

# Sticky prices or sticky information? \*

ALESSIO MORO

## 1. Introduction

The New Keynesian Model (NKM), in its various versions, is the most commonly used instrument for monetary policy analysis. The reason of its success lies in the mix of assumptions used in building the model. On the one hand, the NKM combines elements of dynamic general equilibrium theory, drawn from the neoclassical tradition, such as a utility maximizing agent, problem of intertemporal choice and complete markets. On the other hand, it introduces nominal rigidities in the form of sticky prices or sticky wages as in the Keynesian tradition, in order to have short run real effects in response to monetary and technological shocks.

In its basic formulation, the NKM can be reduced to two equations describing the behaviour of the economy: an aggregate IS relationship, derived from the household problem, and not *ad hoc* as in the textbook IS-LM model, and an aggregate supply relationship in the form of a new Keynesian Phillips curve, which relates inflation to expected inflation and a measure of current output gap. As the model involves the nominal interest rate, a third equation is needed. This is given by the central bank rule for monetary policy. The three equations

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□ Universidad Carlos III de Madrid, Departamento de Economía, Madrid (Spain) and Università degli Studi di Cagliari, Dipartimento di Economia, Cagliari (Italy); e-mail: amoro@eco.uc3m.es.

\* I would like to thank two anonymous referees for the useful comments. The usual disclaimers apply.

are then written in log-linear form and each variable is expressed as the log-deviation from its corresponding non-stochastic steady state value. With these three equations to hand, a number of policy experiments can be performed, using impulse response functions from simulations, once the parameter values have been calibrated.

The NKM can be considered the main tool used for monetary policy analysis. However, a new model recently developed by Mankiw and Reis (2002) revived the debate on the importance information asymmetries can have for monetary policy to produce real effects. As Lucas (1972) argued, an economic environment can experience monetary non-neutralities because agents do not possess complete information about the state of the economy. Mankiw and Reis (2002) assume a flexible price environment in which firms differ in the level of information they have about the state of the economy. In particular, a proportion of firms receives the current information about the state of the economy and can set prices optimally while the remaining proportion sets prices based on information received in the previous periods. This implies that if a monetary shock occurs, firms not receiving the information will not adjust prices in response and the shock will have real effects. This model is labelled Sticky Information Model (SIM) and it represents the main alternative to the NKM.

The purpose of this paper is to survey the NKM and the SIM to highlight the differences between the two. The basic differences between the two models are summarized in the price equations, the new Keynesian Phillips curve and the sticky information Phillips curve. Given these conditions, I shall provide a more detailed exposition of the NKM. With this to hand it will be easy for the reader to follow extension to the SIM.

The paper is organized as follows: section 2 describes the NKM; section 3 presents the SIM and section 4 compares the two models and shows the policy experiments. Finally, section 5 draws the conclusions.

## 2. The New Keynesian Model

There are a number of papers and books describing the New Keynesian Model. The model itself is constructed on the static version of

monopolistic competition by Blanchard and Kiyotaky (1987). A complete version of the NKM is developed in Chari, Kehoe and McGrattan (2000).<sup>1</sup> Among the various books, Woodford (2003) and Walsh (2003) provide complete treatments. Here I follow Walsh (2003) in describing the general model.

### 2.1. Description of the economy

There is a continuum of firms in the economy  $j \in [0,1]$ , each producing the same kind of a differentiated good. The household consumes all kind of goods in the continuum because the consumption index entering the utility function is given by a Dixit-Stiglitz (1977) aggregator of the type

$$C_t = \left[ \int_0^1 c_{jt}^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \quad (1)$$

where  $\theta > 1$  represents the elasticity of substitution among differentiated goods.<sup>2</sup>

This specification implies that in equilibrium all goods are consumed – a point that will be made clear in the solution to the household problem. Firms have a degree of monopolistic power and can set prices optimally. In this way the effect of monetary policy on price setting behaviour can be analyzed. When sticky prices are introduced, the Dixit-Stiglitz aggregator prevents the non-adjusting firms from suffering an incalculably great change in sales, which would be the case with an elasticity of substitution equal to infinity.

### 2.2. The household problem

The household problem can be divided into two parts, one intratemporal and the other intertemporal. In the first step the household minimizes the cost of buying the differentiated goods in each period to reach an amount of total consumption equal to  $C_t$ , while

<sup>1</sup> Chari, Kehoe and McGrattan (2000) employ a Taylor (1980) mechanism of price adjustment. Here I use the Calvo (1983) mechanism.

<sup>2</sup> The parameter must exceed one to have a positive firm's optimal price.

in the second the household decides how to allocate resources intertemporally.

The first problem is stated formally as

$$\min_{c_{jt}} \int_0^1 c_{jt} p_{jt} dj \quad (2)$$

$$\text{s. to} \quad \left[ \int_0^1 c_{jt}^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \geq C_t.$$

The solution to this problem is the demand function for firm  $j$

$$c_{jt} = \left( \frac{p_{jt}}{P_t} \right)^{-\theta} C_t, \quad (3)$$

where  $P_t = \left[ \int_0^1 p_{jt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}}$ . In the second step, the household solves a maximization problem stated to make optimal choices about consumption  $C_t$ , real money balances  $M_t/P_t$ , labour  $N_t$  and bond holdings,  $B_t$ . The formal problem is

$$\max E_t \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} + \gamma \frac{(M_t/P_t)^{1-b}}{1-b} - \chi \frac{N_t^{1-\eta}}{1-\eta} \right\} \quad (4)$$

$$\text{s. to} \quad P_t C_t + M_t + B_t = W_t N_t + M_{t-1} + (1+i_{t-1})B_{t-1} + P_t \Pi_t,$$

where  $\sigma$ ,  $b$ ,  $\eta$ ,  $\chi$  and  $\gamma$  are positive parameters. The budget constraint of the consumer implies that the amount of resources spent on consumption,  $P_t C_t$ , nominal money holdings,  $M_t$ , and bond holdings,  $B_t$ , must be equal to earnings from working  $W_t N_t$ , last period money holdings  $M_{t-1}$ , interest on and repayment of bond holdings  $(1+i_{t-1})B_{t-1}$  and nominal profits from firms ownership  $P_t \Pi_t$ .<sup>3</sup>

The first order conditions for this problem are summarized by the following three equations

$$C_t^{-\sigma} = \beta(1+i_t)E_t \left( \frac{P_t}{P_{t+1}} \right) C_{t+1}^{-\sigma}, \quad (5)$$

<sup>3</sup> As firms possess monopoly power they make positive profits in equilibrium.

$$\frac{\gamma(M_t/P_t)^{-b}}{C_t^{-\sigma}} = \frac{i_t}{1+i_t}, \quad (6)$$

$$\frac{\chi N_t^\eta}{C_t^{-\sigma}} = \frac{W_t}{P_t}. \quad (7)$$

Equation 5 is the usual Euler equation that relates consumption today and tomorrow. This appears clear once it is noted that  $P_t/P_{t+1} = 1/(1+\pi_{t+1})$  where  $\pi_{t+1}$  is the inflation rate at  $t+1$ . Then  $(1+i_t)/(1+\pi_{t+1}) = (1+r_t)$  and the Euler equation can be written in terms of the real interest rate  $r_t$

$$C_t^{-\sigma} = \beta E_t(1+r_t)C_{t+1}^{-\sigma}. \quad (8)$$

Equation 6 can be interpreted as a money demand equation. To see this I rewrite 6 as

$$\frac{M_t}{P_t} = \left[ \gamma C_t^\sigma \left( \frac{1}{i_t} + 1 \right) \right]^{1/b}. \quad (9)$$

In the model presented here there is no investment, so equation 9 relates real money holdings positively to output  $C_t$  and negatively to the nominal interest rate  $i_t$ . As an equilibrium condition, equation 6 relates the marginal rate of substitution between real money holdings and consumption to the relative price of the two goods. This relative price is given by the opportunity cost of holding money,  $i_t/(1+i_t)$ , which is equal to the relative price of real balances to consumption.

