards and Stevens (1987), Bénabou (1992), Franz and Gordon (1993), Cockerell and Russell (1995), de Brouwer and Ericsson (1998), Simon (1999) and Batini, Jackson, and Nickell (2000) identify the negative relationship when inflation and the markup are stationary. While Banerjee, Cockerell, and Russell (2001) and Banerjee and Russell (2001a, 2001b, 2005) identify a negative long-run relationship if inflation and the markup are integrated series.

[2]   The separate treatment of these relationships in the literature is surprising given that the estimated relationships are often derived from common theoretical bases.

[3]   Mitchell (1915), Mills (1927), Okun (1971), Vining and Elwertowski (1976), Parks (1978), Fischer (1981), Mizon, Safford, and Thomas (1991), Parsley (1996), Debelle and Lamont (1997) find a positive relationship between inflation and RPV. Hartman (1991), Reinsdorf (1994), Fielding and Mizen (2001) and Silver and Ioannidis (2001) provide some evidence of a negative relationship especially during recessions.

[4]   The only paper of which we are aware that models inflation and RPV (but excludes the markup) in a systems framework is Mizon (1991) using quarterly United Kingdom data for the period 1965-1987.

Our framework allows us to consider five important questions concerning the relationships between inflation, *RPV* and the markup to which the earlier literature could only provide partial answers. We ask, first, 'What relationships exist between inflation, the markup and *RPV*?' Second, 'Are the relationships between the variables short- or long-run phenomena?' An answer to this question takes us to the heart of the issue of the appropriate econometric treatment of the variables as stationary or cointegrated variables.[5] Third, to distinguish between the two broad sets of explanations we ask, 'Does the system involve two separate relationships, between inflation and the markup and between inflation and *RPV*, or a single relationship among all three variables?' If inflation acts as a proxy for *RPV* then we should be able to replace inflation with *RPV* in the inflation-markup relationship to yield a similar relationship. Fourth, nearly all of the existing empirical analysis of the inflation-*RPV* relationship assumes that single-equation estimation is appropriate. We ask 'Is the assumption of single-equation estimation appropriate and sustainable?' And lastly, 'can we discriminate between the demand-side and supply-side arguments that potentially offer support for the relationships between these variables?'

We estimate a multivariate system comprising inflation, the markup and *RPV*. For comparability with much of the existing empirical literature we estimate the system with *both* quarterly and annual data for the United States *and* the United Kingdom. The following results emerge from our analysis. First, in all four data sets, we re-establish the negative relationship between the markup and inflation and a positive relationship between inflation and *RPV*. Second, those relationships are characterized as long-run relationships as identified from cointegration analysis. This is a central finding since it proceeds from the testable assumption that the data for inflation, markup and *RPV* are all integrated of order one.[6] Third, we are able to accept the restriction that *RPV* does not appear in the markup-inflation relationship, and that the markup does not appear in the inflation-*RPV* equation. From this it follows that inflation does not act as a proxy for *RPV* in the first relationship. Fourth, estimating within a systems framework, we are also able to establish that single-equation estimation of the inflation-*RPV* relationship is valid for three of the four data sets while single

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[5] See Banerjee, Dolado, Galbraith, and Hendry (1993) and Johansen (1995) for a description of the long run in the econometric sense of Engle and Granger (1987).

[6] Banerjee, *et al.* (2001) and Banerjee and Russell (2001a) have argued at length the case in favour of regarding inflation and markup as I(1) variables. We re-establish this finding for all the data sets examined in this paper including the RPV series.

equation estimation of the inflation-markup relationship is not valid in any of the data sets examined. Therefore, the inflation-*RPV* relationship should be investigated within a system, since this facilitates the simultaneous consideration of exogeneity, integration of the variables and inter-linkages between the cointegrating relationships. Lastly, we find evidence consistent with a supply-side argument for a relationship between inflation, *RPV* and the markup. All five findings establish the existing results while making a compelling case that the markup-inflation and *RPV*-inflation relationships should be considered in a systems context.

The economic importance of the empirical issue discussed above arises from the literature often referred to as the 'sand in the wheels' view is attributed to Lucas (1973, 1994) and Barro (1976) *inter alia*. It underlies the opinion that inflation is costly to welfare and is often justified by demonstrating that the dispersion of prices increases with the average level of inflation (c.f. Hercowitz, 1981). However, many authors have challenged the opinion that higher inflation generates welfare losses by claiming that the countervailing influences of inflation on competition and market power need also to be considered. Therefore it is important to estimate the inflation-RPV-markup relationship carefully in order to make a proper judgement on the welfare considerations of inflation.

In the next section we briefly consider the economic literature on the inflation-markup and inflation-*RPV* relationships. Section 3 sets out the long-run relationships, discussing the measurement issues, data sources and the econometric framework for estimation. Section 4 reports the empirical results. Section 5 concludes.

2. ECONOMIC BACKGROUND

2.1 Inflation and the Markup

The literature on the inflation-markup relationship can be separated into 'demand-side' and 'supply-side' explanations. On the demand-side, Bénabou (1988, 1992) and Diamond (1993) focus on the interaction of inflation with the demand for a firm's output. The essential element in this approach is that consumers on the demand side search across firms to find the best priced goods. The consumer gains utility from consuming the good and this is offset against the cost of purchase i.e. the price. In these models higher inflation increases price dispersion and consumers have a greater incentive to engage in search behaviour to identify 'bargains'. Like the menu cost literature, firms face costs of changing posted prices of goods in their inventory and therefore when there is inflation, goods that

have been kept on the stocks for some time will appear to be 'cheap' relative to newly produced goods[7]. When inflation increases, consumers engage in search to discover 'bargain' priced goods with their fixed posted prices that have not kept pace with inflation. This search behaviour by consumers leads to an increase in competition among sellers and results in a subsequent fall in the markup. This explanation implies that the increase in *RPV* associated with higher inflation is the cause of the lower markup. We return to this issue in Section 4 when we discuss whether inflation is a proxy for *RPV*.

The most prominent supply-side explanation is the 'menu' cost argument of Mankiw (1985) and Parkin (1986) which relies on the proposition that firms face costs when adjusting posted prices i.e. catalogue prices in response to realised demand shocks. Although small, these costs have large welfare effects. Firms have insufficient incentives to adjust prices and thereby bring the market back to equilibrium, but the costs to society from being out of equilibrium are substantial. The asymmetry in the incentive structure results in prices that can be 'stuck' at levels that are too high.

Users of this approach include Rotemberg (1983), Kuran (1986), Naish (1986), Danziger (1988), Konieczny (1990) and Bénabou and Konieczny (1994) who model the price setting behaviour of firms in this way. They show that when there is inflation in the economy this has a negative impact on the average markup.[8] These models assume that firms follow a fixed price adjustment rule, which may not be a sustainable assumption in the long run. For example, if these firms notice that their average markup diverges from the profit maximising markup when inflation is stable then they could simply adjust their price rule to eliminate the divergence.[9]

Non-menu cost supply-side explanations may provide a long-run relationship between inflation and the markup. These approaches do not rely on the asymmetry of the incentive structure to motivate such a relationship, but argue that co-ordination between firms becomes

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[7] Unlike the menu cost literature the costs of changing goods prices are not fixed. It is assumed that there is no cost to changing the price of a newly produced good, but there is a cost to changing the price of an item in the inventory. Therefore, prices can change costlessly if a good is sold and replaced by a newly produced good.

[8] Bénabou and Konieczny (1994) show, in an encompassing model of the menu cost papers, that the relationship between inflation and the markup may be either positive or negative depending on the relative size of inflation, the 'menu' costs, the discount rate, as well as whether the profit function is left- or right-skewed. However, under 'reasonable' assumptions it is likely the relationship between inflation and the markup is negative.

[9] See Ball, Mankiw, and Romer (1988), Sims (1988) and Dotsey, King, and Wolman (1999).

more difficult as the marketplace becomes more 'noisy'. For example, Athey, Bagwell and Sanichiro (1998) indirectly argue that higher inflation is associated with higher variability in input costs making it harder for firms to collude on final goods prices. This results in greater competition and the markup is reduced in the long run if the *RPV* is sustained. Further supply-side explanations are provided by Russell, Evans, and Preston (2002), and Chen and Russell (2002). The first paper argues that marginal costs are difficult to apportion between jointly-produced output and are not known with certainty. Furthermore, it argues that inflation increases the uncertainty about the appropriate price of the output. Firms faced with these uncertainties will have incentives to minimise the expected loss from setting an incorrect markup, and will veer towards a 'low' markup to avoid losses when inflation increases. The result is that the markup can deviate systematically from their 'correct' setting. The second paper explores the difficulties that firms face when attempting to coordinate price changes in an inflationary environment. These papers argue explicitly that there exists a negative relationship between the markup and steady state rates of inflation that may be thought of as a long-run relationship. In these models, the lower markup associated with higher inflation is interpreted as the cost to firms of overcoming the missing information when setting prices.

