The New Consensus in Monetary Policy: Is the NKM fit for the purpose of inflation targeting?

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Abstract

In this paper we examine whether or not the NKM is fit for the purpose of providing a suitable basis for the conduct of monetary policy through inflation targeting. We focus on a number of issues: the dynamic response of inflation to interest rates in a theoretical NKM under discretion and commitment to a Taylor rule; the implications for the specification of the New Keynesian Phillips equation of alternative models of imperfect competition in a closed and an open economy; the general equilibrium underpinnings of the IS function; the extent of empirical support for the NKM; what the empirical evidence on the NKM implies for inflation targeting. Our findings reveal a number of problems with the NKM. Theoretically, the NKM predicts that a discretionary increase in interest rates will increase inflation, not reduce it. This is supported by our VAR evidence. Estimates of the NKM indicate a negative relation between interest rates and inflation, but the signs in the structural equations are inconsistent with the theory. We conclude that the standard specifications of the inflation and output equations are inadequate and that these equations should be embedded in a larger model.

Keywords: Inflation targeting, monetary policy, New Keynesian model

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1 Introduction

The new consensus in monetary policy is based on inflation targeting carried out by a central bank setting a short-term interest rate using its discretion rather than following a formal rule. The theoretical basis of inflation targeting is a simple two-equation model of the inflationary process consisting of an expectations augmented Phillips equation for inflation and an output equation derived loosely from an inter-temporal model of the economy called the new "IS" function. This model is commonly known as the New Keynesian model (NKM).[1] This reflects the introduction of price stickiness through a Phillips equation in a dynamic stochastic general equilibrium (DSGE) model of the economy. Even when a larger model of the economy is employed in inflation targeting, such as the Bank of England's new quarterly model, see Bank of England (2005), these two equations usually form its core.

In this paper we examine whether or not the NKM is fit for the purpose of providing a suitable basis for the conduct of monetary policy through inflation targeting. We focus on a number of issues: the dynamic response of inflation to interest rates in a theoretical NKM under discretion and commitment to a Taylor rule; the implications for the specification of the New Keynesian Phillips equation of alternative models of imperfect competition in a closed and an open economy; the general equilibrium underpinnings of the IS function; the extent of empirical support for the NKM; what the empirical evidence on the NKM implies for inflation targeting and whether this is consistent with evidence from an atheoretical VAR.

Although there seems to be little disagreement about basing inflation targeting on the NKM, it can be shown that the relation between inflation and interest rates depends on whether a policy of discretion or commitment is used. Under a policy of discretion an increase in interest rates will raise inflation not reduce it; however, under a policy of commitment to a Taylor rule a positive interest rate shock is predicted to reduce inflation.

[1] There is a vast literature on inflation targeting via the NKM. For recent surveys see Clarida, Gali and Gertler (1999), Walsh (2003), Woodford (2003) and Bernanke and Woodford (2005).

There is much less agreement on how to specify the two equations of the NKM. This has considerable significance for the transmission mechanism, and hence the potential effectiveness, of monetary policy. For example, the precise role of output in these new formulations of the Phillips equation is largely unresolved. This is a crucial question as monetary policy in the NKM works through interest rates affecting output, and output affecting inflation. For monetary policy to be effective both links must be strong. In early versions of the New Keynesian Phillips equation, inflation was related to the output gap. More recently, attempts have been made to base the Phillips equation on firmer micro foundations in which firms have a degree of monopolistic control over prices with the consequence that cost increases and changes in the price mark-up due to demand fluctuations directly determine prices. They are passed on over time as prices display stickiness. The result has been a partial return to the old-style Phillips equation with costs being the main determinant of prices along with demand, but with the addition of forward-lookingness in price setting.

Most of the research on inflation targeting and the NKM has assumed a closed economy. In an open economy, however, the exchange rate may also play an important role in the transmission mechanism. Changes in the exchange rate, perhaps as a result of domestic monetary policy, may affect costs more directly and the impact on prices would not be dependent on the output part of the transmission mechanism. Considerations of imperfect competition influence the strength of this effect. In a large open economy, importers are more likely to price to the domestic market than in a small open economy which is more likely to have to accept world prices denominated in foreign currency. Hence, the exchange rate channel becomes more important in a small than in a large open economy. Perhaps this explains why the Bank of England places the exchange rate fourth in its list of channels for the transmission mechanism.[2]

The specification of the New Keynesian output equation has proved less contentious than that of the inflation equation. It is based on the consumption Euler equation of a DSGE model.

[2] See Bank of England (1999).

This equation is commonly interpreted as implying that an increase in the current interest rate will reduce consumption, and hence output. We argue in this paper that this is an incorrect interpretation. It assumes that expected future consumption (output) is given, which logically it is not as it is determined simultaneously with current consumption. Strictly, the Euler equation determines the response of the expected future change in consumption to an expected future change in the interest rate. To find the effect on current consumption of a change in the current interest rate it is necessary to derive the consumption function by combining the Euler equation with the inter-temporal budget constraint. It then becomes clear that the sign of this effect depends on whether households hold net assets or net liabilities. Following an increase in the current interest rate, consumption will only decrease if households hold net liabilities. In our view this seriously undermines the usefulness of the NKM.

The aim of monetary policy is to return inflation to its target level following (or in anticipation of) shocks to the economy. The NKM, with its emphasis on using interest rates to control output, is much better suited to dealing with demand than supply shocks as it raises no conflict between the objectives of inflation and output stabilization. A positive demand shock raises output, and hence inflation, and this is offset by raising interest rates. But a supply shock will raise inflation and reduce output. An increase in interest rates to control inflation will further reduce output. Inflation and output control are now in conflict. Little is known about the size of the output costs of inflation control following a supply shock.

The paper is set out as follows. In Section 2 we analyse the dynamic response of inflation to interest rates under discretion and commitment to a Taylor rule. In Section 3 we discuss the specification of the New Keynesian Phillips equation under imperfect competition in a closed and an open economy. We consider the general equilibrium underpinnings of the IS function in Section 4. In Section 5 we provide estimates of various specifications of the NKM based on UK quarterly data 1970-2005. In Section 6 we analyse the implications of these estimates for inflation targeting and compare these with the impulse responses from a VAR based on the NKM. We present our conclusions in Section 7.

2 The New Keynesian Model

In this section we examine the implications of the NKM for inflation targeting. We compare a policy of discretion with one of commitment to a rule.[3] A typical stylised NKM consists of the following two equations[4]

$$\pi_t = \mu + \beta E_t \pi_{t+1} + \gamma x_t + e_{\pi t} \quad (1)$$

$$x_t = E_t x_{t+1} - \alpha(i_t - E_t \pi_{t+1} - \theta) + e_{xt} \quad (2)$$

where $0 < \beta \leq 1$, $\alpha, \gamma, \mu, \theta > 0$, π_t is inflation and is measured either by the CPI or the GDP deflator, $x_t = y_t - \bar{y}_t$ is the output gap, y_t is GDP, $\bar{y}_t$ is a measure of trend or of equilibrium GDP, i_t is the policy instrument (a nominal interest rate such as the Bank of England's repo rate or the US Federal Funds rate) and $e_{\pi t}$ and e_{xt} are respectively zero mean and serially uncorrelated supply and demand shocks. Here a positive $e_{\pi t}$ raises inflation if output is fixed. Equation (1) is the Phillips equation, (2) is the new IS equation and the Fisher equation

$$r_t = i_t - E_t \pi_{t+1} \quad (3)$$

defines the real interest rate, r_t. Assuming that in equilibrium, the rate of inflation is the target rate π^*, the output gap is zero and the real interest rate is $\bar{r}$, then $\mu = (1 - \beta)\pi^*$, the long-run value of i_t is $\bar{r} + \pi^* = \theta + \pi^*$, and hence $\theta = \bar{r}$. In general equilibrium θ is the rate of time preference.

