Misperceived Money and Inflation Dynamics*

Fabrice Collard[†] and Harris Dellas[‡]

Abstract

The baseline version of the new Keynesian (NK) model has important empirical limitations, in particular with regard to inflation, output and interest rate dynamics. Some of its recent extensions fare better empirically but only by relying on implausible pricing schemes. We offer an alternative approach that emphasizes informational imperfections regarding monetary aggregates. Monetary misperceptions give rise to a standard signal extraction problem that enables the NK model to exhibit inflation inertia, realistic inflation and output dynamics and a liquidity effect. Unlike previous work, we establish that misperceived money growth is quantitatively important and also matters significantly for economic activity.

JEL class: E32 E52

Keywords: New Keynesian model, monetary mis–perceptions, data revisions, signal extraction, inflation inertia

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*We would like to thank Fabio Canova, Jordi Galí, Bob King, Robert Kollmann, Dirk Krueger, Stefano Neri, Philippe Weil as well as participants in ESSIM in Cyprus, the 3rd ECB/IMOP Workshop on Dynamic Macroeconomics, the University of Frankfurt and AUEB for valuable suggestions.

[†]CNRS-GREMAQ, Manufacture des Tabacs, bât. F, 21 allée de Brienne, 31000 Toulouse, France. Tel: (33-5) 61–12–85–42, Fax: (33–5) 61–22–55–63, email: `fabrice.collard@univ-tlse1.fr`, Homepage:`http://fabcol.free.fr`

[‡]Department of Economics, University of Bern, CEPR, IMOP. Address: VWI, Schanzeneckstrasse 1, CH 3012 Bern, Switzerland. Tel: (41) 31–631–3989, Fax: (41) 31–631–3992, email: `harris.dellas@vwi.unibe.ch`, Homepage: `http://www.vwi.unibe.ch/`

Introduction

The New Keynesian model has gained wide acceptance. Nevertheless, the original version of the model has a number of important implications that seem to be at variance with the empirical evidence. Most prominent among them are the predicted monotone dynamics of inflation, output and nominal interest rates in response to a monetary shock. This is inconsistent with evidence presented by Christiano, Eichenbaum and Evans (henceforth, CEE), 2005 suggesting that following a monetary shock, there is a delayed, hump shaped response of inflation, a hump shaped response of output and a liquidity effect.

A considerable amount of work has been devoted to addressing these difficulties. Broadly speaking, two distinct approaches have been pursued. The first, advocated by Mankiw and Reis, 2002, assumes information rather than price stickiness. While this seems attractive and is reminiscent of Lucas' imperfect information model, it does not provide a solution to the problem. As shown by Collard and Dellas, 2004, and Dupor and Tsuruga, 2005, the sticky information version requires an implausibly large amount of informational stickiness in order to generate satisfactory macro–dynamics.

The second approach involves the introduction of backward looking agents. For instance, Gali and Gertler, 1999 assume the existence of myopic agents who set prices in a mechanical fashion. In a similar vein, CEE, 2005, assume that a fraction of the agents index their prices to past inflation.[1] With the inclusion also of several *real* rigidities, the modified version of the NK model has proved very successful in generating inertial movements in inflation, output and the nominal interest rate (CEE, 2005). Nonetheless, a key problem with this approach is that it seems to be at variance with observed pricing patterns, as documented for instance in a recent ECB report (Dhyne et al. 2005). Consequently, a specification that relies on backward price indexation in order to generate realistic inflation dynamics may be problematic.

In this paper we propose an alternative approach which matches the performance of models with backward indexation regarding but uses a more defensible pricing scheme. The approach embeds Lucas' story of mis–perceptions about monetary aggregates and signal extraction in a model with sticky prices of the NK variety. Hence both unperceived and unanticipated money matter.[2] Clearly, one cannot claim that information on nominal aggregate variables is only available with substantial time lags, as it was implied by the early vintage of the flexible price, rational expectations models. But while information on monetary aggregates is readily available,

[1] Minford and Peel, 2004, argue that allowing such agents to adjust prices based on expected rather than on past inflation eliminates the new Phillips curve.

[2] Woodford, 2002, examines the effects of nominal shocks in a model with signal extraction but with flexible prices and wages. Such a model does not perform as well as its staggered prices counterpart.

observations of the current or recent monetary data (the preliminary figures) are ridden with measurement error, which is only gradually corrected through subsequent data revisions. In order to establish that such "noise" in preliminary data plays an important role in the monetary transmission mechanism (as suggested by King, 1981) we establish two things. First, that the measurement error –the difference between preliminary and revised data– in money growth is quantitatively significant. And second, that this error (which represent unperceived money) matters for economic activity.