2.2   Inflation and Relative Price Variability

Explanations of the relationship between inflation and *RPV* can be separated into three categories. The first is also based on the Mankiw (1985) and Parkin (1986) 'menu' cost literature mentioned above. This model can generate a positive relationship between inflation and *RPV* if inflation pushes prices above the upper threshold price in an (S,s) framework (Sheshinski and Weiss (1977)) and the majority of the empirical literature supports this view. However, when there is negative inflation, pushing prices below the lower threshold, there may no longer be a positive relationship. Furthermore, Rotemberg (1983) and Ball and Mankiw (1994) argue that price dispersion may fall with inflation if firms try to avoid the menu costs of continual adjustment or the costs of losing market share.

The second set of explanations is based on the 'sand in the wheels' argument of Lucas (1973). Hercowitz (1981), Lach and Tsiddon (1992) and Debelle and Lamont (1997) argue that higher inflation causes an increase in misperceptions that lead in turn to higher *RPV*. The issue facing buyers is to decide whether they have been offered a price by a high-priced seller or an average-priced seller (in a situation where the price rises in line with inflation). The

increase in the inflation rate makes it more difficult for the buyer to distinguish between the signal and the noise, and *RPV* increases.

A third explanation suggests that the relationship is simply an artefact of the aggregation of the data or the time period examined. Fischer (1981), Hartman (1991) and Driffill, Mizon, and Ulph (1990) argue that shocks to food and energy prices in the 1970s simultaneously increased inflation and measures of *RPV* and thereby created or overstated the positive relationship between inflation and *RPV*. In this case there is no underlying economic reason for the relationship, only a statistical association.

3. THE LONG-RUN RELATIONSHIPS

The long-run relationships between inflation and the markup on the one hand and inflation and *RPV* on the other can be derived from any of the previous theories. We will determine which of the theories are consistent with the evidence by examining the nature of the relationships in the next section, but in this section we define the long-run relationships, consider the measurement issues, discuss our data sources and describe our econometric methodology.

The long-run relationship between the markup and inflation from the economic models above can be written as:

$$mu_t = q - \lambda \Delta p_t \tag{1}$$

and

$$rpv_t = \zeta_0 + \zeta_1 \Delta p_t \tag{2}$$

In equation (1), mu_t is the estimated markup of price on unit costs 'net' of the costs of inflation, and Δp_t represents inflation; q is the 'gross' markup, and λ is a positive parameter and is termed the 'inflation cost' coefficient. In equation (2), rpv_t is relative price variability and ζ_0 and ζ_1 are positive parameters. Lower-case variables are measured in natural logarithms. In our systems approach described in section 3.3 we need not impose coefficient restrictions that result in these long-run relationships although the data support them and we describe the system with the appropriate restrictions imposed.

3.1 Measurement Issues

The markup, mu, for k inputs of the production process is defined as:

$$mu \equiv p - \sum_{i=1}^{k} \psi_i c_i \qquad (1a)$$

where the c_i represents the logarithms of the costs of production for input i, and $\sum_{i=1}^{k} \psi_i = 1$. If

the latter condition is satisfied then the relationship between prices and costs can be termed

the markup on unit costs.[10] The condition $\sum_{i=1}^{k} \psi_i = 1$ imposes linear homogeneity and implies

that, *ceteris paribus*, a change in unit costs will be fully reflected in the price level in the long

run leaving the markup unchanged. In our case, *ceteris paribus* includes no change in the

rate of inflation. In a 'standard' macroeconomic framework $\lambda = 0$ and inflation has no effect

on the markup in the long run. In the estimates reported here, $\lambda > 0$ and the markup, net of

the cost of inflation, is lower with higher inflation and *vice versa* in the long run.

Imposing linear homogeneity, we can write the markup defined in (1a) as the

weighted sum of the markup of price on unit labour costs, and the 'real exchange rate' where

the latter is defined appropriately for the measure of prices used in the estimation. When the

markup is calculated using consumer prices, we write (1) as:

$$mu_{1t} = mu_{Lt} + \rho \, rer_{Mt} = q - \lambda \Delta p_t \qquad (3)$$

where $mu_{Lt} = p_{Ct} - ulc_t$, (ulc_t is unit labour costs) and the difference between the

consumer price and unit import costs is the real exchange rate, $rer_{Mt} = p_{Ct} - pm_t$, (pm_t is

unit import costs).[11] The estimated markup written in the form of (1a) with linear

homogeneity imposed and derived from (3) is:

$$mu_{1t} = p_{Ct} - \frac{1}{1+\rho} ulc_t - \left(1 - \frac{1}{1+\rho}\right) pm_t \qquad (4)$$

and may be interpreted as the markup of price on unit labour and import costs.[12]

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[10] The standard literature focuses on the relationship between inflation and the markup on marginal costs. If the short-run perturbations of marginal costs around some long-run level of costs are due to the business cycle and therefore stationary, then the use of the markup on unit costs is valid when estimating the long-run inflation-markup relationship. Banerjee and Russell (2005) consider this issue further.

[11] The terms rer_{Mt} and rer_{Xt} may be referred to as the 'real exchange rate' due to their similarity to the relative price of traded and non-traded goods used by Swan (1963) as a measure of the real exchange rate.

[12] Richards and Stevens (1987), Franz and Gordon (1993), Cockerell and Russell (1995) and de Brouwer and Ericsson (1998) define the markup in a similar fashion in their empirical markup models of inflation.

Alternatively, if the markup in (1a) is calculated using the GDP deflator, p_{GDP}, the real exchange rate must instead be defined as $rer_{Xt} = p_{GDPt} - px_t$ to adjust the price series for export prices, px_t. The estimated markup is then:

$$mu_{2t} = p_{GDPt} - \frac{1}{1+\rho} ulc_t - \left(1 - \frac{1}{1+\rho}\right) px_t \qquad (5)$$

We can interpret mu_{2t} as the markup of the price of non-traded GDP on unit labour costs. This interpretation is explained later in the appendix.

As the next section makes clear, we use both annual and quarterly data sets to cross-check our findings. For quarterly data we use consumer prices to construct the markup using the first measure, while for annual data we rely on GDP deflators and use the second measure of the markup.

The measure of *RPV* is based on the method followed by Parks (1978), Blejer and Leiderman (1980), Cukierman and Leiderman (1984), Parsley (1996), and Fielding and Mizen (2001):

$$RPV_t = \left(\sum_{i=1}^{n} s_i \left(\Delta p_{it} - \Delta p_T\right)^2\right)^{\frac{1}{2}} \qquad (6)$$

where s_i is the share of each component index in the total index, and Δp_{it} is the rate of inflation of the individual component index and Δp_T is the rate of inflation of the total price index. RPV_t is therefore the weighted average of the component inflation rates relative to the aggregate measure of annualised inflation.

Four alternative measures of *RPV* are set out in Table 1 of Fielding and Mizen (2001). While all these measures capture the variability of prices around the average, a closer look at the relevant literature shows that the overwhelming majority of studies use the measure of *RPV* used here. For example, Hartman (1991), Mizon (1991), Ball and Mankiw (1994), Parsley (1996) and Fielding and Mizen (2001) have examined the inflation-RPV relationship using variants of our measure of *RPV*. In addition, our chosen measure of *RPV* avoids the problem of trending relative prices in the component indexes due to different productivity growth rates between the sectors.

3.2   Data

The sources and definitions of the data are reported in Table 1. We use both quarterly and

annual data for the US and the UK. This allows comparison of our results, and reduces the possibility that we will be drawing country- or data-frequency specific conclusions. It also imposes on us the discipline that the relationships between the variables for the same country at different frequencies should give a common interpretation.[13]

We use two measures of prices in the calculation of the markup on unit labour costs, the real exchange rate, and inflation. The first is the private consumption implicit price deflator and the second is the gross domestic product implicit price deflator. Both are derived from national accounts data. Unit labour costs are measured on an aggregate economy-wide basis while imports and exports prices are the respective goods and services implicit price deflators.

