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An I(2) Analysis of Inflation and the Markup

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and
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An I(2) Analysis of Inflation and the Markup*

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Abstract

An I(2) analysis of Australian inflation and the markup is undertaken within an imperfect competition model. It is found that the levels of prices and costs are best characterised as integrated of order 2 and that the levels cointegrate to the markup which is integrated of order 1. A further cointegrating relationship is found to exist where higher price inflation results in a lower markup in the steady state. The negative correlation between inflation and the markup is interpreted as the cost to firms of overcoming missing information when adjusting prices in an inflationary environment.

Keywords: Inflation, Wages, Prices, Markup, I(2), Polynomial Cointegration.
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TABLE OF CONTENTS

1 INTRODUCTION 1

2 AN INFLATION COST MARKUP MODEL OF PRICES 5

2.1 The Costs of Inflation and the Markup 8

2.2 Inflation and the Markup in the Steady State 8

2.3 The Statistical Properties of Inflation 9

3 THE ESTIMATED PRICE EQUATION 12

3.1 A Brief Survey of the I(2) Theory 13

3.2 Reduction from I(2) to I(1): Estimating an I(2) System 20

3.3 Reduction from I(1) to I(0): Estimating an I(1) System 23

3.4 Estimating a Single Price Equation 29

3.4.1 Causation, the Markup and Inflation 34

4 INFLATION AND THE MARKUP IN THE STEADY STATE 36

5 CONCLUSION 37

REFERENCES 39

1 INTRODUCTION

The pricing models of Bénabou (1992) and Russell *et al.* (1997) predict that higher inflation leads to a lower markup. Bénabou argues that the lower markup is due to greater competition as a result of the higher inflation. Russell *et al.* argues that higher inflation makes it more difficult for firms to overcome missing information concerning the profit maximising price when setting prices. The lower markup is interpreted as the higher cost of the missing information with higher inflation. Furthermore, it is argued that the negative correlation between inflation and the markup will persist in the steady state if the information remains 'missing'.

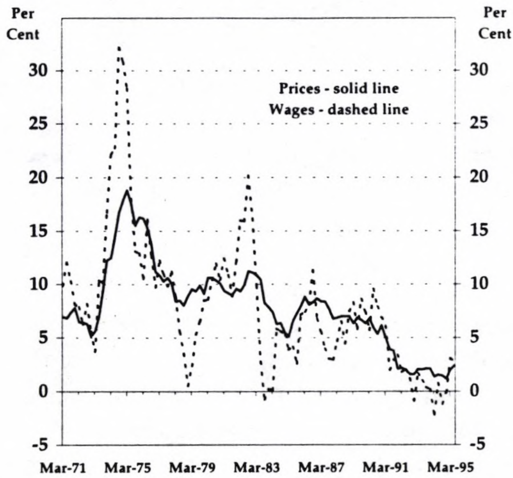
This paper investigates the proposition that inflation and the markup are negatively correlated in the steady state. The possibility of a *steady state* relationship imposes a definite modelling strategy on the investigation. First, the inflation data used to investigate the proposition must follow a non-stationary statistical process. If inflation is a stationary statistical process with a constant mean then inflation displays only one value in the steady state. Therefore, by assuming inflation is stationary, no steady state relationship between a range of inflation rates and the markup can be identified from the data even if the variables are related over a range of steady state rates of inflation. The second aspect of the modelling strategy follows from the first. If inflation is a non-stationary statistical process and possibly integrated of order 1 then the empirical investigation must accommodate the *possibility* that the price level is I(2).[1]

These two aspects of the modelling strategy are followed in the paper. Australian data is chosen for the empirical analysis as the inflation data appears to be non-stationary. Graph 1 shows that Australian inflation has varied widely over the past 25 years displaying a number of distinct inflationary periods. Following low inflation in the early 1970s, inflation rose substantially with the first OPEC oil price shock and successive wage shocks. Inflation rose again in the late 1970s and early 1980s with a wage boom associated with a buoyant mining industry and the second OPEC oil price shock before moderating

[1] The notation I(d) represents the phrase 'integrated of order d'. For a comprehensive discussion on the statistical properties of data and the order of integration see Banerjee *et al.* (1993) or Johansen (1995a).

through the 1980s. During the recession beginning in 1989, inflation declined to rates not seen since the beginning of the period.

Graph 1: Wage and Price Inflation*
Four Quarter Ended Percentage Change



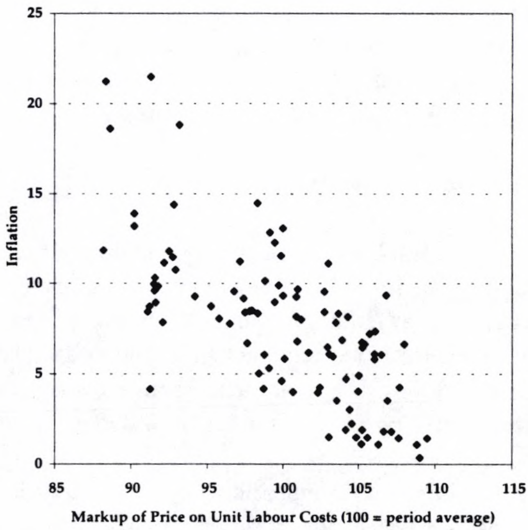
* Prices are defined as the consumption deflator and wages as non-farm unit labour costs and are measured on a national accounts basis.

The evidence of distinctly different inflationary periods is consistent with standard macroeconomic models where economies can experience any constant rate of inflation in the steady state. This implies, that in a statistical sense, inflation can exhibit changes in its mean between periods and may follow an integrated statistical process.

Following from the above, a necessary but not sufficient condition for the proposition to be correct is that the markup is also non-stationary. As a general measure of the markup, Graph 2 shows the markup of price on unit labour costs. The wage shocks in the early 1970s led to a large fall in the markup that persisted until the late 1980s. The extended period of a low markup may simply represent slow price adjustment in response to the wage shocks in the early 1970s. However, this representation should be questioned since the adjustment appears so slow and a case could be established for the markup to be a genuinely integrated process.

Graph 2: The Markup of Price on Unit Labour Costs*

Graph 3: The Markup of Price on Unit Labour Costs and Inflation



* The markup is calculated as prices divided by wages and the period average of the index is 100. Inflation is the annualised quarterly value.

It is proposed that the non-stationary characteristics of inflation and the wide variations in the markup are closely related and that high inflation is associated with a low markup as argued by Bénabou (1992) and Russell *et al.* (1997). Comparing inflation and the markup in Graph 3 reveals the veracity of this proposition. However, whether the negative correlation between inflation and the markup will persist in the steady state cannot be determined graphically and requires a more sophisticated empirical analysis.

The second aspect of the modelling strategy is aimed at investigating if the negative correlation persists in the steady state. We argue that the variables of interest, namely the levels of prices and costs are best described as I(2) statistical processes. From this starting point we proceed to estimate an I(2) system using techniques developed by Johansen (1995a, b). We find that the levels of prices and costs cointegrate to an I(1) process as the markup of price on labour and import costs. This constitutes the reduction of the system from I(2) to I(1) space.

In addition there is a further reduction available by cointegrating the markup with a linear combination of the differences of the core variables. We proceed to establish the existence of this cointegrating vector by looking at the bivariate system given by the markup and inflation. This constitutes the reduction from I(1) to I(0) that can also be confirmed directly from the I(2) analysis. Finally, we establish that the markup is weakly exogenous in the bivariate system enabling us to estimate a single price equation.

The results at each stage of the reduction corroborate each other in establishing the main results that (a) the levels of prices and costs are best described as I(2) statistical processes; (b) they cointegrate to an I(1) process as the markup; and (c) the markup and price inflation are cointegrated with a higher steady state rate of inflation associated with a lower markup in the long-run. The lower markup is interpreted as the cost to firms of higher inflation.

In the next section an imperfect competition model of prices is set out where inflation imposes costs on firms in the steady state. The theoretical support for the proposition that inflation imposes costs on firms is briefly reviewed before we consider the statistical properties of inflation. In Section 3 we estimate an Australian price equation using quarterly data for the period 1972 to 1995.

If inflation and the markup are stationary variables then the correlation displayed in Graph 3 is only due to the short-run dynamics in the variables. While this may be of interest in understanding the short-run behaviour of the variables, the proposition that inflation and the markup are negatively correlated in the steady state has a number of important economic implications. First, if inflation is negatively correlated with the markup then inflation is positively correlated with the real wage for a given level of productivity. If unemployment is, in part, dependent on the real wage then it follows that it is unlikely that the long-run Phillips curve is vertical. Second, the negative correlation provides an explanation of the widely reported international evidence of the negative correlation between stock returns and inflation.[2] The lower stock returns simply reflect the impact of inflation on the profitability of firms. Third, the negative correlation provides an explanation as to why firms may desire a low rather than high rate of inflation in the steady state as lower inflation reduces the cost of the missing information borne by firms.