2.1 Discretion

Under a policy of discretion the monetary authority chooses the interest rate. Intuitively, an increase in the interest rate reduces output and hence inflation. However, in the NKM a surprising

[3] Discussion of the dynamic properties of the NKM under monetary policy rules may also be found in Bullard and Mitra (2002) and Walsh (2003), pp244-248.

[4] All variables apart from interest rates are expressed in natural logarithms.

result occurs. Eliminating y_t from the model gives the following dynamic equation for π_t

$$\pi_t - (1 + \beta + \alpha\gamma)E_t\pi_{t+1} + \beta E_t\pi_{t+2} = \alpha\theta\gamma - \alpha\gamma i_t + e_{\pi t} + \gamma e_{xt}$$

The long-run solution is

$$\pi_t = i_t - \theta$$

To analyse the short-run dynamics we note that the auxiliary equation is

$$\lambda(L) = 1 - (1 + \beta + \alpha\gamma)L^{-1} + \beta L^{-2} = 0$$

where $E_t\pi_{t+n} = L^{-n}\pi_t$. Setting $L = 1$ gives $\lambda(1) = -\alpha\gamma < 0$. Therefore, despite having forward expectations and no lags, the solution of the equation is a saddlepath with one of the roots greater than unity and the other less than unity; both are positive. Denoting the roots by $\lambda_1 > 1$ and $\lambda_2 < 1$ it can be shown (see Wickens (1993) for details) that the solution can be written as

$$\pi_t = -\frac{\alpha\theta\gamma}{\lambda_1} + \lambda_1\pi_{t-1} + \frac{\alpha\gamma}{\lambda_1}(\Sigma_{s=0}^{\infty}\lambda_2^{-(s+1)}E_t i_{t+s} + i_{t-1}) + \delta_\pi e_{\pi t} + \delta_x e_{xt} - \frac{1}{\lambda_1}(e_{\pi,t-1} + \gamma e_{x,t-1})$$

where δ_π and δ_x are arbitrary constants, implying that the solution is not unique. It follows that a discretionary increase in interest rates either in the previous period, the current period or in the future is expected to increase, not decrease, inflation as the above intuition might lead one to expect. Moreover, the appropriate setting for interest rates to counteract current supply and demand shocks is unclear as their effect on inflation is indeterminate. It would seem therefore that the use of the NKM under discretion does not provide a satisfactory basis for inflation targeting.

2.2 Rules based monetary policy

It is informative to compare the solution under a policy of discretion with that in which interest rates are determined under commitment to a Taylor rule. The standard Taylor rule is

$$i_t = \theta + \pi^* + \mu(\pi_t - \pi^*) + \upsilon x_t + e_{it}$$

with $\mu = 1.5$ and $\nu = 0.5$. The random variable e_{it} is introduced to allow for unexpected departures from the rule. Solving the NKM together with the Taylor rule results in both x_t and i_t being eliminated and gives

$$[1 + \alpha(\upsilon + \mu\gamma)]\pi_t - [1 + \beta(1 + \alpha\upsilon) + \alpha\gamma]E_t\pi_{t+1} + \beta E_t\pi_{t+2} = z_t$$

$$z_t = \alpha\pi^*[\nu(1 - \beta) + \gamma(\mu - 1)] + (1 + \alpha\upsilon)e_{\pi t} - E_t e_{\pi,t+1} + \gamma e_{xt} - \alpha\gamma e_{it}$$

The auxiliary equation is

$$\lambda(L) = [1 + \alpha(\upsilon + \mu\gamma)] - [1 + \beta(1 + \alpha\upsilon) + \alpha\gamma]L^{-1} + \beta L^{-2} = 0$$

As $\lambda(1) = \alpha[\nu(1 - \beta) + \gamma(\mu - 1)] > 0$ and $1 > \frac{\beta}{1+\alpha(\upsilon+\mu\gamma)} > 0$ the roots of the auxiliary equation lie inside the unit circle and hence the model is globally unstable. It can be shown (see Wickens (1993)) that there is now a unique solution and this can be written as

$$\begin{aligned} \pi_t &= \frac{1}{1 + \alpha(\upsilon + \mu\gamma)}[\frac{\lambda_1}{\lambda_1 - \lambda_2}\Sigma_{s=0}^{\infty}\lambda_1^s E_t z_{t+s} - \frac{\lambda_2}{\lambda_1 - \lambda_2}\Sigma_{s=0}^{\infty}\lambda_2^s E_t z_{t+s}] \\ &= \pi^* + \frac{1}{1 + \alpha(\upsilon + \mu\gamma)}[(1 + \alpha\upsilon)e_{\pi t} + \gamma e_{xt} - \alpha\gamma e_{it}] \end{aligned}$$

Thus inflation deviates from target due to the three shocks. Positive inflation and output shocks cause inflation to rise above target, but positive interest rate shocks cause inflation to fall below target. We note that a forward-looking Taylor rule in which $E_t\pi_{t+1}$ replaces π_t and $E_t x_{t+1}$ replaces x_t gives a similar result.

If the NKM is a good representation of the economy then these results support a policy of commitment to a rule. We now investigate whether the NKM is a suitable representation by examining the specification of each equation in more detail. First we consider the Phillips equation.

3 The New Keynesian Phillips equation

3.1 Which inflation measure to use?

The first issue to address is the measure of inflation to target. We can then discuss how this measure should be determined. Arguably, only two measures are worth considering. These are CPI inflation and the GDP deflator. Broadly, the GDP deflator measures the price of domestic production, whereas the CPI measures the price of domestic consumption which has greater response to import prices. The more open the economy, the larger are likely to be the differences between the two.

A distinction is often made between "core" and "headline" inflation. The GDP deflator is closely related to core inflation whereas the CPI, which is affected by external influences, corresponds more to headline inflation. The Treasury's original remit to the Bank of England was to target 'prices in the shops'. A measure of the CPI was chosen which excludes mortgage interest payments in order to avoid inflation being directly affected by changes in interest rates. Although central banks typically target CPI inflation, most econometric work uses the GDP deflator.

3.2 Some general theoretical considerations

Inflation equations usually have two elements: an equilibrium pricing equation and a dynamic adjustment to equilibrium. Reflecting its inter-temporal underpinnings and in contrast to the old-style Phillips equation, the equilibrium pricing equation is usually forward-looking. The choice of driving variable for inflation lies between using a measure of the output gap or of marginal cost. A positive output gap - in which output is in excess of equilibrium, or trend output, or capacity - increases inflation. The impact on inflation of changes in marginal cost and in the mark-up over marginal cost depends on the factors affecting the degree of monopoly power of firms. Additional influences arising from external effects depends on the degree of openness of the economy and its size.

The dynamic adjustment to equilibrium depends on the extent of price stickiness, a key feature of Keynesian models. The adjustment speed may be a choice variable for firms, and may be part of the equilibrium process, as in state dependent models, or it may be outside a firm's control as in Calvo pricing and other dominant time-dependent pricing models.

