Price-setting behaviour, competition, and mark-up shocks in the New Keynesian model

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Abstract

Recent research and policy discussions have noted that the potentially increased competition among firms since the 1990s may affect inflation and economic activity. This paper considers the implications of this structural change on short-run inflation dynamics, and for assessing shocks to inflation and output. The importance of firms' price-setting behaviour is highlighted in this context using a standard New Keynesian model with microfoundations. It is well known that both Rotemberg and Calvo price-setting assumptions imply the same reduced-form New Keynesian Phillips Curve (NKPC). Increased competition among firms, however, increases price flexibility in the former, and has either no effect or decreases price flexibility in the latter. The effects of mark-up shocks on inflation and output are small when firms' price-setting behaviour incorporates concerns about potential loss of market share. These effects are further dampened in an environment of more intense competition. Under the assumption of increased competition, both models lead to unambiguous predictions about the direction of change in the slope of the Phillips curve. Rolling estimates of the NKPC indicate that the slope has declined or flattened for several countries since the 1990s. This evidence is consistent with the prediction of the Calvo model.

Key words: Competition, price-setting, inflation.

JEL classification: E31, E32.

Summary

Recent research and policy discussions have noted that the potentially increased competition among firms since the 1990s may affect inflation and economic activity. Deregulation, globalisation and reduction in trade barriers are often discussed as drivers underlying this structural change. Although direct evidence on increased competition is not available, some indirect measures do corroborate the view that competition among firms may have become more intense since the 1990s.

While there is broad agreement that an increase in the degree of competition among firms should put downward pressure on the price level, its implications for inflation dynamics and the assessment of shocks are unclear. For example, a one-off or steady-state increase in the degree of competition may mean that firms adjust their prices more often. This would amplify short-run inflationary pressures. On the other hand, it may mean that firms stand to lose market share and are therefore less willing to adjust their relative prices; this would dampen inflationary pressures.

The paper uses the standard New Keynesian framework, based on optimising behaviour of monopolistically competitive firms which face constraints on nominal price adjustments. In this framework, the elasticity of substitution between goods captures the degree of competition among firms. A rise in this elasticity implies that goods in the economy are relatively closer substitutes for each other, indicating more intense competition between firms.

This paper considers two specific price-setting assumptions: quadratic costs of nominal price adjustments and probabilistic price adjustment. Both are commonly used in small structural monetary policy models and have the same reduced-form Phillips curve specification. Under the former, however, increased competition among firms unambigously increases price flexibility. Under the latter, increased competition either has no effect or decreases price flexibility. Price flexibility unambigously decreases in the latter model when real rigidities in the goods and labour markets are considered. The paper finds that ‘cost-push’ or mark-up shocks to inflation are substantially dampened under the probabilistic price adjustment model with real rigidities, relative to the quadratic cost of adjustment model.

The main implications of the findings are as follows. First, assumptions about firms’ price-setting behaviour determine how increased competition among firms affects the

short-run dynamics of inflation. In particular, it determines how the slope of the New Keynesian Phillips Curve and the impact of shocks on inflation and output depends upon the price-setting behaviour. Second, models with microfoundations map out explicitly the relationship between the parameters in the reduced-form equations and the underlying structural or 'deep' parameters. This feature can help to avoid pitfalls and to clarify the different channels through which price-setting behaviour and structural changes may affect inflation and output. At several central banks micro-founded models are increasingly being used to inform policy. To the extent that assumptions about firms' price-setting behaviour are key aspects of these models, it is important to highlight transmission channels that these assumptions may or may not capture. Third, testing the predictions of the two models may help to choose the relevant model to examine the implications of potentially increased competition since the 1990s.

1 Introduction

Recent research and policy discussions have noted that potentially increased competition among firms since the 1990s in several countries may have effects on inflation and economic activity.[(1)] Deregulation, globalisation, reduction in trade barriers are often discussed as underlying drivers behind this structural change in several countries. Direct evidence on increased competition is, however, difficult to obtain. But there are indirect measures which corroborate the view that competition among firms may have increased since the 1990s. In the United Kingdom, for example, the ratio of nominal imports to nominal GDP (at market prices) - the import penetration ratio - averaged for each decade has increased steadily over the past decades (See Table 1).[(2)]

Table 1
Average import penetration ratio for the United Kingdom

1960s	1970s	1980s	1990s	2000s
20.1	26.1	26.3	27.5	29.0

For the United States, Duca and VanHoose (2000) document that the aggregate price elasticity index - which indicates the degree of overall competition in the US economy - has risen since the 1980s.

Understanding the implications of potentially increased competition among firms is relevant to monetary policy and inflation dynamics. In a recent speech, for example, Rachel Lomax, the Deputy Governor of the Bank of England, mentioned

> 'To the extent that a fierce competitive struggle is squeezing retail margins, it is likely to affect the short-run outlook for inflation.'
> *Bank of England Quarterly Bulletin*, Spring 2004, pages 77-82.

(1) Rogoff (2003) has emphasised that increased competition among firms may explain declines in average or long-term inflation witnessed across the globe. Along similar lines, Bayoumi, Laxton and Pasenti (2003) estimate large benefits and spillovers of greater competition on standard measures of economic activity.
(2) Wadhwani (2000) interprets the increasing import penetration over the late 1990s as *prima facie* evidence of increased competition among firms.

Higher competition among firms is generally seen to put downward pressure on the price level. But in the presence of frictions on nominal price adjustments, the implications for short-run dynamics of inflation are unclear. Furthermore, the response of inflation and output to shocks may depend on the prevailing competitive environment. This paper uses the standard New Keynesian framework based on optimising behaviour of monopolistically competitive firms which face constraints on nominal price adjustments to examine these issues. It shows that assumptions about firms' price-setting behaviour in the face of a structural change in competition determines the consequences for inflation dynamics and assessment of 'cost-push' or mark-up shocks.

In the New Keynesian framework, the Dixit and Stiglitz (1977) elasticity of demand captures the degree of substitutability between goods. This elasticity is inversely related to the desired mark-up over cost that firms want to charge for their product. A higher substitutability between goods implies a higher level of competition among firms and a lower desired mark-up (a reduction in firms' pricing power). A structural increase in competition among firms corresponds to a one-off increase in the elasticity.[(3)]

We consider two ways of modelling price-setting behaviour that are commonly used as microfoundations for the New Keynesian Phillips Curve (NKPC) within this framework. Both models are convenient ways to describe firms' pricing behaviour in the goods market. First, the Rotemberg (1982) 'quadratic price adjustment cost' model (the R model) in which firms compare the profit loss from letting the desired nominal price move away from actual price with the cost of price adjustment. They choose the price in a way that minimises the two costs. Second, the Calvo (1983) 'random price adjustment signal' model (the C model) in which a firm adjusts its price only when it receives an adjustment signal. Such occasions for a firm are assumed to occur at random time intervals.