2 AN INFLATION COST MARKUP MODEL OF PRICES

A markup model of prices for a closed economy may be derived using an imperfect competition model of inflation in the Layard-Nickell tradition.[3] We can write the firm's desired markup as:

$$p - w = \omega_0 - \omega_1 U - \omega_2 \Delta U + \omega_3 z_p - \omega_4 \left(p - p^e\right) - \omega_5 \phi - \omega_6 \Delta p \qquad (1)$$

and labour's desired real wage as:

$$w - p = \gamma_0 - \gamma_1 U - \gamma_2 \Delta U + \gamma_3 z_w - \gamma_4 \left(p - p^e\right) - \gamma_5 \phi \qquad (2)$$

where p, p^e, w, U and ϕ are prices, expected prices, wages, the unemployment rate and productivity respectively. The lower case variables are in logs, Δ is the change in the variable and all coefficients are positive. The variables z_w and z_p capture shifts in the bargaining position of labour and

---

2 For example see Bodie (1976), Jaffe and Mandelker (1976), Nelson (1976), Fama and Schwert (1977), Gultekin (1983) and Kaul (1987).

3 This model is based on Layard *et al.* (1991). See Cockerell and Russell (1995) for a more detailed discussion of the standard model in relation to a markup model of prices.

firms respectively.[4] For labour, z_w includes unemployment benefits, tax rates, and measures of labour market skill mismatch. Similarly for firms, z_p includes measures of the firm's competitive environment or market power, indirect taxes, and non-labour input costs including oil prices. The unemployment term in the firm's desired markup equation is simply an output measure using Okun's law.

The cost to firms of inflation in this model is represented by $\omega_6 \Delta p$. In the standard model $\omega_6 = 0$ and inflation imposes no costs on the firm. In the more general model where $\omega_6 > 0$, the desired markup of firms is lower with higher inflation.

These two equations represent the desired claims of firms and labour on the real output of the economy. By design the *ex post* markup of firms must be equivalent to the inverse of labour's real wage. We can, therefore, eliminate the markup, $p-w$, from (1) and (2) to provide an expression for the unemployment rate. Alternatively, we can eliminate the unemployment rate to provide the following expression for the markup:

$$\begin{aligned} p-w=&(\gamma_1+\omega_1)^{-1}\{-(\omega_1\gamma_0-\omega_0\gamma_1)-(\omega_2\gamma_1-\omega_1\gamma_2)\Delta U-\omega_1\gamma_3 z_w+\omega_3\gamma_1 z_p\} \\ &+(\gamma_1+\omega_1)^{-1}\{-(\omega_4\gamma_1-\omega_1\gamma_4)(p-p^e)-(\omega_5\gamma_1+\omega_1\gamma_5)\phi-\omega_6\gamma_1\Delta p\}. \end{aligned} \quad (3)$$

Defining the long-run as $\Delta U = 0$ and $p = p^e$, then the long-run markup is:

$$\overline{p-w}=(\gamma_1+\omega_1)^{-1}\{\omega_0\gamma_1-\omega_1\gamma_0-\omega_1\gamma_3 z_w+\omega_3\gamma_1 z_p-(\omega_5\gamma_1+\omega_1\gamma_5)\phi-\omega_6\gamma_1\Delta p\} \quad (4)$$

where the bar over the variable indicates its long-run value. If we assume firms price independently of demand and that income shares are independent of the level of productivity then the long-run markup collapses to:[5]

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4 For a detailed discussion of the theory underlying these shift variables see Layard *et al.* (1991) or for a simple taxonomy of explanations see Coulton and Cromb (1994).

5 If firms price independently of demand then $\omega_1 = 0$. Normal cost markup and kinked demand curve models suggest the price level is largely insensitive to demand fluctuations. See Hall and Hitch (1939), Sweezy (1939), Layard *et al.* (1991), Carlin and Soskice (1990), Coutts *et al.* (1978), Tobin (1972), Bils (1987). For labour and firms to maintain stable income shares in the long-run and for these shares not to continually rise or fall with trend productivity, the coefficient on productivity in the long-run markup equation

$$\overline{p-w} = \omega_0 + \omega_3 z_p - \phi - \omega_6 \overline{\Delta p}. \tag{5}$$

The markup in the long-run, therefore, is independent of wage pressure shocks z_w but dependent on the competitive environment captured by z_p. With $\omega_6 = 0$ as in the standard model, the markup is independent of inflation in the long-run. In the general model, $\omega_6 > 0$ and the markup is negatively correlated with the rate of inflation in the long-run.[6]

Rewriting (5) as a price equation gives:

$$\overline{p} = \omega_0 + \omega_3 z_p + (w - \phi) - \omega_6 \overline{\Delta p}. \tag{6}$$

Equation (6) shows that for a given competitive environment the long-run price level depends on the markup, $\omega_0 + \omega_3 z_p$, the level of unit labour costs, $w - \phi$, and the steady state rate of inflation, $\overline{\Delta p}$.

Finally, an important issue is whether the standard model as outlined in (1) and (2) when $\omega_6 = 0$ is identified.[7] If the equations represent the bargaining behaviour of labour and firms then it can be expected that the variables that impact on the bargaining behaviour of one group, will automatically impact on the other group. For example, union strength will not only affect labour's bargaining position but also how firms conduct negotiations with labour. In a bargaining model, therefore, z_w and z_p enter both the price and wage equations and the standard model where inflation imposes no costs on firms is not identified. However, in the more general model where the inflation cost term appears only in the price equation, this identifies the model in an important way

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$(\omega_5 \gamma_1 + \omega_1 \gamma_5)/(\gamma_1 + \omega_1)$ must equal one. This condition is met if linear homogeneity is assumed and $\omega_5 = 1$ and $\gamma_5 = 1$. However, if firms price independently of demand and maximise profits (which implies $\omega_5 = 1$) then this condition will hold irrespective of γ_5.

6 This specification is not strictly true for it implies that the markup approaches zero as inflation tends to an infinite rate. However, over a small range of inflation the relationship may be a good approximation. Russell (1998) overcomes this problem by specifying the cost of inflation as; $\omega_6 \left[\Delta p/(\Delta p + \Delta e)\right]$ where Δe is trend productivity.

7 The model is not identified if adding a multiple of one equation to the other leaves the form of the equation unchanged. A number of authors, including Manning (1994), have raised doubts as to whether the imperfect competition model is identified.

that can be tested. This issue is returned to following the estimation of the model.

Before we proceed with the estimation of the price equation, we will address in turn three issues. First, why does higher inflation reduce the markup? Second, can the negative correlation between inflation and the markup persist in the steady state? And finally, the implications of how we characterise the shifts in the mean rate of inflation for the statistical properties of the inflation data.

2.1 The Costs of Inflation and the Markup

The negative correlation between inflation and the markup may be explained in one of two ways. Bénabou (1992) argues within a price-taking model that higher inflation leads to greater search by customers in a customer market and that the subsequent increase in competition reduces the profit maximising markup.

In contrast with Bénabou's price-taking model and in keeping with the imperfect competition model proposed above, Russell *et al.* (1997) explains the negative correlation within a price-setting model. In this model, the lower markup is the cost to firms of overcoming missing information in an inflationary environment. Firms are assumed to face an asymmetric loss function where mistakenly setting a 'high' price relative to the unknown (full information) profit maximising price costs the firm more than setting a 'low' price. The asymmetry exists because of increasing returns to scale, a kinked demand curve or the firm trades in a customer market. Firms that minimise the expected loss of setting an incorrect price when faced with uncertainty will act cautiously and set a 'low' price relative to the (full information) profit maximising price. Implicitly, firms are also setting a 'low' markup. It follows that if uncertainty increases with inflation then firms will act more cautiously with higher inflation and set a lower markup.

2.2 Inflation and the Markup in the Steady State

It is unlikely that the mechanism proposed by Bénabou (1992) that underpins the negative correlation between inflation and the markup will persist in the steady state. The 'trigger' for the customer to search in Bénabou's model is a change in the price level. Presumably, the 'true' trigger is the change in the price level relative to the general rate of inflation. In the steady state when the firm's prices are increasing in line with general inflation, the trigger disappears and competition will return to its steady state level along with the markup.

Alternatively, in the model proposed by Russell *et al.* (1997), the negative correlation will persist in the steady state if the uncertainty due to missing information also persists in the steady state. If the uncertainty is due to firms not knowing the average rate of inflation then uncertainty will disappear in the steady state and any short-run relationship between inflation and the markup will also disappear. In a price-taking model with perfectly competitive firms, this may well be a good characterisation of the uncertainty faced by firms. To maximise profits, firms simply need to accurately predict the price level so that they can set the profit maximising level of output.

However, for price-setting firms this may be a poor characterisation of uncertainty. Uncertainty may be more than just not knowing the average rate of inflation. For price-setting firms, the uncertainty may be due to the difficulty in coordinating price changes in an inflationary environment and the profit maximising price remains uncertain. This difficulty may persist even when firms are aware of the average rate of inflation and, therefore, the relationship between inflation and the markup may also persist in the steady state.[8] Furthermore, price-setting firms must respond to higher inflation by changing prices more often, by larger amounts in real terms, or by some combination of these responses. These responses are likely to increase the difficulty of coordinating price changes. Therefore, uncertainty is likely to increase with inflation as the firm's difficulty in coordinating price changes also increases.

