Dissecting the new Keynesian model

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Abstract

The original ("baseline") version of the new Keynesian (NK) model has important, empirical limitations, in particular with regard to its implied inflation, output and interest rate dynamics. Recent extensions seem to perform much better (Christiano et al. 2005, Smets and Wouters, 2003). We identify the crucial feature of the new versions of NK models that is responsible for this superior performance, namely, the assumption of *backward* price *indexation*. In its absence, price and/or wage stickiness cannot generate inertial behavior for inflation, irrespective of the type of real rigidities. This finding presents a major challenge to the NK model because of the apparent inconsistency of this assumption with observed pricing behavior.

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Introduction

The standard version of the New Keynesian (henceforth, NK) model has well known, important empirical limitations. Most prominent among them is its inability to produce plausible inflation and output dynamics following a monetary shock, in particular, the delayed, hump shaped response of inflation documented by Christiano, Eichenbaum and Evans, 2005; and to generate a liquidity effect (Gali, 2003).

Various modifications have been proposed in order to improve its performance. Broadly speaking these efforts can be classified according to whether they adhere to strict rationality or not. The models of sticky information of Mankiw and Reis, 2002, incomplete information of Collard and Dellas, 2004, and predetermined expenditure of Rotemberg and Woodford, 1997, represent the main examples in the first category. Christiano et al., 2005, Gali and Gertler, 1999, Ireland, 2000, Smets and Wouters, 2003, are the main representatives of the second category. The latter class of models also typically contains several sources of costly real adjustments (in consumption, investment, capital and so on) along side the nominal rigidities. The performance of the models of Christiano et al, 2005, and Smets and Wouters, 2003, offer support to the widely held view that these models represent the most empirically successful variant of the NK model. Our objective in this paper is to shed some light on the features of these models that are responsible for this success.

We begin with the original (baseline) version of the NK model and demonstrate its well known failure to produce plausible dynamics for inflation, output and interest rates[1]. This obtains independent of whether price or wage rigidity is assumed. We then add various *real* rigidities that have proved popular in the literature: habit persistence, variable capital utilization, predetermined spending, capital adjustment costs, investment adjustment costs, lagged information. We find that in spite of the presence of nominal price or wage rigidities, none of these real rigidities individually or in combination can generate inertial behavior for inflation. Moreover, none of them individually can generate inertia in output or a liquidity effect but in combination they do, especially with the help of predetermination in spending.

We then consider a version of the model where some of the firms (or the workers) simply index their prices to aggregate inflation (the indexation scheme popularized by Christiano et al, 2005). With this price setting mechanism, the model can generate inflation inertia. Investment adjustment costs play a key role for this pattern too. Moreover, with the help of the other real rigidities, the model also generates inertia in output and a liquidity effect. Nonetheless, the ability to generate plausible dynamics for key macroeconomic variables is not

[1]It must be emphasized that, unlike Chari et al. 2000, who focus on the ability of the model to generate inflation persistence, our focus is on inflation dynamics. As Mankiw and Reis, 2002, have argued, the former issue does not seem to pose a major threat to the NK model because inflation persistence is easy to generate if there is enough persistence in monetary policy.

accompanied by success across the board. In particular, the model generated unconditional moments do not fit the data well. Most prominent among these failures is the predicted strong countercyclicality in nominal and real interest rates.

What is the problem with making such an assumption? From a conceptual point of view, it seems controversial as it violates strict rationality in the sense that an alternative indexation scheme would lead to higher profits. As Minford and Peel, 2004, have argued, if the firms indexed their prices to expected rather than lagged inflation (both pieces of information are equally easily available) that would generate higher profits for them and in the process it would eliminate the lagged inflation term from the Phillips curve. But the most important criticism of this assumption[2] is that it seems to be at variance with the empirical evidence regarding pricing behavior, as documented, for instance, in a recent ECB report (Dhyne et al. 2005). Namely, the observation that individual price changes do not move in tandem with aggregate inflation. Unlike the lagged indexation assumption that implies that individual prices move roughly at the rate of aggregate inflation "...prices changes are sizeable compared to the inflation rate prevailing in each country..."(Dhyne et al. 2005).