Finally, equation 7 is a static general equilibrium relationship that equates the marginal rate of substitution between labour and consumption to the real wage.

### 2.3. The firm problem

All firms  $j \in [0,1]$ , produce a differentiated good using the same constant returns to scale technology with labour as the only input

$$y_{jt} = A_t N_{jt}, \quad (10)$$

where  $A_t$  can be interpreted as a stochastic technological level with  $E(A_t) = 1$ . The operator  $E$  represents the unconditional expectation over the process  $A_t$ . Capital is excluded from the basic model for two reasons: the first is tractability and the second is the observation that capital does not change much at business cycle frequencies. Recently Sveen and Weinke (2005) and Woodford (2003) showed that, when capital is firm-owned, it can influence firms pricing decisions in a Calvo setting.<sup>4</sup>

The Calvo (1983) mechanism is summarized as follows: each period fraction  $\lambda$  of randomly chosen firms in the economy are not allowed to change the price while the remaining  $1 - \lambda$  set prices optimally. Thus the single firm faces a probability of changing prices which is given by a Poisson process with mean  $1 - \lambda$ , and expected duration of the price set in the current period of  $1/(1 - \lambda)$ . The difference between Calvo (1983) and Taylor (1980) is that the former is a stochastic mechanism in which adjusting firms are randomly chosen from the population, while in the latter each producer is forced to keep prices fixed for a predetermined length of time.

With production function 10 to hand, the cost minimization problem for the single firm can be stated. Note that constant returns to scale imply that all firms are always at the same marginal cost level. To obtain an expression for the marginal cost, I write the inverse function of 10,  $N_{jt} = f^{-1}(y_{jt})$ ,

$$N_{jt} = \frac{y_{jt}}{A_t}.$$

The derivative of this function with respect to  $y_{jt}$  gives the additional labour needed to produce one more unit of output

$$\frac{dN_{jt}}{dy_{jt}} = \frac{1}{A_t}.$$

As each additional unit of labour costs  $W_t/P_t$ , the real marginal cost for each firm will be

$$MC_t = \frac{1}{A_t} \frac{W_t}{P_t}. \quad (11)$$

<sup>4</sup> See also Galí, Lopez-Salido and Valles (2004) for a sticky price model with capital.

The problem of a firm allowed to change price at time  $t$  is

$$\max_{P_{jt}} E_t \sum_{k=0}^{\infty} \lambda^k \Delta_{t,t+k} \left[ \frac{P_{jt}}{P_{t+k}} - MC_{t+k} \right] c_{jt+k}. \quad (12)$$

The firm maximizes the expected discounted value of the stream of current and future real profits. Here  $\Delta_{t,t+k} = \beta^k (C_{t+k}/C_t)^{-\sigma}$  represents the stochastic discount factor from  $t+k$  to  $t$  for the firm. The latter is an equilibrium condition, derived from the consumer's problem through the Euler equation 5 and its generalization to subsequent periods.

Each firm adjusting price at  $t$  faces the same optimization problem and thus sets the same price. Then, subscript  $j$  is omitted and  $p_t$  is used to indicate the optimal price set by all firms adjusting at  $t$ . The solution to problem 12 is

$$p_t = \frac{\theta}{\theta-1} \frac{E_t \sum_{k=0}^{\infty} (\beta\lambda)^k C_{t+k}^{1-\sigma} MC_{t+k} (P_{t+k}/P_t)^\theta}{E_t \sum_{k=0}^{\infty} (\beta\lambda)^k C_{t+k}^{1-\sigma} (P_{t+k}/P_t)^{\theta-1}} P_t. \quad (13)$$

This is a particular case of the pricing decision of the monopolistically competitive firm. If the firm were able to adjust prices in each period,  $\lambda = 0$ , it would set

$$p_t = \frac{\theta}{\theta-1} MC_t P_t. \quad (14)$$

Optimal price is set as mark-up  $\theta/(\theta-1)$  over nominal marginal cost  $MC_t P_t$ . The above formula also makes clear that  $\theta > 1$  must hold in order to have a positive optimal price. When prices are not flexible, a firm must take into account that it might not be able to adjust prices in the subsequent period so that all future marginal costs matter in setting the optimal price. This behaviour is summarized in equation 13, which shows that optimal price is a pure forward-looking variable depending on the future value of the nominal marginal cost.

Note that from the definition of  $P_t = \left[ \int_0^1 p_{jt}^{1-\theta} dj \right]^{1/(1-\theta)}$  the price index at  $t$  satisfies

$$P_t^{1-\theta} = \lambda P_{t-1}^{1-\theta} + (1-\lambda) p_t^{1-\theta}, \quad (15)$$

as  $1 - \lambda$  of firms set the optimal price while  $\lambda$  of them keep the price fixed from the previous period. As non-adjusting firms are randomly chosen from the population, the price index of all non-adjusting firms is  $P_{t-1}$ .

#### 2.4. Steady state and linearization

As pointed out in the introduction, the NKM can be reduced to a two-equation linear system in output gap, inflation and the nominal interest rate. With an additional equation representing the way the central bank sets interest rates, the model can be closed.

With flexible prices, the NKM reduces to a standard dynamic general equilibrium model with money in the utility function. The latter shows a steady state in which the level of real variables is independent of money; that is, the model displays neutrality. This steady state represents the benchmark case: this is the point to which the system converges when prices are flexible and no monetary or technological disturbance is present. The strategy is to write the system in terms of log-deviations from the steady state. I define variable  $\hat{z}_t$  as

$$\hat{z}_t = \log z_t - \log z^{ss} \quad (16)$$

where  $z_t$  is the value of a generic variable in the NKM above and  $z^{ss}$  is the corresponding non-stochastic steady state value. In the non-stochastic steady state all stochastic variables are at their average level.

The natural level of output is defined as the log-deviation of output, when prices are flexible, from its steady state level

$$\hat{Y}_t^f = \log Y_t^f - \log Y^{ss}. \quad (17)$$

This deviation depends only on technological disturbances

$$\hat{Y}_t^f = \left( \frac{1 + \eta}{\sigma + \eta} \right) \hat{A}_t. \quad (18)$$

Log-linearizing equations 5, 13 and 15, an aggregate IS relationship

$$x_t = E_t x_{t+1} - \frac{1}{\sigma} \left[ \hat{i}_t - E_t \pi_{t+1} \right] + u_t, \quad (19)$$



and an aggregate supply relationship, given by the new Keynesian Phillips curve

$$\pi_t = \beta E_t \pi_{t+1} + \tilde{\kappa} x_t \quad (20)$$

are obtained, where  $x_t = \hat{Y}_t - \hat{Y}_t^f$  is the output gap at time  $t$  and