2.3 The Statistical Properties of Inflation

Rewriting (6) in the form given by (7) highlights the dependence of the long-run or steady state markup, $\overline{mu}$, on inflation and the exogenous variables and gives useful insight into the possible integration properties of the data.

$$\overline{mu} = \overline{p-(w-\phi)} = (\omega_0 + \omega_3 z_p) - \omega_6 \overline{\Delta p} . \tag{7}$$

[8] A number of authors argue firms find difficulty in co-ordinating their price changes. For example, see Ball and Romer (1991), Eckstein and Fromm (1968), Blinder (1990), and Chatterjee and Cooper (1989).

Abstracting for the moment from structural breaks, it may be seen from (7) that the order of integration of the markup, $\overline{mu}$, must match the order of integration of inflation assuming that the exogenous variables are all I(0). Similarly, allowing for structural breaks implies that if inflation is I(0) or I(1) with breaks then so too is the markup.[9]

Table 1 lists the possible combinations of orders of integration for the markup and inflation that are consistent with (7).[10] Because we are interested in explaining the correlation between the markup and inflation evident in Graph 3, only (a) and (c) need to be considered when empirically investigating any steady state relationship.[11] The choice of how to characterise the integration properties of inflation and the markup can be made on practical and conceptual levels.

Shifts in the mean rate of inflation over the period reflect changes in the target rates of inflation by the monetary authorities.[12] Therefore, understanding the 'true' statistical process of inflation depends, in part, on how we characterise the behaviour of the monetary authorities in response to inflation shocks and the nature of the shocks themselves.

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9 The implications for the markup of structural breaks in inflation also apply to the exogenous unmodelled processes of competition. However, in order to be succinct we consider only the cases that relate to the structural breaks in inflation.

10 The theory of I(2) processes described in Section 3.1 allows one further case that is not reported in Table 1 where prices and costs are I(2) and the markup is I(0) (*i.e.* the effect of cointegrating the levels of the variables leads to a reduction in the order of integration by two). This case however is inconsistent with (7) where the markup and inflation are of the *same* order of integration. Our subsequent empirical analysis in Section 3.2 shows this further case is not empirically relevant which is in accord with the economic theory that underpins (7).

11 Option (b) is consistent with the standard macroeconomic model where inflation and the markup are uncorrelated in the steady state.

12 The term 'target' is used loosely and does not imply that the monetary authorities explicitly state a target rate of inflation. Instead, the 'target' refers to the revealed preference of the authorities following shocks to the 'general' level of inflation. If the authorities were not satisfied with the 'general' level of inflation, they would have adjusted monetary policy to achieve a 'general' rate of inflation with which they were satisfied.

Table 1: Integration of the Markup and Inflation

	Order of Integration for Prices and Costs	Implications for the Markup	Implication for Inflation	Possibility of negative steady state correlation
(a)	I(2)	I(1)	I(1)	Yes
(b)	I(1)	I(0)	I(0)	No
(c)	I(1) with breaks	I(0) with breaks	I(0) with breaks	Yes

Focussing first on option (c) in Table 1. If the authorities hold a series of unique inflation targets that are independent of the inflation shocks then inflation will follow a stationary process with shifting mean. If one were able to identify the timing of every shift in the target rate of inflation then a dummy variable can be introduced to capture each shift in the target. The maximum number of dummies would be one less than the number of observations in the sample investigated. In practice one would introduce enough dummies to 'render' inflation a stationary series. Given the well-known low power of unit root tests and tests of breaks in series, it is likely the series would be 'rendered' stationary with the inclusion of a small number of dummies. However, in practice this approach is unsatisfactory as it is unlikely that the number of dummies would be identical to the 'true' number of shifts in the target rates of inflation by the monetary authorities. On a conceptual level this approach is also unsatisfactory due to the lack of economic interpretation of the dummies and the model structure it entails.

An alternative way to proceed is to focus on option (a) and characterise the monetary authorities as at least partially adjusting their inflation target in response to the inflation shocks in each period. In this case, inflation is likely to follow a non-stationary statistical process. Given the Australian monetary authorities have responded to both unemployment and inflation when setting monetary policy over most, if not all, of the period in question, the second characterisation of the monetary authorities appears the most relevant.

While acknowledging the possibility that the 'true' statistical process of inflation may be stationary about a frequently (but unknown) shifting mean, this paper proceeds to investigate the relationship between inflation and the markup by allowing for the *possibility* that either or both series are integrated.

3 THE ESTIMATED PRICE EQUATION

We propose an imperfect competition model of prices based on (6) where firms desire in the long-run a constant ratio (or markup) of price on unit costs net of the cost of inflation. Short-run deviations in the ratio are the result of shocks and the economic cycle. For an open economy, costs include those for labour and imports and, assuming that the competitive environment is unchanged, the long-run price equation can be written:[13]

$$P = Q\left(\frac{P_t}{P_{t-1}}\right)^{-\lambda} ULC^{\delta}\ PM^{1-\delta} \tag{8}$$

where P_t/P_{t-1} is the proportional rate of growth of prices, ULC is unit labour costs, PM is the price per unit of imports and the coefficients λ and δ are positive.[14] The coefficients δ and $1-\delta$ are the long-run price elasticities with respect to unit labour costs and import prices respectively. Long-run homogeneity is imposed with these coefficients summing to one.[15] That is, for a given rate of inflation, an increase in either unit labour costs or import prices will see prices fully adjust in the long-run to leave the markup unchanged.

Equation (8) collapses to the standard imperfect competition markup model of prices when $\lambda = 0$. In the more general case when $\lambda \neq 0$, inflation imposes costs on firms and the markup net of inflation costs is reduced.

The remainder of this section seeks to estimate a price equation using quarterly Australian data. We now turn briefly to the theoretical issues associated with estimating a price equation allowing for the possibility that the levels of prices and costs are I(2).

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13 The form of the long-run price equation is similar to that estimated in de Brouwer and Ericsson (1995).

14 In terms of equation (6), $\lambda = \omega_6$ and $\ln(Q) = \omega_0 + \omega_3 z_p$.

15 Without linear homogeneity Q does not represent the markup of prices on costs.

3.1 A Brief Survey of the I(2) Theory

This section introduces the theory of systems of equations where the core variables of the system are integrated at most of order 2. That is, second-differencing is the most that is required for the series to be stationary. The theory is complex, particularly in relation to the handling of deterministic components such as constants and trends, and introduces important elements beyond those required for the now standard I(1) framework of system estimation. No more than a sketch of the formal analysis is attempted here. For a more detailed analysis the reader is referred to Haldrup (1997), Johansen (1995a, b) and Paruolo (1996). Engsted and Haldrup (1998) and Juselius (1998) also provide useful empirical applications.

The heart of the empirical analysis of the paper is to model three core variables as an I(2) system. The core variables are the logarithms of prices, unit labour costs and unit import prices and are denoted p_t, ulc_t and pm_t respectively. The analysis is conditioned on a number of predetermined variables that are assumed to be integrated of order 0 and are described in due course.[16] Nevertheless, the 'important' assumption is that the three core variables in the system are integrated of order 2.

This 'important' assumption poses some quite interesting and econometrically tricky modelling challenges. However, working in I(2) space allows us to consider the scenario where the core variables cointegrate as the markup of price on labour and import costs, mu_t, such that:

$$mu_t = p_t - \theta\, ulc_t - (1-\theta)\, pm_t \qquad (9)$$

where θ is a positive parameter and the markup is I(1). In this scenario, taking a linear combination of the core variables leads to a reduction in the order of integration by only 1. In addition there are two other interesting possibilities for cointegration. First, the I(2) core variables may cointegrate directly to a stationary variable. That is, the markup, mu_t, in (9) is I(0). Second, if the markup is I(1), a linear combination of mu_t with the *differences* of the core

16 The data set used in the empirical analysis is an updated version of that used in Cockerell and Russell (1995) with 3 extra quarterly observations. The predetermined variables were tested extensively in Cockerell and Russell (1995) using ADF and KPSS unit root tests and found to be best described as I(0) statistical processes.

variables may lead to an I(0) variable. The second possibility is of particular interest since it allows us to investigate the proposition that there is a relationship between the markup, mu_t, and inflation in the steady state. The second possibility is referred to in the I(2) literature as polynomial cointegration or multicointegration. We prefer the former terminology as established by Yoo (1986), Johansen (1992, 1995b), Gregoir and Laroque (1993, 1994), and Juselius (1998).

The objective of our empirical analysis is to start with a system where the core variables are potentially I(2) but to end, after a process of reduction, with a single-equation representation of the inflation process as a function of the markup.

