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The Impact of Inflation and Uncertainty on the Optimum Markup Set by Firms

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The Impact of Inflation and Uncertainty on the Optimum Markup Set by Firms*

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Abstract

This paper argues that non-colluding price setting firms in an uncertain economic environment will set a 'low' markup relative to the profit maximising markup if; (a) they are uncertain of the profit maximising markup; and (b) the cost to firms of mistakenly setting a 'high' markup is greater than if they mistakenly set a 'low' markup. Furthermore, firms will set a lower markup the higher is the level of uncertainty. It follows, therefore, that if uncertainty increases with inflation then firms will choose a lower markup the higher is inflation.

Keywords: Inflation, Wages, Prices, Markup,
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CONTENTS

1 INTRODUCTION

The proposition that there is a negative relationship between inflation and the markup has received increasing empirical support. Bénabou (1992) using US retail sector data, Simon (1999) using 4 digit US manufacturing sector data, and Batini, Jackson and Nickell (2000) using aggregate UK data show that inflation and the markup are negatively related.[1] These papers explicitly or implicitly assume that inflation and the markup are stationary variables and therefore the relationship is of a short-run nature. In contrast, Banerjee, Cockerell and Russell (2001), Banerjee and Russell (2000, 20001a, 2001b) and Banerjee, Mizen and Russell (2002) show using a range of data for the G7 economies and Australia that (except for Japan) there is a negative long-run relationship in the Engle and Granger (1987) sense between inflation and the markup.[2]

Monopolistic pricing models that explain the negative relationship can be separated into two broad groups. The first group considers the interaction of inflation with small 'menu' costs of price adjustment in the tradition of Mankiw (1985) and Parkin (1986).[3] These papers consider a number of issues including the impact of inflation on the average markup for a given profit maximising markup. Bénabou and Konieczny (1994) show in a model that encompasses the papers in this first group that the relationship between inflation and the markup may be either positive or negative depending on the relative size of inflation, the

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1 Richards and Stevens (1987), Franz and Gordon (1993), Cockerell and Russell (1995), and de Brouwer and Ericsson (1998) estimate error correction 'markup' models of inflation and provide indirect support of the negative relationship. In these models the error correction term with linear homogeneity imposed can be interpreted as the markup and is, therefore, negatively related with inflation.

2 The long-run relationship has been identified using aggregate macroeconomic and industry data when the markup is defined on unit or marginal costs.

3 For example see Rotemberg (1983), Kuran (1986), Naish (1986), Danziger (1988), Konieczny (1990) and, in particular, Bénabou and Konieczny (1994).

'menu' costs and the discount rate, as well as whether the profit function is left or right skewed.[4]

In the models that focus on the interaction between inflation and 'menu' costs, it is (implicitly or explicitly) assumed that firms operate independently of each other and that the demand and cost functions are exogenous. The second broad group of explanations considers the direct impact of inflation on the equilibrium markup. Bénabou (1988, 1992) and Diamond (1993) model how inflation affects the profit maximising markup when the cost and demand functions are endogenous and affected by inflation. Further papers by Russell (1998) and Chen and Russell (2002) provide behavioral equilibrium models of the relationship between inflation and the markup and conclude explicitly that inflation and the markup are negatively related in the steady state.[5]

All these models explain the impact of inflation on the markup ignoring uncertainty concerning the profit maximising markup. In contrast, this paper argues that in an uncertain economic environment with missing information, higher inflation will reduce the markup relative to the profit maximising markup if the cost to firms of mistakenly setting a 'high'

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4 Following Konieczny (1990), the profit function $F(\bullet)$ is left-skewed if for each markup, z, $F'(z_1) < -F'(z_2)$ for every $z_1 < z_m < z_2$ and $F(z_1) = F(z_2)$ where z_m is the profit maximising markup. A right-skewed profit function reverses the inequalities. The skewness represents an asymmetry in marginal profits around the profit maximising markup. In the case of a left-skewed profit function, the impact on profits of setting a low price, $z_m - \varepsilon$, relative to the profit maximising markup is less then setting a similarly high markup and $F(z_m - \varepsilon) > F(z_m + \varepsilon)$.