As shown by Rotemberg (1987) and Roberts (1995), the reduced-form inflation dynamics - the NKPC - implied by both the R and the C models are observationally equivalent. They are the only two models which give this particular reduced form.[(4)] But a change in the degree of competition affects the coefficients of the Phillips curve in different ways. Consequently, implications for the slope of the Phillips curve and the impact of shocks differ across the two models.

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(3) It is, however, useful to view a change in the elasticity more broadly as representing other aspects of market structure such as increase in the number of firms and increase in foreign competition.

(4) The Taylor (1980) fixed contract duration model implies a somewhat different Phillips curve than the NKPC. Since the NKPC is extensively used in theoretical and empirical analyses we focus on this particular Phillips curve.

Higher competition in the R model *increases* the slope of the Phillips curve. The reason is that in the presence of quadratic adjustment costs, each firm's pricing decision involves minimising profit loss from not charging the desired price today and in the future. As the elasticity of demand increases and the economy moves closer to perfect competition, not only does the level of desired mark-up fall but also changing prices become relatively cheaper. The latter occurs because the size of optimal price adjustment falls. This effect promotes price flexibility in the R model and increases the slope of the Phillips curve.

In the C model, however, higher competition has either *no effect* or can *decrease* the slope of the Phillips curve. So inflationary pressures either remain benign or get dampened. The reason is that, unlike the R model, relative prices can differ across firms. This implies that a firm's marginal cost may depend not only on the average level of output but also its own output (hence its own relative price). When adjusting prices a firm may not want a large difference in its price relative to the average price so as not to lose market share. This concern for potential market share loss means that relative prices can be rigid or 'real rigidity' can prevail in the goods market as explained by Ball and Romer (1990) and Kimball (1995). Market share loss is large when the elasticity of substitution between goods is high, that is, when the degree of competition among firms is high. A higher competition implies greater real rigidity and amplifies inertia in price adjustments. This effect decreases the slope of the Phillips curve. When real rigidity does not prevail, higher competition does not affect the slope. We follow Woodford (2003) and use the terminology 'strategic complementarity' and 'strategic substitutability' in firms' pricing decisions to indicate if real rigidity is present or not, respectively.

While it is useful to consider a one-off change in the degree of competition to examine the effects on the slope of the Phillips curve, competition may evolve over time. Using the R model, Ireland (2004) estimates that shocks to competition, or 'mark-up shocks' are important, relative to technology shocks, in explaining fluctuations in output and inflation in the US data. In view of this finding, we consider how the assumed nature of firms' price-setting behaviour affects the assessment of mark-up shocks in the New Keynesian model. We assume that monetary policy is implemented via an interest rate rule and consider standard calibration of parameters from the literature.

We find that higher competition reduces the impact effects of mark-up shocks on inflation and output for both the R and the C models. The actual magnitude, however, differs substantially. The impact effects are approximately four times smaller in the C model with strategic complementarity relative to the R model.

It is a common practice to calibrate the cost of adjustment parameter in the R model by equating the slope of the Phillips curves in the R and the C models. This procedure provides an economic interpretation to the cost of adjustment parameter in terms of the average duration of price stickiness. Moreover, it also means that the effect of shocks in a calibrated model will be identical across the two models. Since higher competition affects the slope differently in the two models, a mechanical re-calibration of the the cost of price adjustment in the R model has pitfalls. First, a mechanical calibration would imply that the cost of nominal price stickiness in the R model increase without any corresponding change frequency of price adjustment in the C model. In other words, one needs to assume that the costs associated with adjustment in nominal price must rise when the degree of competition among firms is higher to make the R model equivalent to the C model. Second, the calibration of the cost of adjustment parameter in the R model may imply quantitatively implausible magnitudes of price stickiness. This aspect echoes the concern highlighted by Danthine and Donaldson (2002) that in the New Keynesian model, cost of price adjustment may turn out to be implausibly higher than that of adjusting the capital stock.

To highlight the effects of strategic complementarity alone, we contrast the impact effects under the C model with and without strategic complementarity. Under the former, the impact effects are approximately twelve times smaller. This suggests that the assumptions made in the New Keynesian model regarding the structure of labour and capital markets affect the assessment of shocks in an important manner.

In the face of higher competition among firms, both the R and the C models have different predictions about the direction of change in the slope of the Phillips curve. The R model predicts unambiguously that the slope should increase. The C model predicts unambiguously that the slope should not increase. Given these predictions, we examine rolling estimates of the slope of the NKPC curve for the United Kingdom, United States, Canada, and the euro area. These estimates indicate that the slope has, in general, declined or flattened since the 1990s. This evidence is consistent with the prediction of the C model. It is also consistent with the findings of Duca and VanHoose (2000), who use a traditional Phillips curve analysis and find that increased competition has flattened the slope of the Phillips curve in the United States during the 1990s.

The rest of the paper is organised as follows. Section 2 presents a brief description of the New Keynesian model and the price-setting assumptions. Section 3 discusses the implications of higher competition on the NKPC. Section 4 computes a general equilibrium solution of the model and assesses the impact on inflation and output of mark-up shocks. Section 5 presents rolling estimates of the slope of the NKPC. Finally, Section 6 concludes.

2 The New Keynesian model

Consider an economy with a representative household at time t that maximises a discounted sum of expected utilities:

$$E_t \sum_{j=0}^{\infty} \beta^j \left[\frac{C_{t+j}^{1-\sigma^{-1}}}{1-\sigma^{-1}} - \int_0^1 \frac{H_{t+j}(i)^{1+\phi}}{1+\phi} di \right] \tag{1}$$

subject to the standard budget constraint (see, for example, Woodford (2003)). The parameter β is the subjective discount factor, $C_t = [\int_0^1 C_t(i)^{(\theta-1)/\theta} di]^{\theta/(\theta-1)}$ is the Dixit-Stiglitz constant-elasticity-of-substitution consumption index, $C_t(i)$ represents consumption of the ith good, $H_t(i)$ is the supply of type-i labour to the production of good of variety i, $\sigma > 0$ is the intertemporal elasticity of substitution of aggregate expenditure, ϕ is the disutility of labour. For our purpose, the relevant utility-maximising condition is the intratemporal condition of the choice of labour supply of type i:

$$\frac{W_t(i)}{P_t} = \frac{H_t(i)^{\phi}}{C_t^{-\sigma^{-1}}} \tag{2}$$

where $P_t = [\int_0^1 P_t(i)^{1-\theta_t}]^{1/(1-\theta_t)}$ is the price index. $W_t(i)$ is the wage rate per unit labour of type i.