Thus, consider a second-order vector autoregression of the core variables, x_t, of dimension $p \times 1$:

$$x_t = \Pi_1 x_{t-1} + \Pi_2 x_{t-2} + \Phi D_t + \mu + \varepsilon_t \tag{10a}$$

where μ is a constant term that may be unrestricted and D_t is a vector of predetermined variables on which the empirical analysis is conditioned. This may be rewritten in vector error correction (VECM) form as:

$$\Delta x_t = \Gamma_1 \Delta x_{t-1} + \Pi x_{t-1} + \Phi D_t + \mu + \varepsilon_t \tag{10b}$$

where $\Pi = \Pi_1 + \Pi_2 - I_p$ and $\Gamma_1 = -\Pi_2$. Equation (10b) can also be written as:

$$\Delta^2 x_t = -\Gamma \Delta x_{t-1} + \Pi x_{t-1} + \Phi D_t + \mu + \varepsilon_t \tag{10c}$$

where $\Gamma = I_p + \Pi_2$.

The predetermined variables may or may not enter the cointegrating space depending on the restrictions imposed during estimation of the system and may include seasonal or intervention step or spike dummies. The variable ε_t is a p-dimensional vector of errors assumed to be Gaussian with mean vector 0 and variance matrix Σ. The parameters $(\Pi_1, \Pi_2, \Pi, \Phi, \mu, \Sigma)$ are assumed to be variation free. The VECM has been restricted to two lags without any loss of generality since one can consider extensions to any order of the lag structure without altering any of the basic arguments.

In our specific empirical model, $p = 3$ and x_t is the vector of core variables defined earlier. The predetermined variables, D_t, are set out in Table 2.

Table 2: The Pre-Determined Variables

Inside Unemployment	Logarithm of inside unemployment defined as the unemployed with at least 2 weeks of full time work in the past 2 years, taken as a percentage of employment plus inside unemployment.*
Δ Tax	Calculated as the first difference of the log of the variable (1 + tax/100) where tax is defined as non-farm indirect tax plus subsidies as a proportion of non-farm GDP at factor cost.
Δ Petrol Prices	First difference of the log of petrol prices.
Strikes	Strikes measured as working days lost as a proportion of employed full and part-time persons. The variable is adjusted for a shift in the mean in the March quarter of 1983.
Dummies	Spike intervention dummies for June and September 1973, September 1974 and December 1975.

* For a detailed discussion of the inside unemployment variable and its construction see Cockerell and Russell (1995).

The matrix Π in (10b) is the long-run matrix and encapsulates the main cointegration possibilities in the system. In traditional I(1) analysis the hypothesis that the core variables, x_t, are I(1) is formulated as the combination of the following two rank conditions on matrices. First we require that:

$$\Pi = \alpha \beta' \tag{11}$$

where α and β are $p \times r$ dimensional matrices of rank r. The matrix α is called the loading matrix and gives the weights with which each of the r cointegrating relationships enters each of the p equations in the system. The r columns of the matrix β are the cointegrating vectors.

Thus the long-run matrix Π is of reduced rank r, with r providing the cointegrating rank or the number of cointegrating vectors for the system. There is the additional requirement to rule out the possibility that the process is I(2) and that is the matrix given by:

$$\alpha_{\perp}' \Gamma \beta_{\perp} \tag{12}$$

is of full rank, where the matrices indexed by $\perp$ represent the orthogonal complements of the corresponding matrices and are each of rank $p - r$. In a system composed solely of I(1) variables, the matrix $\beta' x_t$ gives the r cointegrating or I(0) relationships of the system. The matrix $\beta_{\perp}' x_t$ gives the $p - r$ non-cointegrating relationships or common trends of the process. In the I(1) analysis the decomposition of the system can be written:

$$\text{I(0) cointegrating relationships:} \quad r \quad \beta' x_t; \tag{13a}$$

$$\text{I(1) non-cointegrating relationships:} \quad p - r \quad \beta_{\perp}' x_t. \tag{13b}$$

Therefore, if an empirical system with $p = 3$ had one cointegrating relationship and hence $r = 1$, there should be two I(1) non-cointegrating relationships or common trends assuming that the system can be characterised satisfactorily as lying in I(1) space. In other words, the characteristic polynomial of the system, $A(z)$, given by:

$$A(z) = I_p - \sum_{i=1}^{k} \Pi_i z_i \tag{14}$$

would have two unit roots, one from each of the common trends. For an I(2) system, some further enriching possibilities present themselves. For a system to be I(2) requires not only that $\alpha\beta'$ is of reduced rank but that $\alpha_{\perp}' \Gamma \beta_{\perp}$, which is a $(p - r) \times (p - r)$ matrix is also of reduced rank s.[17] This latter matrix is, therefore, expressible as:

$$\alpha_{\perp}' \Gamma \beta_{\perp} = \xi\eta' \tag{15}$$

where ξ and η are matrices of order $(p - r) \times s$ with $s < p - r$.

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17 Technically we need to check further rank condition(s) to rule out the possibility that the system is I(3). Since both statistically and economically this might be regarded as an extremely unlikely case we assume that the conditions which rule out I(3) behaviour hold in our analysis.

Having met this requirement the I(2) system is now decomposable into I(0), I(1) and I(2) directions with dimensions r (as before), s and $p - r - s$ respectively. Moreover, the r cointegrating relationships are further decomposable into r_0 directly cointegrating relationships where the levels of the I(2) variables cointegrate directly to an I(0) variable and r_1 polynomially cointegrating relationships where the levels cointegrate with the differences of the levels to give an I(0) variable. Thus:

$$\beta_0' x_t \sim I(0) \text{ where } \beta_0 \text{ is } p \times r_0 \text{ with rank } r_0; \tag{16a}$$

$$\beta_1' x_t + \kappa' \Delta x_t \sim I(0) \text{ where } \beta_1 \text{ and } \kappa \text{ are } p \times r_1; \tag{16b}$$

$$r_0 + r_1 = r. \tag{16c}$$

It is possible of course for either r_0, r_1 or both to be zero. In general, however, the algebra of the processes dictates that the number of polynomially cointegrating relationships equals the number of I(2) common trends in the system. Therefore; $r = r_0 + r_1$ and $r_1 = p - r - s \equiv s_2$. If s_2 equals zero, or equivalently $p - r = s$, the I(2) system collapses to the I(1) case.

Consider now the empirical analysis of direct interest to us as an I(2) system. If we persist with the assumption that $r = 1$ so that there are two common trends in the process and allow for one I(1) and one I(2) trend, we should find three unit roots in the estimated characteristic polynomial. The first derived from the I(1) common trend and the other two from the I(2) trend. Stated in reverse, if the characteristic polynomial were to provide three unit roots and the assumption of one cointegrating vector can be maintained, the system must be an I(2) system since the extra unit root cannot otherwise be accounted for.

The all important step, therefore, is the determination of the so called 'integration indices' r, and s, and the decomposition of r into its r_0 directly cointegrating and r_1 polynomially cointegrating components. The asymptotic theory for I(2) processes and the determination of the integration indices is largely in its infancy and is contained mainly in papers by Johansen (1992, 1995a), Paruolo (1996) and Jørgensen *et al.* (1996). Moreover, it is well established that the behaviour of the statistics used to establish the indices are very sensitive to the presence or absence of 'nuisance' parameters and the specification of the predetermined variables on which the analysis is conditioned.[18] Consequently, there is a shortage of usable critical values relating to finite samples. Paruolo (1996) and Jørgensen *et al.* (1996) have computed some tables or critical values reported in Johansen (1995b) may be used. In common with much of the existing empirical analysis of I(2) processes, our main restriction on the nuisance parameters is that the constant is restricted in such a way that quadratic trends are disallowed in the data and there is no trend in the cointegrating space.[19]

Despite the potential difficulties due to the sensitivity of the analysis to various 'nuisance' parameters and the specification of predetermined variables, we find that inference in our empirical model seems remarkably straightforward and unambiguous.

The two indices r and s index the null hypotheses on the number of cointegrating vectors (r) and the number of I(1) common trends (s). The number of I(2) common trends is thus given by $p - r - s$ in the I(2) analysis. Table 3 shows the set of possibilities for the specific case where $p = 3$.

Thus, for example, the square labelled H_{11} corresponds to the case where there is one cointegrating vector ($r = 1$), one I(1) common trend ($s = 1$) and one I(2) common trend ($p - r - s = 1$). The last column of the table gives the set of possibilities where the I(2) hypotheses collapse on to their I(1) counterparts since the number of I(2) trends in this column is equal to zero. Various other restrictions of these hypotheses are possible depending upon the restrictions applied to the deterministic parts of the process. For the I(1) model Johansen (1995b) provides a very detailed description of the subtleties of dealing with deterministic components in Chapter 6.

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18 Examples of 'nuisance' parameters may include trends and constants. The indices are also sensitive to whether the 'nuisance' parameters are unrestricted or restricted to the cointegrating space. Jørgensen *et al.* (1996) propose methods of making inference not depend on the trend.