5 The steady state is defined as when all nominal variables are growing at the same constant rate. If the underlying causes of the short-run relationships in the models set out above persist in the steady state then the relationship elicited in these papers will also persist in the steady state.

markup relative to the profit maximising markup is greater than the cost of mistakenly setting a ‘low’ markup.[6]

The economic intuition of the argument is straightforward. If the profit maximising markup is unknown, non-colluding price setting firms will attempt to minimise the expected cost of setting the wrong markup. When the loss function is asymmetric with the cost of setting a ‘high’ markup relative to the ‘true’ profit maximising markup is larger than setting a ‘low’ markup then firms will be cautious and set a ‘low’ markup. Firms, therefore, set a ‘low’ markup to insure against the disproportionately bad outcome of mistakenly setting too high a markup. Furthermore, as uncertainty surrounding the (full information) profit maximising markup increases, firms will act more cautiously and set an even lower markup. It follows, therefore, that if uncertainty increases with the general level of inflation then the markup set by firms will fall relative to the (full information) profit maximising markup as inflation rises.

Importantly this paper also argues that the negative relationship will persist in the steady state because the missing information and uncertainty faced by firms is not of a type that can be overcome in the steady state.

The proposition that inflation and the markup are negatively related in the *steady state* has a number of important macroeconomic implications. The most important deals with the slope of the long-run Phillips curve. If unemployment is partly dependent on the real wage then with steady state inflation impacting on the markup, and therefore the real wage, it is unlikely that the long-run Phillips curve is vertical. The negative relationship also helps to explain the international evidence that stock returns and inflation are negatively related.[7] The lower

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6 Using Konieczny (1990) terminology, the profit function is assumed to be left skewed.

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

stock returns with higher inflation simply reflect the impact of both present and expected inflation on the profitability of firms.

The next section considers some of the methodological issues concerning the modeling of missing information before a constrained optimising model of price setting under uncertainty is set out in Section 3. Section 4 considers a number of issues concerning the model.

2 MODELLING MISSING INFORMATION

Two broad approaches to modeling the pricing behaviour of monopolistically competitive firms present themselves. The first assumes, either with or without missing information, that firms know their marginal cost and marginal revenue functions and the firm's optimising problem is solved using standard techniques. This approach is powerful on an intellectual level when production functions are suitably differentiable. However, on a practical level, marginal costs may not simply be unknown but undefined when the production process includes joint products.[8]

Marginal costs may be undefined for two reasons. First, there is no clear distinction between fixed and variable costs and, in particular, the concept of overhead labour is not uniquely defined.[9] In this case output may be a joint product of labour. Second, non-labour inputs may also have joint outputs. Consequently the cost of the input must be apportioned in some fashion to each of the joint outputs. Again, how the costs are apportioned is not unique. For

8 The difficulties associated with modeling the economics of joint products has a long pedigree in the literature. For example see, Marshall (1920, 1927), Sraffa (1960) and more recently an important series of papers by Baumol (1976, 1977), Panzar and Willig (1977) and Willig (1979).

9 In practice the profit maximising price is not independent of the apportioning of costs into fixed and variable components. Furthermore, variable costs may not be a continuous function of output and remain fixed over ranges of output before making discreet changes in level. For example, supermarkets may sell an extra unit of goods with no change in labour input. However, given enough of an increase in sales a discrete increase in labour may be necessary.

example, a lamb produces a range of joint products including legs of lamb and lamb cutlets. The marginal costs of each product is not defined even though there is presumably a set of profit maximising prices for both the joint products of the lamb. That is, the existence of a set of profit maximising prices is not a sufficient condition for a corresponding set of marginal costs to exist.

It follows, therefore, that while there must be a set of output prices that maximise the firm's profits the concept of marginal costs is of little practical use in setting the price of each of the joint products.[10] Faced with this problem firms may search for the profit maximising set of prices. However, search takes time which introduces its own problems. Due to the changing economic environment firms cannot undertake search assuming *ceteris paribus* when comparing outcomes of different sets of prices. Furthermore, if trading in a customer market, changes in relative prices may have prolonged (or possibly permanent) effects on sales. Consequently, the solution of searching for the optimum set of prices is understandably not popular with firms.

If marginal costs are undefined then a second way to proceed is to model the behaviour of the price setters directly. In this case, a hypothesis of the decision maker's behaviour is set out that may be verified by direct observation. The implications of the hypothesised behaviour are then established and compared with the data. We now turn to one such behavioural model of price setting for non-colluding monopolistic firms when information concerning the profit maximising price is missing.