On the supply side, firms operate in a monopolistically competitive market and are uniformly distributed on the interval $[0, 1]$. Each firm i faces a demand curve, $Y_t(i)$,

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta_t} Y_t \tag{3}$$

where $Y_t = [\int_0^1 Y_t(i)^{(\theta_t-1)/\theta_t}]^{\theta/(\theta-1)} di$ is aggregate demand, $P_t(i)$ is the price of firm i's good, and θ_t is the time-varying elasticity of demand for firm i that fluctuates around its steady-state level θ. Firm i produces output using a technology

$$Y_t(i) = H_t(i)^a, \quad 0 < a \leq 1 \tag{4}$$

where $H_t(i)$ is the labour input and a is the elasticity of output with respect to labour. We implicitly assume that capital stock is 'firm-specific' and constant over time.

2.1 *The Rotemberg (R) model: quadratic cost of nominal price adjustment*

Following Rotemberg (1982), each firm faces a quadratic cost of nominal price adjustment, measured in terms of the final good and given by

$$\frac{c}{2}\left(\frac{P_t(i)}{\pi P_{t-1}(i)}-1\right)^2 Y_t \qquad \textbf{(5)}$$

where $c \geq 0$ determines the magnitude of the price adjustment cost and $\pi \geq 1$ is the gross steady-state inflation rate. Given **(3)**, **(4)**, **(5)**, and wages in the labour market, a firm chooses a sequence for $P_t(i)$ to maximise the expected sum of future discounted profits.

$$E_t \sum_{j=0}^{\infty} R_{t+j}\left[\left(\frac{P_{t+j}(i)}{P_{t+j}}\right)^{1-\theta_{t+j}} Y_{t+j}-\left(\frac{P_{t+j}(i)}{P_{t+j}}\right)^{-\theta_{t+j}/a} \frac{W_{t+j}(i)}{P_{t+j}} Y_{t+j}^{1/a}-\frac{c}{2}\left(\frac{P_{t+j}(i)}{\pi P_{t-1+j}(i)}-1\right)^2 Y_{t+j}\right] \qquad \textbf{(6)}$$

where $R_t=\beta^t C_t^{-\sigma^{-1}}$ is the stochastic discount factor. In a symmetric equilibrium the optimal price P_t^* is the same for all firms, $P_t^*(i)=P_t$. In addition, $H_t(i)=H_t$, $Y_t(i)=Y_t$, $W_t(i)=W_t$ and the aggregate resource constraint is

$$Y_t=C_t+\frac{c}{2}\left(\frac{\pi_t}{\pi}-1\right)^2 Y_t \qquad \textbf{(7)}$$

where $\pi_t=P_t/P_{t-1}$ is the gross inflation rate. The first-order condition for **(6)** can be written as

$$P_t=\left[\frac{1}{\left(\frac{\theta_t}{\theta_t-1}\right)^{-1}+\frac{c}{\pi\theta_t}\left((\frac{\pi_t}{\pi}-1)-\beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma^{-1}}\left(\frac{Y_{t+1}}{Y_t}\right)\pi_t\right]\right)}\right]\frac{1}{a}W_t Y_t^{1/a-1}=\mu_t\frac{1}{a}W_t Y_t^{1/a-1} \qquad \textbf{(8)}$$

where μ_t is the mark-up over the marginal cost, $1/aW_tY_t^{1/a-1}$. In **(8)**, there are two terms in the denominator of the mark-up, μ_t. The first term, $\theta_t/(\theta_t-1)$, represents the mark-up and the second term

$$\frac{c}{\pi\theta_t}\left((\frac{\pi_t}{\pi}-1)-\beta E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma^{-1}}\left(\frac{Y_{t+1}}{Y_t}\right)\pi_t\right]\right)$$

represents the net cost associated with price adjustment. When there is no price stickiness ($c=0$), the mark-up is the same as the desired mark-up, $\theta_t/(\theta_t-1)$.

2.2 *The Calvo (C) model: random price adjustment signal*

Under the Calvo (1983) pricing structure each firm faces an exogenous probability, $(1-\alpha)$, of adjusting its price in each period. As advocated in Woodford (2003), we consider an environment of 'strategic complementarity' in pricing decisions of firms (or 'real rigidity' as in Ball and Romer (1990)) introduced via the segmented or 'firm-specific' labour market assumption in **(1)** and **(4)** and the 'firm-specific' capital market assumption in **(4)**. Strategic complementarity implies that a firm has more incentive to increase its price when other firms increase theirs. In contrast, under common factor markets 'strategic substitutability' in pricing decisions prevails which implies that a firm has less incentive to lower its price when other firms lower theirs.

A firm chooses its price $P_t(i)$ to maximise current and discounted future (real) profits:

$$E_t \sum_{j=0}^{\infty} \alpha^j Q_{t,t+j} \left[\left(\frac{P_t(i)}{P_{t+j}}\right)^{1-\theta_{t+j}} Y_{t+j} - \frac{W_{t+j}(i)}{P_{t+j}} \left(\left(\frac{P_t(i)}{P_{t+j}}\right)^{-\theta_{t+j}} Y_{t+j} \right)^{\frac{1}{a}} \right] \quad \textbf{(9)}$$

where $Q_{t,t+j} = \beta^j (C_t/C_{t+j})^{-\sigma}$ is the stochastic discount factor. The first-order condition for **(9)** is:

$$E_t \sum_{j=0}^{\infty} \alpha^j Q_{t,t+j} *$$

$$\left((1-\theta_{t+j}) \left(\frac{P_t^*}{P_{t+j}}\right)^{-\theta_{t+j}} \frac{Y_{t+j}}{P_{t+j}} + \frac{\theta_{t+j}}{a} \frac{W_{t+j}(i)}{P_{t+j}} \left(\left(\frac{P_t^*}{P_{t+j}}\right)^{-\theta} Y_{t+j} \right)^{\frac{1}{a}-1} \left(\frac{P_t^*}{P_{t+j}}\right)^{-\theta_{t+j}-1} \frac{Y_{t+j}}{P_{t+j}} \right) = 0 \quad \textbf{(10)}$$

where P_t^* is the optimal price charged by firms who receive the price adjustment signal (see Yun (1996)). The aggregate price level under the Calvo model evolves according to

$$P_t = \left[(1-\alpha) P_t^{*1-\theta} + \alpha P_{t-1}^{1-\theta} \right]^{\frac{1}{1-\theta}} \quad \textbf{(11)}$$