What is the value added of our finding on the critical role of backward indexation? There already exists some work in the literature that compares the performance of the NK model in the presence and absence of backward price indexation. Eichenbaum and Fisher, 2004, estimate such a model and find the model with backward indexation receives support from the data (as judged by the J statistic in the context of GMM estimation) when it is augmented to also include firm specific capital and endogenous mark ups. Nevertheless, this finding does not tell us anything about the sine qua non property of this assumption for *inflation dynamics*. Similarly, de Walque, Smets and Wouters, 2005, estimate a related model and find that the model performs well even when the parameter of backward indexation is close to zero. But the fact that the model without indexation is not rejected by the data according to a likelihood criterion does not mean that it performs satisfactorily along the inflation dynamics dimension. It is this dimension that often serves as the litmus test for the NK model in the domain of policy analysis (see Mankiw and Reis, 2002). Consequently, our paper is the first one in the literature to sift through the multitude of popular features of the NK model and reveal the critical role of this assumption.

Our findings then suggest that, in spite of the significant progress made during the last few years in developing and refining the NK model, the current state of affairs is not fully satisfactory. On the one hand, we have a model (the original version of NK with fully rational agents and with or without real rigidities) that has good theoretical foundations but which

[2] Another perhaps contentious issue is that the critical real rigidity in these model is investment adjustment costs. Unlike capital adjustment costs which have a long tradition and have been the subject of considerable empirical scrutiny, the concept of adjustment costs is still young and untested.

does not perform well empirically. On the other hand, we have a model (the Christiano et al. 2005 model) that scores very well empirically but relies on price setting assumptions that are contradicted by the empirical evidence. While there exist alternative theories that do not require indexation to lagged inflation, namely the model of sticky information of Mankiw and Reis, 2002, and that of learning of Collard and Dellas, 2004, neither of these models has yet been subjected to the battery of validation tests that Christiano et al, 2005 and Smets and Wouters, 2003, have met with success. So it remains an open question which of these models will provide the best combination of theoretical and empirical properties.

The rest of the paper is organized as follows. Section 1 presents the model(s). Section 2 studies the effects of various real rigidities in that fully rational version of the model. Section 3 repeats the analysis in the model with limited rationality. Section 4 concludes.

1 The model

The set up is the new Keynesian model with price and wage nominal rigidities, augmented to include various real rigidities. Below we describe the behavior of the households and firms. 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, X_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 $\theta \in (-\infty, 1)$. Profit maximization and free entry lead to the general price index

$$P_t = \left(\int_0^1 P_{it}^{\frac{\theta}{\theta-1}} \mathrm{d}i \right)^{\frac{\theta-1}{\theta}} \tag{2}$$

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

$$y_(it) = a_t(u_{it}k_{it})^\alpha n_{it}^{1-\alpha} \text{ with } \alpha \in (0,1) \tag{3}$$

where k_{it} and n_{it} respectively denote the physical capital and the labor input used by firm i in the production process. a_t is an exogenous, stationary, stochastic, technology shock, whose properties will be defined later. Assuming that each firm i operates under perfect competition in the input markets, the firm determines its production plan by minimizing its total cost

$$\min_{\{u_{it}k_{it},n_{it}\}} P_tW_tn_{it} + P_tz_tu_{it}k_{it}$$

subject to (3). This leads to the following expression for total costs:

$$P_ts_ty_{it}$$

where the real marginal cost, S, is given by $\frac{W_t^{1-\alpha}z_t^\alpha}{\alpha^\alpha(1-\alpha)^{1-\alpha}a_t}$.