Except for the quarterly United States data, *RPV* is calculated using the component indices of the aggregate price index used for measuring inflation and the markup. The measures of *RPV* are therefore consistent with the measures of inflation and the markup. For the quarterly United States data, results obtained from *RPV* (calculated from the All Urban Consumer Price Index (CPI-U)) and inflation (calculated from the private consumption implicit price deflator or the Consumer Price Index) showed some instability and were not robust to changes in the lag structure of the system. Consequently, although there were numerous indications that the results were consistent with those from the other data sets, the United States quarterly inflation and the markup are calculated using national accounts gross domestic product data and *RPV* is calculated using CPI-U data.

The short-run impact of the business cycle on inflation, the markup and *RPV* is represented by the difference in the logarithm of the unemployment rate. The variable is stationary and avoids the 'errors in measurement' problem when using de-trended constant price gross domestic product in association with national accounts price data.[14]

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[13] There are some obvious qualifications to this statement as a result of the different data definitions employed at each frequency.

[14] Measurement errors in national accounts data often have a simultaneous impact on the price and output series so as to offset each other. Consequently, estimates of the relationship between price and output data would be contaminated by the presence of common measurement errors. This contamination is not likely to be serious if the price series spans a small component of the output series. However, in our case the span of the price series and output series are the same or very similar.

The annual and quarterly measures of *RPV* are highly skewed and bounded at zero.[15] The explosive nature of the 'spikes' in the data often leads to non-normal and serially correlated system residuals. We identified in section 2 that shocks to certain components of the price series used to generate inflation and RPV measures could be responsible for a positive association between the two variables, quite independently of any economic relationship. In order to control for this effect we wish to remove the largest shocks from the RPV series which are responsible for the spikes in the series. While the contemporaneous impact of these 'spikes' on the dependent variables can be accounted for by the introduction of dummy variables in the long-run relationships it is more difficult to account for their impact on the dynamic system. Instead we pre-filter the series to reduce the skewness of the data by regressing *RPV* on a series of dummy variables that coincide with observations of more than 2.5 standard deviations from the mean of the series.[16] The dummies coincide with periods of high inflation and, therefore, removing these observations is likely to make it more difficult to find a positive relationship between inflation and *RPV*. We use the de-spiked RPV series in place of the original, and even after removing the spikes we continue to find that our results below are consistent with the general view in the literature of a positive relationship between inflation and *RPV*. We can then be sure that the criticisms of earlier empirical work made by Fischer (1981), Hartman (1991) and Driffill, *et al.* (1990) that simultaneous shocks to inflation and *RPV* are the cause of a positive relationship between *RPV* and inflation do not apply here.

Prior to estimation, the integration properties of the data were investigated using PT and DF-GLS univariate unit root tests from Elliot, Rothenberg and Stock (1996).[17] We find that inflation, the markup, the real exchange rate and *RPV* variables may be characterized as I(1), and the logarithm of the unemployment rate is I(1). The estimates, therefore, are given by an I(1) system consisting of four core variables: the markup on unit labour costs, the 'real exchange rate', inflation and *RPV*. Estimation of the system is conditioned upon the change

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[15] Vining and Elwertowski (1976) and Mizon, *et al.* (1991) similarly find that the assumption of normality is strongly rejected for RPV due to strong skewness and kurtosis. Banerjee, Mizen and Russell (2002) report graphs and descriptive statistics of the annual and quarterly measures of RPV.

[16] The initial system estimates based on *RPV* provide similar results to those we report below. For the quarterly United Kingdom data it was found that to reduce the skewness to 'manageable' levels in terms of the system diagnostics, dummy variables were necessary for observations greater than 2 standard deviations from the mean and reported in the data appendix of Banerjee *et al.* (2002).

[17] These results are available on request from the authors.

in the logarithm of unemployment representing the business cycle and a set of spike dummies to capture the occasionally erratic behaviour of the data particularly in the turbulent mid- to late-1970s.[18] To allow for the possibility of structural change in the economy that leads to shifts in the long-run relationships, a trend is included in the cointegrating space and omitted whenever insignificant. Estimates are given at both the annual and quarterly frequencies for the United States and the United Kingdom.

3.3 Econometric methodology

Taking our two log-linear equations (1) and (2) we include intercepts and trends (where appropriate) to ensure that the long-run reduced form disturbances have zero means:

$$mu_t = \delta_0 + \delta_1 t + \delta_2 \Delta p_t + \delta_3 rer_t + \xi_{1t} \tag{7}$$

$$rpv_t = \zeta_0 + \zeta_1 t + \zeta_2 \Delta p_t + \xi_{2t} \tag{8}$$

the equations (7) and (8) can then be written as a long-run compact form as:

$$\xi_t = \boldsymbol{\beta}' \mathbf{z}_t - \mathbf{b}_0 - \mathbf{b}_1(t) \tag{9}$$

where
$$\xi_t = (\xi_{1t}, \xi_{2t})', \mathbf{z}_t = \left(mu_t, rpv_t, \Delta p_t, rer_t\right)',$$
$$\mathbf{b}_0 = (\delta_0, \zeta_0)', \mathbf{b}_1 = (\delta_1, \zeta_1)$$

and
$$\boldsymbol{\beta}' = \begin{pmatrix} 1 & 0 & -\delta_2 & -\delta_3 \\ 0 & 1 & -\zeta_2 & 0 \end{pmatrix}.$$

In estimation we embed the two long run relations given by (7) and (8) in the vector error correction framework given by:

$$\Delta \mathbf{z}_t = \mathbf{a}_z - \boldsymbol{\alpha}\xi_{t-1} + \sum_{j=1}^{J} \boldsymbol{\Gamma}_{zj} \Delta \mathbf{z}_{t-j} + \mathbf{u}_{zt} \tag{10}$$

where $\mathbf{a}_z$ is a (4x1) matrix of intercepts, $\boldsymbol{\alpha}$ is a (4x2) matrix of loading coefficients, $\boldsymbol{\Gamma}_{zj}$ is a set of (4x4) matrices of short-run coefficients. Finally, $\mathbf{u}_{zt}$ is a (4x1) vector of disturbances assumed to be iid(0, $\boldsymbol{\Sigma}_z$). Here we have followed Sims (1980), Pesaran, Shin and Smith (2002), Pesaran and Shin (2002) and Garratt, Lee, Pesaran, and Shin (2003) in assuming that deviations from long-run reduced forms can be approximately captured by a

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[18]   The dummies differ from those used to 'de-spike' the RPV series and are reported in Tables 3a to 3d.

finite number of lags in the explanatory variables. The variables in $\mathbf{z}_t$ are all assumed to be first-difference stationary.

4. EMPIRICAL RESULTS

Our initial concern is for the long run properties of the system. We therefore first determine the number of cointegrating vectors using the Johansen (1988, 1995) maximum likelihood systems estimator following a methodology outlined in Banerjee *et al.* (1993). Table 2 establishes the existence of two cointegrating vectors in each system. In all four cases, for US and UK data at both annual and quarterly frequencies, we can reject the null that there is at least one cointegrating relationship between the variables. We cannot reject the null that there are at least two (the value of the test statistic can be compared to the critical value in brackets beneath). Further evidence of two cointegrating vectors is provided by the roots in modulus of the companion matrix and the stationarity of both cointegrating vectors.[19] This finding that there are two cointegrating vectors in all four systems considered implies that we can be reasonably assured that there are two distinct relationships between our four variables identified in the data.

Tables 3a to 3d report the two long-run relationships detected in the system. The first four columns in each table give the adjustment coefficients in the dynamic equations for each of the variables and report the feedback on each variable from the deviation from the estimated long-run relationship (given in the final column of each table).

The estimated long-run relationship is obtained by normalising each of the two cointegrating vectors on one of the variables. On theoretical grounds we interpret one of the relationships to be between the markup and inflation and the other to be between inflation and *RPV*. Accordingly we normalize on the markup on unit labour costs (*mu*) in the first row and on inflation (Δp) in the second row.[20] Later in the paper we consider an alternative specification of the long-run relationships (see Table 4). The diagnostic tests reported in

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[19] The roots in modulus of the companion matrix are consistent with the maintained hypothesis of two cointegrating vectors in a four variable system where we expect the first two roots to be unity and the remaining roots bounded away from unity. Both cointegrating vectors in each case visually appear stationary and this can be verified by univariate unit root tests.