3 A MODEL OF PRICE SETTING UNDER UNCERTAINTY

This section sets out a model of price setting under uncertainty for non-colluding firms where it is assumed that the general level of inflation is determined in aggregate by the monetary authorities. The model focuses on the desired 'equilibrium' markup set by firms.

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[10] This is in contrast with economic models that deal with suitably differentiable cost functions where the marginal cost functions are easily determined.

Consequently we assume that firms are not undertaking any short-run strategic pricing, the industry structure is fixed with no entry or exit of firms and that firms behave symmetrically in the sense that all firms are attempting to set the profit maximising markup with missing information. The issue of industry structure is addressed following the formal model in Section 4.

Assume that the firm's loss function, L, can be written

(1) $$L = \begin{cases} a\left(\Pi^* - \Pi\right) if \;\; \Pi \leq \Pi^* \\ b\left(\Pi - \Pi^*\right) if \;\; \Pi > \Pi^* \end{cases}$$

where a and b are non-negative constants, Π^* is the profit maximising markup that may vary between minus infinity and infinity, and Π is the markup set by firms. One interpretation of the loss function is that it is a linear approximation of the 'true' loss function in the vicinity of the profit maximising markup. Alternatively, in keeping with the 'missing information' approach in this paper, firms may not know their 'true' loss function and (1) simply represents the loss function that they believe they face in the vicinity of the profit maximising markup.[11]

It is trivial to show that without uncertainty the loss function is minimised when the markup is the profit maximising markup. However, due to missing information concerning the firm's cost and demand functions, assume the profit maximising markup is unknown to firms with certainty. Instead, assume that firms hold a subjective probability density function, $f\left(\Pi^*\right)$, of the profit maximising markup and that the uncertainty faced by firms increases with the variance of $f\left(\Pi^*\right)$. The function $f\left(\Pi^*\right)$ is symmetric about the mean, μ, of Π^* and,

11 Assuming a linear rather than a quadratic loss function simplifies the analysis, allows the model to focus on the asymmetric loss function and leads to an easy interpretation of the results.

unknown to the firm, the mean coincides with the 'true' full information profit maximising markup, $\tilde{\Pi}$, such that $\mu = \tilde{\Pi}$, The mean and variance, σ, are defined[12]

$$\mu = \int_{-\infty}^{\infty} \Pi^* f\left(\Pi^*\right) d\Pi^*, \qquad \sigma = \int_{-\infty}^{\infty} \left(\Pi^* - \mu\right)^2 f\left(\Pi^*\right) d\Pi^* .$$

It is a strong assumption that μ coincides with $\tilde{\Pi}$. However, this assumption allows the results from the model not to depend on any bias associated with $f\left(\Pi^*\right)$ that serves to either reinforce or ameliorate the results of the model. This issue is considered further below.

The expectation of the loss function can be written

(2) $$E(L) = a \int_{\Pi}^{\infty} \left(\Pi^* - \Pi\right) f\left(\Pi^*\right) d\Pi^* + b \int_{-\infty}^{\Pi} \left(\Pi - \Pi^*\right) f\left(\Pi^*\right) d\Pi^* .$$

The first term of $E(L)$ represents the expected loss if the chosen markup is less than the profit maximising markup while the second term is the expected loss if the markup is greater than the profit maximising markup. Through this model, we wish to establish the impact of uncertainty on the optimum markup chosen by price setting firms.

Assume the firm chooses its markup, Π, to minimise the expected loss function subject to the constraint of uncertainty. Formally this is achieved when $\partial E(L)/\partial \Pi = 0$. From (2) it can be shown that[13]

(3) $$\frac{\partial E(L)}{\partial \Pi} = -a\left(1 - F(\Pi)\right) + bF(\Pi)$$

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12 The general form of the subjective probability function does not exclude the possibility that outside some range of the markup firms believe there is a zero probability that the markup is the profit maximising markup.