$u_t = E_t(\hat{Y}_{t+1}^f - \hat{Y}_t^f)$ . The coefficient of the output gap is given by

$$\tilde{\kappa} = (\eta + \sigma)(1 - \lambda)(1 - \beta\lambda)\lambda^{-1}.$$

Equation 19 is a standard linearized Euler equation. It is common to every dynamic general equilibrium model and relates the levels of consumption over time. Equation 20, on the other hand, is typical of the NKM. It relates inflation today with inflation tomorrow and a measure of economic activity, here represented by the output gap. This is a pure forward-looking relationship which can be solved forward to obtain

$$\pi_t = E_t \sum_{k=0}^{\infty} \beta^k \tilde{\kappa} x_{t+k}. \quad (21)$$

Inflation today depends only on current and expected future values of the output gap, and there is no past variable involved. At  $t$ ,  $\lambda$  of firms do not change prices and the remaining  $1 - \lambda$  set them looking at the present and the future. Thus the only expectations involved are those of today with respect to tomorrow. This is in contrast with the new classical Phillips curve of the Seventies, to derive which it is, in fact, assumed that  $1 - \lambda$  of firms set prices today based on current information and the remaining  $\lambda$  set today's prices based on yesterday's expectations about today. The new classical Phillips curve is given by

$$\pi_t = E_{t-1} \pi_t + \varepsilon x_t, \quad (22)$$

where  $\varepsilon$  is a parameter depending on the ratio  $(1 - \lambda)/\lambda$  and the degree of strategic complementarity among firms in the economy.<sup>5</sup>

<sup>5</sup> Woodford (2003, p. 161) argues that "pricing decisions are strategic complements if an increase in the prices charged for other goods increases the price that it is optimal to charge for one's own good".

Note the difference between the two relationships: in the new classical Phillips curve inflation is determined by past expectations about today, and when the central bank sets about implementing today's policy, these expectations are therefore given. The effect on inflation occurs only through the output gap. In the new Keynesian Phillips curve, on the other hand, when the central bank takes steps today, it will influence today's inflation through the output gap but also through inflation expectations about tomorrow. This implies that expectations about the future matter in determining current equilibrium values. As will be made clear in the following sections, the Sticky Information Model is closely related to the new classical model of the Seventies.

### 2.5. *Monetary policy*

Equations 19 and 20 contain three variables: the output gap, inflation and the nominal interest rate. To obtain a rational expectations linear system another equation is needed, and this is given by the rule the central bank uses to set the nominal interest rate  $i$ . This rule has to be formulated with care for the system to display a single solution. In particular, the interest rate rule must satisfy the *Taylor Principle*. According to the latter, the monetary authority should respond more than one-for-one to inflation deviations from target. Taylor (1993) showed that the Federal Reserve applied monetary policy during the Volcker-Greenspan era following the rule

$$i = \pi + 0.5x + 0.5(\pi - 2) + 2, \quad (23)$$

where  $i$  is the federal funds rate,  $x$  is the percentage deviation of output from a deterministic trend (the output gap) and  $\pi$  is the average inflation over the past four quarters. Thus, if the inflation rate is at 2%, which represents the target, and the output gap is zero, the interest rate is set at 4%. From the original contribution, policy rules like the one in 23 are labelled Taylor Rules.

To see why the Taylor principle must hold it is sufficient to use the Fisher equation

$$i_t = E_t \pi_{t+1} + r_t, \quad (24)$$

together with a central bank rule for the interest rate, which depends on the inflation level

$$i_t = \delta\pi_t + \tau_t, \quad (25)$$

where  $\tau_t$  is a random shock with zero mean. I write 24 in steady state as

$$i^{ss} = \pi^{ss} + r^{ss},$$

or

$$i^{ss} = r^{ss}, \quad (26)$$

because the steady state considered involves a zero inflation rate. Subtract 26 from 24 to get

$$\hat{i}_t = E_t \pi_{t+1} + \hat{r}_t. \quad (27)$$

Equation 25 in steady state is

$$i^{ss} = 0,$$

so from 25

$$\hat{i}_t = \delta\pi_t + \tau_t. \quad (28)$$

I use 28 in 27 to obtain

$$\pi_t = \frac{1}{\delta} [E_t \pi_{t+1} + \hat{r}_t - \tau_t]. \quad (29)$$

This is a difference equation that can be solved forward to get

$$\pi_t = E_t \sum_{k=0}^{\infty} \frac{1}{\delta^k} \hat{r}_{t+k} - \frac{1}{\delta} \tau_t, \quad (30)$$

where I used  $E_t \tau_{t+k} = 0 \quad \forall k=1, 2, \dots, \infty$ . The solution in 30 exists if  $\delta > 1$ , or in other words when the Taylor principle holds. If a solution to equation 30 exists, it follows from 28 that a  $\hat{i}_t$  implying a bounded inflation rate exists as well. The simple argument of the Taylor principle given here can be extended to the NKM once one notes that the linearized Euler equation can be written as

$$\hat{r}_t = \sigma (E_t \hat{C}_{t+1} - \hat{C}_t). \quad (31)$$

Use 31 in 30 and  $Y_t = C_t$  to obtain

$$\pi_t = E_t \sum_{k=0}^{\infty} \frac{1}{\delta^k} \sigma (\hat{Y}_{t+k+1} - \hat{Y}_{t+k}) - \frac{1}{\delta} \tau_t. \quad (32)$$

After observing that  $\hat{Y}_{t+1} - \hat{Y}_t = \log Y_{t+1} - \log Y^{\text{ss}} - \log Y_t + \log Y^{\text{ss}} = \log(Y_{t+1}/Y_t) \approx \gamma_t$ , where  $\gamma_t$  is output growth rate at  $t$ ,  $(Y_{t+1} - Y_t)/Y_t$ , assuming that the central bank makes no mistakes in applying its policy,  $\tau_t = 0$ , inflation at  $t$  can be written as

$$\pi_t = E_t \sum_{k=0}^{\infty} \frac{1}{\delta^k} \sigma \gamma_{t+k}. \quad (33)$$

Inflation is a weighted discounted average of future output growth rates. Note that expressions 30 and 33 have been derived without resorting to the new Keynesian Phillips curve. The Taylor principle, in fact, must hold regardless of the rule firms use to set prices.

Various authors have estimated different versions of the Taylor rule. For instance, Clarida, Galí and Gertler (2000) estimate a forward looking rule of the type

$$i = \bar{i} + \phi_x E(x_t | \Omega_t) + \phi_\pi E(\pi_{t+1} - \bar{\pi} | \Omega_t). \quad (34)$$

These authors suggest that the central bank reacts to movements in expected inflation and expected output gap. Here  $\bar{i}$  and  $\bar{\pi}$  are the long run desired nominal interest rate and inflation level and  $E(\cdot | \Omega_t)$  is the expectation operator conditional on the information set  $\Omega_t$ , known at  $t$ .<sup>6</sup>

Clarida, Galí and Gertler (2000) estimate 34 and find that the coefficient of inflation,  $\phi_\pi$ , is significantly larger than one in the Volcker-Greenspan period and smaller before. The result is in line with Taylor (1993) although the estimation of 34 uses expected inflation instead of past inflation. Here it need only be pointed out that, given the highly persistent nature of inflation, the result is hardly surprising.