2.3 The Phillips curve specifications

To get the NKPC for the R model, we substitute out W_t/P_t using **(2)** and **(4)** in **(8)**. Log-linearising the resulting equation and the **(A-3)** around the zero-inflation ($\pi_t = \pi = 1$), flexible price equilibrium with a constant degree of competition among firms, $\theta_t = \theta$. Define $y_t = \log(Y_t/Y^e)$, $y_t^n = \log(Y_t^n/Y^e)$ (where Y^e is the flexible price, efficient steady state of the economy), $\pi_t = \log(\pi_t/\pi)$, and $\hat{\theta}_t = \log(\theta_t/\theta)$.[5] The details for the derivation of the NKPC in the C model are now common and presented elsewhere (see, for example, Woodford (2003)).

The reduced-form NKPC specifications for both the R and the C (both Css and Csc cases) models can be written the same way but they are not identical:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda^i (y_t - y_t^n) - \gamma^i \hat{\theta}_t, \quad i = R, C \quad \textbf{(12)}$$

According to **(12)**, inflation in both models is determined by current expectations of next period's inflation, the output gap, and a $\hat{\theta}_t$ term. This latter term can be interpreted as a

(5) See Appendix A for details.

'cost-push' shock to inflation, as in Clarida, Galí and Gertler (1999), or a mark-up shock, as in Steinsson (2003) (we follow the 'mark-up shock' terminology here). The coefficients on the output gap and mark-up shock, however, depend on the specific price-setting behaviour assumptions of the R and the C models, and in the latter case, strategic complementarity or substitutability in firms' pricing decisions.

Table 2 shows the coefficients for the different cases.

Table 2
Coefficients of the Phillips curve

Model	Slope (λ^i)	Coefficient of mark-up shock (γ^i)
R	$\frac{(\theta-1)}{c}(\omega+\sigma^{-1})$	$\frac{1}{c}$
Css	$\frac{(1-\alpha)(1-\alpha\beta)}{\alpha}(\omega+\sigma^{-1})$	$\frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\left(\frac{1}{\theta-1}\right)$
Csc	$\frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\left(\frac{\omega+\sigma^{-1}}{1+\omega\theta}\right)$	$\frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\left(\frac{1}{(\theta-1)(1+\omega\theta)}\right)$

$\omega=\phi/a+1/a-1$

2.4 Competition and the slope of the NKPC

The steady-state elasticity of demand for a firm, θ, captures the degree of substitutability between its good and those of its competitors. This elasticity is inversely related to the desired mark-up over cost that firms want to charge for their good. A higher substitutability between goods implies a higher degree of competition among firms, and a lower desired mark-up (a reduction in firms' pricing power). A structural increase in competition among firms is interpreted in terms of a one-off increase in the (steady-state) elasticity.[6]

In the R model, higher competition among firms *increases* the slope of the Phillips curve and tends to magnify inflationary pressures (see Table 1). The intuition for this result is as follows. From **(8)**, higher competition not only reduces the level of desired mark-up but also makes changing prices relatively cheaper (the second term in the denominator). For a given magnitude of the price adjustment cost, c, a higher θ lowers the net cost associated with adjusting prices. This occurs because as the elasticity of demand increases and the economy moves closer to perfect competition, the size of optimal price adjustment falls

(6) Note that the inflationary pressures, captured by the output gap (in log-linearised terms), do not change when comparing across the low and high level of a steady-state competition.

which makes price adjustments relatively cheaper for a firm when facing quadratic adjustment cost. This effect promotes price flexibility in the R model and increases the slope of the Phillips curve.

In the C model, by contrast, higher competition can either *decrease* or have *no effect* on the slope of the Phillips curve (see Table 1). So inflationary pressures captured by the output gap either get dampened or remain benign. Unlike the R model, relative prices can differ across firms due to price staggering. If factor markets are segmented (that is, there is strategic complementarity), a firm's marginal cost depends both on average output and its own output (hence its own relative price). When adjusting the price, a firm therefore does not want a large difference in its price relative to the average, to avoid loss of market share. Higher competition among firms implies greater strategic complementarity and therefore lower price flexibility. Consequently, the slope of the NKPC decreases. Under strategic substitutability, the degree of competition among firms does not affect the slope.

3 Effects of mark-up shocks

In this section we examine the effects on inflation and output of mark-up shocks. Recently, Ireland (2004) has emphasised the quantitative importance of such shocks within a New Keynesian framework using the R model.

3.1 General equilibrium

This section computes the general equilibrium solution to the New Keynesian model. We assume that the aggregate demand side is characterised by a forward-looking IS curve

$$y_t = E_t y_{t+1} - \sigma^{-1}(r_t - E_t \pi_{t+1}) \qquad \textbf{(13)}$$

where r_t is the short-term nominal interest rate. We close the model with a simple monetary policy rule, in our case, a Taylor rule (Taylor (1993))[(7)]

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \hat{\epsilon}_t^r \qquad \textbf{(14)}$$

where $\hat{\epsilon}_t^r$ is a monetary policy shock. We solve the system of equations **(12)**, **(13)**, and **(14)** using the procedure described in Sims (2002) and further generalised by Lubik and Schorfheide (2002). To highlight the main point we consider only white noise mark-up

(7) As advocated by Svensson (1999) an alternative to assuming a Taylor rule is to specify the central bank's loss function and characterise optimal monetary policy. Rotemberg and Woodford (1997) provide a utility-based microfoundation for a loss function that is defined over the squared deviation of inflation and output from their respective target levels and when firms' price-setting behaviour under the C model. It is, however, not possible to provide a microfoundation for this loss function in the case of the R model as there is no relative price variability in the model. The paper abstracts from this conceptual issue and assumes a simple Taylor rule to highlight the implications.