Intermediate goods producers are monopolistically competitive, and therefore set prices for the good they produce. We follow Calvo, 1983, in assuming that firms set their prices for a stochastic number of periods. In each and every period, a firm either gets the chance to adjust its price (an event occurring with probability γ) or it does not. If it does not get the chance, then it is assumed to set prices according to

$$P_{it} = \xi_tP_{it-1} \tag{4}$$

We will use two versions of equation 4: Under the first one $\xi_t = \overline{\pi}$ where $\overline{\pi}$ is the steady state rate of inflation. This assumption allows the model to have good long term properties, namely to satisfy long term money neutrality, but is innocuous from a business cycle perspective as it leave the dynamic properties of the model unaffected. Under the second specification, $\xi_t = \pi_{t-1}$ with $\pi_t = P_t/P_{t-1}$. That is, the firms index their prices to the lagged, economy wide rate of inflation. 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.

On the other hand, a firm i that sets its price optimally in period t chooses a price, $P_t^\star$, in order to maximize:

$$\max_{P_t^\star} \mathbb{E}_t \sum_{\tau=0}^{\infty} \Phi_{t+\tau}(1-\gamma)^\tau \left(P_t^\star\Xi_{t,\tau} - P_{t+\tau}s_{t+\tau}\right) y_{it+\tau}$$

subject to the total demand it faces

$$y_{it+\tau} = \left(\frac{P_t^\star\Xi_{t,\tau}}{P_{t+\tau}}\right)^{\frac{1}{\theta-1}} y_{t+\tau}$$

[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.

and where

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

$\Phi_{t+\tau}$ is an appropriate discount factor derived from the household's evaluation of future relative to current consumption. This leads to the price setting equation

$$P_t^\star = \frac{1}{\theta} \frac{\mathbb{E}_t \sum_{\tau=0}^{\infty} (1-\gamma)^\tau \Phi_{t+\tau} P_{t+\tau}^{\frac{2-\theta}{1-\theta}} \Xi_{t,\tau}^{\frac{1}{\theta-1}} s_{t+\tau} y_{t+\tau}}{\mathbb{E}_t \sum_{\tau=0}^{\infty} (1-\gamma)^\tau \Phi_{t+\tau} \Xi_{t,\tau}^{\frac{\theta}{\theta-1}} P_{t+\tau}^{\frac{1}{\theta-1}} y_{t+\tau}} \tag{5}$$

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

In each period, a fraction γ of contracts ends and $(1-\gamma)$ survives. Hence, from (2) and the price mechanism, the aggregate intermediate price index writes

$$P_t = \left(\gamma P_t^{\star \frac{\theta}{\theta-1}} + (1-\gamma)(\xi_t P_{t-1})^{\frac{\theta}{\theta-1}} \right)^{\frac{\theta-1}{\theta}} \tag{6}$$

1.3 The Household

There exists an infinite number of households distributed over the unit interval and indexed by $j \in [0,1]$. Households have market power over the labor services they provide. We will assume that households are heterogenous in the sense that in each period a household may or may not reoptimize her wage with probability γ_w. Since this uncertainty is idiosyncratic, households supply different level of labor and earn different wages. Therefore consumption, investment, money holdings decisions are heterogenous across agents. Nevertheless, since we assume there exists a complete set of state contingent securities, B_t, in equilibrium all agents choose the same level of consumption, and assets. Thus, our notation will not make any reference to the type of the agent. The preferences of household j are given by

$$\mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^\tau \left[\log(c_{t+\tau} - \vartheta c_{t+\tau-1}) + \frac{\nu^m}{1-\sigma_m} \left(\frac{M_{t+\tau}}{P_{t+\tau}} \right)^{1-\sigma_m} - \frac{\nu^h}{1+\sigma_h} h_{jt+\tau}^{1+\sigma_h} \right] \tag{7}$$

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_{jt} is the quantity of labor supplied by the representative household of type j.