3.3 Equilibrium pricing under imperfect competition

It is increasingly common to find that the inflation equation is based on an imperfect competition model. We distinguish between a model with a single output and many imperfectly substitutable factors, and one with a single factor and many imperfectly substitutable goods and services. We then consider pricing in an open economy under imperfect competition.

3.3.1 A single output and many imperfectly substitutable factors

A profit maximising firm that takes unit costs as given sets price P proportional to marginal total cost MC so that

$$P = \frac{1}{1 - \frac{1}{\epsilon_D}} MC$$

where $\epsilon_D = -\frac{\partial Y}{\partial P}\frac{P}{Y}$ is the price elasticity of demand and $(1 - \frac{1}{\epsilon_D})^{-1}$ is the price mark-up or wedge. Under perfect competition ϵ_D is infinite and the mark-up is unity. In equilibrium, the ratio of the marginal cost of the i^{th} factor MC_i to its marginal product MP_i is equal to marginal total cost, i.e.

$$MC = \frac{MC_i}{MP_i}$$

The marginal cost of each factor is determined by

$$MC_i = 1 + \frac{1}{\epsilon_{X_i}} W_i$$

where $\epsilon_{X_i} = \frac{\partial X_i}{\partial W}\frac{W}{X_i}$ is the factor supply elasticity (factor price mark-up or wedge) and W_i is the price per unit of the factor. Hence

$$P = \frac{1 + \frac{1}{\epsilon_{X_i}}}{1 - \frac{1}{\epsilon_D}} \frac{W_i}{MP_i}$$

For example, for the Cobb-Douglas production function

$$Y = \Pi_{i=1}^{n} X_i^{\alpha_i}, \quad \Sigma_{i=1}^{n} \alpha_i = 1$$

where Y is output and $MP_i = \alpha_i \frac{Y}{X_i}$,

$$P = \frac{1 + \frac{1}{\epsilon_{X_i}}}{1 - \frac{1}{\epsilon_D}} \frac{W_i X_i}{\alpha_i Y} \tag{4}$$

implying the share of the i^{th} factor is

$$\frac{W_i X_i}{PY} = \alpha_i \frac{1 - \frac{1}{\epsilon_D}}{1 + \frac{1}{\epsilon_{X_i}}}$$

We now consider the implications for inflation. First, the change in the price of a single substitutable factor doesn't affect inflation if the factor is substitutable. This is because an increase in the unit cost of a single factor would result in a decrease in its use and hence an increase in its marginal product. If ϵ_{X_i} is constant, then $\frac{W_i}{MP_i}$ and $\frac{MC_i}{MP_i}$ will remain unchanged. In other words, the change in a single factor price will cause a relative price change and the factor proportions will alter, but the price of goods would be unaffected. If a factor is required in fixed proportion to output then substitutability between factors is not possible. In this case, its marginal product is fixed and so its marginal cost, and hence the price of the good, will increase. Output will then fall which will reduce the demand for all factors. In practice, in the short run, all factors will tend to be only partly flexible. Consequently, the case of fixed proportions may be a good approximation to the short-run response to an increase in the price of a single factor, but it will not necessarily be appropriate in the long run. Only if all factor prices increase in the same proportion (and their supply elasticities and the price elasticity of demand are constant) will the price of goods increase by the same proportion. Thus, if factors are substitutable, inflation in the long run is the result of a general increase in costs, not an increase in the price of a single factor. This is particularly relevant when considering the effect of something like an oil price increase. It suggests a temporary, but not a permanent, effect on inflation.

3.3.2 Many imperfectly substitutable goods and a single factor

The case of many imperfectly substitutable goods and a single factor is the one usually considered. Examples are Dixit and Stiglitz (1977), Blanchard and Kiyotaki (1987), Ball and Romer (1991) and Dixon and Rankin (1994). The production function for the i^{th} firm is assumed to depend on a single common factor, for example labour:

$$Y_t(i) = F_i[L_t(i)]$$

where $Y_t(i)$ is the output of i^{th} firm, $L_t(i)$ is the labour input of the i^{th} firm and there are n firms each producing a different good. Once again price is proportional to marginal cost so that

$$P_t(i) = \frac{\epsilon_{D_i}}{\epsilon_{D_i} - 1} \frac{W_t}{F_i'[L_t(i)]} \tag{5}$$

where $P_t(i)$ is the output price, W_t is the common wage rate and ϵ_{D_i} is the price elasticity of demand for the i^{th} good.

The general price level P_t is derived as a function of individual prices. It is assumed that each good is an imperfect substitute and that households maximise a utility function derived from consumption of these goods. If the utility function is $U(C_t)$ where total consumption C_t is

$$C_t = \left[\sum_{i=1}^{n} C_t(i)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}} \tag{6}$$

$\phi > 1$ is the elasticity of substitution ϵ_{D_i}, and the total household expenditure on goods and services is

$$P_t C_t = \sum_{i=1}^{n} P_t(i) C_t(i)$$

then the general price level satisfies

$$P_t = \sum_{i=1}^{n} P_t(i) \frac{C_t(i)}{C_t} \tag{7}$$

Maximising utility subject to the household budget constraint for a given level of income gives

$$\frac{C_t(i)}{C_t} = \left[\frac{P_t(i)}{P_t}\right]^{-\phi} \tag{8}$$

Substituting into equation (7) gives

$$P_t = \left[\sum_{i=1}^{n} P_t(i)^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{9}$$

From equation (5) we obtain

$$P_t = \frac{\phi}{\phi - 1} W_t \left[\sum_{i=1}^{n} F_i'[L_t(i)]^{-(1-\phi)}\right]^{\frac{1}{1-\phi}}$$

For the Cobb-Douglas production function

$$Y_t(i) = L_t(i)^{\alpha_i}$$

$$P_t = \frac{\phi}{\phi - 1} W_t \left[\sum_{i=1}^{n} [\alpha_i \frac{L_t(i)}{Y_t(i)}]^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{10}$$

In the special case where the production functions are identical the subscript i may be dropped when

$$P_t = \frac{\alpha\phi}{\phi - 1} \frac{W_t L_t}{Y_t}$$

implying a constant labour share. In this case the inflation rate $\pi_t = \Delta \ln P_t$ is

$$\pi_t = \ln \frac{\alpha\phi}{\phi - 1} + \Delta w_t - \Delta \ln \frac{Y_t}{L_t} \tag{11}$$

where $w_t = \ln W_t$. Thus increases in the wage rate and productivity will now have a strong effect the rate of inflation.

3.3.3 The effect of output

According to these theories output may affect inflation in three ways. One way is through its affect on productivity. Here an increase in output is predicted to reduce inflation, not raise it. A second way is if the price elasticity of demand ϵ_D (or ϕ) varies with output. In order for output increases to raise inflation the price elasticity of demand would need to fall as output increases. But whether this effect would be strong enough in practice is not clear. A third way is if additional production becomes more costly near to full capacity perhaps due to factor supply constraints. This would imply that ϵ_{X_i} decreases (the factor mark-up increases) with factor use due to higher output demand. In this case inflation would increase as output increases. Of these three ways in which changes in output can affect inflation, only the two mark-up effects can cause the positive relation of the traditional Phillips equation. Of these, the last - increasing pressure on factor supplies due to high factor demand - seems the more likely to generate a sizeable effect.