shock. The analysis can be easily extended to include exogenous persistence and other shocks.[8] The general equilibrium law of motion for output, inflation, and interest rates is

$$\begin{pmatrix} y_t \\ \pi_t \\ r_t \end{pmatrix} = \frac{1}{1+\sigma^{-1}(\phi_y+\lambda^i\phi_\pi)} \begin{pmatrix} -\sigma^{-1} & \gamma^i\sigma^{-1}\phi_\pi \\ -\lambda^i\sigma^{-1} & -\gamma^i(1+\sigma^{-1}\phi_y) \\ 1 & -\gamma^i\phi_\pi \end{pmatrix} \begin{pmatrix} \hat{\epsilon}_t^r \\ \hat{\theta}_t \end{pmatrix} \qquad \textbf{(15)}$$

3.2 More intense competition and effects

In **(15)**, when $\phi_\pi = 1.5$, $\phi_y = 0.5$ (as in Taylor (1993)), and $\sigma = 1$ (log-utility), we can write the effects on inflation and output in terms of the coefficients in the NKPC in Table 2 as $\pi_t = \frac{-\gamma^i}{1+\lambda^i}$, $y_t = \frac{\gamma^i}{1+\lambda^i}$. Table 3 shows how the degree of competition among firms influences these effects.

Table 3
Impact effects of a 1% mark-up shock on inflation and output

Variable	R	Css	Csc
π_t	$\frac{-1}{c+(\theta-1)(\omega+1)}$	$\frac{-\kappa}{(\theta-1)(1+\kappa(\omega+1))}$	$\frac{-\kappa}{(\theta-1)(1+\kappa(\omega+1)+\omega\theta)}$
y_t	$\frac{1}{c+(\theta-1)(\omega+1)}$	$\frac{\kappa}{(\theta-1)(1+\kappa(\omega+1))}$	$\frac{\kappa}{(\theta-1)(1+\kappa(\omega+1)+\omega\theta)}$

$\kappa = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$

3.3 Effect of strategic complementarity

Higher competition reduces the effect of a mark-up shock for both the R and the C models. When price staggering exists, as in the C model, the effect on inflation and output is $[1+\omega\theta/(1+\kappa(\omega+1))]^{-1}$ times smaller under strategic complementarity relative to strategic substitutability. For standard calibration of parameters in the literature $\beta = 0.99$, $\alpha = 0.75$ (price changes on average every four quarters), $\theta = 10$ (desired mark-up of 10%, $\omega = 1.25$ (see Woodford (2003)) the effect of mark-up shocks under strategic complementarity is approximately twelve times smaller than that under strategic substitutability.

[8] Khan and Moessner (2004) consider the interaction of competitiveness and positive steady-state inflation, and the effect of monetary policy shocks using the C model under strategic complementarity.

3.4 A comparison of the R and Csc models

Next, we contrast the impact effects across the R and the Csc models of price-setting behaviour. Consider a low competition environment where firms have a 25% desired mark-up ($\theta = 5$). We calibrate the parameter as

$$c = (\theta - 1)(1 + \omega\theta)\kappa^{-1} = 337.86$$

in the R model so that the coefficients of the Phillips curve are identical. Consider a structural change in the economy such that there is a one-off increase in degree of competition among firm. This change is represented by a lower desired mark-up of 10% ($\theta = 10$). The impact effect of a 1% mark-up shock on inflation and output is four times smaller in the Csc model relative to the R model.

3.5 Pitfalls of mechanical calibration

With a higher level of competition, $\theta = 10$, a mechanical re-calibration of $c = 1415.5$ would give equivalent results across the two models. But it has two pitfalls. First, it is unclear why the cost of nominal price adjustment must increase when the average duration (in the C model) remains fixed at four quarters. Second, mechanical calibration may imply that the cost of adjusting nominal prices in the R model are implausibly large. This aspect echoes the concern highlighted by Danthine and Donaldson (2002) that in the New Keynesian model with costly capital accumulation, the cost of price adjustment may turn out to be implausibly higher than that of adjusting the capital stock.

4 Interpreting changes in the slope of the NKPC

In the face of higher competition among firms, both the R and the C models have different predictions about the direction of change in the slope of the Phillips curve. The R model predicts unambiguously that the slope should increase. The C model predicts unambiguously that the slope should not increase. In this section we present rolling estimates (with increasing observations) based on the 'hybrid-NKPC' (ie NKPC with one lag of inflation) proposed by Galí and Gertler (1999).[9] This assumes a fraction of firms to use 'rule-of-thumb' pricing when they get an opportunity to change their price. The hybrid-NKPC specification also resembles another formulation proposed by Christiano, Eichenbaum and Evans (2001) and Woodford (2003) where firms index their prices to past inflation in between periods of reoptimisations. Both extensions imply a similar reduced form and are extensively used in theoretical and empirical literature, although the details of

(9) See Rudd and Whelan (2002) and Galí, Gertler and López-Salido (2003) for the debate on the robustness of hybrid-NKPC estimates.

the reduced-form coefficients are different. Importantly, the coefficient on the lagged inflation term under either formulation does not depend on θ. Thus, a change in competition does not directly influence the degree of persistence in inflation.[10]

We estimate the following hybrid NKPC for the United Kingdom (1972 Q1-2001 Q4), the United States (1970 Q1-2003 Q4), Canada (1970 Q1-2001 Q4), euro area (1970 Q1-1998 Q4), using GMM.[11]

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda rmc_t^{avg} \qquad \textbf{(16)}$$

where rmc_t^{avg} is the (average) real marginal cost. We use the labour share proxy as a measure of real marginal cost that is based on the assumption of Cobb-Douglas technology as in Sbordone (2002).[12] The rolling estimates of the hybrid model remain quantitatively similar when the labour share is modified under the assumption of alternative production technologies (see Gagnon and Khan (2004)). The estimates presented in Charts 2-5 indicate that the slope has declined and flattened over the 1990s for the United Kingdom, the United States, Canada, and the euro area, although there are wide confidence intervals.[13] If the level of competition among firms has indeed increased, then this evidence is consistent with the prediction of the C model.