We show that a specification with a very *small* amount of measurement error in nominal aggregates works quite well. Not only is it superior to the standard, full information version but it also performs as well as the most successful empirically NK version (the one with backward agents) regarding macroeconomic dynamics and unconditional properties. Signal extraction allows the model to produce a weak instantaneous response to current shocks; a delayed, hump shaped response of inflation and output following a monetary shock; and a liquidity effect.

The remaining of the paper is organized as follows. Section 1 presents the model. Section 2 discusses the calibration. Section 3 presents the main results. The last section offers some concluding remarks.

1 The model

We first describe the behavior of the firms and the households in the case without a signal extraction problem. The basic set up is the new Keynesian model with price rigidities, augmented to include various real rigidities. The production side of the economy consists of two sectors: one producing intermediate goods and the other a final good. The intermediate good is produced with capital and labor and the final good with intermediate goods. The final good is homogeneous and can be used for consumption (private and public) and investment purposes.

1.1 Final sector

The final good, y, is produced by combining intermediate goods, y_i, by perfectly competitive firms. The production function is given by

$$y_t = \left(\int_0^1 y_{it}^{\theta} \mathrm{d}i \right)^{\frac{1}{\theta}} \tag{1}$$

where $\theta \in (-\infty, 1)$.

The final good may be used for consumption — private or public — and investment purposes.

1.2 Intermediate goods producers

Each firm i, $i \in (0,1)$, produces an intermediate good by means of capital and labor according to a constant returns–to–scale technology, represented by the Cobb–Douglas production function

$$y_{it} = a_t(u_{it}k_{it})^{\alpha} n_{it}^{1-\alpha} \text{ with } \alpha \in (0,1) \tag{2}$$

where k_{it} and n_{it} are physical capital and labor used by firm i. a_t is an exogenous, stationary, stochastic, technology shock. u_{it} is the rate of capital utilization.

Intermediate goods producers are monopolistically competitive, and therefore set prices for the good they produce. Following Calvo, we assume that in each and every period, a firm either gets the chance to adjust its price (with probability γ) or it does not. If it does not get the chance, then it sets its price according to

$$P_{it} = \xi_t P_{it-1} \tag{3}$$

We still have to place assumption on the behavior of ξ_t. We consider two scenarios. In the first one, which will be used in the version of the model with the signal extraction formulation, the price is assumed to remain fixed until the firm gets a call that allows it to reset its price optimally. In this case, we have $\xi_t = 1$. In our view, this is the more realistic scenario as the evidence on price setting suggests that firms set their prices infrequently and discretely. The second scenario is the one suggested by CEE, and has these firms index their prices to the lagged, economy wide rate of inflation. This case amounts to assume that $\xi_t = \pi_{t-1}$. This scheme is quite popular in the literature in spite of the fact that it is not rational[3], and it also introduces a completely free parameter.

For a firm i that sets its price optimally in period t, its price, $P_t^{\star}$, is given by

$$P_t^{\star} = \frac{1}{\theta} \frac{\mathbb{E}_t \sum_{\tau=0}^{\infty} (1-\gamma)^{\tau} \Phi_{t+\tau} P_{t+\tau}^{\frac{2-\theta}{1-\theta}} \Xi_{t,\tau}^{\frac{1}{\theta-1}} \psi_{t+\tau} y_{t+\tau}}{\mathbb{E}_t \sum_{\tau=0}^{\infty} (1-\gamma)^{\tau} \Phi_{t+\tau} \Xi_{t,\tau}^{\frac{\theta}{\theta-1}} P_{t+\tau}^{\frac{1}{\theta-1}} y_{t+\tau}} \tag{4}$$

where ψ is real marginal cost, P is the aggregate price index, $\Phi_{t+\tau}$ is an appropriate discount factor derived from the household's optimality conditions and

$$\Xi_{t+\tau} = \begin{cases} \prod_{\ell=0}^{\tau-1} \xi_{t+\ell} & \text{for } \tau \geqslant 1 \\ 1 & \tau = 0 \end{cases}$$

Since the price setting scheme is independent of any firm specific characteristic, all firms that reset their prices will choose the same price.

[3] The firms could easily index their price to the expected aggregate rate of inflation instead. Such information is as readily available as that on lagged inflation from surveys, central bank forecasts or targets and so on.

1.3 The Household

The preferences of the representative household are given by

$$\mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^{\tau} \left[\log(c_{t+\tau} - \vartheta c_{t+\tau-1}) + \frac{\nu^m}{1-\sigma_m} \left(\frac{M_{t+\tau}}{P_{t+\tau}} \right)^{1-\sigma_m} - \frac{\nu^h}{1+\sigma_h} h_{t+\tau}^{1+\sigma_h} \right] \tag{5}$$

where $0 < \beta < 1$ is a constant discount factor, c_t denotes consumption in period t, M_t/P_t is real balances and h_t is the quantity of labor she supplies. Preferences are characterized by habit persistence governed by the parameter ϑ.