13 The model is considered in more detail in the mathematical appendix.

where $F(\Pi)=\int_{-\infty}^{\Pi} f(\Pi^*)d\Pi^*$ is the cumulative distribution function of the profit maximising markup evaluated at the chosen markup, Π.[14] Thus if $\Pi=\hat{\Pi}$ when $\partial E(L)/\partial\Pi=0$ then (3) gives the result

(4) $$F(\hat{\Pi})=\frac{a}{a+b}.$$

Hence, if the loss function is symmetric around the profit maximising markup (i.e. $a=b$) then $F(\hat{\Pi})=0.5$ and, therefore, $\Pi = \mu \equiv \tilde{\Pi}$. That is, the firm chooses the 'true' profit maximising markup as the optimum markup.

Alternatively, firms may believe they face an asymmetric loss function for the following reasons. First, firms may trade in a customer market.[15] In this case the impact on the firm of setting a 'high' markup (i.e. a high price) cannot simply be reversed by setting the profit maximising markup in the following period. Having set a 'high' markup, some customers search for relatively lower prices which, if found, they will accept. The lost customer cannot be induced back to the old supplier by a reduction in the old supplier's markup because the impetus to search is now triggered by the new supplier and not the old supplier. Without the new supplier inducing further search by raising their markup, the lost customer will not search and find that the prices offered by their old supplier have fallen. A 'high' markup, therefore, may have a long term and large impact on the number of customers while a 'low' markup has little impact. A second reason is that firms may believe they face a 'kinked'

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14 As $\partial^2 E(L)/\partial \Pi^2 = (a+b)\partial F(\Pi)/\partial \Pi > 0$ then the value of Π for which $\partial E(L)/\partial \Pi = 0$ represents a minimum of the expected loss function.

15 For customer markets see Okun (1981) in particular, but also McDonald and Spindler (1987), Bils (1989), McDonald (1990).

demand curve.[16] Setting a high markup (and price), therefore, will have a larger impact on output and profits than setting a 'low' markup. A third reason is that firms may face increasing returns to scale. In this case, the impact of a 'high' markup (and price) on output reduces profits by more than the impact of a 'low' markup on output.[17]

If the loss function is not symmetric and the cost of choosing a 'high' markup relative to the profit maximising markup is greater than choosing a 'low' markup (i.e. $a<b$) then $F\left(\hat{\Pi}\right)<0.5$. This implies the firm chooses an optimum markup, $\hat{\Pi}$, that is less than the 'true' profit maximising markup, $\tilde{\Pi}$. Finally, if the cost of setting a 'low' markup is greater than setting a 'high' markup (i.e. $a>b$) then $F\left(\hat{\Pi}\right)>0.5$ and the optimum markup in an uncertain environment is greater than the 'true' profit maximising markup, $\tilde{\Pi}$. For simplicity, this possibility is not elaborated further as it implies behaviour inconsistent with the arguments set out above and will be shown below to be inconsistent with the short-run and long-run empirical results reported in the introduction.

3.1 The Impact of Uncertainty on the Optimum Markup

We now wish to investigate the dependence of the optimum markup, $\hat{\Pi}$, on the degree of uncertainty which is represented in this model by the variance of the probability distribution, σ. For this purpose we write (4) in the following form

(5) $$F\left(\hat{\Pi}(\sigma),\sigma\right)=\frac{a}{a+b}$$

to emphasise the dependence on the variance, σ, of both the optimum markup, $\hat{\Pi}$, and the cumulative distribution function, F.

16 For 'kinked' demand curves see Sweezy (1939), Hall and Hitch (1939), Stigler (1947, 1978), Maskin and Tirole (1988).

17 An alternative interpretation of the asymmetric loss function is that it reflects risk averse firms.

Considering the variance, σ, as an independent variable and assuming that the constants a and b are independent of the variance, then differentiating (5) gives[18]

(6) $$\frac{d\hat{\Pi}}{d\sigma} = -\frac{\partial F(\hat{\Pi})}{\partial \sigma} \Big/ f(\hat{\Pi}).$$

We now discuss the implications of (6) for symmetric and asymmetric loss functions. For the symmetric loss function when $a = b$, the optimum markup, $\hat{\Pi}$, is always the profit maximising markup, $\tilde{\Pi}$, which is the mean of the distribution (i.e. $\hat{\Pi} = \mu \equiv \tilde{\Pi}$). In this particular case, $\frac{\partial F(\hat{\Pi})}{\partial \sigma} = 0$ and the optimum markup is independent of the variance when the loss function is symmetric and, hence, $d\hat{\Pi}/d\sigma = 0$. It follows that when the loss function is symmetric then the optimum markup is not affected by uncertainty.