Although the Taylor principle is sufficient for equilibrium uniqueness in the standard NKM, Svein and Weinke (2005) showed that this might not be the case when capital accumulation is in-

<sup>6</sup> The authors make the assumption that the output gap at  $t$  does not belong to  $\Omega_t$ . In other words, the output gap is not known when the nominal interest rate is set.

volved. This is because capital accumulation affects marginal cost determination. Imagine an increase in investment demand. This raises marginal cost because production is expanding. At the same time, the expected future marginal cost decreases because the stock of capital will be larger. As firms set prices in a Calvo (1983) fashion, optimal price is an average of current and future marginal costs. Thus, if the second of the effects of capital accumulation on marginal cost prevails, the optimal prices will be lower than the current price index and there will be deflation. If the central bank follows a simple Taylor rule, it will lower interest rates, fostering the demand for investment. This is a sunspot equilibrium in which an initial change in investment demand leads the system to justify that increase. In this case, the Taylor principle alone is not sufficient to guarantee determinacy of the equilibrium. Sveen and Weinke (2005) show that the parameter governing the frequency of price adjustment becomes crucial for the system to display determinacy when capital accumulation is modelled. These authors find that a Taylor rule that weighs inflation 1.5, as in the original Taylor (1993) contribution, displays indeterminacy of the system for values of the price stickiness parameter greater than 0.65. However, as shown in Bils and Klenow (2004), the median firm in the US sets prices every 4.3 months, implying a stickiness parameter of 0.3. Taking into this value account, the criticism advanced by Sveen and Weinke (2005) against the standard Taylor rule does not apply.

To conclude this subsection, it is worth noting the differences in the conduct of monetary policy between the Federal Reserve (Fed) and the European Central Bank (ECB). The task of the former is to "promote the objectives of maximum employment, stable prices, and moderate long-term interest rates"<sup>7</sup> while that of the ECB "is to maintain price stability".<sup>8</sup> The European bank focuses only on inflation deviations from target regardless of the output gap measures such as employment. This posits the following question: is it right to focus only on one of the two targets, inflation and output gap? In the context of the standard NKM the answer is affirmative because of the *divine coincidence*, highlighted by Blanchard and Galí (2005). These

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<sup>7</sup> From <http://www.federalreserve.gov/pf/pf.htm>, "Monetary Policy and the Economy".

<sup>8</sup> From <http://www.ecb.int/mopo/html/index.en.html>.

authors stress that in the NKM the gap between the natural level of output and the efficient level of output is invariant to shocks. Then, stabilizing the output gap coincides with closing the welfare relevant output gap, that is, the distance between actual and efficient output. In the NKM, stabilizing inflation coincides with closing the output gap and, in turn, with closing the welfare relevant output gap. As the authors stress, this coincidence is a feature of the standard NKM which is not realistic and not common to modified new Keynesian models.<sup>9</sup>

The implication here is that policy rules that focus on inflation only, such as that declared by the ECB, do not maximize welfare, as they focus only on price stability, which does not automatically imply stabilizing the output gap. Imagine a higher than target inflation rate and a lower than target output (a negative output gap). If the weight on output in 23 is zero, the nominal rate is set higher than the case in which the coefficient on output is positive. This happens because in the latter case the monetary authority wants not only to stabilize prices but also to close the output gap. Setting a high nominal interest rate will pursue the first objective but will be in contrast with the second.

### 3. The Sticky Information Model

In this section I present the SIM and compare it with a simplified version of the NKM. As argued in the introduction, the NKM is the most commonly used tool for monetary policy analysis. However, there are some facts that the NKM is not able to reproduce. In particular Mankiw and Reis (2002) are concerned with the following three observations: disinflations are always contractionary, the maximum impact of a monetary shock on inflation happens with some delay, inflation is correlated with the level of economic activity.<sup>10</sup> The NKM model fails to reproduce these facts, while the SIM model is consistent with them.

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<sup>9</sup> Blanchard and Galí (2005) introduce wage rigidities to show this aspect.

<sup>10</sup> On this point, see also Galí and Gertler (1999), who argue that output gap leads inflation. Thus output gap leads display a higher correlation with inflation than contemporaneous output gap.

Mankiw and Reis (2002) use four policy experiments to explain the differences between the two models, and this seems to me the best strategy to proceed in this work as well. I first describe the SIM model and then compare the equations with a simplified version of the NKM. Next, using impulse response functions, I describe the dynamic properties of the two models.

The basic assumption of the SIM is that prices are flexible but information disseminates slowly over firms. There is a continuum of firms  $j \in [0,1]$  in the economy. Each period, a fraction  $1 - \phi$ ,  $\phi \in [0,1]$ , of the population of firms receives the information about current economic conditions while the remaining  $\phi$  does not. In this model, the information some firms are lacking is the current (and possibly past) evolution of the exogenous disturbances. Thus, if a monetary shock occurs but the firm does not receive the information, it will set prices on the basis of the information held before the shock occurred.

Here I present the macro model; no micro-foundations are provided or discussed. Reis (2006) provides micro-foundations for the SIM on the basis of firms' "inattentiveness": as information gathering is costly, the single firm decides optimally to remain inattentive to shocks for given time lengths. Information is acquired only in the instants between two inattentiveness periods.

Following Mankiw and Reis (2002), define the desired price at  $t$  as

$$p_t^* = p_t + \alpha y_t. \quad (35)$$

This can be interpreted as a logarithmic version of 14. Here  $p_t^*$  is the logarithm of the optimal price at  $t$ ,  $p_t$  is the logarithm of the price index and  $y_t$  is the logarithm of output. Assume that the logarithm of potential output is zero so that  $y_t$  is interpreted as the output gap. The marginal cost  $MC_t$  and the output gap satisfy a linear relationship so the use of  $y_t$  in 35 should not be surprising. A firm that received the information at  $t-j$  sets the optimal price as

$$x_t^j = E_{t-j} p_t^*. \quad (36)$$

That is, the optimal price  $x_t^j$  is set at the level that, at  $t-j$ , was thought to be right for time  $t$ . Whatever shock happened between  $t-j$

and  $t$  does not belong to the firm's information set and so cannot be used to set the optimal price. The price index in the economy will be

$$p_t = (1 - \phi) \sum_{j=0}^{\infty} \phi^j x_t^j, \quad (37)$$

that is, a weighted average of the prices set by firms grouped by the vintage of their information. Using 35, 36 and 37, the price index can be written as

$$p_t = (1 - \phi) \sum_{j=0}^{\infty} \phi^j E_{t-j}(p_t + \alpha y_t). \quad (38)$$

The sticky information Phillips curve then becomes

$$\pi_t = \frac{\alpha(1 - \phi)}{\phi} y_t + (1 - \phi) \sum_{j=0}^{\infty} \phi^j E_{t-1-j}(\pi_t + \alpha \Delta y_t), \quad (39)$$

where  $\Delta y_t = y_t - y_{t-1}$  is the growth rate of output. See the appendix for the derivation. Compared to the new Keynesian Phillips curve, the sticky information equivalent still depends on the output gap but also on past expectations about current inflation and the growth rate of output. Note the similarity with the new classical Phillips curve in equation 22

$$\pi_t = E_{t-1} \pi_t + \varepsilon x_t.$$

In both 39 and 22 what matter are past expectations about current economic conditions. In the new Keynesian Phillips curve it is current expectations about future economic activity that matter. The SIM shares some features with the monetary literature of the Seventies and also with the Calvo mechanism.