3.3.4 Open economy pricing

In an open economy it is necessary to distinguish between GDP and CPI inflation, and to take into account the size of the economy. Inflation measured by the GDP deflator is

$$\pi_t^d = (1 - s_t^{nt})\pi_t^t + s_t^{nt}\pi_t^{nt}$$

where π_t^d is the inflation rate of domestically produced goods and services and s_t^{nt} is the share of non-traded goods. This is a weighted average of π_t^{nt}, the inflation rate of domestic non-traded goods and π_t^t, the inflation rate of domestic traded goods. CPI inflation is measured by a weighted average of π_t^d and the inflation rate of imported goods π_t^m

$$\pi_t = (1 - s_t^m)\pi_t^d + s_t^m\pi_t^m$$

where s_t^m is the share of imports.

In a small open economy producers, having no monopoly power, must set domestic traded goods prices equal to world prices expressed in domestic currency. Thus

$$\pi_t^t = \pi_t^m = \pi_t^w + \Delta s_t$$

where π_t^w is the world inflation rate and Δs_t is the proportionate rate of change of the exchange rate (the domestic price of foreign exchange). In a large open economy producers may have a degree of monopoly power, hence import prices will be fully or partly priced to market. Consequently,

$$\pi_t^m = \varphi(1 - \eta)(\pi_t^w + \Delta s_t) + (1 - \varphi)\eta\pi_t^t$$

where $\varphi = 1$ for full exchange rate pass through and $\eta = 1$ for full pricing-to-market (both lie in the interval $[0, 1]$), and π_t^t is determined domestically.

Thus the GDP deflator inflation in a small open economy is given by

$$\pi_t^d = s_t^{nt}\pi_t^{nt} + (1 - s_t^{nt})(\pi_t^w + \Delta s_t)$$

and in a large open economy it is

$$\pi_t^d = (1 - s_t^{nt})\pi_t^t + s_t^{nt}\pi_t^{nt}$$

CPI inflation in a small open economy is given by

$$\pi_t = (1 - s_t^m)s_t^{nt}\pi_t^{nt} + [1 - s_t^m(1 - s_t^{nt})](\pi_t^w + \Delta s_t)$$

and in a large open economy it is

$$\pi_t = (1 - s_t^m)s_t^{nt}\pi_t^{nt} + [(1 - s_t^m)(1 - s_t^{nt}) + s_t^m(1 - \varphi)\eta]\pi_t^t + s_t^m\varphi(1 - \eta)(\pi_t^w + \Delta s_t)$$

The impact on inflation of changes in the exchange rate is different in each case. It has no effect on the GDP deflator of a large open economy. For a small economy, it has greater effect on CPI inflation than GDP inflation.

3.4 Dynamic adjustment to equilibrium

Inter-temporal models of inflation typically have a dynamic structure that has both forward and backward looking components. We briefly summarise some of these models with a view to showing that they produce a similar dynamic specification.

(i) **Taylor over-lapping contracts model for two periods**

In the Taylor (1979) over-lapping contracts model price is a mark-up over average wages formed from new and past wage contracts each of which last more than one period. The new wage contract is based on the average real wage until the end of the contract. This introduces a forward-looking component as prices may change in the future. For two-period contracts inflation is given by

$$\pi_t = E_t[\pi_{t+1}] + 2(\ln MPL_t + \ln MPL_{t-1}) + 4v_t + \eta_t$$

where the equilibrium real wage is equated to MPL_t, the marginal product of labour, v_t is the price markup and $\eta_t = -(p_t - E_{t-1}[p_t])$, $E_{t-1}\eta_t = 0$ where $p_t = \ln P_t$.

(ii) **Calvo staggered pricing model**

In the Calvo (1983) pricing model the general price level is the average price across all firms. Firms face an exogenous probability of not being able to change their price when they wish to. When they are able to change their price they set the new price to minimise the present value of the cost of deviations of the newly adjusted price. The resulting rate of inflation is given by

$$\pi_t = \gamma E_t[\pi_{t+1}] + \rho(1-\gamma)(p_t^* - p_{t-1})$$

where p_t^* is the equilibrium long-run price level and ρ is the proportion of firms able to reset prices optimally. A variant is to assume that if firms can't reset their prices optimally then they index their current price change to the past inflation rate. This has the effect of adding a term in π_{t-1} to the right-hand side of the equation and changing the coefficients on the other terms.

(iii) **Optimal dynamic adjustment model**

This approach to deriving optimal dynamics has a long history, and has been used in the analysis of inflation most notably by Rotemberg (1982). Here firms set prices optimally to minimise an inter-temporal quadratic cost function with two types of cost: the cost of prices deviating from the equilibrium price and the cost of changing prices. The result is the inflation equation

$$\pi_t = \frac{\beta}{1+\alpha} E_t[\pi_{t+1}] + \frac{\alpha}{1+\alpha}(p_t^* - p_{t-1})$$

where p_t^* is the long-run equilibrium price level assuming no costs in changing the price level, β is the discount rate and α is the relative cost of price deviations from equilibrium. A variant of this is where a fraction $1-\lambda$ of firms set prices using a rule of thumb based on the previous period's inflation. The inflation equation then becomes

$$\pi_t = \lambda\frac{\beta}{1+\alpha} E_t[\pi_{t+1}] + \lambda\frac{\alpha}{1+\alpha}(p_t^* - p_{t-1}) + (1-\lambda)\pi_{t-1}$$

3.5 Summary

No single specification emerges from this discussion, but certain features are common to most of the models. The general form of the inflation equation seems to be

$$\pi_t = \beta_0 + \beta_1 E_t \pi_{t+1} + \beta_2 \pi_{t-1} + \beta_4 x_t + \beta_5 \Delta w_t - \beta_6 \Delta \ln \frac{Y_t}{L_t} + \beta_7(\pi_t^w + \Delta s_t) + e_{\pi t} \qquad (12)$$

where the variables retain their previous definitions and all coefficients are expected to be positive. Depending on the length of a period, the output gap, the rate of wage inflation, labour productivity, world inflation and the change in the exchange rate may all need to be lagged. The shorter the time period, the more likely this is. It may also be necessary to take account of the price changes in certain non-substitutable factors such as oil. For inflation defined by the GDP deflator, it may be possible to omit the last variable.

3.6 Two examples

To illustrate, we note two examples of the Phillips equation from the literature. Both refer to the GDP deflator. One is a simple marginal cost pricing model, the other has many of the features of the more general model above.

1. Gali and Gertler (1999), Gali, Gertler and Lopez-Salido (2005)

   They assume that the equilibrium price equals marginal cost, hence

$$\begin{aligned} p_t^{*d} &= \ln MC_t = mc_t \\ \pi_t^d &= \beta E_t[\pi_{t+1}^d] + \gamma(mc_t - p_t^d) + \lambda \pi_{t-1}^d \end{aligned}$$

2. Batini, Jackson and Nickell (2005)

   They assume marginal cost pricing and a quadratic cost function in which the change in employment is an additional cost. This gives

$$\begin{aligned} \pi_t^d &= \beta E_{t-1}[\pi_{t+1}^d] + \gamma E_{t-1}(mc_t - p_t) + \lambda E_{t-1}\mu_t - \rho E_{t-1}(\phi \Delta \ln L_{t+1} - \Delta \ln L_t) \\ mc_t - p_t &= const + s_{L,t} + \delta(p_t^m - p_t) \\ \mu_t &= const + z_{p,t} + \theta_1 x_t + \theta_2(w_t - p_t) \end{aligned}$$

where $s_{L,t}$ is the share of labour, μ_t is the price mark-up, p_t^m is the price of oil, p_t^w is the world price and $z_{p,t}$ reflects long-term trade effects.