[20] Normalisation does not imply direction of causation because we could normalize on any of the variables in the cointegrating vector whilst maintaining the same long-run relationship between them.

Tables 3a to 3d accept the null of no serial correlation and normality of the residuals in all cases suggesting that the system is correctly specified.

The common feature of all four estimated inflation-markup relationships is a negative and significant relationship between the markup and inflation and a positive and significant relationship between inflation and *RPV*. The second result is obtained even though the outliers have been removed from the *RPV* series, which *a priori* makes the finding less likely since the correction removes high *RPV* values associated with times of high inflation. In some cases there is also a trend in the cointegrating relation, which has a small but significant coefficient. These findings confirm the most commonly reported results in the empirical literature since they deliver the expected signs of the coefficients in all cases. Thus, in answer to our first and second questions, we can confirm the finding of two long-run relationships within the system and can demonstrate that the long-run relationships have the same signs as the relationships reported previously in the separate empirical literatures.

Once annualised, the estimates from quarterly data are similar to those derived from annual data for the United States.[21] This is encouraging since the two systems were estimated independently, and were not constrained in any way to yield similar results. The results are numerically similar to those reported in Banerjee and Russell (2001a, 2001b) for the United States even though the samples differ and the system estimated here contains *RPV*.

There are however some minor divergences evident between annual and quarterly systems for the United Kingdom. For example, for quarterly data, the annualised 'inflation cost' coefficient on inflation is 0.904, which contrasts with 0.299 derived from annual data. The sensitivity of the United Kingdom results to sampling frequency may be explained by the different price indexes used for the two different frequencies and the presence of a trend in the proportion of 'non-traded GDP' in the economy (in the annual data estimates). This point may also explain the presence of the significant trend terms in the United States cointegrating vectors.

The third question we addressed in the introduction is whether inflation acts as a proxy for the *RPV* measure. This amounts to asking the question whether *RPV* could replace inflation in the markup equation if all three variables appeared in the same system. We test and can accept for all the data sets the restrictions that RPV is not significant in the inflation-

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[21] The long-run coefficients in the inflation-markup relationship are also very similar to those reported in Banerjee and Russell (2001a, 2001b) for the United States.

markup long-run relationship and the markup is not significant in the inflation-RPV long-run relationship. This identifies the inflation-markup and inflation-RPV pairs as the long-run relationships in the data. The *chi-squared* tests for excluding the variables from each long-run relationship are reported in Tables 3a-3d.

We note that we could alternatively have identified the cointegrating vectors by restricting the inflation term to zero in the first cointegrating vector, leaving the identifying restriction for the second cointegrating vector unchanged.[22] Table 4 supports our argument in favour of the first identifying scheme instead of the alternative. Table 4 reports a reformulation of the systems in Tables 3a to 3d without imposing identifying restrictions (see notes to Table 4). In order for the alternative identifying scheme to be appropriate, we require that *mu* is insignificant in Cointegrating Vector 1 and significant in Cointegrating Vector 2. Table 4 shows that this combination of restrictions cannot be supported for any of the four data sets. For three of the data sets we reject the restriction that *mu* is equal to zero in Cointegrating Vector 1 and accept the restriction that the coefficient on *mu* is equal to zero in Cointegrating Vector 2. For the fourth data set (annual United Kingdom) we reject the hypothesis that the coefficient on *mu* is zero in both cointegrating vectors. This is evidence in favour of considering the relationship between inflation and the markup to be the 'primitive' one, with the alternative identifying scheme being a rewriting of the first.

These results suggest that inflation cannot be replaced by *RPV* in the inflation-markup relationship; nor can the markup be included in the inflation-*RPV* long-run relationship. By implication, the explanations provided by Bénabou (1988, 1992), and Diamond (1993) of the inflation-markup relationship (that rely on the impact of *RPV* on competition) do not explain our long-run inflation-markup results.[23]

Turning to the fourth question posed in the introduction, we have shown the existence of two cointegrating vectors that have the expected signs and functional form corresponding to the long-run relationships described in section 3. However, the existence of two distinct cointegrating vectors does not necessarily imply that single-equation estimation of each relationship is valid. Such a simplification requires weak-exogeneity conditions to hold and

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[22] We are grateful for correspondence with Neil Ericsson that drew our attention to this alternative restriction that generated the subsequent analysis.

[23] Acceptance of these restrictions does not preclude the possibility that these explanations may explain any short-run relationship between the variables through the dynamics of the system.

these requirements can be investigated using our results in Tables 3a to 3d by noting how the error-correction terms enter the system.

For example, our results based on annual data for the United States (Table 3a) and the annual and quarterly data for the United Kingdom (Tables 3c and 3d) shows that the second cointegrating relationship enters significantly only into the *RPV* equation (this is the only adjustment coefficient that is significantly different from zero on the basis of the *t*-statistics in brackets beneath the estimated coefficients). Taken together with the result that the *RPV* variable does not enter the first cointegrating relationship (a result we confirmed in Table 4), we expect that if we examine a bivariate system consisting of inflation and *RPV*, the cointegrating relationship between inflation and *RPV* would not enter with a significant coefficient in the inflation equation. This would establish the weak exogeneity status of inflation in this bivariate system and justifies the estimation of the relationship between *RPV* and inflation (with *RPV* being the dependent variable) using single-equation methods. The quarterly United States results in Table 3b (where the second cointegrating relationship does enter with a significant coefficient in the inflation equation) is the only exception. Here inflation is unlikely to be weakly exogenous in this bivariate system and we can verify this formally.

Even though inflation is not weakly exogenous in any of the four variable systems that we examine, our intuition based on the results from our system estimates is correct in that we can establish for the data used in Tables 3a, 3c and 3d that inflation is weakly exogenous in a bivariate system comprising inflation and *RPV*. Furthermore, inflation is not weakly exogenous in a bivariate system using the quarterly United States data from Table 3b as expected.[24]

In order to highlight the impact of the endogeneity of inflation in this inflation-*RPV* relationship, Table 5 reports the single-equation and system estimates of the inflation-*RPV* long-run relationship for all four data sets. The single equation estimates are derived from estimating the Bewley (1979) transform of the ADL(m,n) model and the system results are taken from the results reported in Tables 3a to 3d. Consistent with our finding that inflation is endogenous in the quarterly United States data, the single equation estimates differ from the system estimate by approximately 50 percent. For the remaining data sets, where inflation is weakly exogenous, such divergences do not appear.

Based on the results presented in Tables 3a to 3d on the adjustment coefficients and the associated *t*-statistics we may deduce that single-equation estimation of the inflation-markup relationship is unlikely to be valid, since neither inflation nor the markup on unit labour costs are weakly exogenous in the four-variable system.

Finally we turn to the graphical illustration of our annual results.[25] Graphs 1a and 1b show as solid lines the long-run relationships between inflation and the markup and between inflation and *RPV* and are labelled as LR(1) and LR(2) respectively.[26] Shown as dots on the graphs are the actual values for inflation and *RPV* along with the estimated markup from the system analysis. Marked with crosses are the observations corresponding to the dummy variables in the system analysis.

We have shown that paying due regard to the integration properties of the data, the inter-linkages between the relationships and the exogeneity status of the variables are all important for a proper analysis of the two interrelated themes in the literature. In particular, only a complete systems analysis is capable of judging the validity of the simplifications adopted in much of the existing empirical literature. Our results are estimated more consistently than those of the single equation studies and permit short-term dynamic interactions that the former studies ignore.

5. CONCLUSIONS

In this paper we argue that although the empirical literatures on the relationships between inflation and the markup and between inflation and *RPV* were developed separately they should be considered together in order to address five important questions. The questions are: 'What relationships exist between the variables in our system?', 'Are they long-run or short-run relationships?', 'Are there two relationships (between inflation and the markup on the one hand and RPV and inflation on the other) or one relationship between all three variables?', 'Is a system estimate more appropriate than single equation estimation?' and 'can we determine

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[24]   These results are available from the authors.

[25]   Equivalent graphs of the quarterly results are reported in Banerjee *et al.* (2002).

[26]   For ease of interpretation, the graphs show annual inflation as the change in the natural logarithm of the price index multiplied by 100.

whether demand- or supply-side arguments are more consistent with the empirical relationships we have identified?'

The first two questions can be answered positively, since we reconfirm the findings of a negative relationship between inflation and the markup and a positive relationship between inflation and *RPV* in the long run. In answer to the third question there are two relationships between the three variables; these are the inflation-markup and inflation-*RPV* relationships. *RPV* is not admissible in the inflation-markup equation, and that the markup can be excluded from the inflation-*RPV* relationship in the long run. We answer our fourth question by concluding that single equation estimation of the inflation-RPV and inflation-markup relationships are unlikely to be valid although it cannot be categorically ruled out.