However, when the loss function is asymmetric with $a < b$, then $\partial F(\hat{\Pi})/\partial \sigma > 0$ for values of $\hat{\Pi}$ less than the mean, μ. This can be seen in Figure 1 which shows the impact on the cumulative probability distribution, F, of a mean preserving increase in the variance from σ_1 to σ_2. This increase in the variance shifts upwards the cumulative distribution function, F, over the range $\Pi^* < \mu$. Hence, as $\partial F(\hat{\Pi})/\partial \sigma > 0$ then, from (6), $d\hat{\Pi}/d\sigma < 0$ and the optimum markup decreases as the variance increases. This can also be seen in Figure 1 where for an optimum value $a/(a+b)$ of F, given for example by $\hat{\Pi} = \hat{\Pi}_1$, the optimum markup $\hat{\Pi}$ falls from $\hat{\Pi}_1$ to $\hat{\Pi}_2\,(<\hat{\Pi}_1)$ as the variance increases from σ_1 to $\sigma_2\,(>\sigma_1)$.

It follows, therefore, that an increase in uncertainty leads firm's to choose a lower optimum markup if the loss function is asymmetric with $a < b$. Furthermore, if uncertainty increases with inflation (as argued in section 4.2 below), then higher inflation leads firms to choose a lower markup relative to the profit maximising markup. Finally if the impact of inflation on

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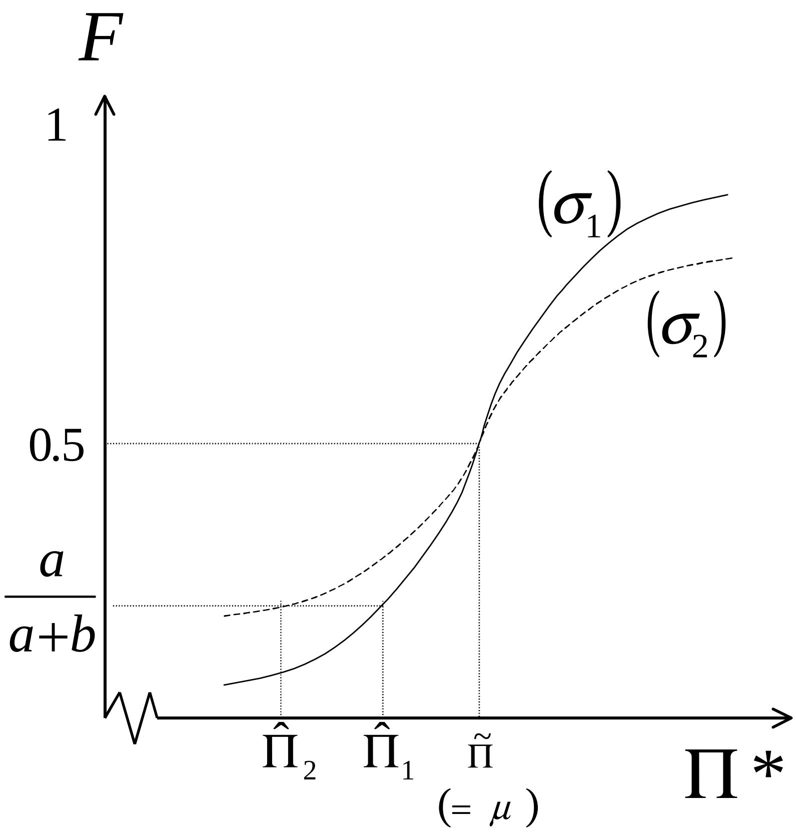
18 Implicit in the derivation of (6) is the mean and other parameters of the cumulative distribution function, F, are held constant.

uncertainty is positive but declining, then as inflation increases to an infinite rate the markup asymptotes to some minimum value.

We can now see why an asymmetric loss function with $a>b$ is inconsistent with the empirical results. If $a>b$ then firms would set a higher markup with higher inflation leading to a positive relationship between inflation and the markup.