4 The output equation

The New Keynesian output equation (2) is usually interpreted as implying that an increase in interest rates reduces current output. The theoretical basis of this forward-looking IS function is the consumption Euler equation in a dynamic general equilibrium model of the economy. To illustrate we consider a simple life-cycle theory model. The problem is how to combine the Euler equation with the household budget constraint. The method used has important consequences for the interpretation of the effect on interest rate changes on consumption, and hence output.

The representative household is assumed to maximise

$$E_t \sum_{s=0}^{\infty} \beta^s U(C_{t+s}), \ \beta = \frac{1}{1+\theta}$$

subject to the budget constraint

$$A_{t+1} + C_t = X_t + (1 + r_t)A_t$$

where X_t is exogenous income and A_t is the stock of assets held at the start of the period and r_t is their real return. (If households have net liabilities we write $B_t = -A_t$.) This gives the Euler equation

$$E_t[\beta \frac{U'(C_{t+1})}{U'(C_t)}(1 + r_{t+1})] = 1$$

Ignoring considerations of risk (if r_t is a risky return) and approximating marginal utility by

$$U'(C_{t+1}) \simeq U'(C_t) + U''\Delta C_{t+1}$$

gives

$$E_t \Delta \ln C_{t+1} = \frac{1}{\sigma}(E_t r_{t+1} - \theta) \tag{13}$$

where $\sigma = -\frac{C_t U''}{U'}$ is the coefficient of relative risk aversion.

In order to obtain the New Keynesian IS function (2) it is necessary to combine the Euler equation with the household budget constraint. The common way to proceed is simply to assume that deviations of log consumption from trend equal those of log output from its trend. This is equivalent to assuming that the budget constraint is $C_t = Y_t$ which could be rationalised by assuming a closed economy with no physical capital and arguing that net financial assets in the economy are zero.

An alternative way is to use the following log-linear approximation to the budget constraint

$$\frac{A}{X}\ln A_{t+1} + \frac{C}{X}\ln C_t = \ln X_t + (1+r)\frac{A}{X}\ln A_t + \frac{A}{X}r_t$$

where r is the average interest rate which, in general equilibrium, will be the rate of time preference θ. Equating income X_t with output Y_t, and taking deviations about equilibrium, gives

$$y_t = E_t y_{t+1} - \frac{1}{\sigma}\frac{C}{Y}(E_t r_{t+1} - \theta) - \frac{A}{Y}[E_t \Delta^2 a_{t+2} + r a_t - E_t \Delta r_{t+1}]$$

where a_t is the deviation of the logarithm of A_t from trend. Thus there are additional terms compared with (2), and the coefficient on the interest rate term is slightly different.

A third approach - one not usually adopted - is to derive the consumption function by solving the budget constraint forwards. Using the log-linear approximation, the log inter-temporal budget constraint is

$$E_t \frac{\ln A_{t+n}}{(1+r)^n} + \frac{C}{A}\sum_{s=0}^{n-1}\frac{E_t \ln C_{t+s}}{(1+r)^s} = \frac{X}{A}\sum_{s=0}^{n-1}\frac{E_t \ln X_{t+s}}{(1+r)^s} + \sum_{s=0}^{n-1}\frac{E_t r_{t+s}}{(1+r)^s} + (1+r)\ln A_t$$

Taking the limit as $n \to \infty$, assuming that $\lim_{n\to\infty} \frac{\ln A_{t+n}}{(1+r)^n} = 0$ and that $E_t r_{t+s} = \theta$ so that $E_t \ln C_{t+s} = \ln C_t$ gives

$$\ln C_t = \frac{r}{1+r}\frac{X}{C}\sum_0^{\infty}\frac{\ln X_{t+s}}{(1+r)^s} + \frac{r}{1+r}\frac{A}{C}\sum_{s=0}^{n-1}\frac{E_t r_{t+s}}{(1+r)^s} + r\frac{A}{C}\ln A_t \tag{14}$$

Thus log consumption depends on the expected present value of log income, on the log asset stock and the interest rate. If households hold net liabilities then the log-linear approximation becomes

$$\ln C_t = \frac{r}{1+r}\frac{X}{C}\sum_0^{\infty}\frac{\ln X_{t+s}}{(1+r)^s} - \frac{r}{1+r}\frac{B}{C}\sum_{s=0}^{n-1}\frac{E_t r_{t+s}}{(1+r)^s} - r\frac{B}{C}\ln B_t \tag{15}$$

It follows that the effect on consumption of an increase in interest rates depends on whether households hold net assets or net liabilities. If households have net liabilities ($B_t > 0$) then consumption, and hence output, will decrease due to the extra cost of borrowing. But if households have net assets ($A_t > 0$) then consumption, and hence output, will increase due to the extra interest income. For example, a tightening of current monetary policy by a one-period unit increase in the current interest rate r_t will increase $\ln C_t$ by $\frac{r}{1+r}\frac{A}{C}$ if households have net assets, and decrease $\ln C_t$ by this amount if they have net liabilities, but $E_t \ln C_{t+1}$ would be unchanged in both cases. In other words, if households have net assets, a temporary tightening of monetary policy would be a stimulus to the economy, not a depressive as assumed in the New Keynesian inflation targeting model. Since at any point of time there will be some households with net assets and others with net liabilities, the strength of the interest rate effect on consumption may be quite weak, or even zero for a closed economy where, in the aggregate, net financial assets are zero.

There is a more fundamental distinction to be made in comparing this third solution with the New Keynesian IS function. Correctly interpreted, the Euler equation says that an increase in the expected interest rate in period $t+1$ simultaneously affects both current and expected future consumption such that the expected change in consumption between periods t and $t+1$ also increases. It does not say that current consumption falls as the New Keynesian IS function is said to imply. Further, since the budget constraint must also be satisfied, there will be a change in asset holdings for period $t+1$.

To find out what this is, consider the effect of a unit change in $E_t r_{t+1}$ from its initial value of θ such that interest rates in all other periods are assumed unchanged. From the consumption functions for periods t and $t+1$, with income fixed and net assets, and from the Euler equation (13),

$$\begin{aligned} E_t \ln C_{t+1} - \ln C_t &= -\frac{r}{1+r}\frac{A}{C}r_t + \frac{r}{1+r}\frac{A}{C}(1-\frac{1}{1+r})E_t r_{t+1} + r\frac{A}{C}(E_t \ln A_{t+1} - \ln A_t) \\ &= \frac{1}{\sigma}(E_t r_{t+1} - \theta) = 0 \end{aligned}$$

Hence, as a result of a unit change in $E_t r_{t+1}$, the change in $E_t \ln C_{t+1} - \ln C_t$ is

$$\begin{aligned} (E_t \ln C^*_{t+1} - \ln C^*_t) - (E_t \ln C_{t+1} - \ln C_t) &= \frac{r}{1+r}\frac{A}{C}(1-\frac{1}{1+r}) + r\frac{A}{C}(E_t \ln A^*_{t+1} - E_t \ln A_{t+1}) \\ &= \frac{1}{\sigma} \end{aligned}$$

This implies that the change in expected assets is

$$E_t \ln A^*_{t+1} - E_t \ln A_{t+1} = -\frac{1}{\sigma}\frac{r}{(1+r)^2}$$

A corresponding result can be derived for the case of households having net liabilities.