19 See Engsted and Haldrup (1998), Haldrup (1997), Juselius (1998).

Table 3: Combinations of the Integration Indices r and s

p-r	*r* *(Cointegrating Vectors)*				
3	0	H_{00}	H_{01}	H_{02}	H_{03}
2	1		H_{10}	H_{11}	H_{12}
1	2			H_{20}	H_{21}
$p-r-s \Rightarrow$ *(I(2) Common Trends)*		3	2	1	0

The estimation of the integration indices proceeds in two steps.[20] The first step is to solve the reduced rank regression problem associated with $\Pi = \alpha\beta'$ and calculate α and β and their orthogonal complements for each permissible value of r. The second step is to consider the same problem but this time associated with $\alpha'_\perp \Gamma \beta_\perp$, solved for $s = 0, 1, \ldots, p-r-1$ using the estimated matrices $\alpha_\perp$ and $\beta_\perp$ derived from the first step. Inference about the integration indices consists of using likelihood ratio statistics, computed from the eigenvalues derived from the two reduced rank regressions, and comparing them with the tabulated critical values.

There are two main methods for making inference in relation to r and s postulated in the literature. The first method, which may be called the conditional procedure, is to first determine the I(0) relationships whether directly or polynomially cointegrating. Then, conditional on this choice of r which fixes the row in Table 3, the task is to determine s by proceeding along that row looking for the first acceptance. The critical values used at each stage are subject of course to allowing for restrictions in the deterministic parts of the process and are given in Chapter 15 of Johansen (1995b).

The second method referred to here as the joint procedure is to determine the integration indices r and s jointly.[21] Under this procedure the model H_{rs} is rejected for all $i < r$ and $j \leq s$. Therefore we use the ordering in Table 3 by

20 See Haldrup (1997) for a very useful summary of the estimation method.

21 See Jørgensen *et al.* (1996), Paruolo (1996).

proceeding from left to right and from top to bottom. The integration indices are determined as the first pair of r and s, that is not rejected. The likelihood ratio statistics used here differ from those in the first method and the critical values for some of the more interesting cases are given in the references cited in Haldrup (1997).[22]

Fortunately for our empirical analysis, it does not matter which method is adopted since the conclusion as to the number of cointegrating relationships is the same using either method.

3.2 Reduction from I(2) to I(1): Estimating an I(2) System

We proceed now to presenting the results of estimating our I(2) system described in the previous section. Turning first to the determination of r and s. Using the conditional procedure the following in Table 4 may be noted. From the first panel of Table 4 we easily accept the hypothesis at the 10 per cent significance level that there is 1 cointegrating vector. The second panel using $Q(s/r)$ shows that $s = 1$ since proceeding along the row corresponding to $r = 1$ the first acceptance occurs at $s = 1$. Note that the second stage of this conditional procedure is conducted under the restriction of no quadratic trends in the model.

Therefore, from the first two panels of Table 4 we conclude that $r = 1$, $s = 1$, and thus $p - r - s = 1$. This implies an important restriction in the form of the cointegrating relationship. Since the number of I(2) trends in the model equals the number of polynomially cointegrating relationships, the arithmetic implies that the only cointegrating relationship detected above must be of the polynomially cointegrating variety and confirms the empirical relevance of option (a) in Table 1. Thus p_t, ulc_t and pm_t cointegrate from I(2) to I(1) and this must further cointegrate with the first differences of the core variables to provide the so-called 'dynamic' error correction term.[23] The findings concerning integration from the conditional procedure is supported by the method of joint determination of the indices in the bottom panel of Table 4.

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22 For technical details the reader should consult Haldrup (1997) and references contained therein.

23 The estimated 'dynamic' error correction term for the I(2) analysis is reported in (17) below.

Table 4: The I(2) System Analysis

The 'Conditional Procedure' for Estimating r and s

Null Hypothesis H_0: r =	*Eigenvalues*	*Estimated Trace Statistic Q(r)*
0	0.3198	47.56 {26.70}
1	0.0673	11.34 {13.31}
2	0.0497	4.79 {2.71}

Estimated Values of Q(s|r)

p-r	*r*				*Q(r)*
3	0	196.52	88.92	28.56	47.56
2	1		73.78 [17.79]	7.33 [7.5]	11.34
1	2			11.68	4.79
p-r-s		3	2	1	0

The 'Joint Procedure' for Estimating r and s

Estimated Values of Q(s, r) = Q(s|r) + Q(r)

p-r	*r*				*Q(r)*
3	0	244.08	136.48	76.12	47.56
2	1		85.12	18.66	11.34
1	2			16.48	4.79
p-r-s		3	2	1	0

Notes: Statistics are computed with 2 lags of the core variables. The estimation sample is March 1972 to June 1995 with 94 observations and 80 degrees of freedom.

Q(r) is the likelihood ratio statistic for determining *r* in the I(1) analysis. *Q(s|r)* is the corresponding statistic for determining *s* conditional on *r*.

Shaded cells indicate acceptance at the 10 per cent level of significance. Critical values shown in curly brackets { } are from Table 15.3 and in square brackets [ ] are from Table 15.2 of Johansen (1995b).

The results presented in Table 4 therefore provide formal justification of the existence of I(2) trends in the data. However, given the doubts pertaining to the use of asymptotic critical values, in particular the sensitivity of these values to the inclusion of nuisance parameters and predetermined variables, we undertook a sensitivity analysis to determine the robustness of our findings. The cointegration results are essentially the same if the analysis is repeated with all the predetermined variables excluded. Further evidence may be provided graphically by looking at the cointegrating combination $\beta_1' x_t$ which looks more stationary if one controls for the differences of x_t.

Finally, the roots of the characteristic polynomial computed for our analysis and reported in Table 5 provides very strong evidence in favour of an I(2) trend. With reference to Table 5, if I(1) analysis was all that was required then imposing the null hypothesis of 1 cointegrating relationship should lead to 2 unit roots remaining in the characteristic polynomial if the common trends are both I(1). However if one of the common trends is I(1) and the other is I(2), then one would expect to find 3 unit roots in this polynomial. This of course is exactly the case with the value of the third largest root being 0.9857 with the remaining roots well within the unit circle. It should be noted here that this is a remarkably robust finding and not altered by numerous respecifications of the model to allow for various combinations of predetermined variables and restrictions on nuisance parameters. Therefore, we proceed under the maintained assumption of one I(1) trend and one I(2) trend.

Table 5: Roots of the Characteristic Polynomial

Real	1.0000	1.0000	0.9857	0.2777	- 0.2385	0.1066
Complex	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Modulus	1.0000	1.0000	0.9857	0.2777	0.2385	0.1066

Turning now to the estimated cointegrating matrix β' reported in Table 6, only the first row of the matrix has a valid economic interpretation. The estimated coefficients for ulc_t and pm_t normalised on p_t very nearly sum to one even without any *a priori* restriction and formal testing confirms the linear homogeneity restriction of equation (8). Therefore, the cointegrating vector in the first row with the linear homogeneity restriction imposed represents the markup of price on labour and import costs. Consequently, from this point in the system analysis we define the markup as: $mu_t = p_t - 0.8\,ulc_t - 0.2\,pm_t$ and this constitutes the reduction from I(2) to I(1) space. Furthermore, the polynomially cointegrating relationship given by the I(2) analysis is: $mu_t + (2.605, 2.616, 2.944)' \Delta x_t$. In the notation adopted in (16b), $mu_t \equiv \beta_1' x_t$ and $(2.605, 2.616, 2.944)' \equiv \kappa'$.

Table 6: The Cointegrating Matrix β'

p_t	ulc_t	pm_t
27.235	-21.749	-4.775
-3.398	16.003	-12.576
16.779	-19.407	-0.043

Normalised Cointegrating Vector β_1'

p_t	ulc_t	pm_t
1	- 0.799	- 0.175

Defining the steady state as $\Delta p_t = \Delta ulc_t = \Delta pm_t$ implies a steady state relationship between the markup and inflation of:

$$\overline{mu_t} = -8.165\,\overline{\Delta p_t}\,, \tag{17}$$

where the dynamics and, more importantly, the impact of the predetermined variables are ignored in calculating the steady state relationship. Having completed the reduction of the I(2) system to an I(1) system where the core variables cointegrate to an I(1) markup we now proceed to estimate an I(1) system.

3.3 Reduction from I(1) to I(0): Estimating an I(1) System

In order to continue the reduction to a single equation we transform the variables to an I(1) system given by mu_t, Δp_t, Δulc_t and Δpm_t since tests of hypotheses such as weak exogeneity are more easily dealt with in this framework. As the first of these four variables is constructed from the levels of the remaining three, our system is in fact not four-dimensional. Given our empirical interest in the markup, modelling in I(1) space will therefore require us to work with the markup, mu_t, and at most two of the other three variables.

In choosing which subset of variables to work with, an important point needs to be borne in mind. Since the existence of polynomial cointegration has been established above, inclusion of the markup, mu_t, in any subsequent analysis is necessary to establish cointegration. The system given with the markup *excluded* is not valid for the reasons presented in Gregoir and Laroque (1993, 1994) and Engsted and Johansen (1997). The integral of the error correction term in such a system, given by: $\sum_{j=1}^{t}(\Delta p_j - \alpha_1 \Delta ulc_j - \alpha_2 \Delta pm_j)$ and is simply the markup if $\alpha_1 = 0.8$ and $\alpha_2 = 0.2$. This integral is thus cointegrated with Δx_t, which is the vector of variables in this I(1) system considered and, following Gregoir and Laroque (1993, 1994) and Engsted and Johansen (1997), the ECM representation (and therefore its estimation) is no longer valid.