A simplified version of the NKM can be derived as follows. As before,  $\lambda$  is the Calvo parameter. The desired price at  $t$  is defined as in 35. Optimal price at  $t$  is a weighted average of current and future desired prices

$$x_t = (1 - \lambda) \sum_{j=0}^{\infty} \lambda^j E_t p_{t+j}^*. \quad (40)$$

The price level is an average of all optimal prices set over time

$$p_t = (1 - \lambda) \sum_{j=0}^{\infty} \lambda^j x_{t-j}, \quad (41)$$



which can be written as

$$p_t = (1 - \lambda)x_t + \lambda p_{t-1}, \quad (42)$$

that is, as a convex combination of optimal price today and the  $t-1$  price index. Using 40, 41 and 42 the resulting new Keynesian Phillips curve is<sup>11</sup>

$$\pi_t = E_t \pi_{t+1} + \frac{\alpha(1-\lambda)^2}{\lambda} y_t. \quad (43)$$

#### 4. Policy experiments

Here I follow Mankiw and Reis (2002) in describing four policy experiments in terms of which I can compare the NKM and the SIM.

First, I define a simple demand for money holdings

$$m = p + y, \quad (44)$$

which is interpreted as a logarithmic version of the quantity theory of money with velocity equal to one. Using this to substitute for output in 35, the desired price can be written as

$$p_t^* = (1 - \alpha)p_t + \alpha m_t. \quad (45)$$

The last equation shows that the desired price at  $t$  depends on the price level, and thus on other firms' prices, and on the level of aggregate demand  $m_t$ . When  $\alpha \rightarrow 1$  the single firm will not care about other firm's price while, when  $\alpha \rightarrow 0$ , the level of aggregate demand will be irrelevant.

Mankiw and Reis (2002) consider different exogenous processes for  $m_t$ . These are interpreted as the central bank behaviour. Using impulse response functions, the response of inflation and output to changes in the  $m_t$  process are analyzed.<sup>12</sup>

The parameter values are  $\alpha = 0.1$ ,  $\varphi = 0.75$  and  $\lambda = 0.75$ . These numbers imply that firms are not very sensitive to macroeconomic

<sup>11</sup> Note that the only difference with the new Keynesian Phillips curve derived in 20 is that now I consider  $\beta = 1$  and  $\alpha = \eta + \sigma$ .

<sup>12</sup> All figures described in the next sections are derived through simulations. For details of the computational procedure see appendix C in Mankiw and Reis (2002).

conditions and that in the NKM firms adjust prices on average once per year, while in the SIM they receive information with that frequency.

FIGURE 1

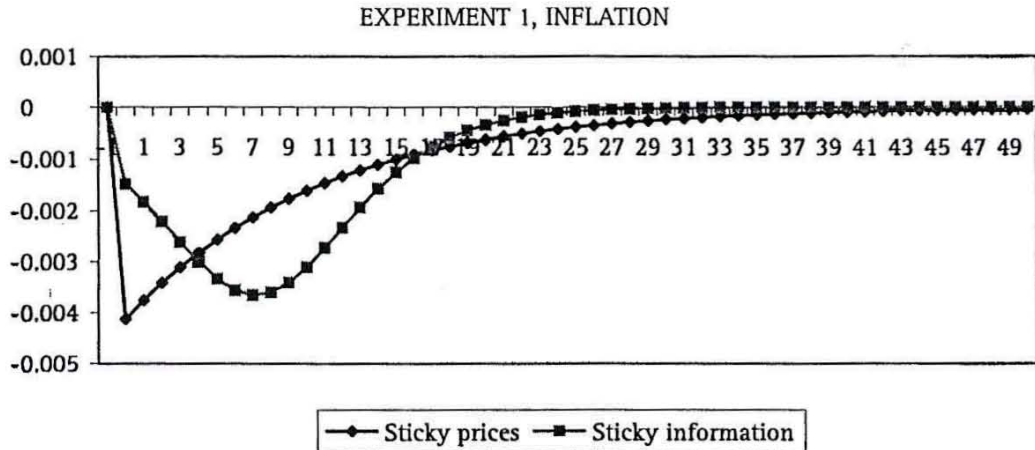
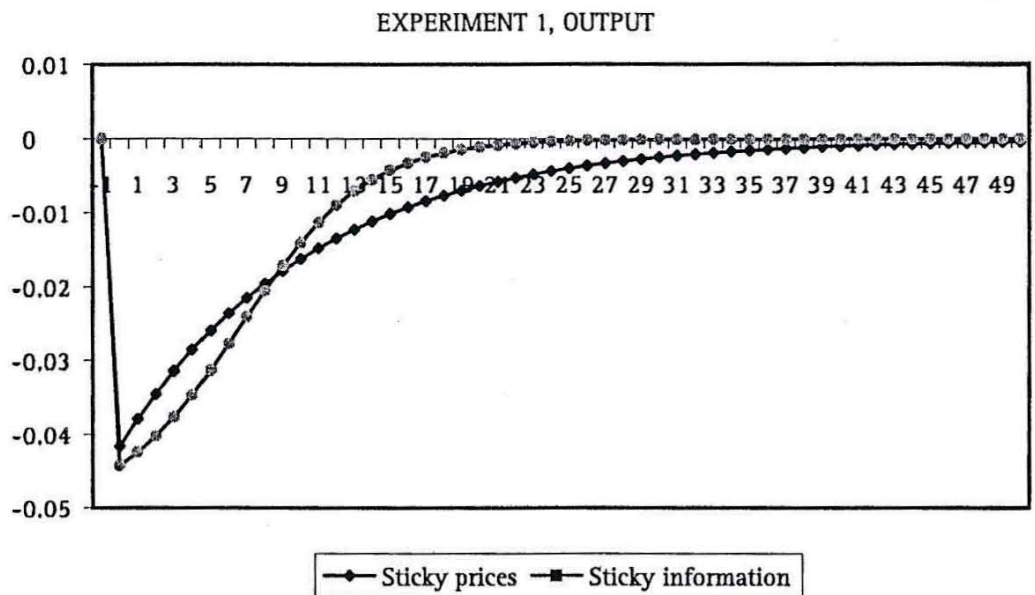


FIGURE 2



*Experiment 1: A drop in the level of  $m_t$*

Suppose that the sequence  $\{m_t\}_{t=-\infty}^{-1}$  is such that  $m_t = m, \forall t = -\infty, \dots, -1$ . At  $t = 0$  there is a 10% drop in the level of  $m_t$  and the sequence  $\{m_t\}_{t=0}^{\infty}$  is such that  $m_t = (1 - 0.1)m, \forall t = 0, \dots, \infty$ .

Figure 1 and 2 show the impulse response functions for inflation and output in the two models. As described above, the maximum impact of the shock in the NKM occurs in the same period as the shock.