Clearly, the low-inflation environment since the 1990s may have contributed to the flattening of the Phillips curve by increasing the length of nominal contracts. This would be captured by larger values of α and c in the C and the R models, respectively. It is important to note, however, that according to the C model, an increase in competition would reinforce the flattening or the decline of the slope due to the move to the low-inflation environment since the 1990s. According to the R model, an increase in competition would offset the decline in the slope.[14]

5 Conclusion

We examined the implications of a higher level of competition on short-run inflation dynamics using the New Keynesian framework. As often emphasised, the two commonly used price-setting assumptions based on Rotemberg (1982) and Calvo (1983) imply the

(10) Although persistence in inflation will be influenced by the degree of competition if we consider the complete system of equations for the hybrid model.
(11) The appendix gives details of the data and instrument set used in the estimation.
(12) Under this approach, effects of supply shocks such as exogenous changes in total factor productivity and oil prices are captured in the measure of real marginal cost.
(13) Similar evidence for the United Kingdom is presented in Balakrishnan and López-Salido (2002).
(14) An alternative way to examine the prediction of the two models could be in a cross-country setting in the spirit of Ball, Mankiw and Romer (1988). One could plot the reduced-form estimates of the slope of the NKPC in **(12)** in individual countries against the average degree of competition (or its proxies, for example, the average import penetration ratio or the average price elasticity index) for several countries.

same reduced-form inflation dynamics. However, the implications of a change in the degree of competition among firms are quite different across the two models. Higher competition in competition unambiguously increases price flexibility in the former while it may decrease price flexibility in the latter. The impact of mark-up shocks on inflation and output are small when firms' price-setting behaviour incorporates concerns of potential market share loss. These effects get further dampened in a higher competition environment.

In the face of increased competition, both models have unambiguous macroeconomic predictions about the direction of change in the slope of the Phillips curve. Evidence from rolling estimates of the slope of the NKPC indicate that the slope has declined or flattened in the 1990s for several countries. Under the assumption of increased competition in the 1990s, this evidence is consistent with the prediction of the Calvo model.

The New Keynesian framework is increasingly being used to inform policymakers on a wide range of issues. This paper highlighted that the assumptions made about firms' price-setting behaviour can affect the conclusions drawn regarding the effects of competition and mark-up shocks on inflation. Therefore, understanding the nature of actual pricing behaviour of firms is clearly important to monetary policy.

Appendix A: Derivation of the NKPC under the R model

A firm chooses a sequence for $P_t(i)$ to maximise the expected sum of future discounted profits.

$$E_t \sum_{j=0}^{\infty} R_{t+j} \left[\left(\frac{P_{t+j}(i)}{P_{t+j}} \right)^{1-\theta_{t+j}} Y_{t+j} - \left(\frac{P_{t+j}(i)}{P_{t+j}} \right)^{-\theta_{t+j}/a} \frac{W_{t+j}(i)}{P_{t+j}} Y_{t+j}^{1/a} - \frac{c}{2} \left(\frac{P_{t+j}(i)}{\pi P_{t-1+j}(i)} - 1 \right)^2 Y_{t+j} \right] \quad \textbf{(A-1)}$$

where $R_t = \beta^t C_t^{-\sigma^{-1}}$ is the stochastic discount factor.

The first-order condition is

$$\beta^t C_t^{-\sigma^{-1}} \left((1-\theta_t) \left(\frac{P_t^*(i)}{P_t} \right)^{-\theta_t} \frac{Y_t}{P_t} + \frac{\theta_t}{a} \left(\frac{P_t^*(i)}{P_t} \right)^{-\theta/a-1} \frac{W_t}{P_t} \frac{Y_t^{1/a}}{P_t} - c \left(\frac{P_t^*(i)}{\pi P_{t-1}^*(i)} \right) \frac{Y_t}{\pi P_{t-1}^*(i)} \right)$$
$$\beta^{t+1} C_{t+1}^{-\sigma^{-1}} \left(-c \left(\frac{P_{t+1}^*(i)}{\pi P_t^*(i)} - 1 \right) Y_{t+1} \left(-\frac{P_{t+1}^*(i)}{\pi (P_t^*(i)^2)} \right) \right) = 0 \quad \textbf{(A-2)}$$

In a symmetric equilibrium the optimal price $P_t^*(i)$ is the same for all firms, $P_t^*(i) = P_t$. In addition, $H_t(i) = H_t$, $Y_t(i) = Y_t$, $W_t(i) = W_t$ and the aggregate resource constraint is

$$Y_t = C_t + \frac{c}{2} \left(\frac{\pi_t}{\pi} - 1 \right)^2 Y_t \quad \textbf{(A-3)}$$

where $\pi_t = P_t / P_{t-1}$ is the gross inflation rate. The first-order condition for **(A-1)** can be written as

$$P_t = \left[\frac{1}{\frac{\theta_t - 1}{\theta_t} + \frac{c}{\pi \theta_t} \left(\left(\frac{\pi_t}{\pi} - 1 \right) - \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma^{-1}} \left(\frac{Y_{t+1}}{Y_t} \right) \pi_t \right] \right)} \right] \frac{1}{a} W_t Y_t^{1/a-1} \quad \textbf{(A-4)}$$

When there is no price stickiness ($c = 0$), from **(A-4)**, firms charge a mark-up over current marginal cost

$$P_t = \frac{\theta_t}{(\theta_t - 1)} \frac{1}{a} W_t Y_t^{1/a-1} \quad \textbf{(A-5)}$$

In the flexible-price equilibrium ($c = 0$), the equilibrium output, Y_t^n, is given by

$$1 = \frac{\theta_t}{(\theta_t - 1)} Y_t^{\omega} C_t^{\sigma^{-1}} \quad \textbf{(A-6)}$$

and the aggregate resource constraint is

$$C_t = Y_t \quad \textbf{(A-7)}$$

Using **(A-6)** and **(A-7)**, Y_t^n is

$$Y_t^n = \left(\frac{\theta_t - 1}{\theta_t} \right)^{\frac{1}{\omega + \sigma^{-1}}} \quad \textbf{(A-8)}$$

The efficient level of output, Y_t^e, in the absence of technology or preference shocks is

$$Y_t^e = 1 \quad \textbf{(A-9)}$$

The log-linearised aggregate resource constraint **(A-3)** is

$$y_t = c_t \quad \textbf{(A-10)}$$

Next, (i) substituting out W_t/P_t, using **(2)** and **(4)** under the symmetric equilibirium, from **(A-4)**, (ii) log-linearising the resulting equation around the flexible-price equilibrium with constant θ, and (iii) using **(A-10)** we get

$$\pi_t = \beta E_t \pi_{t+1} + \frac{\theta - 1}{c}(\omega + \sigma^{-1}) y_t - \frac{1}{c}\hat{\theta}_t \quad \textbf{(A-11)}$$

where $y_t = \log(Y_t/Y_t^e) - \log(Y_t^n/Y_t^e)$.