In order to simplify the analysis further we exploit the very similar statistical behaviour of the three variables comprising Δx_t and we proceed to analyse the bivariate system given by mu_t and Δp_t. In other words we estimate an equation of the form given by (7) above. This system contains sufficient information to establish a robust and properly specified steady state relationship between the markup, mu_t, and inflation, Δp_t.[24] Finally we complete the reduction and

[24] In order to estimate the steady state relationship between the markup and inflation, which is the primary area of our concern, such a simplification is made without loss of generality because by definition $\Delta p_t = \Delta ulc_t = \Delta pm_t$ in the steady state. To examine whether any information is lost when not in the steady state, particularly due to the restrictions implicitly imposed on the dynamics, we undertook the following supplementary analysis. Formal testing of the I(2) system showed that the I(0), I(1) and I(2) directions of the data are given by the vectors $\beta_1' \equiv (1,-0.8,-0.2)$, $\beta_2' \equiv (-1/3,-2/3,1)$ and $\beta_3' \equiv (1,1,1)$ respectively which are orthogonal to each other. In particular, the first two vectors lie in the space orthogonal to β_3'. A basis for this space is given by the matrix $H = \begin{pmatrix} 1 & 1 \\ -1 & 0 \\ 0 & -1 \end{pmatrix}$.

Thus $\begin{pmatrix} H' x_t \\ a' \Delta x_t \end{pmatrix}$, where a is any 3×1 vector that satisfies the restriction that $a' \beta_3 \neq 0$, provides the transformation to I(1) which keeps all the cointegrating and polynomially cointegrating information. Hence if we take a to be $(1,0,0)'$, then the trivariate system estimate a single-equation representation of the relationship between the markup and inflation in the next section. This final reduction is justified by the easily interpretable diagnostics available from the bivariate system.

Thus estimating the bivariate system, gives the results reported below where the only predetermined variable included in addition to those already in the I(2) system is a spike dummy to account for the fourth quarter of 1975 and the system is estimated with four lags.

Turning first to the number of cointegrating relationships in the system. The existence of a single cointegrating relationship normalised on Δp_t is clearly established in Table 7 and reported in Table 8.[25]

Table 7: Testing for the Number of Cointegrating Vectors

Null Hypothesis H_0: r =	***Eigenvalues***	***Estimated Trace Statistic Q(r)***
0	0.3051	34.45 {13.31}
1	0.0103	**0.96** {2.71}

Statistics are computed with 4 lags of the core variables. The estimation sample is September 1972 to June 1995 with 92 observations and 75 degrees of freedom.

Shaded cells indicate acceptance at the 10 per cent level of significance. Critical values shown in curly brackets { } are from Table 15.3 of Johansen (1995b).

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given by $\begin{pmatrix} p_t - ulc_t \\ p_t - pm_t \\ \Delta p_t \end{pmatrix}$ is a valid full reduction. Note that the $(1,1,1)'$ vector implies that the I(2) common trend in the data enters with equal weight in the three components of the I(2) system. The transformation above implies that the markup of price on unit labour costs and the markup of price on import prices are both I(1) variables. Finally, estimating this trivariate system gives the long-run relation between the markup, mu_t, and inflation, Δp_t, as: $\overline{mu_t} + 7.94\overline{\Delta p} \sim I(0)$ which is congruent with the estimate derived from the partial or bivariate system estimated in Section 3.3 and reported in Table 13. We are very grateful to Hans-Christian Kongsted for the analysis in this footnote.

25 Re-estimating the system without any predetermined variables does not alter the main finding of the long-run relationship between the markup and inflation.

Table 8: The Cointegrating Matrix β'

Δp_t	mu_t
- 222.593	- 23.832
- 99.883	- 32.944

Normalised Cointegrating Vector

Δp_t	mu_t
1	0.107

Inverting (17) to express inflation as a function of the markup yields a coefficient in the neighbourhood of 0.122. The similarity with the estimated long-run coefficient on mu_t in Table 8 is taken as strong corroborative evidence for our results in the previous section since the estimates of the long-run relationship are 0.01 apart (to two decimal places). Some differences must be expected owing to the slightly different specifications of the exogenous variables, the lag structure and the order of integration of the variables in the system (with different implications for standard errors and rates of convergence of the coefficient estimates.)

Further evidence of a single cointegrating relationship is provided by the eigenvalues of the companion matrix reported in Table 9 which show one root imposed at unity and all the other roots well inside the unit circle.

Table 9: Roots of the Characteristic Polynomial

Real	1.0000	0.7243	- 0.6331	- 0.0366	-0.0366	0.5371	-0.3232	-0.3232
Complex	0.0000	0.0000	0.0000	- 0.6185	- 0.6185	0.0000	0.2542	-0.2542
Modulus	1.0000	0.7243	0.6331	0.6196	0.6196	0.5371	0.4112	0.4112

Having established a single cointegrating relationship in the data, we turn to the estimated price and markup equations from the I(1) system. These estimates are reported in Table 10. The loading vector α provides the weight, or load, with which the error correction term (ECM) enters each of the two equations.

Since the system is formulated in I(1) space, the t-values on the error correction terms can be used conventionally to test for weak exogeneity. The polynomially cointegrating relationship from the I(2) system re-emerges, with a strong error correction coefficient in only the price equation. The insignificance of the error correction coefficient in the markup equation establishes the weak exogeneity of the markup for determining the *long-run* relationship between inflation and the markup. This justifies the final stage of the modelling strategy where we model inflation by single equation methods conditional upon the markup and the predetermined variables.

Finding the ECM, and therefore inflation, appears significantly only in the price equation provides strong evidence that the underlying imperfect competition model outlined in Section 2 is identified. The issue of identification of the standard model can therefore be ignored.

The estimated short-run matrices Γ_i where i = 1, 2, 3 in Table 10 report the dynamics of the I(1) system as a result of lags in $\Delta^2 p_t$ and Δmu_t.[26] The final estimates reported in Table 10 are those of the constant and the predetermined I(0) variables.

Excluding the insignificant variables in Table 10 on a 5 per cent t-criterion the final form of the inflation and markup equations in the system can be represented as:

$$\Delta^2 p_t = \mu_1 + \alpha\left(\Delta p_{t-1} + \delta\, mu_{t-1}\right) + \sum_1^3 \gamma_i\, \Delta^2 p_{t-i} + \delta_1\, \Delta mu_{t-2} + \phi_1' D_t + \varepsilon_{1t}\,; \quad (18a)$$

$$\Delta mu_t = \mu_2 + \delta_2\, \Delta mu_{t-1} + \phi_2' D_t + \varepsilon_{2t}\,. \quad (18b)$$

Equation (18a) is used later in the paper to derive the long-run systems estimate of the relationship between inflation and the markup. Equation (18b) shows the form of the markup equation as a simple generalisation of a random walk model.

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26 Note that $\Gamma_i = -\sum_{j=i+1}^{4} \Pi_j$. The lags in the dynamics of the endogenous variables run up to t-k+1 where k is the original choice of the length of the lag. In our case $k = 4$ and we thus have lags up to t-3.

Table 10: I(1) System Analysis of Inflation and the Markup
September 1972 – June 1995

Dependent Variable	lag	*Price Equation* Δ Inflation	*Markup Equation* Δ Markup
Loading Matrix α			
Error Correction Term	1	- 0.566 (- 6.3)	- 0.034 (- 0.1)
Short-run Matrices Γ_i			
ΔInflation	1	- 0.311 (- 3.3)	- 0.579 (- 1.8)
ΔInflation	2	- 0.141 (- 1.6)	- 0.550 (- 1.8)
ΔInflation	3	- 0.153 (- 2.1)	- 0.375 (- 1.5)
ΔMarkup	1	- 0.019 (- 0.7)	- 0.211 (- 2.1)
ΔMarkup	2	- 0.086 (- 3.1)	0.019 (0.2)
ΔMarkup	3	- 0.019 (- 0.7)	0.059 (0.6)
Predetermined Variables D_t			
Constant	0	- 0.064 (- 5.4)	- 0.021 (- 0.5)
Inside Unemployment	0	- 0.010 (- 5.1)	0.011 (1.7)
Strikes	1	0.018 (2.5)	- 0.080 (- 3.2)
ΔTax	0	0.252 (2.8)	0.227 (0.7)
ΔPetrol Prices	0	0.031 (4.1)	- 0.017 (- 0.6)
Dummy: June 1973	0	0.014 (3.5)	- 0.014 (- 1.0)
Dummy: September 1973	0	0.010 (2.4)	0.013 (0.8)
Dummy: September 1974	0	0.018 (3.9)	- 0.027 (- 1.7)
Dummy: December 1975	0	0.024 (5.3)	0.005 (0.3)

Notes: Reported in brackets are *t*-statistics. The ECM is calculated from the cointegrating matrix β' as: $ECM_t = \Delta p_t + 0.107\, mu_t$. All variables are in logs except the strikes variable.