In each period, the representative household faces the budget constraint

$$E_t Q_t B_t + M_t + P_t(c_t + i_t + a(u_t)k_t) = B_{t-1} + M_{t-1} + P_t z_t u_t k_t + P_t w_t h_t + \Omega_t + \Pi_t \tag{6}$$

where B_t is state contingent deliveries of the final good and Q_t is the corresponding price of the asset that delivers these goods. M_t is end of period t money holdings. P_t, the nominal price of goods. c_t and i_t are consumption and investment expenditure respectively; k_t is the amount of physical capital owned by the household and leased to the firms at the real rental rate z_t. Only a fraction u_t of the capital stock is utilized in any period, which involves an increasing and convex cost $a(u_t)$. w_t is the real wage. Ω_t is a nominal lump-sum transfer received from the monetary authority and Π_t denotes the profits distributed to the household by the firms.

Capital accumulates according to the law of motion

$$k_{t+1} = \Phi(i_t, i_{t-1}, k_t) + (1-\delta)k_t \tag{7}$$

where $\delta \in [0,1]$ denotes the rate of depreciation. $\Phi(\cdot)$ is a general specification that allows the modeling of either capital or investment adjustment costs (its properties will be discussed later).

1.4 The monetary authorities

We assume that monetary policy involves an exogenous money supply rule, with money evolving according to

$$M_t = \exp(\mu_t) M_{t-1} \tag{8}$$

The gross growth rate of the money supply, μ_t, is assumed to follow an exogenous stochastic process. We have also repeated the analysis under a standard interest rate policy rule without any change in the results (see discussion in the results section).

1.5 The government

The government finances government expenditure on the domestic final good using lump sum taxes. The stationary component of government expenditures is assumed to follow an exogenous stochastic process, whose properties will be defined later.

2 Parametrization

For comparison purposes, the parametrization of the model relies heavily on CEE, 2005. The model is parameterized on US quarterly data for the post WWII period. When necessary, the data are taken from the Federal Reserve Database.[4] The parameters are reported in Table 1.

Table 1: Calibration: Benchmark case

Discount factor	β	0.988
Habit persistence	ϑ	0.650
Inverse labor supply elasticity	σ_h	1.000
Money demand elasticity	σ_m	10.500
Capital elasticity of intermediate output	α	0.281
Parameter of markup	θ	0.850
Depreciation rate	δ	0.025
Adjustment costs parameter	φ	0.330
Probability of price resetting	γ	0.250
Steady state money supply growth (gross)	μ	1.000
Share of government spending	g/y	0.200

The capital accumulation function $\Phi(i_t, i_{t-1}, k_t)$ is assumed to take the following form

$$\Phi(i_t, i_{t-1}, k_t) = \left(1 - \omega S\left(\frac{i_t}{i_{t-1}}\right) - (1-\omega)\frac{\varphi}{2}\left(\frac{i_t}{k_t} - \delta\right)^2 \frac{k_t}{i_t}\right) i_t$$

The function $S(\cdot)$ satisfies $S(1) = S'(1) = 0$ and $S''(1) = \varphi > 0$. $\Phi(i_t, i_{t-1}, k_t)$ nests two investment adjustment costs ($\omega = 1$) and capital adjustment costs ($\omega = 0$). We mainly focus on the investment adjustment costs case and therefore set $\omega = 1$. The investment adjustment cost parameter φ is then chosen so that the model can match the first order autocorrelation of output (0.84). This implies $\varphi = 0.33$. Note, however, that the same results obtain when we borrow the value of φ used in CEE ($\varphi = 2.5$), instead of calibrating it. The capital utilization function $a(u_t)$ satisfies $a(1) = 0$, $a''(1)/a'(1) = 1/\sigma_a$. We set $\sigma_a = 100$.

[4]URL:`http://research.stlouisfed.org/fred/`

The three shocks, the technology shock, $a_t = \log(A_t/\overline{A})$, the fiscal shock, g_t, and the money supply shock are assumed to follow independent, AR(1) processes with persistence parameters ρ_a, ρ_g, ρ_μ respectively and standard deviation of innovations $\sigma_a, \sigma_g, \sigma_\mu$ respectively. These values are given in table 2. The process for government expenditures was estimated on historical data. σ_a was selected so that the model matches the volatility of output (1.49) and σ_μ in order to match the volatility of inflation (0.16) in the model with backward looking price indexation.