General equilibrium solution

Following Sims (2002), the model equations are written in the canonical form as

$$\Gamma_0 Y_t = \Gamma_1 Y_{t-1} + \Psi \epsilon_t + \Pi \eta_t \quad \textbf{(A-12)}$$

As in Lubik and Schorfheide (2002), we use **(14)** to eliminate r_t in **(13)** and reduce the system to two equations. Define $\xi_t^y = E_t y_{t+1}$ and $\xi_t^\pi = E_t \pi_{t+1}$ with the corresponding endogenous expectational errors $\eta_t^y = y_t - E_{t-1} y_t$ and $\eta_t^\pi = \pi_t - E_{t-1}\pi_t$ such that $\xi_t = \begin{pmatrix} \xi_t^y & \xi_t^\pi \end{pmatrix}'$, $\epsilon_t = \hat{\theta}_t$, and $\eta_t = (\eta_t^y \quad \eta_t^\pi)'$. Using these definitions, we can rewrite the system as

$$\begin{pmatrix} 1 & \sigma^{-1} \\ 0 & \beta \end{pmatrix} \begin{pmatrix} \xi_t^y \\ \xi_t^\pi \end{pmatrix} = \begin{pmatrix} (1+\sigma^{-1}\phi_y) & \sigma^{-1}\phi_\pi \\ -\lambda^i & 1 \end{pmatrix} \begin{pmatrix} \xi_{t-1}^y \\ \xi_{t-1}^\pi \end{pmatrix} + \begin{pmatrix} \sigma^{-1} & 0 \\ 0 & \gamma^i \end{pmatrix} \begin{pmatrix} \hat{\epsilon}_t^r \\ \hat{\theta}_t \end{pmatrix} + \begin{pmatrix} (1+\sigma^{-1}\phi_y) & \sigma^{-1}\phi_\pi \\ -\lambda^i & 1 \end{pmatrix} \begin{pmatrix} \eta_t^y \\ \eta_t^\pi \end{pmatrix} \quad \textbf{(A-13)}$$

Rewriting **(A-13)** as

$$\xi_t = \Gamma_0^{-1}\Gamma_1 \xi_{t-1} + \Gamma_0^{-1}\Psi\hat{\theta}_t + \Gamma_0^{-1}\Pi\eta_t \quad \textbf{(A-14)}$$

The dynamics of the system depend on the eigenvalues of the matrix $\Gamma_0^{-1}\Gamma_1$. If both eigenvalues are greater than one (in absolute value) then the equilibrium is uniquely determined. This stable solution is $\xi_t = 0 \; \forall t$ which uniquely determines the endogenous forecast errors according to

$$\Gamma_0^{-1}\Psi\epsilon_t + \Gamma_0^{-1}\Pi\eta_t = 0 \quad \textbf{(A-15)}$$

or

$$\eta_t = -\left(\Gamma_0^{-1}\Pi\right)^{-1}\Gamma_0^{-1}\Psi\epsilon_t \quad \textbf{(A-16)}$$

From **(A-16)** we obtain **(15)**.

Appendix B: Variables and data sources

Under the assumption of Cobb-Douglas technology, the labour share ($S_t = \frac{W_t N_t}{P_t Y_t}$) is a theoretically appropriate observable proxy for (average) real marginal cost where $W_t N_t$ is labour compensation in the national accounts and $P_t Y_t$ is nominal output. In **(16)**, $rmc_t^{avg} = 100 * \log(S_t/S)$ where S is the sample mean.

The data sources and the mnemonics for the individual data series are as follows: UK (Bank of England and Batini, Jackson and Nickell (2002)), US (NIGEM - Bank of England), Canada (Bank of Canada and Statistics Canada), and euro area (Fagan, Henry and Mestre (2001)).

Variable	UK	Canada	US	Euro area
P_t	$PGDP$	$D15612$	$USPY$	YED
Y_t	GDP	$I56001 - I56013 - I56018$	USY	YER
N_t	$(E + SE)^*$	$LFSA201$: 1970:1-1975:4 $D980595$: 1976:1-2001:4	$USE * USHOURS$	LNN
W_t	W	$\frac{D17023}{N_t}$	$\frac{USCOMP}{N_t}$	$\frac{WIN}{N_t}$
S_t	$\frac{AW}{GDP}^*$	$\frac{D17023-D17001}{D15612*Y_t}$	$\frac{USCOMP}{USNOM}$	$\frac{WIN}{YEN}$

* Source: Batini *et al* (2002).

UK: 1972 Q1 to 2001 Q4: Employed plus self employed = $(E + SE)$, compensation of employees W, labour share adjusted for self-employed workers = $\frac{AW}{GDP}^*$.

Canada: 1970 Q1 to 2001 Q4: Total labour income = $D17023$, farm (agriculture + fishing $\&$ trapping) labour income = $D17001$, total GDP deflator = $D15612$, total real GDP = $I56001$, farm GDP = $I56013$ (agriculture) + $I56018$ (fishing & trapping), employment, 'total employed persons' = [$LFSA201$ (1970 Q1 to 1975 Q4) and $D980595$ (1976 Q1 to 2001 Q4)].

United States: 1970 Q1 to 2003 Q4: Nominal output = $USNOM$, real output = GDP, GDP deflator = $USPY$, employee hours = $USE * USHOURS$, compensation = $USCOMP$.

Euro area: 1970 Q1 to 1998 Q4: Total compensation = WIN, nominal GDP = YEN, real GDP = YER, total GDP deflator = YED, total number of employees = LNN.

INSTRUMENT SET:

For the United Kingdom, initial estimates are obtained for the period 1972 Q1-1986 Q4 and then an additional observation is added for each rolling estimation. The instrument set consists of four lags of inflation (RPIX), real marginal cost, wage inflation, and the output gap (quadratic detrended). For the United States, the initial estimation period is 1970 Q1-1984 Q4; for Canada 1970 Q1-1979 Q4; and the euro area 1970 Q1-1979 Q4.