We conclude from this discussion of the output equation that the New Keynesian IS function may give a completely misleading signal of the effects monetary policy even to the extent of giving the wrong sign, and that the correct way to carry out the analysis is with the consumption function. We also note that in dynamic general equilibrium models of the whole economy, additional variables will be present in the New Keynesian IS function. This is because the national resource constraint will reflect the other variables in the national income identity such as government expenditures and trade variables. In a full model of the economy there will also be physical capital and in an open economy there will be a net holding of foreign assets. All of this will make the analysis of the effect of a change in interest rates more complicated. It is beyond the scope of this paper to take this up.

5 Empirical evidence

We now examine empirical evidence about the NKM. We want to know how much support there is for the standard NKM, whether less restrictive specifications of the inflation and output equations perform better, and what the estimated NKM implies for the dynamic response of inflation to interest rates. This evidence is based on quarterly data for the UK 1970 - 2005.

5.1 Econometric models and their estimation

The standard Phillips equation for the GDP deflator in the NKM is a restricted version of

$$\pi_t^d = \alpha_0 + \alpha_1 E_t \pi_{t+1}^d + \alpha_2 \pi_{t-1}^d + \alpha_3 x_t + e_{\pi t}$$

without lagged inflation. This encompasses the alternative dynamic formulations offered by the Calvo model, the simple quadratic adjustment cost model and the Taylor model. We estimate both the restricted version and the above equation where we employ an assumption of either rule of thumb firms or indexing to past inflation as a justification for the presence of lagged inflation.

A second form of Phillips equation based on the formulation of Gali, Gertler and Lopez-Salido (2001) is

$$\pi_t^d = \alpha_0 + \alpha_1 E_t \pi_{t+1}^d + \alpha_2 \pi_{t-1}^d + \alpha_3 s_{Lt} + e_{\pi t}$$

where we also make their assumption that the difference between marginal costs and price is well-measured by the wage share. A third form which aims to capture a key open economy aspect, the potential role of import prices in the measurement of marginal cost as identified by Batini, Jackson and Nickell (2005), is

$$\pi_t^d = \alpha_0 + \alpha_1 E_t \pi_{t+1}^d + \alpha_2 \pi_{t-1}^d + \alpha_3 s_{Lt} + \alpha_4 (p_t^m - p_t) + e_{\pi t}$$

The output equation has the general form

$$(y_t - y_t^*) = \beta_0 + \beta_1 E_t (y_{t+1} - y_{t+1}^*) + \beta_2 (y_{t-1} - y_{t-1}^*) + \beta_3 r_t + \beta_4 (y_t^w - y_t^{w*}) + e_{yt}$$

This includes lagged dynamics in the output gap and output deviations from trend for the remaining G6 countries to reflect simple open economy effects. The lagged dynamics in the output gap are consistent with the implications of habits in consumption and adjustment costs/time to build effects in investment discussed, for example, by Fuhrer and Rudebusch (2004).

The method of estimation favoured by most in this field is GMM with instruments drawn from lags of the included variables plus some additional variables. Any serial correlation in the errors $e_{\pi t}$ and e_{yt} caused by the presence of expectational errors is assumed to be soaked up by employing the general robust form of the covariance matrix of errors suggested by Newey and West. The difficulty that this causes for our analysis is that it obscures any serial correlation caused by the use of an incorrect form of dynamic specification. We therefore adopt an alternative strategy based on Wickens (1993) which uses two steps. Wickens shows that this method will provide consistent estimates of the parameters and not require estimation robust to serial correlation.

1. Forecast π_t and y_t from lags of all of the variables, including extra variables not in the equations but in the information set of economic agents.

2. Replace $E_t\pi_{t+1}$and $E_t y_{t+1}$ with the forecast for $t+1$ and estimate by instrumental variables making sure not to include time t endogenous variables such as π_t as instruments even though π_t is used to forecast π_{t+1} and y_{t+1}.

The format of the models also allows us to employ the automatic dynamic model selection methods (GETS) proposed by Hendry and Krolzig (2001) and reviewed in Hendry and Krolzig (2005) (albeit in a rather different context to that discussed by those authors). Having established the set of instrumental variables and the maximum length of the lags allowed, we allow the automatic dynamic model selection process provided by the GETS program to choose the precise form of the dynamics. In each case the program chooses a simplification of the single lead and multiple lags in inflation and output, in the two equations, and the current value and lags in all of the right hand side variables in each model. Hendry and Krolzig (2005) show that this process of model selection is superior to the application of simple information criteria such as AIC or

BIC. The process ensures that the final model satisfies tests of misspecification whilst being an acceptable simplification of the initial general unrestricted model (GUM). We provide a test of the variable exclusion restrictions implied in the final model.

5.2 Estimates

In Table 1 we present the various estimates of the Phillips curve. The instruments used are: lags 1 to 5 of inflation, output gap, labour share, real price of imports, growth of oil price, growth of employment, real price of exports and wages.

Column 1 presents an estimate of the basic inflation equation based on the output gap, equation (1). Both forward and backward-looking inflation dynamics are significant. The coefficient on expected future inflation is three times the size of that of lagged inflation and the sum of the two is not significantly different from one. The output gap has a small and insignificant positive effect. However, the significant serial correlation and heteroskedasticity in the estimated error makes inference unreliable. Employing the GETS technology with a maximum of four lags on lagged inflation and the output gap produces as final estimates those shown in column 2. Whilst suggesting that the dynamics of the output gap are more complicated, the dynamics of inflation that emerge are like those in the basic model. Interestingly, there is no evidence of serial correlation or heteroskedasticity in the errors of this equation. The test of the overidentifying restrictions implied by the selection of included variables and instruments does not reject the equation. Likewise the F-test of this final model against the GUM is not rejected at the 10% level. In column 3 we investigate the effect of restricting the specification by considering a single one-year lag in inflation. This seems to reduce the lag in the response of inflation to output.

Table 1

New Keynesian Phillips Curves

Δp_t	1.	2.	3.	4.	5.
cnst.	0.0006	0.001	0.234	-0.396	-0.359
	(0.41)	(0.15)	(2.15)	(2.07)	(2.84)
$E_t(\Delta p_{t+1})$	0.714	0.815	0.649	0.362	0.369
	(6.46)	(10.85)	(5.98)	(2.25)	(4.18)
Δp_{t-1}	0.247			0.187	
	(2.79)			(2.14)	
Δp_{t-3}		0.183			
		(2.15)			
Δp_{t-4}			0.318		0.173
			(4.50)		(2.41)
x_t	0.0193		-0.431		
	(0.268)		(3.01)		
x_{t-1}		0.153	0.589		
		(2.33)	(4.44)		
x_{t-4}		-0.243			
		(2.70)			
x_{t-5}		0.183			
		(2.15)			
sl_t				0.0943	0.251
				(2.07)	(5.14)
sl_{t-2}					-0.166
					(3.66)
$p_t^{\,i} - p_t$				0.0216	-0.0996
				(2.97)	(3.96)
$p_{t-1}^{\,i} - p_{t-1}$					0.152
					(5.34)
$p_{t-5}^{\,i} - p_{t-5}$					-0.028
					(2.51)
$\bar{R}^2$	0.568	0.699	0.636	0.574	0.768
σ_u	0.0101	0.00841	0.0074	0.010	0.0074
Sargan $\chi^2(q)$		34.2			31.3
prob		(0.36)			(0.80)
FpGUM	-	0.0979	-	-	0.737
AR (1-4)	14.06	1.74	8.53	8.40	0.326
prob	(0.007)	(0.14)	(0.074)	(0.078)	(0.86)
Hetero	40.67	0.649	11.51	22.56	0.846
prob	(0.00)	(0.797)	(0.17)	(0.004)	(0.64)
Estimation period:	**1970:1 – 2004:1**	**1976:4 – 2004:1**		**1970:1 – 2004:1**	
Estimation method: Instrumental Variables					

The general picture to emerge from these three sets of estimates is that the response of inflation to output is positive but small, and that the sum of the coefficients on lag and lead inflation is approximately unity, which implies that there is little or no long-run tradeoff between inflation and output. Later we examine some further implications of this finding for the NKM.