Table 2: Shocks

	ρ	σ
Technology	0.9500	0.0042
Fiscal	0.9684	0.0104
Money supply	0.5000	0.0017

2.1 Information

We now specify the structure of information in the case of a signal extraction problem. We assume that while the agents may observe individual specific variables (such as their own consumption, technology shock, capital stock and so on) they can only imperfectly estimate the *true* aggregate state of the economy. Moreover, we assume that the agents learn gradually about the true state using the Kalman filter, based on a set of signals on aggregate variables. Without loss of generality we can assume that some of the aggregate variables may be perfectly observed, some other may not be observed at all and yet some other may be observed with error. For mis–measured variable x we assume that

$$x_t^\star = x_t^{\mathrm{T}} + \eta_t$$

where x_t^{T} denotes the true value of the variable and η_t is a noisy process that satisfies $E(\eta_t) = 0$ for all t; $E(\eta_t \varepsilon_{a,t}) = E(\eta_t \varepsilon_{g,t}) = E(\eta_t \varepsilon_{\mu,t}) = 0$; and

$$E(\eta_t \eta_k) = \begin{cases} \sigma_\eta^2 & \text{if } t = k \\ 0 & \text{Otherwise} \end{cases}$$

Knowledge of the *aggregate* state of the economy matters for the agents because individual price setting depends on expectations of future nominal marginal cost and marginal revenue, which in turn depend on future aggregate prices, wages and so on.

An important principle is that the informational constraints are sensible in terms of location, timing and amount of noise. Recall that the objective of our paper is to examine the effects of a monetary policy shock. We cannot allow the *true* value of this shock to be perfectly observable as this does away with the signal extraction problem. But we cannot assume either (without straining credibility) that the agents do not observe monetary aggregates at all (or that they do so with substantial time lags), a common feature of the early vintage of the flexible price, rational expectations models. Following King, 1981, we argue that while information on monetary aggregates is readily available, observations of the current or recent monetary data (the preliminary figures) are ridden with measurement error. This error is only gradually corrected through subsequent data revisions. In order to establish that this type of noise in preliminary data plays an important role in the monetary transmission mechanism we need to establish two things. First, that the measurement error —the difference between preliminary and revised data— is quantitatively significant. And second, that this error (which represents unperceived money) matters for economic activity. Barro and Hercowitz, 1981, and Boschen and Grossman, 1982, have examined the latter hypothesis, based on tests that build on related theoretical work by King, 1981. Neither pair of authors, however, finds support for the proposition that unperceived money plays a role in the business cycle. We revisit this issue below and establish that monetary misperceptions do matter significantly.

Let us first describe the properties of unperceived money. We have used the quarterly real time data constructed at the Philadelphia FED to compute the measurement error for data for a particular period as reported during that as well as subsequent periods (different vintages). In particular, let $M_{t|k}$ be the monetary aggregate (we use M1) of period t that gets reported in period k and $g_{t|t} = logM_{t|t} - logM_{t-1|t}$ its growth rate. This is the initial data release. Let $M_{t|t+i}$ (resp. $g_{t|t+i} = logM_{t|t+i} - logM_{t-1|t+i}$) be the revised figure for period t that is available in period $t + i, i > 0$. We use $t + i = T$ to represent the "final" release. Unperceived money growth in t is thus defined as $\mu_t = g_{t|T} - g_{t|t}$. Table 3 reports the properties (standard deviation and autocorrelation) of unperceived money growth. And also of unanticipated money shocks, ε_t, measured as the residuals from an autoregressive process for money growth. Unanticipated shocks are computed based on final data. In order to gain some idea about the quantitative significance of successive revisions of the preliminary data we also report the properties of $\mu_{t|t+i} = g_{t|t+i} - g_{t|t}$ for $i = 1, 2, 4, 8$.

As can be seen, the measurement errors are substantial, with a standard deviation that is about half the size of that of unanticipated money. The process of revision is gradual but there is little autocorrelation (and hence predictability) in unperceived money. We view these finding as establishing that misperceived money is quantitatively important.

We now turn to the question of whether these measurements errors matter for macroeconomic activity. We have used two alternative methodologies for assessing this issue. One follows Boschen and Grossman, 1982. We regress the growth rate of output in period t on its lagged

Table 3: Properties of the shocks

	Std. Dev. (%)	$\rho(1)$	$\rho(4)$	Min.(%)	Max.(%)
μ_t	0.41	0.04	0.59	-1.19	1.18
ε_t	0.86	-0.14	-0.17	-2.24	3.44
$\mu_{t,t+1}$	0.12	-0.06	0.03	-0.68	0.42
$\mu_{t,t+2}$	0.17	0.08	-0.01	-0.74	0.42
$\mu_{t,t+4}$	0.28	0.20	0.07	-1.79	0.62
$\mu_{t,t+8}$	0.34	0.09	0.38	-1.82	0.74

values as well as on unperceived money growth during that and previous periods.