Figure 1: The Impact of the Variance on the Optimum Markup



4 ISSUES CONCERNING THE MODEL

4.1 Is the Probability Density Function Unbiased?

The model assumes that firms are unaware that the probability density function, $f\left(\Pi^*\right)$, is unbiased. While this assumption simplifies the analysis it may lead to an over estimate of the optimum markup set by firms. Consider the possibility that firms determine the characteristics of the probability density function from the impact that past markups have had on profits. If firms in an uncertain inflationary environment set a ‘low’ markup on average, then information that the firm acquires will not only be drawn from a sample of ‘low’ markups that the firm has set but also from an environment where all firms are setting ‘low’ markups. It is not clear that with this bias in the ‘sampling technique’ that firms will hold an unbiased probability distribution. If firms only experience an environment of ‘low’ markups then the probability distribution may be biased with the mean less than the profit maximising markup. This would further reduce the optimum markup set by firms relative to the profit maximising markup, especially at persistently high rates of inflation.

This issue is not important, however, if the relationship of interest is between inflation and the optimum markup which will hold irrespective of the relationship between the optimum markup and the ‘true’ profit maximising markup.

4.2 The Relationship between Inflation and Uncertainty

Although the link between inflation and uncertainty is widely held it is not easily demonstrated empirically. This is partly because the nature of the uncertainty is not clearly stated. Friedman (1977) conjectures that inflation and uncertainty are positively correlated and as a result concludes that the long-run Phillips curve has a positive slope. Early empirical work that assumes relative price variability is a proxy for uncertainty supports Friedman’s conjecture.[19]

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19 For example see Mills (1927), Okun (1971), Lucas (1973), Logue and Willett (1976), Vining and Elwertowski (1976), Klein (1977), Fischer (1981), Mizon, Safford and Thomas (1991), Parsley (1996), Debelle and Lamont (1997), Banerjee, Mizen and Russell (2002) who provide evidence of a positive relationship between relative price variability and inflation. Recently, however, Hartman (1991), Reinsdorf (1994) and Fielding and Mizen (2000) provide some evidence that higher inflation may be associated with lower relative price variability.

Using an ARCH model of inflation, Engle (1983) shows that the higher inflation in the 1970s was only slightly less predictable than inflation in the 1960s and that, therefore, uncertainty did not increase with the higher inflation.[20] Implicitly, Engle is assuming the nature of the uncertainty is the inability of agents (including firms) to predict the rate of inflation. This assumption is not unreasonable in a price taking world. However, in a price setting world with missing information, aggregate inflation may be highly predictable but uncertainty may persist due to the difficulty in coordinating price changes between firms. Higher inflation leads to more frequent and / or larger real changes in prices which creates greater uncertainty concerning the coordination of price changes.

Evans (1991) also argues that the uncertainty is derived from the inability to predict inflation but, in contrast with Engle's work, Evans makes the distinction between predicting inflation in the short-run and in the long-run. Evans argues that even though higher inflation is predictable in the short-run, it is more difficult to predict the long-run (or steady state) rate of inflation. By making this distinction, Evans explains the seemingly inconsistent results of the ARCH models (which focus on short-run inflation) with those of Wachtel (1977), Carlson (1977) and Cukierman and Wachtel (1979) who find a positive correlation between the variance of longer-term inflation forecasts and inflation from the Michigan and Livingston surveys.

Finally, in contrast with earlier papers that look at the correlation between inflation and uncertainty, Holland (1995) uses the variance of six and twelve month inflation forecasts as a proxy for uncertainty and concludes that inflation Granger-causes uncertainty.

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20 Holland (1984), Cosimano and Jansen (1988) and Jansen (1989) follow Engle (1983) in using ARCH models of inflation and also show that higher inflation is not less predictable.

4.3 Inflation, Uncertainty and the Steady State

The relationship between inflation and the markup suggested in Bénabou (1988, 1992), and Diamond (1993) and that described in the model above differ in one important respect. In the former models, inflation impacts on the profit maximising markup. In the model set out above, the uncertainty generated by inflation impacts on the optimum markup set by firms while the profit maximising markup is unchanged.

The model has demonstrated that in an uncertain environment when the costs of setting a 'high' markup is greater than setting a 'low' markup, firms will set an optimum markup that is less than the profit maximising markup. We can interpret this lower markup as the cost to firms of overcoming the uncertainty.