Estimation results for the marginal-cost-based Phillips curves are given in columns 4 and 5. In column 4 a simple open economy version of the model is presented. The importance of the forward-looking dynamics is quantitatively smaller than in the output gap-based models and the sum of the forward and backward-looking components of the dynamics is substantially below one. The labour share and real import price are both significant and have the positive effect we expect from equation (12). Again, inference is limited by the significant serial correlation and heteroskedasticity that we find in the errors. The GETS procedure presents a somewhat different result in this case, as shown in column 5. A much more complicated dynamic relationship emerges from the GUM. In particular, the backward dynamics in inflation involves inflation with a lag of one year. Tests of misspecification favour this model over the simple version in column 4 and an F-test supports this equation against the GUM. The sum of the coefficients on lead and lag inflation are significantly less that one, implying that there is a long-run tradeoff between inflation and output. This result is common in estimates for the UK, as for example in Batini et al (2005).

Comparison of the two types of Phillips equation suggests a number of questions about the NKM. The output gap and a measure of marginal cost are often treated as interchangeable in estimation. But as Gali and Gertler (1999) show, this is only possible under very restrictive conditions, for example, that the labour market is competitive. Judging how important this is empirically depends also on the measurement of the output gap. In our data the correlation between the labour share and the output gap is -0.3 rather than the positive value which would confirm their interchangeability. An alternative to the data-generated trend output series we employ in our output gap series is a model-based measure such as that proposed by Neiss and Nelson (2006). The problem with their approach is that the potential output series they generate is very volatile and therefore may not be measuring the trend that policy makers have in mind in setting monetary policy. Perhaps further investigation of the wage markup model along the lines proposed by Erceg, Henderson and Levin (2000) may provide a compromise estimate.

Table 2

New Keynesian Output Equation

x_t	1.	2.	3.
cnst.	0.234 (2.15)	0.0008 (1.41)	0.0001 (0.91)
$E_t(x_{t+1})$	0.610 (11.9)	0.612 (11.8)	0.637 (10.4)
x_{t-1}	0.434 (9.61)	0.371 (7.03)	0.414 (7.65)
$i_t - E_t(\Delta p_{t+1})$	-0.160 (3.65)	-0.157 (3.11)	-0.156 (3.68)
$i_{t-1} - E_{t-1}(\Delta p_t)$	0.148 (3.75)	0.0800 (1.63)	0.138 (3.56)
$x^w{}_t$		0.0440 (2.07)	
$x^w{}_{t-2}$			0.0778 (2.14)
$x^w{}_{t-3}$			-0.134 (2.43)
$x^w{}_{t-4}$			0.0927 (2.54)
$\overline{R}^2$	0.923	0.922	0.929
σ	0.0035	0.0035	0.00338
Sargan $\chi^2(q)$ $(prob)$	51.07 (0.58)		44.4 (0.50)
FpGUM	0.660	-	0.555
AR (1-4)	0.241	4.54	0.663
prob	(0.914)	(0.338)	(0.619)
Hetero	0.717	4.41	0.589
prob	(0.583)	(0.353)	(0.671)

Estimation period: 1976:4 2004:1
Estimation method: Instrumental Variables

Estimates of the New Keynesian output equation (2) are presented in Table 2. The instruments used are: lags 1 to 5 of inflation, output gap, labour share, real price of imports, growth of oil price, growth of employment, real price of exports, wages, world output gap and real interest rate (lags 2 to 5).

In column 1 we present a closed economy model selected by GETS. This provides for rather limited dynamics even though the GUM allowed for 4 lags in all relevant variables. The parameters have the expected sign and size. There is little evidence against the model in any of the tests of misspecification. The significance of the lagged output gap is consistent with the results in Fuhrer (2000) and Fuhrer and Rudebusch (2004), although we also find that the expected future output effect continues to be important in size and significance.

A simple generalisation of this model for the open economy is given in column 2 and a full dynamic search employing GETS is presented in column 3. The positive effect of output shocks from overseas seems to be rather more delayed and extended over time than the simple version suggests. This equation appears well determined with little evidence of misspecification and is not rejected as a simplification of the GUM. Likewise the Sargan test provides no evidence against the model at normal significance levels. These estimates suggest that open economy effects on output are important and should not be ignored. Like the estimates of the Phillips equation, the coefficients of lag and lead terms sum to unity. We also note that the real interest rate terms have coefficients of approximately equal and opposite size. We examine the implications of these two findings below.

5.3 Implications for inflation targeting

We have seen that a common feature of the inflation and output equations is that the sum of the lag and lead coefficients is approximately unity. This implies that the solutions have a unit root. Further, the relative sizes of the lead and lag terms affects both the form of the solution and the sign of the impact of the other variables.

Consider the following model

$$y_t = \alpha E_t y_{t+1} + (1-\alpha) y_{t-1} + \beta x_t + e_t$$

where e_t is an zero mean *iid* random variable. The presence of a unit root can be seen if the solution is re-written as

$$(1-\alpha)\Delta y_t - \alpha E_t \Delta y_{t+1} = \beta x_t + e_t$$

It follows that the model is stable or unstable depending on whether the root $|\frac{\alpha}{1-\alpha}|$ is greater or less than unity, i.e. on whether $1 > \alpha > \frac{1}{2}$ or $0 < \alpha < \frac{1}{2}$. If $1 > \alpha > \frac{1}{2}$ the solution is non-unique and a backward-looking model in Δy_t

$$\Delta y_t = \frac{1-\alpha}{\alpha}\Delta y_{t-1} - \frac{\beta}{\alpha} x_{t-1} + \delta_x (x_t - E_{t-1} x_t) + \delta_y e_t - \frac{1-\alpha}{\alpha} e_{t-1} \tag{16}$$

where δ_x and δ_y are arbitrary constants. If $0 < \alpha < \frac{1}{2}$, the solution is unique and is the forward-looking model

$$\Delta y_t = \frac{\beta}{1-\alpha}\Sigma_{s=0}^{\infty}(\frac{\alpha}{1-\alpha})^s E_t x_{t+s} + \frac{1}{1-\alpha}e_t \tag{17}$$

See Wickens (1993) for further details of the solution.

Now consider the output equation given by Table 2 (col. 1). This can be expressed approximately as

$$x_t = 0.6E_t x_{t+1} + 0.4x_{t-1} - 0.15\Delta r_t + e_{xt}$$

or as

$$0.4\Delta x_t = 0.6E_t\Delta x_{t+1} - 0.15\Delta r_t + e_{xt}$$

Noting that the root is greater than unity, the solution can be re-written as the non-unique backward-looking model

$$\Delta x_t = 0.67\Delta x_{t-1} + 0.25\Delta r_{t-1} + \delta_r(\Delta r_t - E_{t-1}\Delta r_t) + \delta_x e_{xt} - 0.67e_{x,t-1}$$

where δ_r and δ_x are arbitrary constants. Thus, due to the unit root, changes in the ouput gap are related to changes in the interest rate. The greater the increase in the previous period's real interest rate, the greater the increase in the output gap. The effect of an unanticipated increase in the real interest rate at time t is not determined.