We have estimated equations for HP–filtered output and the inflation rate according to the specification

$$x_t = \sum_{i=1}^{p} \rho_i x_{t-i} + \sum_{\ell=0}^{n} \left[\alpha_i \mu_{t-\ell|T} + \beta_i \varepsilon_{t-\ell}\right] + u_t \tag{9}$$

The unanticipated money shocks $\varepsilon_{t-\ell}$ have been included in the regressions along side the unperceived one, $\mu_{t-\ell}$, to allow us to judge the relative importance of the two sources of monetary non-neutralities: One arising from nominal rigidities (unanticipated shocks). And the other from informational frictions (unperceived shocks). We test for the significance of unperceived and unanticipated shocks using an F–test. The data start in 1966:Q1, the earliest date available in the real data series constructed by the Philadelphia FED. They end in 2000:Q4 in order to provide room for computing subsequent revisions. We report results for the whole sample and also for the period 1966–1982. The results are robust to including only unperceived money, using different lag structures, using 1979 as the cut off point and so on. The number of lags is selected based on standard information criteria. The results are reported in Table (4).

There are two main findings. First, both sources of errors matter for economic activity. And second, unanticipated shocks have had a relatively more significant influence on output in the more distant past and unperceived shocks in the more recent past. As can be seen, measurement errors did not have a statistically significant effect on real economic activity in the early period, a finding consistent with those of Barro and Hercowitz, 1981, and Boschen and Grossman, 1982.

The second method for evaluating the role of measurement error in monetary aggregates relies on VARs of the type that are commonly used in the literature to assess the effects of monetary policy. We have run two VARs. One considers unanticipated (based on final data) money shocks and uses a specification similar to that of CEE, 2005. In particular, we estimate a VAR for money growth, output growth, CPI inflation and the federal fund rate. Standard likelihood ratio tests and information criteria favor the use of a VAR(2) representation. Money appears

Table 4: The effects of unperceived and unanticipated money, F- Tests

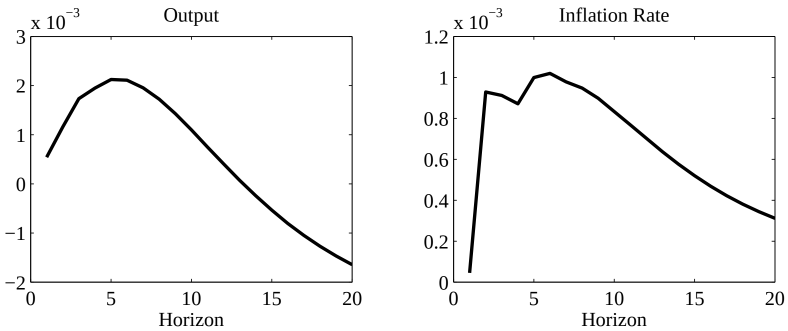
	Output			Inflation Rate		
	(n,ℓ)	μ_t	ε_t	(n,ℓ)	$\mu_{t\|T}$	ε_t
1966Q1–2000Q4	(3,2)	2.5726	1.9889	(4,3)	3.1897	3.1158
		[0.0574]	[0.1194]		[0.0159]	[0.0179]
1966Q1–1982Q3	(1,2)	1.1135	9.3852	(1,1)	2.9586	9.2952
		[0.3534]	[0.0001]		[0.0614]	[0.0004]
1982Q4–2000Q4	(3,0)	4.6480	3.2793	(3,0)	0.0086	2.8933
		[0.0356]	[0.0757]		[0.9263]	[0.0947]
1966Q1–2000Q4	(3,2)	3.0247	–	(4,4)	4.0750	–
		[0.0323]			[0.0019]	
1966Q1–1982Q3	(1,2)	2.2521	–	(4,0)	3.2130	–
		[0.0940]			[0.0794]	
1982Q4–2000Q4	(3,0)	3.6878	–	(4,0)	0.0118	–
		[0.0600]			[0.9141]	
1966Q1–2000Q4	(3,2)	–	2.4206	(4,1)	–	3.3150
			[0.0694]			[0.0397]
1966Q1–1982Q3	(1,2)	–	11.5994	(1,1)	–	7.3237
			[0.0000]			[0.0016]
1982Q4–2000Q4	(3,0)	–	2.3183	(3,0)	–	2.9500
			[0.1336]			[0.0915]

Note: p–values in brackets (they correspond to the F-test of the significance of each type of shock). (n,ℓ) refers to the number of lags of the endogenous variable, n, and of the monetary shocks, ℓ. μ_t is unperceived and ε_t is the unanticipated money shock.