Whether or not the negative relationship between inflation and the optimum markup is a steady state relationship depends on the nature of the uncertainty. If the uncertainty is simply due to firm's not knowing the average rate of inflation then the uncertainty will disappear in the steady state and the relationship posited in this paper is only a short run phenomena. Alternatively, if the uncertainty is due to missing information in a wider sense and due to the difficulty for firms to coordinate price changes in an inflationary environment, then uncertainty will persist even though average inflation may be unchanged in the steady state.[21] The relationship between inflation and the markup would then exist in the steady state. Without considering the numerous possible definitions of what constitutes a steady state, the notion that uncertainty exists in the steady state appears a better representation of stable inflation in the world we are attempting to model.

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21 Eckstein and Fromm (1968), Chatterjee and Cooper (1989), Blinder (1990) and Ball and Romer (1991) argue price setting firms find it difficult to coordinate price changes.

4.4 Entry, Exit and the Steady State

Relaxing the assumption of a fixed industry structure reduces but does not eliminate the negative relationship between inflation and the markup in the steady state. Consider the case where the monetary authorities lower the rate of steady state inflation and this leads to an increase in the steady state markup. If firms enter the industry in response to the increased markup and the entire increase in the markup is competed away then we would have two industry structures with different levels of competition but only one markup in the steady state. This implies that industry structure is independent of the markup in the steady state. To avoid this result we must conclude that entry does not compete away all the increase in the markup and only serves to reduce the negative relationship between inflation and the markup.

5 CONCLUSION

This paper set out to show that in an uncertain environment with non-colluding price setting firms, inflation and the markup are negatively related in the steady state. This result relied on three conditions. First, the profit maximising markup is unknown to firms and that firms aim to minimise the expected loss associated with setting the 'wrong' markup. Second, firms believe that the loss function they face is asymmetric. Specifically, the cost of setting a 'high' markup relative to the profit maximising markup must be greater than the cost of setting a 'low' markup. This condition was considered likely if firms trade in a customer market, they face a 'kinked' demand curve, or are subject to increasing returns to scale. The third condition is that uncertainty increases with inflation. This condition is thought to hold if the source of the firm's uncertainty is their difficulty in coordinating changes in prices. Higher inflation, therefore, implies more frequent and larger changes in prices and so greater coordination problems and greater uncertainty.

6 MATHEMATICAL APPENDIX[22]

The Expected Loss Function

The loss function, L, is written:

$$L = g(\Pi) = \begin{cases} a(\Pi^* - \Pi) \; if \;\; \Pi \leq \Pi^* \\ b(\Pi - \Pi^*) \; if \;\; \Pi > \Pi^* \end{cases} \tag{1}$$

where a and b are non-negative constants; Π^* is the profit maximising markup that may vary between minus infinity and infinity; and Π is the markup of the output set by firms.

The expectation of the loss function, $E(L)$ for a given value of Π:

$$E(L) = \int_{-\infty}^{\infty} g(\Pi) f(\Pi^*) \, d\Pi^* \tag{1b}$$

where $f(\Pi^*)$ is the firm's subjective probability density function of the profit maximising markup. The function is symmetric about the mean of Π^*, μ, which coincides with the 'true' profit maximising markup (i.e. $\mu = \tilde{\Pi}$) and variance, σ, defined as

$$\mu = \int_{-\infty}^{\infty} \Pi^* f(\Pi^*) d\Pi^*, \qquad \sigma = \int_{-\infty}^{\infty} (\Pi^* - \mu)^2 f(\Pi^*) d\Pi^*$$

From (1) and (1b):

$$E(L) = a \int_{\Pi}^{\infty} (\Pi^* - \Pi) f(\Pi^*) d\Pi^* + b \int_{-\infty}^{\Pi} (\Pi - \Pi^*) f(\Pi^*) d\Pi^* \tag{2}$$

The expectation of the loss function is represented by the integral of the losses evaluated for a given Π as the profit maximising markup goes from minus infinity to infinity.

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22 The equation numbers in the appendix correspond to those in the main body of text.