The inflation equation (Table 1, col.3) can be written approximately as

$$\pi_t = 0.24 + 0.66E_t\pi_{t+1} + 0.33\pi_{t-4} - 0.5\Delta x_t + e_{\pi t}$$

or as

$$\Delta\pi_t = 0.72 + 2E_t\Delta\pi_{t+1} - \Sigma_{s=1}^{3}\Delta\pi_{t-s} - 1.5\Delta x_t + 3e_{\pi t}$$

A rough idea of the solution may be obtained by replacing $\Sigma_{s=1}^{3}\Delta\pi_{t-s}$ by $3\Delta\pi_{t-1}$ to give

$$\Delta\pi_t = 0.72 + 2E_t\Delta\pi_{t+1} - 3\Delta\pi_{t-1} - 1.5\Delta x_t + 3e_{\pi t}$$

or

$$z_t = 0.24 + 0.33 E_t z_{t+1} - 0.5 \Delta x_t + e_{\pi t}$$

where $z_t = \Delta\pi_t + \Delta\pi_{t-1}$. From (17) this has the unique solution

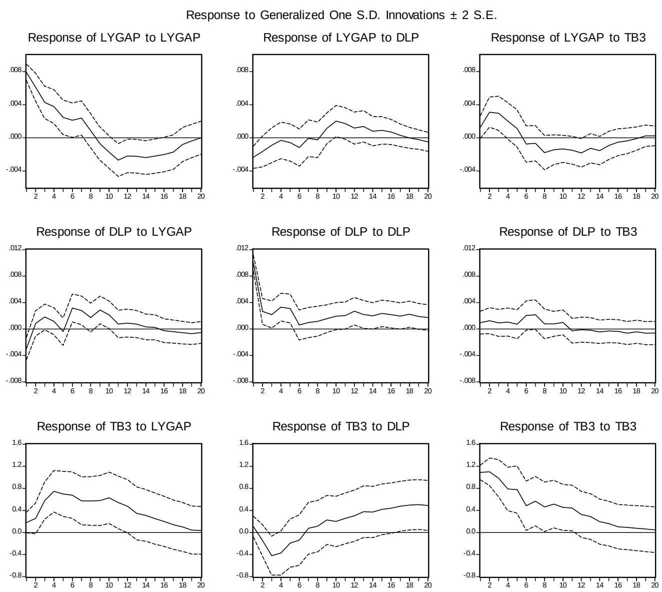
$$\Delta\pi_t = 0.48 - \Delta\pi_{t-1} - 0.5 \Sigma_{s=0}^{\infty} 0.33^s E_t \Delta x_{t+s} + e_{\pi t}$$

Thus, higher current and expected future increases in the output gap reduce the increase in inflation immediately.

Taken together, these results imply that increases in the change in interest rates will lower the change in inflation. Whilst this accords with the intuition of the NKM, the transmission mechanism does not as the sign of interest rates on the output gap and of the output gap on inflation are the opposite to those expected.

An alternative way of examining the effect of the interest rate on inflation and output that has the advantage of not being model dependent is through a VAR in π_t, x_t and i_t. Support for such a VAR representation is provided by the backward-looking solution of the estimated NKM. We obtain the following generalised impulse responses over 5 years for a VAR(8).

Figure 1. VAR impulse response functions



We observe that the responses of both inflation and output to an interest rate shock are positive in the short run. The response of inflation is very weak and is insignificant in the short run, and close to zero in the long run. The response of output is positive and significant in the short run, but zero in the long run. These responses are consistent with our findings on the properties of the estimated New Keynesian model.

6 Conclusions

We have sought to determine whether the New Keynesian model is fit for the purpose of providing a find a suitable basis for inflation targeting in which the aim is, for example, to raise interest rates in order to reduce inflation. Our findings are not encouraging. Assuming that the standard NKM is a correct representation of the economy, we have shown that a discretionary increase is predicted to raise inflation, not reduce it. In contrast, under commitment to a rule - such as a Taylor rule - unexpectedly high interest rates are predicted to reduce inflation.

Based on data for the UK, we have found that there is strong support for the forward-looking dynamic specification of the NKM. The model seems to contain a unit root with the implication that changes in interest rates affect changes in the output gap and changes in inflation. We find that the larger the increase in interest rates the smaller the change in inflation. Whilst this accords with the intuition of the NKM, the transmission mechanism does not as the sign of interest rates on the output gap and of the output gap on inflation are the opposite to those expected. Finally, we estimated the response of inflation to an interest shock in a three variable VAR consisting of inflation, the output gap and the Treasury Bill rate. We now find that inflation responded positively to interest rates.

A close analysis of the theoretical underpinnings of the NKM suggests the problem may lie in the specification of the inflation and output equations of the NKM. In the literature most attention has been paid to the Phillips equation. We contrast the standard Phillips equation with imperfect competition open economy models of the equation and show that the latter have better empirical support. An important question still to be resolved is how output affects inflation in these models. If it is through markup effect, are they via the price or the wage markup?

Perhaps more important, however, but far less considered in the literature, is the new Keynesian IS equation. We argue that it is incorrect to base the output equation just on the Euler equation of a DSGE model and that it is necessary to solve this together with the budget constraint or the national resource constraint. We show that the sign of the effect of an increase in interest rates on output depends on whether households have net assets or liabilities. Only in the latter case is the sign negative as assumed in the NKM model. Further, taking account of the national resource constraint, implies that additional variables are required in the equation such as trade effects.

Taken together, these findings suggest that the standard NKM does not provide a sound basis either in theory or in the light of empirical evidence. The specification of the two equations needs much more thought and the two equations should be embedded in a somewhat more complete model of the economy.

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Data Appendix

The data are quarterly for the UK from 1970:1 2004:1

Variables:

p_t Gross Value Added Deflator (GVAD), (National Statistics: ABML/ABMM).

y_t Gross value added measured at basic prices, excluding taxes less subsidies (National Statistics: ABMM)

y_t^* Hodrick-Prescott trend output (λ=1600).

$x_t = y_t - y_t^*$ Output gap

sl_t Labour share of value added adjusted for payments to the self-employed and for general government gross value added (National Statistics: (HAEA-NMXS)*A/(ABML-GGGVA)) where A=(BCAJ+DYZN)/BCAJ. (Bank of England supplied)

p_t^i Price of imports (National Statistics: IKBI/IKBL)

p_t^w World GDP deflator (Bank of England data)

y_t^w World trade measured as G6 excluding UK GDP (Bank of England data).

n_t Employment (National Statistics: BCAJ+DYZN)

w_t Wages (National Statistics: (HAEA*A)/(BCAJ+DYZN)) where A=(BCAJ+DYZN)/BCAJ.

p_t^o Price of oil : average spot price in Sterling (PETSPOT/AJFA) (Bank of England data)

$x_t^w = y_t^w - y_t^{w*}$ World output gap : world trade minus Hodrick-Prescott trend.

i_t nominal 3-month treasury bill interest rate

$r_t = i_t - \Delta p_{t+1}^d$ Real interest rate

i_t^w World interest rate: G6 excl. UK nominal 3-month interest rate (Bank of England data)

$r_t^w = i_t^w - \Delta p_{t+1}^w$ World real interest rate

All variables apart from interest rates are measured in natural logarithms.