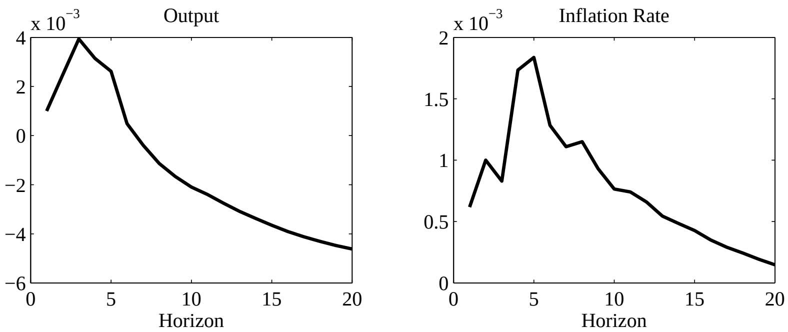
first in the identification scheme but the results are robust to alternative orderings in the VAR. The other VAR considers unperceived money and uses the μ series described above. In this case, as unperceived money growth ought to be unexplained by any of the other variables in the VAR, we estimate a VARX for output growth, CPI inflation and the federal fund rate where μ_t is introduced as an exogenous variable. Standard likelihood ratio tests and information criteria recommend the use of three lags in the VAR part and the current value and three lags of the unperceived money growth series.

As can be seen, from Figure 1 the reaction of output and inflation to a shock, whether unanticipated or misperceived is quite similar. Both output and inflation follow a hump shaped pattern. The effects of misperceived shocks are quantitatively larger.

Figure 1: Response to shocks
(a) unanticipated shock



(b) unperceived shock



Based on this evidence, and without loss of generality we assume that the agents receive noisy signals on the key aggregate nominal[5] variables, $\{R_t, \pi, \mu\}$, and in particular on the vector $\{R_t, \pi_t, \pi_{t-1}, \pi_{t-2}, \mu_t, \mu_{t-1}, \mu_{t-2}\}$.

We calibrated the variance of the noise on $\{R, \pi_t, \pi_{t-1}, \pi_{t-2}, \mu_t, \mu_{t-1}, \mu_{t-2}\}$ by matching the first

[5] As is well known from the days of the rational expectations models of the 70s, the Achilles heel of monetary business cycle models concerned their assumptions about the degree of observability of aggregate *nominal* variables.

eight periods in the IRF of inflation to a money shock in the model with backward looking price indexation. The model is thus, by construction, able to generate inertial behavior in inflation comparable to that generated in that model. Consequently, its plausibility can be assessed by checking whether the amount of required noise is realistic and its location plausible and also whether the implications of the model for the other variables is satisfactory. The calibrated values for the volatility of noise appear in Table 5.

Table 5: volatility of noise

R_t	π_t	π_{t-1}	π_{t-2}	μ_t	μ_{t-1}	μ_{t-2}
2.23045e-4	3.1301e-3	1.5707e-3	7.8817e-4	8.2173e-3	4.1161e-3	2.0618e-3

As can be seen, the model requires quite small noise[6]. The measurement error is smaller than that typically used in models of learning in the literature (see, for instance, Woodford, 2002). And it is also smaller than that implied by our analysis of money revisions above. For inflation it is smaller than that in the real world. For instance, the BEA reports "preliminary" and revised values for the GDP deflator. The standard deviation of the difference between announced and revised values for the GDP deflator from 1999–2003 was 0.48%.

3 The results

The model is log–linearized around its deterministic steady state and then solved. The solution method for the case in which the agents solve a signal extraction problem is to be found in a technical appendix available from the authors' web pages.

Figure 2 presents the response of inflation, output, the nominal and the real interest rate to a 1% shock to the growth rate of the money supply under three model specifications: *(i)* The NK model with fully rational, forward looking agents, that is, without any backward price indexation (forward looking); *(ii)* the version with indexation (backward looking); and *(iii)* the version with full rationality and signal extraction. In *all three cases*, the model includes three real rigidities, namely, habit persistence, variable capital utilization and investment adjustment costs.[7].

As can be seen, the three versions perform comparably with one important exception. Namely, the response of inflation. The version with forward looking agents cannot generate inflation

[6]This represents the key difference from Dellas, 2006. Dellas demonstrates that the NK model with a signal extraction problem *may* generate persistence in inflation and output. But in that paper, the amount of noise assumed on aggregate nominal variables is as large as that in real variables and quite large quantitatively. In the present paper the size of the measurement error is much more plausible.