System Diagnostics for Table 10

Schwartz Information Criterion	- 18.09959
Tests for Serial Correlation	
Ljung-Box (23)	$\chi^2(76) =$ 65.928, prob-value = 0.79
LM(1)	χ^2 (4) = 8.833, prob-value = 0.07
LM(4)	$\chi^2(4) =$ 1.140, prob-value = 0.89
Test for Normality	
Doornik-Hansen Test for normality:	$\chi^2(4) =$ 7.141, prob-value = 0.13

The estimated system as represented by (18a) and (18b) describes an economy where there are random shocks to the markup in the form of shocks to wages and import prices and firms respond to the disequilibria by adjusting prices. Therefore, the appearance of the ECM in only the price equation indicates that adjustment to the long-run equilibrium is due to firms adjusting prices and not due to changes in wages and import prices. This form of adjustment to the long-run equilibrium is possibly due to firms setting prices after wage and import costs are known.

Finally the diagnostic analysis on the residuals indicates the acceptance of the null hypothesis of well specified residuals with a confidence level of a minimum of 7%, based on multivariate statistics. The univariate statistics, not reported here, similarly show no evidence of miss-specification with all p-values lying comfortably in excess of 0.05.

3.4 Estimating a Single Price Equation

This section completes the model reduction from I(2) space to I(0) space. The finding in Section 3.3 that the markup is weakly exogenous implies that estimating a single price equation is valid. A second difference unrestricted error correction price equation is estimated that is consistent with the price equations in the two systems analysed above. The price equation is in the form:

$$\Delta^2 p_t = \mu + \Pi x_{t-1} + \sum_{i=1}^{3} \gamma_i \Delta x_{t-i} + \sum_{i=1}^{3} \phi_i' D_{t-i} + \varepsilon_t \tag{19}$$

where x and D are vectors of the core and predetermined variables respectively and defined as above. We proceed with the estimation assuming that the levels of the core variables are I(2), changes in these variables are I(1) and that the predetermined variables and second differences of the core variables are I(0).[27]

The price equation was initially estimated with 3 lags of the differences in the core variables and 3 lags of the predetermined variables. No contemporaneous independent variables were incorporated to mitigate against biases due to any simultaneity of the variables. Given the large number of variables and the impact that this has on the degrees of freedom of the estimates, the parsimonious forms of the regressions were sought and are reported. The insignificant variables were eliminated following individual exclusion tests before the eliminated variables were tested for joint significance and rejected. Fortunately, the process of excluding insignificant variables did not affect the long-run relationships in an economically significant way nor were the findings of cointegration affected at any stage.

Reported in column (1) of Table 11 are ordinary least squares estimates of the price equation (19). Consistent with the estimates obtained in the system analysis, the restriction of linear homogeneity between costs and prices is not rejected at the 5 per cent level of significance.[28] In conjunction with the finding in the I(2) system analysis that the levels of the core variables cointegrate, we can interpret the finding of linear homogeneity in this model as indicating that the levels of prices, labour and import costs cointegrate to the markup.[29] The restriction of linear homogeneity is applied to the price equation and the estimates are reported in column (2) of the table. Finally, the price equation was estimated by replacing the levels of the core variables with the estimated markup using the long-run coefficients obtained from the restricted

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[27] The assumptions concerning the orders of integration of the core variables are valid given the I(2) and I(1) analyses above.

[28] Linear homogeneity exists in this price equation if the coefficients on the levels of the core variables sum to zero.

[29] The finding of cointegration must be based on the I(2) analysis as the t-statistic critical values are unknown in estimating (19) when the core variables are I(2). However, the size of the t-statistic suggests a finding of cointegration is likely if the critical values were known.

estimates in column (2). These estimates are reported in column (3) and referred to as the 'preferred' single price equation.

Given the assumption that inflation is I(1) and that the levels of the core variables cointegrate to the markup and is also I(1), the *t*-statistic on inflation in columns (2) and (3) indicates that inflation polynomially cointegrates with the markup.[30] This finding further corroborates the finding of polynomial cointegration in the I(2) and I(1) system analyses. This long-run, or steady state, relationship between the markup and inflation is considered further in the next section.

The presence of the steady state, or cointegrating, relationship between inflation and the markup subtly alters the interpretation of linear homogeneity in this model of prices. In standard models where inflation and the markup are not related in the steady state, an increase in costs will be fully reflected in higher prices and the markup will be unchanged in the long-run. With inflation and the markup negatively correlated in the steady state, higher costs are only fully reflected in higher prices *if the rate of steady state inflation remains unchanged.* An increase in costs that is associated with an increase in steady state inflation will not be fully reflected in higher prices as the markup of prices on costs falls with the higher steady state inflation.

The estimates of the price equation in Table 11 indicate the speed of adjustment coefficients are all fairly high and range between 0.75 and 0.85. For the preferred equation this implies that the 75 per cent of the deviation of inflation from its long-run rate is corrected for in a single quarter. Given the dependent variable is the change in the rate of inflation and there is no impediment to firms adjusting prices then it can be expected that the firm's price adjustment will be rapid.

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30 Kremers *et al.* (1992) argue that the direct estimation of the error correction coefficient is a more powerful test of cointegration than an ADF test of the residuals. The distribution of the *t*-statistic on the error correction term in the model lies between an N(0, 1) and a Dickey Fuller distribution. The Dickey Fuller critical values (constant included) are: 3.51 (1%), 2.89 (5%) and 2.58 (10%).

Table 11: Inflation and the Markup
Dependent Variable: Second Difference of the Price Level
September 1972 – June 1995

	lag	(1)	(2)	(3)
Constant		- 0.126	- 0.187	- 0.157
		(- 3.8)	(- 7.4)	(- 6.8)
Inflation	1	- 0.849	- 0.787	- 0.753
		(- 9.5)	(- 9.1)	(- 7.9)
Prices	1	- 0.092	- 0.111	
		(- 5.9)	(- 7.8)	
Unit Labour Costs	1	0.067	0.091	
		(4.5)	(7.2)	
Import Prices	1	0.020	0.020	
		(3.7)	(3.8)	
Markup	1			- 0.093
				(- 6.0)
Δ Inflation	1	- 0.176	- 0.204	- 0.186
		(- 2.7)	(- 3.1)	(- 2.5)
Δ Unit Labour Costs	1	- 0.073	- 0.066	
		(- 2.2)	(- 2.0)	
Inside Unemployment	1	- 0.013	- 0.123	- 0.011
		(- 5.5)	(- 5.2)	(- 4.3)
Strikes	1	0.024	0.031	0.025
		(3.4)	(4.7)	(2.7)
Strikes	2	0.002	- 0.003	- 0.008
		(0.2)	(- 0.3)	(- 0.7)
Strikes	3	0.029	0.025	0.019
		(3.8)	(3.3)	(2.4)
Δ Taxes	1	- 0.120	- 0.164	
		(- 1.3)	(- 1.8)	
Δ Petrol Price	1	- 0.004	0.007	
		(- 0.5)	(0.8)	
Δ Petrol Price	2	- 0.012	- 0.012	
		(- 1.7)	(- 1.6)	
Dummy: June 1973	0	0.011	0.017	0.016
		(4.2)	(15.5)	(16.5)
Dummy: September 1973	0	0.011	0.015	0.012
		(3.8)	(7.1)	(7.2)
Dummy: September 1974	0	0.014	0.019	0.019
		(2.5)	(3.5)	(3.1)
Dummy: December 1975	0	0.030	0.030	0.026
		(15.7)	(16.0)	(16.5)

Notes: *t*-statistics are reported in brackets. All variables except strikes are in logs. The markup in column (3) is calculated using the long-run estimates from column (2).

Diagnostics and Long-Run Coefficients for Table 11

	(1)	(2)	(3)
Diagnostics			
$\overline{R}^2$	0.65	0.60	0.60
DW	2.21	2.10	2.23
AR(1) [Prob value]	6.18 [0.01]	6.18 [0.01]	2.47 [0.12]
AR(1-4) [Prob value]	7.13 [0.13]	7.14 [0.13]	3.8 [0.43]
SEE	0.004	0.004	0.005
Long-Run Coefficients			
Unit Labour Costs	- 0.733	- 0.819	- 0.819*
Import Prices	- 0.214	- 0.181	- 0.181*
Markup		- 0.130	- 0.123

Notes: Number of observations = 92. AR(1) and AR(1-4) are LM tests of autocorrelation of order 1 and orders 1 to 4 respectively. * Long-run estimates from column (2) applied to the markup in column (3).

The labour market variables of inside unemployment and strikes have the expected signs with higher unemployment causing a fall in inflation and greater strike activity increasing the rate of inflation. The dummies that are incorporated capture the erratic nature of the wage and price processes that occurred at the time of the first OPEC oil price shock.