Our conclusions are that inflation is associated with greater uncertainty as measured by an increase in RPV and a reduction in the markup in both the US and the UK data over our sample period. However, although price dispersion increases, this is not the cause of the reduction in the markup. The systems approach indicates that RPV cannot substitute for inflation, indicating that inflation is not a proxy for price dispersion. This answers our fifth question, since we find evidence that is inconsistent with the demand-side explanation for the reduction of market power when inflation increases, but is consistent with supply-side reasoning. The fact that these results can be supported using data at several frequencies for more than one country is encouraging, although more research is required to establish the generality of the result. Our paper offers an initial step towards integrating the two literatures on inflation-*RPV* and the inflation-markup that have previously been investigated separately.

6. REFERENCES

Athey, S., Bagwell, and C. Sanichiro. (1998). "Collusion and Price Rigidity." MIT Department of Economics Working Paper No. 23.

Ball, L. and N.G. Mankiw. (1994). "Asymmetric Price Adjustment and Economic Fluctuations." *Economic Journal*, 104, pp. 247-61.

Ball, L., N.G. Mankiw, and D. Romer. (1988). "The New Keynesian Economics and the Output-Inflation Trade-off." *Brookings Papers on Economic Activity*, pp. 1-65.

Banerjee, A., L. Cockerell, and B. Russell. (2001). "An I(2) Analysis of Inflation and the Markup." *Journal of Applied Econometrics*, 16 Sargan Special Issue:3 May-June, pp. 221-40.

Banerjee, A., J. Dolado, J.W. Galbraith, and D.F. Hendry. (1993). *Cointegration, Error Correction, and the Econometric Analysis of Non-Stationary Data*. Oxford: Oxford University Press.

Banerjee, A. and B. Russell. (2001a). "The Relationship between the Markup and Inflation in the G7 Economies and Australia." *Review of Economics and Statistics*, 83:2 May, pp. 377-87.

Banerjee, A. and B. Russell. (2001b). "Industry Structure and the Dynamics of Price Adjustment." *Applied Economics*, 33:17, pp. 1889-901.

Banerjee, A. and B. Russell. (2005). "Inflation and Measures of the Markup", *Journal of Macroeconomics*, vol. 27, pp. 289-306.

Banerjee, A., P. Mizen, and B. Russell. (2002). "The Long-Run Relationships among Relative Price Variability, Inflation and the Markup." European University Institute Working Paper, ECO No. 2002/1.

Barro, R.J. (1976) 'Rational Expectations and the Role of Monetary Policy' *Journal of Monetary Economics*, 2, 1-32.

Batini, N., B. Jackson, and S. Nickell. (2000). "Inflation Dynamics and the Labour Share in the UK." Bank of England External MPC Unit Discussion Paper: No. 2 November.

Bénabou, R. (1988). "Search, Price Setting and Inflation." *Review of Economic Studies*, 55:3 July, pp. 353-73.

Bénabou, R. (1992). "Inflation and Markups: Theories and Evidence from the Retail Trade Sector." *European Economic Review*, 36, pp. 566-74.

Bénabou, R. and J.D. Konieczny. (1994). "On Inflation and Output with Costly Price Changes: A Simple Unifying Result." *American Economic Review*, 84:1 March, pp. 290-7.

Bewley, R.A. (1979). "The Direct Estimation of the Equilibrium Response in a Linear Dynamic Model." *Economic Letters*, 3:4, pp. 357-61.

Blejer, M.I. and L. Leiderman. (1980). "On the Real Effects of Inflation and Relative Price Variability: Some Empirical Evidence." *Review of Economics and Statistics*, 62, pp. 539-44.

Chen, Y-F and B. Russell. (2002). "An Optimising Model of Price Adjustment with Missing

Information." European University Institute Working Paper, ECO No. 2002/3.

Cockerell, L. and B. Russell. (1995). "Australian Wage and Price Inflation: 1971-1994." Reserve Bank of Australia Discussion Paper:9509.

Cukierman, A. and L. Leiderman. (1984). "Price Controls and the Variability of Relative Prices." *Journal of Money, Credit and Banking*, 16, pp. 271-84.

Danziger, L. (1988). "Costs of Price Adjustment and the Welfare Economics of Inflation and Disinflation." *American Economic Review*, 78:4 September, pp. 633-46.

de Brouwer, G. and N.R. Ericsson. (1998). "Modelling Inflation in Australia." *Journal of Business and Statistics*, 16, pp. 433-49.

Debelle, G. and O. Lamont. (1997). "Relative Price Variability and Inflation: Evidence from the U.S. Cities." *Journal of Political Economy*, 105:1, pp. 132-52.

Diamond, P. (1993). "Search, Sticky Prices and Inflation." *Review of Economic Studies*, 60:1 January, pp. 53-68.

Dotsey, M, R.G. King, and A.L. Wolman. (1999). "State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output." *Quarterly Journal of Economics*, 114:2, pp. 655-90.

Driffill, J., G.E. Mizon, and A. Ulph. (1990). "Costs of Inflation." *Handbook of Monetary Economics*, Volume II, pp. 1013-66.

Elliot, G., T.J. Rothenberg and J.H. Stock. (1996). "Efficient Tests for an Autoregressive Unit Root". *Econometrica* 64 no. 4 July, 813-836.

Engle, R.F. and C. W. J. Granger. (1987). "Co-Integration and Error Correction: Representation, Estimation, and Testing". *Econometrica*, 55:March, pp. 251-76.

Fielding, D. and P. Mizen. (2001). "The Relationship between Price Dispertion and Inflation: A Reassessment." European University Institute Working Paper, ECO no. 2001/10.

Fischer, S. (1981). "Relative Shocks, Relative Price Variability and Inflation." *Brookings Papers on Economic Activity*, 2, pp. 381-41.

Franz, W. and R.J. Gordon. (1993). "German and American Wage and Price Dynamics: Differences and Common Themes." *European Economic Review*, 37, pp. 719-62.

Garratt, A., Lee, K., Pesaran, M. H., Shin, Y. (2003) "A long run structural model of the UK', *Economic Journal*, pp.412-455.

Hartman, R. (1991). "Relative Price Variability and Inflation." *Journal of Money, Credit, and Banking*, 23:May, pp. 185-205.

Hercowitz, Z. (1981). "Money and Dispersion of Relative Prices." *Journal of Political Economy*, 89, pp. 328-56.

Johansen, S. (1988). "Statistical Analysis of Cointegration Vectors." *Journal of Economic Dynamics and Control*, 12, pp. 231-54.

Johansen, S. (1995). *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press.

Konieczny, J.D. (1990). "Inflation, Output and Labour Productivity when Prices are Changed

Infrequently." *Economica*, 57:May, pp. 201-18.

Kuran, T. (1986). "Price Adjustment Costs, Anticipated Inflation, and Output." *Quarterly Journal of Economics*, 71:5 December, pp. 1020-7.

Lach, F. and D. Tsiddon. (1992). "The Behavior of Prices and Inflation: An Empirical Analysis of Disaggregated Price Data." *Journal of Political Economy*, 100:2, pp. 349-89.

Layard, R., S.J. Nickell and R. Jackman. (1991). *Unemployment, Macroeconomic Performance and the Labour Market*. Oxford University Press: Oxford.

Lucas, R.E., Jnr (1973). "Some International Evidence on Output-Inflation Tradeoffs." *American Economic Review*, 63:3, pp. 326-34.

Lucas, R. E., Jnr. (1994) 'On the Welfare Cost of Inflation' CEPR Working Paper No. 394.

Mankiw, G.N. (1985). "Small Menu Costs and Large Business Cycles: A Macroeconomic Model of Monopoly." *Quarterly Journal of Economics*, 100:May, pp. 529-37.

Mills, F. (1927). *The Behaviour of Prices*. New York: Arno.

Mitchell, W. (1915). "The Making and Using of Index Numbers," in *Introduction to Index Numbers and Wholesale Price in the United States and Foreign Countries*. Bull. Washington DC: United States Bureau of Labor Statistics.

Mizon, G.E. (1991). "Modelling Relative Price Variability and Aggregate Inflation in the United Kingdom." *Scandinavian Journal of Economics*, 93:2, pp. 189-211.