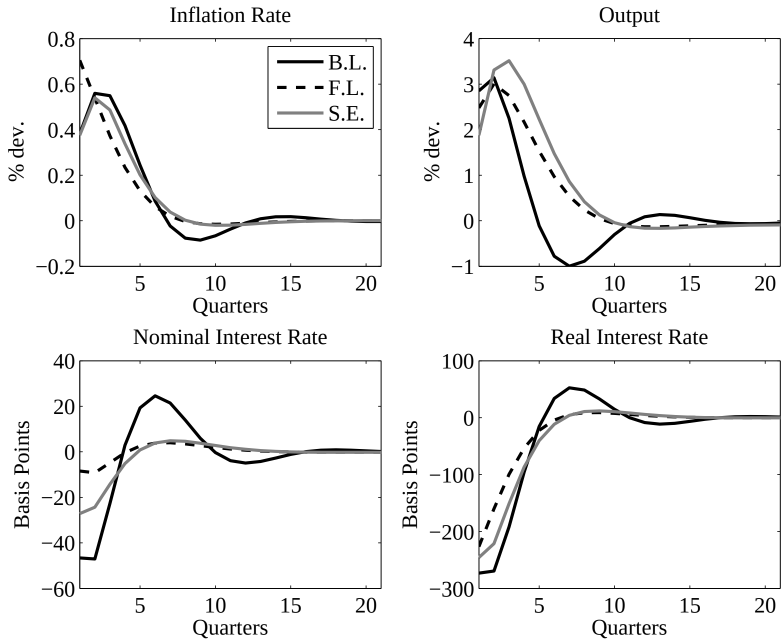
[7]Using capital in place of investment adjustment costs makes no difference for the behavior of the model with signal extraction.

Table 6: HP moments

Var.	Std	Rel. Std	$\rho(\cdot, y)$	$\rho(1)$	$\rho(2)$
		Data			
y	1.49	1.00	1.00	0.88	0.70
c	0.80	0.54	0.86	0.87	0.69
i	6.03	4.04	0.92	0.83	0.61
h	1.88	1.26	0.83	0.92	0.73
π	0.16	0.11	0.32	0.33	0.24
R_{nom}	0.40	0.27	0.21	0.81	0.57
R_{real}	0.33	0.22	0.10	0.73	0.50
		(b) Forward looking (no indexation)			
y	1.35	1.00	1.00	0.87	0.64
c	0.21	0.16	0.86	0.88	0.65
i	4.12	3.06	0.94	0.90	0.70
h	0.83	0.61	0.88	0.76	0.47
π	0.16	0.12	0.61	0.56	0.22
R_{nom}	0.01	0.01	-0.53	0.80	0.45
R_{real}	0.12	0.09	-0.63	0.56	0.21
		(a) Backward looking (indexation)			
y	1.49	1.00	1.00	0.84	0.55
c	0.23	0.16	0.90	0.86	0.60
i	4.49	3.01	0.95	0.88	0.63
h	0.87	0.58	0.90	0.74	0.38
π	0.16	0.11	0.54	0.81	0.43
R_{nom}	0.04	0.03	-0.75	0.74	0.29
R_{real}	0.18	0.12	-0.71	0.70	0.28
		(b) Signal extraction			
y	1.51	1.00	1.00	0.83	0.56
c	0.21	0.14	0.91	0.87	0.62
i	4.19	2.77	0.94	0.89	0.68
h	1.08	0.71	0.91	0.74	0.42
π	0.16	0.11	0.74	0.62	0.27
R_{nom}	0.02	0.02	-0.23	0.67	0.30
R_{real}	0.15	0.10	-0.57	0.66	0.28

Note: All series are HP–filtered. Data cover the period 1960:1–2002:4, except for aggregate weekly hours that run from 1964:1 to 2002:4. Output is defined as $C+I+G$. C is nondurables and services, I includes investment and durables. π is the CPI based inflation rate, R_{nom} is the federal fund rate, and $R_{real} = R_{nom} - \pi$. Std. is standard deviation, Rel. Std is standard deviation of the variable relative to that of output, $\rho(\cdot, y)$ is its correlation with output and $\rho(1)$ and $\rho(2)$ the first and second order autocorrelation.

Figure 2: IRF to a money supply shock



Note: Three model specifications: a) B.L.: Backward looking, b) F.L.: Forward looking, c) S.E.: Signal extraction.

inertia. This finding confirms the well known fact (see Collard and Dellas, 2005) that price staggering does not suffice to produce plausible dynamics. It also demonstrates that real rigidities alone cannot help the NK model deliver the hump either. For instance, there is a widely held view that habit persistence is sufficient to generate inertial behavior. As Figure 2 shows (see also Collard and Dellas, 2005) this is not the case. It must be emphasized that real rigidities are important in order to generate sufficient inertia under either backward indexation or signal extraction. This is illustrated in in the technical Appendix (available at the authors' web pages) which shuts all real rigidities down.

Naturally, there is a trade off between the degree of measurement error and the strength of real rigidities required to produce inertial behavior. As Dellas, 2006, shows, very persistent, hump shaped responses of the key macroeconomic variables can obtain without the need for any real rigidities when the amount of noise on nominal aggregates is high. But real rigidities and signal extraction also play distinct roles. Real rigidities alone (in the absence of signal extraction or backward indexation) cannot produce a hump in the dynamics of inflation, irrespective of their size, while signal extraction can.