FIGURE 3

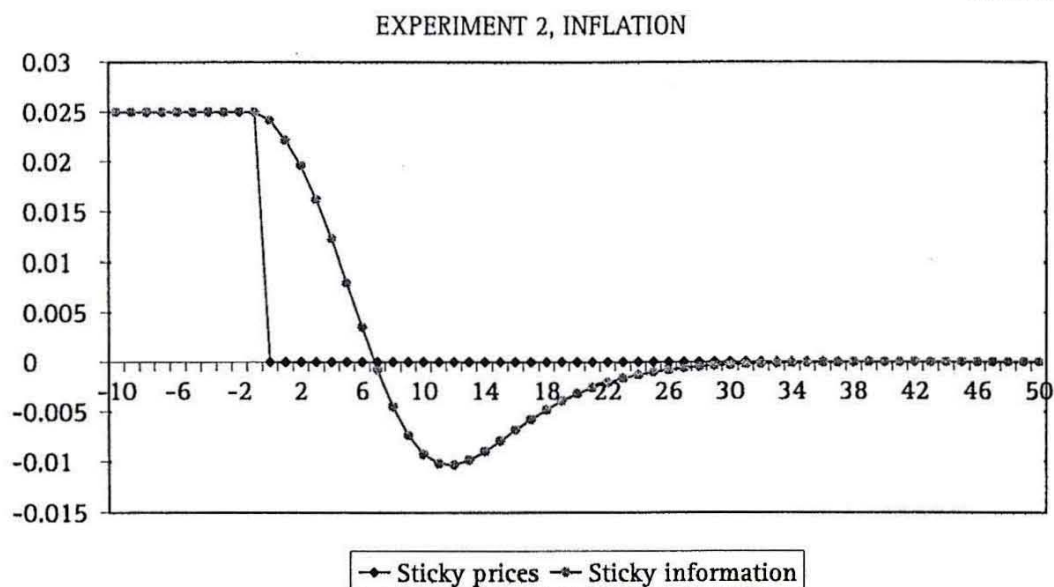
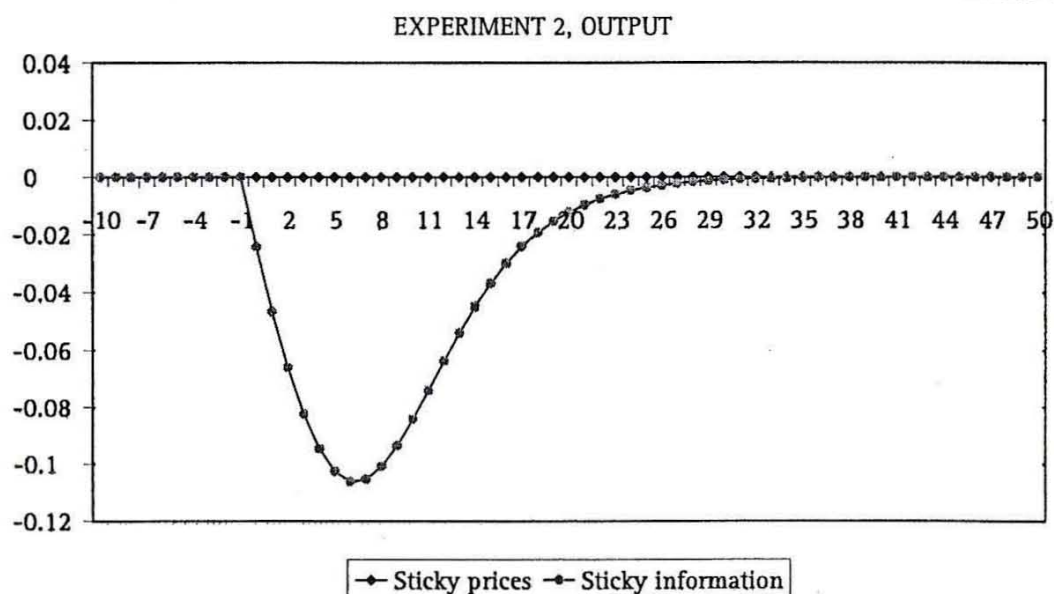


FIGURE 4



In the SIM, there is a drop in output at  $t = 0$ . This is due to the  $1 - \phi$  of firms receiving current information and consequently setting lower prices. This implies that the price index is reduced proportionally less than the quantity of money. From equation 44 output is reduced.

The most interesting feature of this experiment is that the maximum effect on inflation in the SIM is delayed. It occurs seven quarters after the shock occurred. This behaviour is explained through

equation 45. The desired price depends not only on the quantity of money  $m_t$ , but also on the price level  $p_t$ , that is, on the price set by other firms. As  $\phi$  of firms are not receiving the information about current conditions, they do not adjust prices. Firms which are adjusting take this into account in setting the optimal price. As time passes more firms become aware of the change in the quantity of money and adjust the desired price. Then, inflation builds up over time. This is the time needed for a sufficient number of firms to gather information. The timing of the delay depends crucially on the parameter  $\alpha$ , which can be interpreted as the source of strategic complementarity among firms in the economy.<sup>13</sup>

### *Experiment 2: Disinflations*

Assume now that the quantity of money  $m_t$  grows at a constant rate of 10% per year and that, at time  $t = 0$ , the central bank sets  $m_0 = m_{-1}$  and announces that  $m_t$  will be constant at  $m_0$  forever.

The impulse response functions are shown in figures 3 and 4. In the NKM the disinflation is costless in terms of output. This is because, in the period when the policy is changed, inflation switches from a positive value to zero. Output remains at a constant zero level. In the SIM, the impact of the change of policy on inflation is gradual. This is because, when the policy is changed, there are firms which are still posting price on the basis of old information. As a consequence, inflation is decreasing but it does not reach zero in the first period of the shock. The economy faces a recession because the quantity of money is constant but the price index is still rising.

### *Experiment 3: Announced disinflations*

In this experiment, Mankiw and Reis (2002) assume that the disinflation is announced two years before it will take place. Let us assume that the announcement is made at  $t = -8$  and the policy is adopted at  $t = 0$ . The results are given in figures 5 and 6. In the NKM the future

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<sup>13</sup> For a definition of strategic complementarity see note 6 above. Here, the higher it is  $\alpha$ , the less firms' pricing decisions will be strategic complements.