Rearrange terms:

$$E(L)=a\int_{\Pi}^{\infty}\Pi^* f(\Pi^*)d\Pi^* - b\int_{-\infty}^{\Pi}\Pi^* f(\Pi^*)d\Pi^* - a\Pi\int_{\Pi}^{\infty} f(\Pi^*)d\Pi^* + b\Pi\int_{-\infty}^{\Pi} f(\Pi^*)d\Pi^* \quad (2b)$$

$$E(L)=a\int_{\Pi}^{\infty}\Pi^* f(\Pi^*)d\Pi^* - b\int_{-\infty}^{\Pi}\Pi^* f(\Pi^*)d\Pi^* - a\Pi(1-F(\Pi)) + b\Pi F(\Pi) \quad (2c)$$

where $F(\Pi)=\int_{-\infty}^{\Pi} f(\Pi^*)d\Pi^*$ is the subjective cumulative distribution function of the profit maximising markup evaluated at the chosen markup, Π.

The Optimum Markup Under Uncertainty

The firm chooses its markup, Π, to minimise the expected loss function subject to the constraint of uncertainty. This is achieved when $\partial E(L)/\partial\Pi = 0$.

From (2) we have that

$$\frac{\partial E(L)}{\partial \Pi} = -a\Pi f(\Pi) - b\Pi f(\Pi) - a(1-F(\Pi)) + a\Pi f(\Pi) + bF(\Pi) + b\Pi f(\Pi) \quad (2d)$$

$$\frac{\partial E(L)}{\partial \Pi} = -a(1-F(\Pi)) + bF(\Pi) \quad (3)$$

As $\partial^2 E(L)/\partial\Pi^2 = (a+b)\partial F(\Pi)/\partial\Pi > 0$ then the value of Π for which $\partial E(L)/\partial\Pi = 0$ represents a minimum of the expected loss function.

Thus if $\Pi = \hat{\Pi}$ when $\partial E(L)/\partial\Pi = 0$ then (3) gives the result

$$F(\hat{\Pi}) = \frac{a}{a+b}. \quad (4)$$

For a symmetric loss function when $a = b$ then $F(\hat{\Pi}) = 0.5$ and $\hat{\Pi} = \mu \equiv \tilde{\Pi}$. That is, the firm chooses the profit maximising markup as the optimum markup.

If the loss function is not symmetric with $a < b$ then $F(\hat{\Pi}) < 0.5$. That is, the firm chooses an optimum markup, $\hat{\Pi}$, which is less than the profit maximising markup, $\tilde{\Pi}$. Finally, if the loss function is asymmetric with $a > b$ then $F\left(\hat{\Pi}\right) > 0.5$. That is, the optimum markup set by firms is greater than the profit maximising markup.

The Impact of Uncertainty on the Optimum Markup

We now wish to investigate the dependence of the optimum markup on the degree of uncertainty which is represented in this model by the variance of the probability distribution, σ. For this purpose we write (4) in the following form

$$F\left(\hat{\Pi}(\sigma), \sigma\right) = \frac{a}{a+b} \tag{5}$$

to emphasise the dependence on the variance, σ, of both the optimum markup, $\hat{\Pi}$, and the cumulative distribution function, F. Consider the variance, σ, as an independent variable and assuming that the constants a and b are independent of the variance and that the mean and other parameters of the cumulative distribution function, F, are held constant, totally differentiate (5) with respect to σ:

$$\frac{\partial F\left(\hat{\Pi}\right)}{\partial \hat{\Pi}} \frac{d\hat{\Pi}}{d\sigma} + \frac{\partial F\left(\hat{\Pi}\right)}{\partial \sigma} = 0. \tag{5b}$$

Rearranging (5b):

$$\frac{d\hat{\Pi}}{d\sigma} = -\frac{\partial F\left(\hat{\Pi}\right)}{\partial \sigma} \Big/ f\left(\hat{\Pi}\right). \tag{6}$$

For the symmetric loss function when $a = b$, the optimum markup, $\hat{\Pi}$, is always the profit maximising markup, $\tilde{\Pi}$, which is the mean of the profit maximising distribution (i.e. $\hat{\Pi} = \mu \equiv \tilde{\Pi}$). In this particular case, the optimum markup is independent of the variance when the loss function is symmetric and, hence, $d\hat{\Pi}/d\sigma = 0$. It follows that when the loss function is symmetric then the optimum markup is not affected by uncertainty.

However, when the loss function is asymmetric with $a < b$, then for values of $\hat{\Pi}$ less than the mean μ (which is the relevant range for $\hat{\Pi}$ in the asymmetric case), then $\partial F\left(\hat{\Pi}\right)/\partial \sigma > 0$ and $d\hat{\Pi}/d\sigma < 0$.

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