Chart 1: United Kingdom

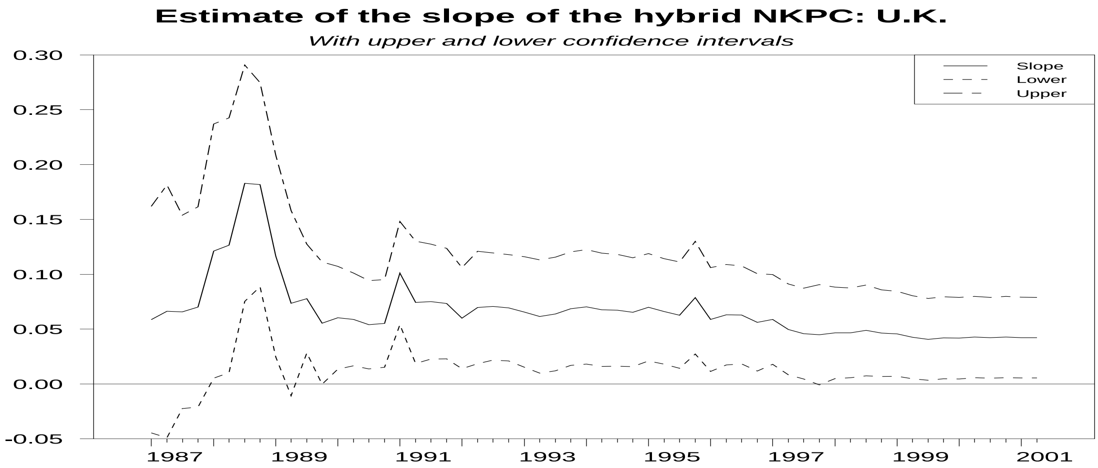


Chart 2: Canada

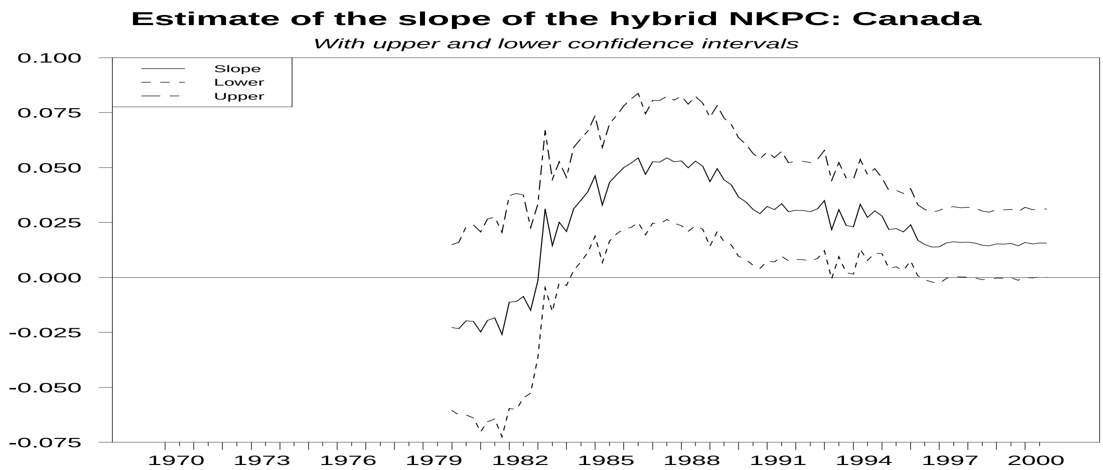


Chart 3: United States

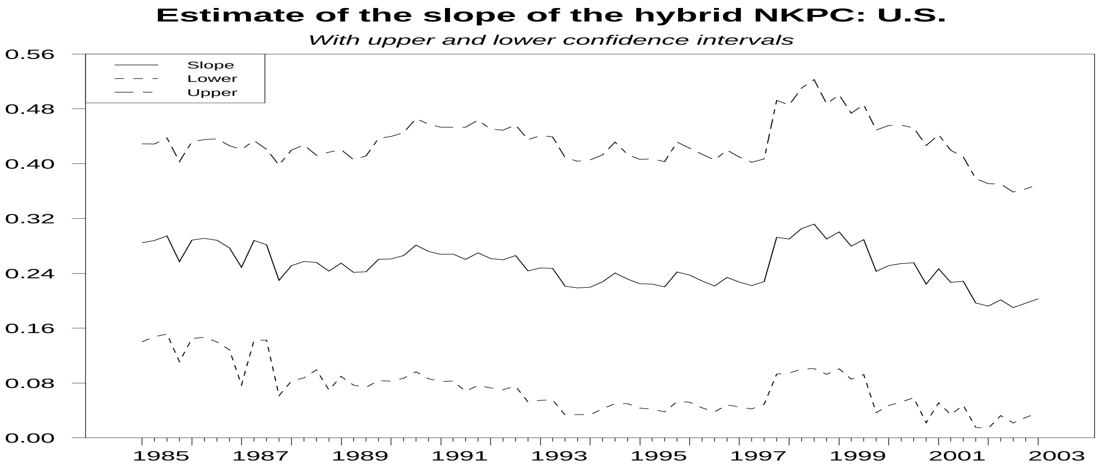
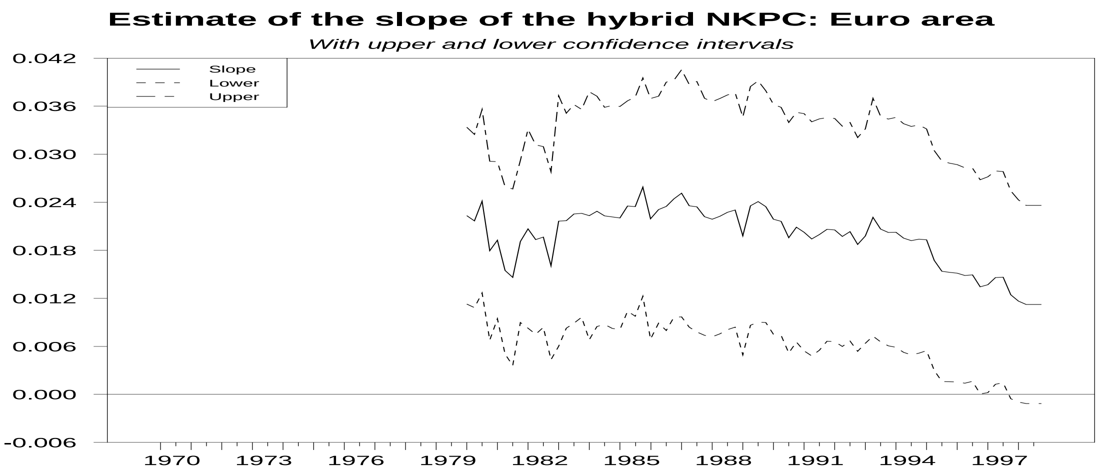


Chart 4: Euro area



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