FIGURE 5

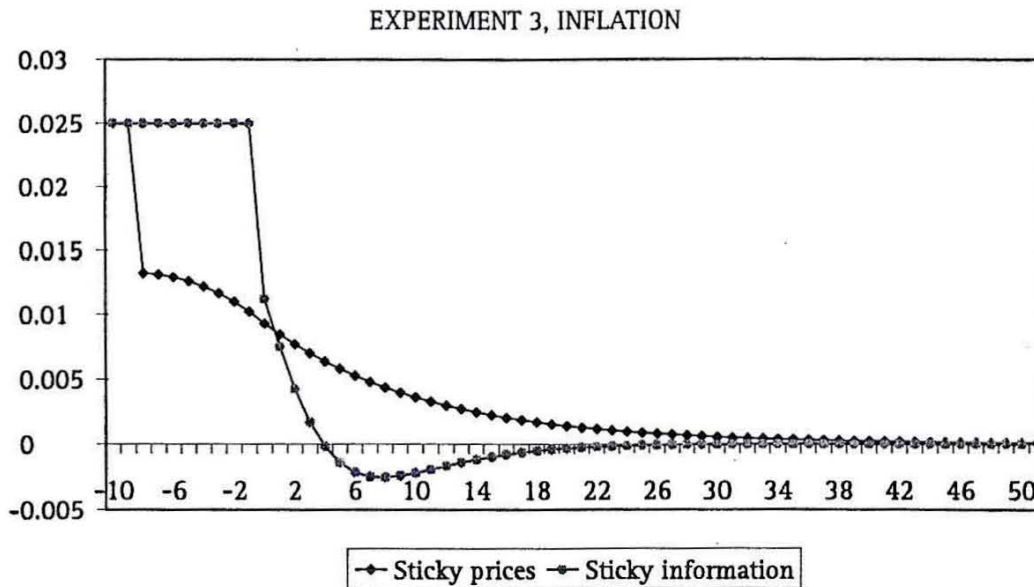
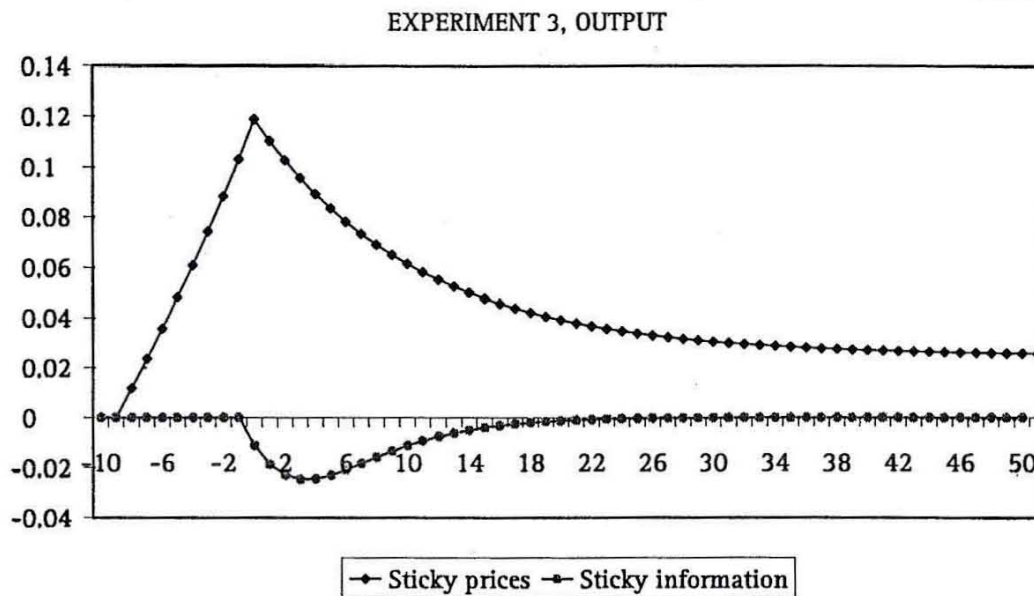
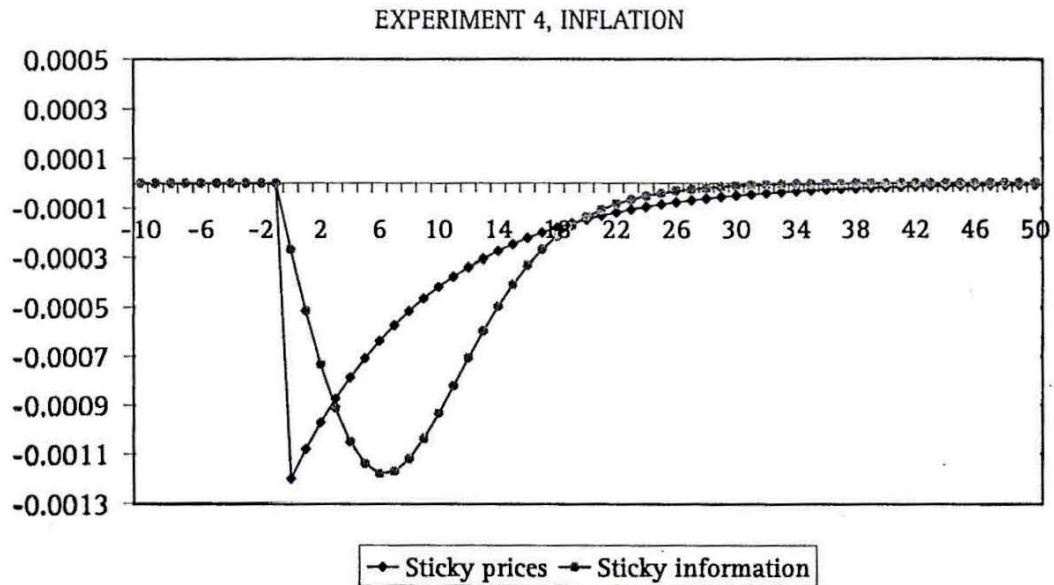


FIGURE 6



disinflation causes an expansion of the economy. This happens because adjusting firms set the optimal price as a discounted average of all future nominal costs. Since at  $t = 0$  the nominal quantity of money will be kept constant forever, the prices set after the announcement will grow by less than 2.5% with respect to those set before, implying that, in the time period  $-8 < t < 0$ , inflation will be decreasing. A lower inflation rate with a constant growth rate of money supply results in an increase in output because the real money balances increase.

FIGURE 7



In the SIM, nothing happens in  $-8 < t < 0$ . Some firms are receiving information in this time span but they will use this information only to set price from  $t = 0$  onwards. Thus, at  $t = 0$ , as some of the firms have knowledge of the policy enacted, inflation decreases. However, it does not reach zero because some firms are not aware of the policy. With growing prices and a constant money supply, the real money balances are decreasing, and so is output. The economy goes through a recession. Note, however, that the recession in this case is milder than the one encountered in the previous experiment. Then, when the central bank can credibly commit itself to a policy, the effects of that policy will be lesser than in the case in which the disinflation is not announced.

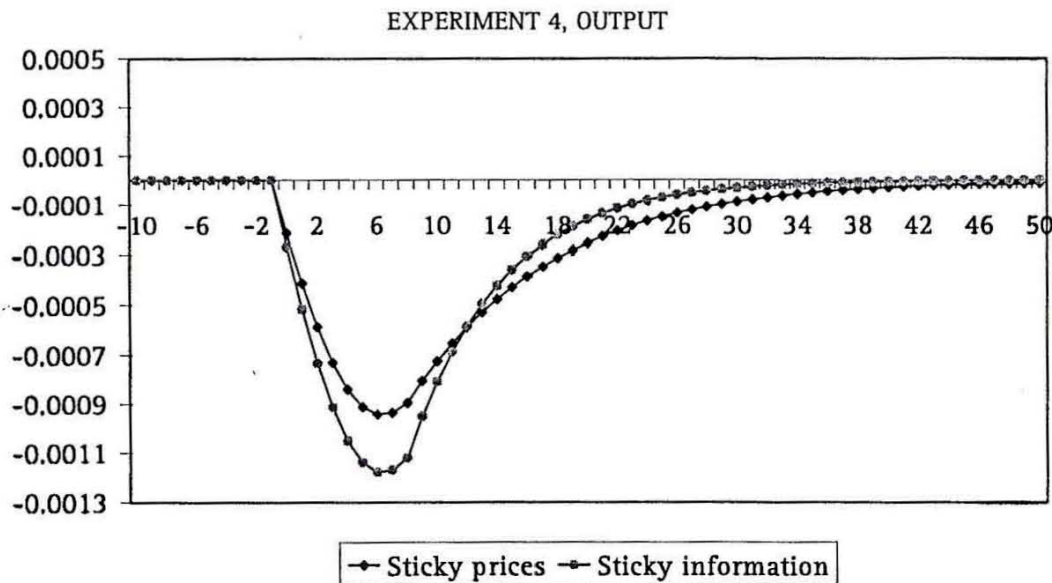
#### *Experiment 4: Inflation persistence*

In their last experiment Mankiw and Reis (2002) show that the SIM is able to replicate the acceleration phenomenon while the NKM is not. By acceleration phenomenon these authors mean the empirical observation that periods of high inflation correspond to periods in which the economic activity is high. To show this, Mankiw and Reis (2002) assume a money supply process of the type

$$\Delta m_t = \rho \Delta m_{t-1} + \varepsilon_t \quad (46)$$

where  $\varepsilon_t$  is white noise with standard deviation  $\sigma$ .