Table 6 reports unconditional moments both in the data and under the three model specifications. The performance of the models is comparable. Their main weaknesses are to be found in the under-prediction of volatilities (in particular of consumption and the nominal interest rate) as well as their implication of counter–cyclicality in the interest rates. Note, that the model with signal extraction does somewhat better along the last dimension. Canzoneri et al. (2004) argue that there exists no model that can adequately capture interest rate behavior, so this weakness is not specific to these NK models.

How robust are our findings with regard to the specification of the monetary policy rule? We have repeated the analysis with a standard interest rate (Henderson-McKibbin-Taylor) rule modified to include a variable inflation target (so that there is a monetary policy shock present in the model).

$$\log(R_t) = \rho_r \log(R_{t-1}) + (1-\rho_r)\left[\log(\overline{R}) + \kappa_\pi(\log(\pi_t) - \log(\pi_t^\star)) + \kappa_y(\log(y_t) - \log(y^\star))\right]$$

where the output target, $y^\star$, is the steady state level of output. $\pi_t^\star$ is the inflation target and is assumed to follow an AR(1) process with persistence parameter 0.9999. The standard deviation of the innovation is set such that, borrowing all other parameters from the previous version of the model, the model matches output volatility. The parameters of the interest rate rule are ρ_r=0.75, κ_y=0.2 and κ_π=1.8. The noise is calibrated as before but now we assume that there is no noise at all in the observations in the interest rate.

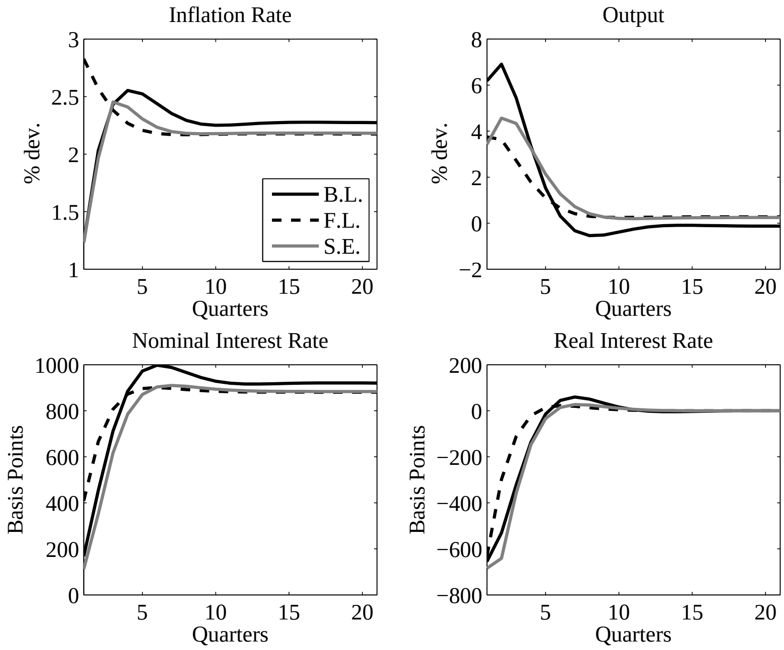
Figure 3 shows the IRFs to an inflation target (policy) shock. They are virtually indistinguishable from those in Figure 2.

4 Conclusions

The new Keynesian model has provided a valuable framework for the analysis of monetary policy. Nevertheless, in spite of its overall success, the model has had difficulties accounting for the empirical behavior of inflation. Its recent extensions, in particular the Christiano, Eichenbaum and Evans, (2005) and Smets and Wouters (2004) version, fare much better empirically but this success owes much to the adoption of questionable backward pricing schemes. These schemes seem to be at variance with the behavior of prices as documented for instance in the ECB project on inflation persistence.

In this paper we have argued that there may exist another, more satisfactory solution. This solution embeds Lucas' signal extraction problem into a model with sticky prices and real rigidities but leaves out backward price indexation. This combination allows short lived mis–perceptions of the state of the economy to constrain initial responses while propagating the shocks over time through the real rigidities. Under a small and empirically plausible amount of imperfect information (noise) the model can generate dynamics for the key macroeconomic variables that

Figure 3: IRF to an inflation target shock



Note: Three model specifications: a) B.L.: Backward looking, b) F.L.: Forward looking, c) S.E.: Signal extraction.

are virtually indistinguishable from those arising in its most successful rivals. We establish also that such "noise" in preliminary data is indeed important empirically for the monetary transmission mechanism. Measurement error –the difference between preliminary and revised data– is quantitatively significant. And this error (which represent unperceived money) matters for economic activity.

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