Mizon, G.E., J.C. Safford, and S.H. Thomas. (1991). "The distribution of consumer prices in the UK." *Economica*, 57, pp. 249-62.

Naish, H.F. (1986). "Price Adjustment Costs and the Output-Inflation Trade-Off." *Economica*, 53, pp. 219-30.

Okun, A. (1971). "The Mirage of Steady Inflation." *Brookings Papers on Economic Activity*, 2, pp. 435-98.

Parkin, M. (1986). "The Output-Inflation Trade-off when Prices are Costly to Change." *Journal of Political Economy*, 94:February, pp. 200-24.

Parks, R.W. (1978). "Inflation and Relative Price Variability." *Journal of Political Economy*, 86:1, pp. 79-95.

Parsley, D. (1996). "Inflation and Relative Price Variability in the Short and Long Run: New Evidence from the United States." *Journal of Money, Credit and Banking*, 28:3, pp. 323-41.

Pesaran, M.H. and Shin, Y. (2002) "Long-Run Structural Modelling" *Econometric Reviews*, 21.

Pesaran, M.H., Shin, Y. and Smith, R.P. (2002) "Structural Analysis of Vector Error Correction Models with Exogenous I(1) Variables" *Journal of Econometrics*, 97, pp.293-343.

Reinsdorf, M. (1994). "New Evidence on the Relationship Between Inflation and Price Dispersion." *American Economic Review*, 84, pp. 720-31.

Richards, T. and G. Stevens. (1987). "Estimating the Inflationary Effects of Depreciation."

Reserve Bank of Australia Research Discussion Paper:8713.

Rotemberg, J.J. (1983). "Aggregate Consequences of Fixed Costs of Price Adjustment." *American Economic Review*, 73:June, pp. 433-6.

Russell, B., J. Evans, and B. Preston. (2002). "The Impact of Inflation and Uncertainty on the Optimum Markup set by Firms." European University Institute Working Paper, ECO No. 2002/2.

Sheshinski, E. and Y. Weiss. (1977). "Inflation and Costs of Price Adjustment." *Review of Economic Studies*, 44:2 June, pp. 287-303.

Silver, M. and C. Ioannidis. (2001). "Intercountry Difference in the Relationship between Relative Price Variability and Average Prices." *Journal of Political Economy*, 109:2, pp. 355-74.

Simon, J. (1999). "Markups and Inflation." Massachusetts Institute of Technology Mimeo.

Sims, C. (1980) "Macroeconomics and Reality" *Econometrica,* 48, pp.1-48.

Sims, C. (1988). "Comments and Discussion." *Brookings Papers on Economic Activity*, 1, pp. 75-79.

Swan, T.W. (1963). "Longer-run problems of the balance of payments," in *The Australian Economy*. H.W. Arndt and W.M. Corden eds. Melbourne: Cheshire, pp. 384-95.

Vining, D.R. and T.C. Elwertowski. (1976). "The Relationship between Relative Prices and the General Price Level." *American Economic Review*, 66:4, pp. 699-708.

7. APPENDIX : INTERPRETING THE ESTIMATED MARKUP

We can interpret mu_2 as the markup of the price of non-traded GDP on unit labour costs in the following way. The GDP deflator may be defined as the weighted average of the implicit price deflators for exports and domestically consumed GDP , such that:

$$p_{GDP} \equiv \omega\, px + (1-\omega)\, p_D \tag{A1}$$

where p_D is the domestically consumed GDP implicit price deflator and ω is the share of exports in GDP. Substituting for the GDP deflator in (3) using (A1) provides the following expression:

$$mu_2 = [(1-\omega)\, p_D - (\delta - \omega)\, px] - (1-\delta)ulc \tag{A2}$$

If the impact of export prices on the GDP deflator is confined only to the direct impact of exports in the price index then the estimate of δ will equal the share of exports in GDP, ω, and the estimated markup, mu_2, collapses to $p_D - ulc$. That is, the estimated markup is of the price of domestically consumed GDP on unit labour costs and will not be affected in the long run by changes in rer_X. However, changes in rer_X will affect in the long-run the markup, $p_{GDP} - ulc$. Alternatively, if export prices have indirect effects on the price of domestically consumed GDP then $\delta > \omega$ and rer_X will have an impact upon the markup $p_D - ulc$ (and $p_{GDP} - ulc$) in the long-run.[27] In this case, if we denote by 'non-traded GDP' that part of GDP not subject to the direct and indirect effects of changes in export prices then the estimated markup, mu_2, represents the markup of the price of non-traded GDP on unit labour costs.

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[27] Indirect effects of higher export prices on the price of domestically consumed GDP may operate through 'supply' and 'demand' channels. The 'supply' effect is due to domestic producers diverting sales overseas reducing the supply of goods and services domestically leading to an increase in the markup of $p_D - ulc$. The 'demand' effect occurs if real export prices increase due to a depreciation of the exchange rate leading to a similar increase in real import prices and therefore to an increase in the price of domestically produced substitutes.

Table 1: Sources and Broad Definitions of the Data

United States	*Inflation and the Markup*	*RPV*	*Sample*
Annual	BEA: Private gross domestic product implicit price deflator at factor cost, exports implicit price deflator and unit labour costs.	BEA: National accounts industry data.	1948 to 1997
Quarterly	BEA: Gross domestic product implicit price deflator at factor cost, exports implicit price deflator and unit labour costs.	BLS: CPI-U data.	March 1967 to June 2001
United Kingdom			
Annual	ONS: Gross domestic product implicit price deflator at factor cost, exports implicit price deflator and unit labour costs.	ONS: National accounts industry data.	1948 to1999
Quarterly	ONS: Private final consumption implicit price deflator at 'factor cost', imports of goods and services implicit price deflator and unit labour costs.	ONS: Private final household consumption data.	March 1963 to March 2001

(a) Acronyms: BEA: United States Bureau of Economic Analysis. BLS: United States Bureau of Labor Statistics. ONS: United Kingdom Office of National Statistics.

(b) Annual United States data is the same as that used in Banerjee and Russell (2001b) where further details concerning the data can be found.

(c) Unit labour costs derived from aggregate national accounts data as total labour compensation divided by constant price gross domestic product.

(d) Exports and imports prices are measured for goods and services.

(e) The 'factor cost' adjustment of the quarterly United Kingdom consumption price index is $P_{FC} = P_{MP} / tax$ where P_{FC} and P_{MP} are prices at factor cost and market prices respectively, tax is GDP_{MP} / GDP_{FC}, where GDP_{MP} and GDP_{FC} are gross domestic product at market prices and factor cost respectively. While the 'factor cost' adjustment is theoretically appealing, in practice it has little effect on the results.

(f) The quarterly measures of *RPV* were seasonally adjusted using four quarter centred seasonal dummies simultaneously with the 'de-spiking' process. The data appendix of Banerjee, Mizen and Russell (2002) provides further details concerning the calculation of RPV and the data involved in the estimation.

Table 2: Testing for the Number of Cointegrating Vectors
Estimated Values of Q(r)

UNITED STATES

Annual			**Quarterly**		
$H_0 : r =$	Eigenvalues	$Q(r)$	$H_0 : r =$	Eigenvalues	$Q(r)$
0	0.7750	121.65 {58.96}	0	0.2945	85.93 {58.96}
1	0.5530	50.05 {39.08}	1	0.1737	39.53 {39.08}
2	0.1485	11.41 {22.95}	2	0.0727	14.15 {22.95}
3	0.0741	3.69 {10.56}	3	0.0304	4.11 {10.56}

UNITED KINGDOM

Annual			**Quarterly**		
$H_0 : r =$	Eigenvalues	$Q(r)$	$H_0 : r =$	Eigenvalues	$Q(r)$
0	0.5247	77.80 {58.96}	0	0.2292	72.07 {43.84}
1	0.4234	41.35 {39.08}	1	0.1755	33.54 {26.70}
2	0.2532	14.37 {22.95}	2	0.0321	4.98 {13.31}
3	0.0013	0.06 {10.56}	3	0.0010	0.15 {2.71}

Notes: Reported are the test statistics of the parsimonious models reported in Table 4. $Q(r)$ is the likelihood ratio statistic for determining the number of cointegrating vectors, r, in the I(1) analysis. 90 percent critical values shown in curly brackets { } are from Tables 15.3 and 15.4 of Johansen (1995).