FIGURE 8



This process implies that the money supply process is non-stationary while its rate of growth is a stationary process. Mankiw and Reis (2002) assign values  $\rho = 0.5$  and  $\sigma = 0.007$ . Simulations are shown in figures 7 and 8. Output shows a hump-shaped response to the shock in both models. Inflation, on the other hand, shows its maximum impact in the period of the shock in the NKM but displays a hump-shaped response in the SIM. The hump-shaped response of inflation represents the reason why the SIM model displays the acceleration phenomenon while the NKM model does not. Inflation falls immediately in the NKM and then starts rising.

On the other hand, output decreases for some periods after the shock. This implies a small negative correlation in the simulated data. Mankiw and Reis (2002) compute correlations of output  $y_t$  with the change in inflation in the year around  $t$ ,  $\pi_{t+2} - \pi_{t-2}$ , and the change in inflation in the two years around  $t$ ,  $\pi_{t+4} - \pi_{t-4}$ . For the NKM these are respectively  $-0.13$  and  $-0.11$ , while for the SIM they are  $0.43$  and  $0.40$ . The actual correlations in the US quarterly data for the 1960-99 period, between GDP and the GDP deflator, the consumer price index CPI and the core CPI are shown in table 1. They are roughly in line with the SIM model.

TABLE 1

## THE ACCELERATION PHENOMENON

Data	Corr. [GDP(t), Infl.(t+2)-Infl.(t-2)]	Corr. [GDP(t), Infl.(t+4)-Infl.(t-4)]
GDP deflator	0.48	0.6
CPI	0.38	0.46
Core CPI	0.46	0.51
Models		
NKM	-0.13	-0.11
SIM	0.43	0.4

Correlations between output and inflation change in the US. Data are quarterly for the period 1960-99. GDP is computed as deviations from an HP trend.

Source: Mankiw and Reis (2002).

## 5. Conclusions

In this work, I survey two models for monetary policy analysis. The first, the New Keynesian Model, is the most commonly used instrument to analyze monetary policy. The reason for its success lies in the mix of assumptions made bringing together elements of general equilibrium theory, drawn from the new classical theory, and elements of the Keynesian tradition, such as sticky prices. The basic version of the model, presented here, proves a relatively simple tool to handle. In particular, it is possible to reduce the model to a three equations rational expectations log-linear system. Using modern theory on rational expectations, this system can be solved numerically using computer codes. With this solution at hand, impulse response functions can be studied. The impulse response functions can be compared to the movements of the IS and LM curve in the basic macroeconomics textbook. In the simulations of the New Keynesian Model the magnitude of the variables reaction can be measured and depends on the parameter values assigned. These values can be calibrated or econometrically estimated. This methodology, *per se*, represents a notable step forward with respect to the standard IS-LM model, in which the responses of the various variables to shocks are not quantifiable.



One critique moved against the New Keynesian Model is the lack of inflation persistence. If the monetary policy rule does not display any sort of persistence, the effects of the shock on inflation die out in one period. Chari, Kehoe and McGrattan (2000) criticize this lack of persistence in the inflation generated by the New Keynesian Model. Since then, many authors have tried to reply to this critique showing that modified versions of the model are able to generate a persistence behaviour of inflation that is absent in the standard model.<sup>14</sup>

Regardless of its appeal, however, the New Keynesian Model is not unanimously accepted as, for instance, is the Neoclassical Growth Model in growth theory. Many scholars do not accept the sticky price assumption which, in fact, is the key assumption to obtain any non-neutrality of monetary policy actions. These critics explored other directions to obtain money non-neutralities, such as cash in advance models, limited participation models or even search models of money. None of these models have proved to be a better tool than the New Keynesian Model. Proof of this lies in the fact the central banks still use the latter as their benchmark.

The only model that has seriously challenged the New Keynesian Model is the Sticky Information Model proposed by Mankiw and Reis (2002). These authors break with the sticky prices tradition using insights from the monetary literature of the Seventies, based on information asymmetries. The Lucas (1972) theory on money non-neutrality, dating to almost forty years ago, was abandoned because it proved difficult to test empirically. Mankiw and Reis (2002) revive these ideas and mix them with a modified Calvo mechanism that now applies to information. For each period, only a fraction of the firms in the population receives the information about current economic conditions, namely the state of the economy, while the remaining ones do not possess updated information. The reasons for this odd distribution of information over the population may be diverse. Reis (2006) argues that firms rationally become inattentive because of costs of acquiring information. Mackowiak and Wiederholt (2004) show that firms may have a limited capacity of absorbing information and have to choose optimally how much information to get about the aggregate state and the idiosyncratic one.

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<sup>14</sup> See Dotsey and King (2006) for instance.

The Sticky Information Model proves able to replicate some monetary facts that the New Keynesian Model misses: in particular, that the effects of a monetary shock on inflation occur with some delay, that deflations are contractionary and that inflation is usually correlated with the level of economic activity. However, not even the Sticky Information Model is immune to criticism. For instance, it is not clear why firms should be completely inattentive to the state of the economy when a shock of high magnitude occurs. In this respect, the Sticky Information Model can be seen as an approximation of the behaviour of firms in periods of low shocks, in which it is practically irrelevant for firms to update information constantly. Another problem with the Sticky Information Model is that the state space is potentially infinite. In fact, to compute a numerical solution one should take into account the prices set by firms that updated their information in the infinite past. Trabandt (2006) proposes a solution method for this difficulty.

#### APPENDIX

Here I follow Mankiw and Reis (2002) in deriving the sticky information Phillips curve. Starting from equation 38 in the text

$$p_t = (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(p_t + \alpha y_t)$$

which can be written

$$p_t = (1 - \varphi)(p_t + \alpha y_t) + (1 - \varphi) \sum_{j=0}^{\infty} \varphi^{j+1} E_{t-1-j}(p_t + \alpha y_t), \quad (47)$$

and summing and subtracting  $p_t = (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(p_t + \alpha y_t)$  to 47 I can write

$$p_t = (1 - \varphi)(p_t + \alpha y_t) + (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(p_t + \alpha y_t) + (1 - \varphi)^2 \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(p_t + \alpha y_t). \quad (48)$$

The analogous of 38 for  $p_{t-1}$  is

$$p_{t-1} = (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-j}(p_{t-1} + \alpha y_{t-1}). \quad (49)$$

Subtracting 49 from 48 I get

$$\begin{aligned} \pi_t &= (1 - \varphi)(p_t + \alpha y_t) + (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(\pi_t + \alpha \Delta y_t) + \\ &- (1 - \varphi)^2 \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(p_t + \alpha y_t). \end{aligned} \quad (50)$$

Now rewrite 47 as

$$(1 - \varphi) \left( p_t - \frac{\alpha(1 - \varphi)y_t}{\varphi} \right) = (1 - \varphi)^2 \sum_{j=0}^{\infty} \varphi^{j+1} E_{t-1-j}(p_t + \alpha y_t), \quad (51)$$

and use this to substitute for the last term in 50 to get

$$\begin{aligned} \pi_t &= (1 - \varphi)(p_t + \alpha y_t) + (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(\pi_t + \alpha \Delta y_t) + \\ &- (1 - \varphi) \left( p_t - \frac{\alpha(1 - \varphi)y_t}{\varphi} \right) \end{aligned} \quad (52)$$

and

$$\pi_t = \frac{\alpha(1 - \varphi)}{\varphi} y_t + (1 - \varphi) \sum_{j=0}^{\infty} \varphi^j E_{t-1-j}(\pi_t + \alpha \Delta y_t),$$

which is equation 39 in text.

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