Table 12 shows the similarity between the I(2) system and single price equation estimates of the long-run coefficients on the core cost variables.[31] The estimates imply that for a given rate of inflation a 10 per cent increase in unit labour costs with no change in the level of import prices will lead to around an 8 per cent increase in prices in the long-run leaving the markup on total costs unchanged. Alternatively, a simultaneous 10 per cent increase in labour and import costs will see price increase by 10 per cent in the long-run.

The estimated markup from column (2) is shown in Graph 4. In a 'standard' price equation where it is assumed that inflation is stationary then the markup, which is the error correction term, should also be stationary. From the graph

[31] The long-run cost coefficients for the I(1) system are not independently estimated and are imposed from the estimates obtained from the I(2) system.

and from the detailed systems analysis above it is clear that the markup is not stationary. However, in the preferred price equation where it is assumed that inflation is I(1) and cointegrates with the markup then the error correction term is a linear combination of inflation and the markup and this is shown in Graph 5. Graphically it appears that the error correction term is stationary and this is a further indication that the model is specified correctly.[32]

Table 12: Long-run Cost Coefficients

Method of Estimation	*Unit Labour Costs*	*Import Prices*
System I(2)	- 0.8	- 0.2
Single Price Equation	- 0.819	- 0.181

3.4.1 Causation, the Markup and Inflation

The theoretical models in Section 2 that underpin the negative correlation between inflation and the markup in the steady state imply the causation runs from the rate of inflation to the level of the markup. This appears to conflict with the estimated empirical models where the markup is weakly exogenous and inflation is conditioned on the level of the markup.

The apparent conflict is easily resolved. The empirical model indicates that the source of the shocks during the period examined are largely from the markets for labour and imports. However, in the long-run, it remains the case that it is the response of the monetary authorities to these shocks that will determine the rate of steady state inflation and therefore the level of the markup. An alternative way to make this point is to note that (6) is an equilibrium relationship derived from the price and cost curves. Furthermore the underlying theoretical model does not specify the source of the shocks to the system that lead to changes in the steady state rate of inflation. In contrast, the empirical model does identify the source of the shocks and they appear to originate in the labour and import markets.

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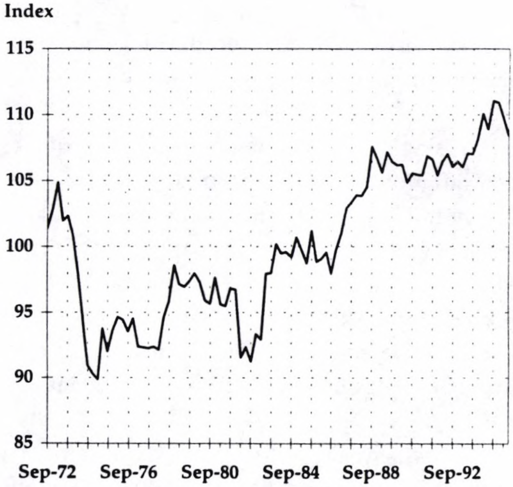
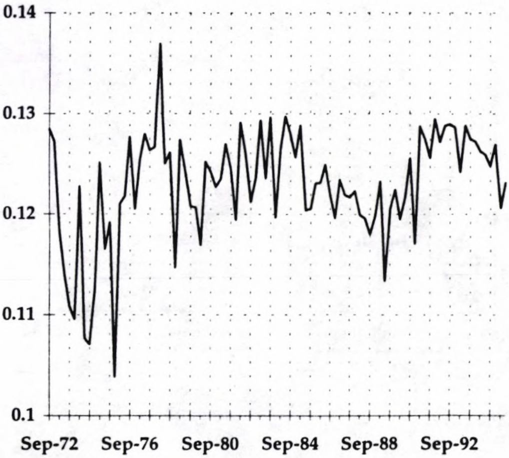
32 This graphical analysis of the error correction terms in Graphs 4 and 5 replicates almost exactly the graphs derived from the I(2) analysis when the path of the cointegrating vector among the levels of the core variables is plotted without and with a dynamic adjustment from the differenced core variables.

Graph 4: The Estimated Markup*



* The markup is calculated as: $mu_t = p_t - 0.819\,ulc_t - 0.181\,pm_t$

Graph 5: The Error Correction Term of the Preferred Price Equation*



* The ECM is calculated as: $ECM_t = -0.753\Delta p_t - 0.093 mu_t$

4 INFLATION AND THE MARKUP IN THE STEADY STATE

The empirical analysis of this paper has been directed at the proposition that inflation and the markup are negatively correlated in the steady state. This section looks at the evidence that supports the proposition.

The I(1) system and single price equation estimates of the steady state relationship between inflation and the markup are shown as the solid thin and thick lines respectively in Graph 6.[33] The scatter plot of diamond dots in the graph are the combinations of the estimated markup from the preferred single price equation and actual annualised quarterly inflation. The crosses on the graph are the four observations that coincide with the dummies in the preferred single equation. The negative correlation between inflation and the markup is evident in the steady state (the solid lines) and is also evident in the actual data.

Table 13 sets out the two system estimates and the single price equation estimate of the steady state relationship between inflation and the markup. The last column of the table provides the respective estimates of the fall in the markup that is associated with a 1 percentage point increase in annual steady state inflation. All three estimates of the steady state relationship indicate that the markup is around 2 per cent lower if inflation is 1 percentage point higher.

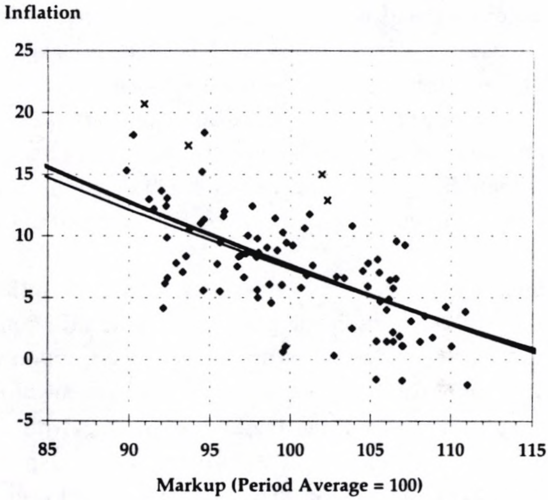
Table 13: Steady State Relationship Between Inflation and the Markup

Method of Estimation	*Steady State Relationship*	*Inverse of Steady State Relationship*	*Decrease in the Markup Associated with a 1 Percentage Point Increase In Inflation**
System I(2)	$\overline{\Delta p} = -0.122\,\overline{mu}$	$\overline{mu} = -8.165\,\overline{\Delta p}$	2.0 %
System I(1)	$\overline{\Delta p} = -0.130\,\overline{mu}$	$\overline{mu} = -7.685\,\overline{\Delta p}$	1.9 %
Single Price Equation	$\overline{\Delta p} = -0.123\,\overline{mu}$	$\overline{mu} = -8.130\,\overline{\Delta p}$	2.0 %

* A percentage point increase in annual inflation is equivalent to an increase in $\overline{\Delta p}$ of 0.25 per quarter.

[33] The steady state relationship in Graph 6 assumes that the predetermined variables are at their steady state or mean values and that the second difference of inflation and the first difference of the markup are zero.

Graph 6: The Markup and Inflation*



* Quarterly inflation at an annualised rate. The markup is calculated using the estimates from column (2) of Table 11 where: $mu_t = p_t - 0.819\,ulc_t - 0.181\,pm_t$

Steady State Relationships:
(a) Single Price Equation Estimate (thick line): $\overline{\Delta p_t} = -0.162 - 0.123\,mu_t$
(b) I(1) System Estimate (thin line): $\overline{\Delta p_t} = -0.147 - 0.144\,mu_t$

The four crosses indicate the four observations corresponding with the dummies in the price equation, namely, from left to right: September 1974, December 1975, June 1973 and September 1973.

5 CONCLUSION

This paper set out to investigate the proposition that inflation and the markup may be negatively correlated in the steady state. It was argued that this proposition imposed a definite modelling strategy on the investigation. In particular it was necessary to use non-stationary inflation data and to allow for the possibility that the levels of prices and costs follow I(2) statistical processes.

Consequently, Australian data was chosen due to the non-stationary characteristics of the inflation data and the possibility of I(2) statistical processes was accommodated by estimating an I(2) system using techniques developed by Johansen (1995a, b). It was found that the levels of prices and costs are best characterised as I(2) statistical process. Furthermore, it was found that two long-run, or cointegrating, relationships are present in the data. The first cointegrating relationship is between the levels of prices and costs and represents the standard linear homogeneity condition that an increase in costs is fully reflected in higher prices leaving the markup unchanged in the long-run.

The second cointegrating vector is between the rate of inflation and the markup. This long-run relationship suggests that higher inflation is associated with a lower markup. The lower markup is interpreted within the imperfect competition model employed in this paper as the cost to firms of higher inflation. Importantly, the fall in the markup associated with an increase in inflation was found to be economically significant with a 1 percentage point increase in steady state inflation associated with a 2 percent lower markup.

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