Table 3a: Cointegrating Vectors and Adjustment Coefficients

	Markup Equation Δmu	'RER' Equation Δrer_X	Inflation Equation $\Delta^2 p$	RPV Equation ΔRPV	Cointegrating Vector
UNITED STATES ANNUAL **1950 to 1997**					
1	- 0.240 (- 4.0)	- 0.097 (- 1.0)	- 0.454 (- 8.1)	1.641 (0.4)	$mu + 0.319\,rer + 1.483\,\Delta p - 0.00192 T$ {0.171} {0.063} {0.188} {0.00032}
2	- 0.002 (- 0.1)	- 0.066 (- 1.2)	- 0.039 (- 1.3)	21.167 (9.4)	$\Delta p_t - 0.037\,rpv_t$ {0.195} {0.003}

Core and pre-determined variables
One lag of the core variables: the markup on unit labour costs, the 'real exchange rate', inflation, *RPV* and trend. Predetermined variables: dummies for 1951, 1973, 1974, 1983 and 1986 and the contemporaneous change in the logarithm of the unemployment rate. Number of observations, 48.

Implicit relationships
Implicit long-run markup-inflation relationship: $mu_2 + 1.124\,\Delta p$ where the implicit markup is
$mu_2 = [p - 0.242\,px] - 0.758\,ulc$.

Tests for serial correlation

LM(1) $\chi^2(16) = 10.76, \quad p-value = 0.82$

LM(4) $\chi^2(16) = 11.50, \quad p-value = 0.78$

Test for normality

Doornik-Hansen test for normality: $\chi^2(8) = 11.29, \quad p-value = 0.19$

Likelihood ratio test of cointegrating vector restrictions
Estimated coefficients are zero for *RPV* in cointegrating vector 1 and for the markup, 'real exchange rate' and trend in cointegrating vector 2 accepted $\chi^2(2) = 1.61, \quad p-value = 0.45$.

NOTES

Reported in ( ) are t-statistics and in { } are standard errors of the estimate. Normalized cointegrating vectors reported after imposing 2 vectors on the cointegration space.

The annual estimation began with two lags of the core variables, the contemporaneous and first lag of the unemployment variable and a trend in the cointegrating space. The quarterly estimation began in a similar fashion except with four lags of the core variables and four lags of the unemployment variable. The parsimonious form of the model was sought with the trend variable and the longest lags of the core variables and the unemployment variable eliminated if insignificant. Spike dummies were introduced for periods with residuals greater than 3 standard errors from zero.

Table 3b: Cointegrating Vectors and Adjustment Coefficients

	Markup Equation Δmu	'RER' Equation Δrer_X	Inflation Equation $\Delta^2 p$	RPV Equation ΔRPV	Cointegrating Vector
UNITED STATES QUARTERLY June 1968 to June 2001					
1	- 0.123 (- 4.3)	- 0.084 (- 2.1)	- 0.032 (- 2.1)	- 1.507 (- 0.3)	$mu_{\{0.368\}} + 0.272_{\{0.057\}} rer + 6.169_{\{1.249\}} \Delta p - 0.00082_{\{0.00033\}} T$
2	0.185 (1.8)	0.344 (2.3)	- 0.134 (- 2.4)	109.514 (6.2)	$\Delta p_{\{0.163\}} - 0.007_{\{0.001\}} rpv - 0.00011_{\{0.00002\}} T$

Core and pre-determined variables

Three lags of the core variables: the markup on unit labour costs, the 'real exchange rate', inflation, *RPV* and trend. Predetermined variables: dummies for September 1968, June 1973, March 1974, December 1977, June 1978, March 1981, March 1982 and March 1991 and the change in the logarithm of the unemployment rate lagged one period. Number of observations, 133.

Implicit relationships

Implicit long-run markup-inflation relationship: $mu_2 + 4.850 \Delta p$ where the implicit markup is

$$mu_2 = \left[p - 0.214\, px \right] - 0.786\, ulc .$$

Tests for serial correlation

LM(1)　　　　　　　　　　　　　　　　　$\chi^2(16) = 22.05, \ p-value = 0.14$

LM(4)　　　　　　　　　　　　　　　　　$\chi^2(16) = 23.89, \ p-value = 0.09$

Test for normality

Doornik-Hansen test for normality:　　　$\chi^2(8) = 10.71, \ p-value = 0.22$

Likelihood ratio test of cointegrating vector restrictions

Estimated coefficients are zero for *RPV* in cointegrating vector 1 and for the markup and 'real exchange rate' in cointegrating vector 2 accepted $\chi^2(1) = 0.03, \ p-value = 0.87$.

See also the notes at the bottom of Table 3a.

Table 3c: Cointegrating Vectors and Adjustment Coefficients

	Markup Equation Δmu	'RER' Equation Δrer_X	Inflation Equation $\Delta^2 p$	RPV Equation ΔRPV	Cointegrating Vector
	UNITED KINGDOM ANNUAL 1951 to 1999				
1	- 0.426 (- 3.0)	0.269 (0.7)	- 0.625 (- 3.4)	- 13.675 (- 0.8)	$mu_{\{0.113\}} + 0.340_{\{0.040\}} rer + 0.400_{\{0.070\}} \Delta p - 0.00509_{\{0.00034\}} T$
2	0.063 (1.6)	- 0.147 (- 1.4)	0.081 (1.6)	31.536 (6.7)	$\Delta p_{\{0.210\}} - 0.041_{\{0.005\}} rpv + 0.00094_{\{0.00041\}} T$

Core and pre-determined variables
Two lags of the core variables: the markup on unit labour costs, the 'real exchange rate', inflation, *RPV* and trend. Predetermined variables: dummies for 1951, 1974, 1975, 1976 and 1981 and the contemporaneous change in the logarithm of the unemployment rate. Number of observations, 49.

Implicit relationships
Implicit long-run markup-inflation relationship: $mu_2 + 0.299 \Delta p$ where the implicit markup is
$$mu_2 = [p - 0.254\, px] - 0.746\, ulc.$$

Tests for serial correlation

LM(1) $\qquad\qquad\qquad\qquad\qquad \chi^2(16) = 23.29,\ p-value = 0.11$

LM(4) $\qquad\qquad\qquad\qquad\qquad \chi^2(16) = 26.56,\ p-value = 0.05$

Test for normality

Doornik-Hansen test for normality: $\qquad \chi^2(8) = 11.85,\ p-value = 0.16$

Likelihood ratio test of cointegrating vector restrictions
Estimated coefficients are zero for *RPV* in cointegrating vector 1 and for the markup and RER in cointegrating vector 2 accepted $\chi^2(1) = 0.93,\ p-value = 0.34$.

See also the notes at the bottom of Table 3a.

Table 3d: Cointegrating Vectors and Adjustment Coefficients

	Markup Equation Δmu	'RER' Equation Δrer_M	Inflation Equation $\Delta^2 p$	RPV Equation ΔRPV	Cointegrating Vector
UNITED KINGDOM QUARTERLY **June 1964 to March 2001**					
1	- 0.136 (- 5.6)	0.020 (0.4)	- 0.074 (- 4.6)	1.800 (0.4)	$mu_t + \underset{\{0.187\}}{} 0.176 \underset{\{0.043\}}{rer_t} + 4.254 \underset{\{0.591\}}{\Delta p_t}$
2	0.030 (1.1)	0.059 (1.0)	- 0.003 (- 0.1)	24.035 (4.9)	$\Delta p_t \underset{\{0.483\}}{} - 0.023 \underset{\{0.004\}}{rpv_t}$

Core and pre-determined variables
Three lags of the core variables: the markup on unit labour costs, the 'real exchange rate', inflation and *RPV*. Predetermined variables: dummies for March 1973, March and December 1975, September 1979 and June 1991 and the change in the logarithm of the unemployment rate lagged one period. Number of observations, 148.

Implicit relationships
Implicit long-run markup-inflation relationship: $mu_1 + 3.617\Delta p$ where the implicit markup is

$$mu = p - 0.850\,ulc - 0.150\,pm$$

Tests for serial correlation

LM(1) $\chi^2(16) = 21.09, \quad p-value = 0.17$

LM(4) $\chi^2(16) = 11.71, \quad p-value = 0.76$

Test for normality

Doornik-Hansen test for normality: $\chi^2(8) = 15.08, \quad p-value = 0.06$

Likelihood ratio test of cointegrating vector restrictions
(a) Estimated coefficients are zero for *RPV* and trend in cointegrating vector 1 and for the markup RER and trend in cointegrating vector 2 accepted, $\chi_1^2 = 1.63$, $p-value = 0.65$.
(b) Estimated coefficients are zero for *RPV* in cointegrating vector 1 and for the markup and RER in cointegrating vector 2 accepted $\chi^2(1) = 1.58$, $p-value = 0.21$.

See also the notes at the bottom of Table 3a.

Table 4: $\chi^2(1)$ Tests of Significance of Markup in Cointegration Vectors

	Cointegrating Vector 1	*Cointegrating Vector 2*
US Annual	13.62, $p-value=0.00$	0.23, $p-value=0.63$
US Quarterly	5.65, $p-value=0.02$	2.63, $p-value=0.10$
UK Annual	12.09, $p-value=0.00$	13.48, $p-value=0.00$
UK Quarterly	17.28, $p-value=0.00$	3.42, $p-value=0.06$

Note: The systems reported in Tables 4a to 4d are reformulated as

$$\text{Cointegrating Vector 1}: \quad \nu_0\, mu \,+\, \nu_1\, rer \,+\, \nu_2\, \Delta p \,+\, \nu_3\, trend$$

$$\text{Cointegrating Vector 2}: \quad \varpi_0\, mu \,+\, \varpi_1\, rer \,+\, \varpi_2\, rpv \,+\, \varpi_3\, trend$$

The reported individual $\chi^2(1)$ tests are that $\nu_0=0$ in cointegrating vector 1 and $\varpi_0=0$ in cointegrating vector 2.

Table 5: Estimates of the Inflation-*RPV* Long-run Relationship

	Single Equation Estimate	*Systems Estimate*
United States Annual	30.200	27.036
	{11.200}	{5.274}
United States Quarterly	98.548	147.152
	{23.817}	{23.986}
United Kingdom Annual	21.849	24.448
	{5.332}	{5.134}
United Kingdom Quarterly	51.795	44.281
	{22.095}	{21.392}

Note: Reported in brackets { } are standard errors. The single equation estimates of the cointegrating parameter, ϑ, and its standard error are derived from estimating the Bewley (1979) transform of the ADL(m,n) model given by:

$$rpvs_t = c + \vartheta \Delta p_t + \sum_{i=0}^{m-1} \alpha_i \Delta rpv_{t-i} + \sum_{j=0}^{n-1} \beta_j \Delta^2 p_{t-j}$$

The Bewley transform is estimated using 2SLS with the lagged endogenous variables and current and lagged exogenous variables as instruments. A trend is included if significant. The system estimates are from Tables 3a to 3d normalized on *rpv*.

Graph 1a: United States

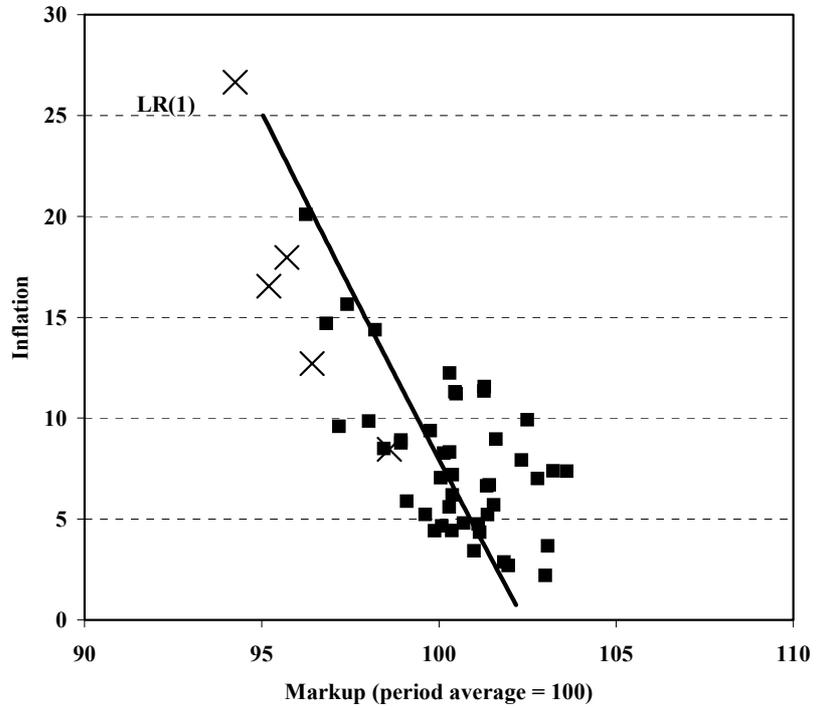## Annual Inflation and the Markup
1950 to 1997
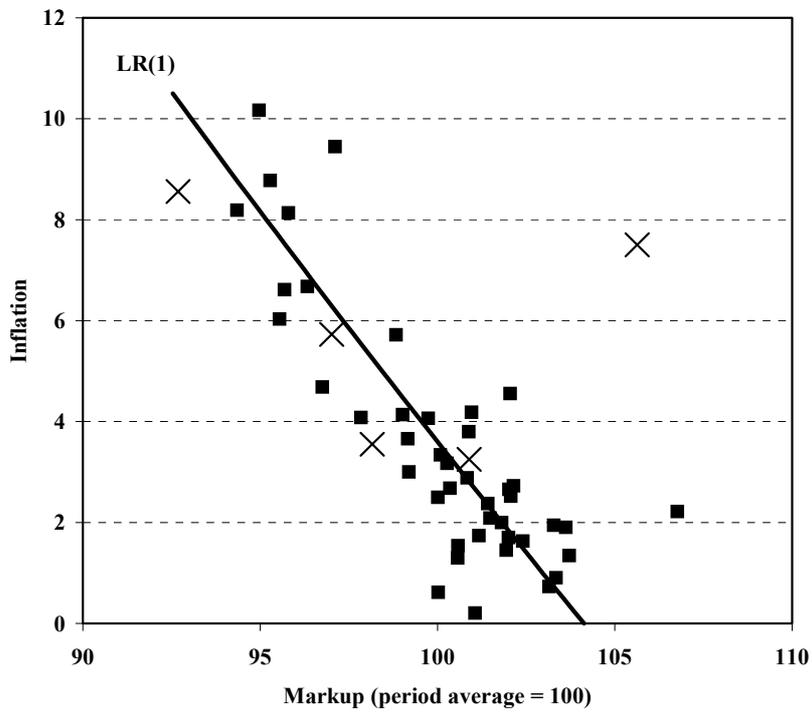
Annual Inflation and Relative Price Variability
1950 to 1997
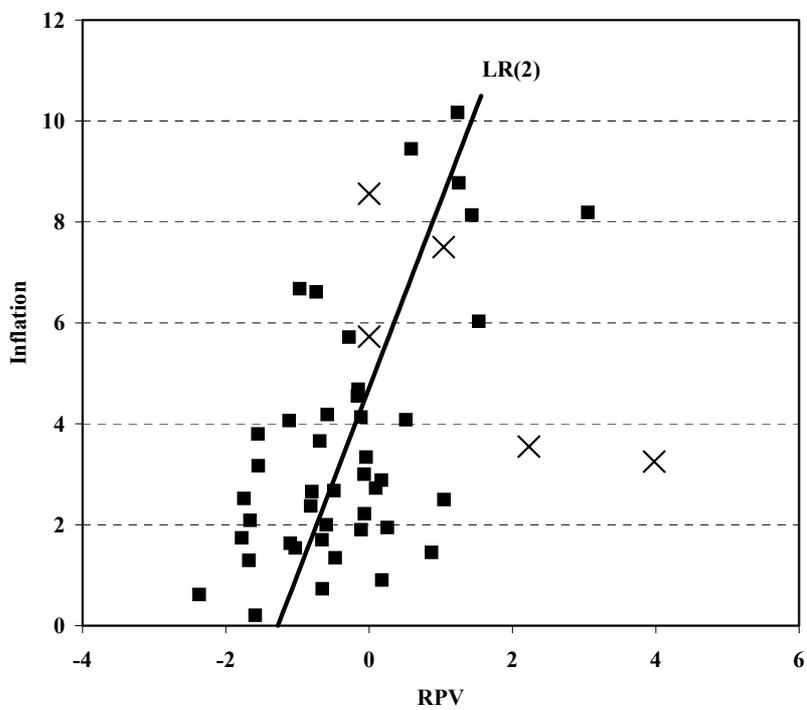
Graph 1b: United Kingdom

Annual Inflation and the Markup
1951 to 1999

Annual Inflation and Relative Price Variability
1951 to 1999