In each period, household j faces the budget constraint

$$E_t B_{t+1} Q_t + M_t + P_t(c_t + i_t + a(u_t)k_t) = B_t + M_{t-1} + P_t z_t u_t k_t + W_{jt} h_{jt} + \Omega_t + \Pi_t \tag{8}$$

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 $a(u)$. W_{jt} is the nominal wage (specific to individual j). 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

$$k_{t+1} = (1-\delta)k_t + \Phi(i_t, i_{t-1}, k_t) \tag{9}$$

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

The workers have monopoly power over their labor services. They sell these services to competitive firms that produce aggregate labor services using the following technology:

$$n_t = \left(\int_0^1 h_{jt}^{\theta_w} \mathrm{d}j \right)^{\frac{1}{\theta_w}} \tag{10}$$

where $\theta_w \in (-\infty, 1)$. Profit maximization and free entry condition on the market implies that aggregate wage takes the form

$$W_t = \left(\int_0^1 W_{jt}^{\frac{\theta_w}{\theta_w - 1}} \mathrm{d}i \right)^{\frac{\theta_w - 1}{\theta_w}} \tag{11}$$

Wages are set for a stochastic number of periods according to the scheme suggested by Calvo, 1983 (see Erceg et al, 1998). In each and every period, a worker either gets the chance to adjust his nominal wage (an event occurring with probability γ) or he does not. If he does not get the chance, then he is assumed to set the wage according to

$$W_{it} = \xi_{wt} W_{it-1} \tag{12}$$

As in the setting of goods prices we will use two versions of equation 12: Under the first one $\xi_{wt} = \overline{\pi}$ where $\overline{\pi}$ is the steady state rate of inflation. Under the second specification, $\xi_{wt} = \pi_{t-1}$. That is, the workers index their wages to the economy wide past rate of inflation.

On the other hand, a worker j that sets his price optimally in period t chooses a wage, $W_t^\star$, in order to maximize expected lifetime utility subject to the budget constraint and total demand it faces. This leads to the wage setting equation[4]

$$W_t^{\star\frac{\theta_w-\sigma_h-1}{\theta_w-1}} = \frac{1}{\theta_w}\frac{\sum_{j=0}^{\infty}(\beta(1-\gamma_w))^j\nu_h X_{t,j}^{\frac{1+\sigma_h}{\theta_w-1}} W_{t+j}^{\frac{1+\sigma_h}{1-\theta_w}} h_{t+j}^{1+\sigma_h}}{\sum_{j=0}^{\infty}(\beta(1-\gamma_w))^j\Lambda_{t+j} X_{t,j}^{\frac{\theta_w}{\theta_w-1}} W_{t+j}^{\frac{1}{1-\theta_w}} h_{t+j}} \tag{13}$$

where Λ_t is the Lagrange multiplier associated to the household budget constraint.

In each period, a fraction γ_w of contracts ends and while the fraction $(1-\gamma_w)$ survives. Hence, from (11) and the wage dynamics, the aggregate wage writes

$$W_t = \left(\gamma_w W_t^{\star\frac{\theta_w}{\theta_w-1}} + (1-\gamma_w)(\xi_t W_{t-1})^{\frac{\theta_w}{\theta_w-1}}\right)^{\frac{\theta_w-1}{\theta_w}} \tag{14}$$

1.4 The monetary authorities

We use two alternative specifications of monetary policy: *(i)* an exogenous money supply rule and *(ii)* a standard Henderson–McKibbin–Taylor (HMT) rule. Under the former, the money supply is assumed to evolve according to

$$M_t = \exp(\mu_t)M_{t-1} \tag{15}$$

where the gross growth rate of the money supply, μ_t, is assumed to follow an exogenous stochastic process whose properties will be defined later. We use this specification in the analysis of the dynamics of the key macroeconomic variables.

Under the latter, the growth of the money supply is selected in order to satisfy

$$\widehat{R}_t = \rho_r\widehat{R}_{t-1} + (1-\rho_r)[k_\pi E_t(\widehat{\pi}_{t+1}-\pi) + k_y(\widehat{y}_t - y_t^\star)] \tag{16}$$

where $\widehat{\pi}_t$ and $\widehat{y}_t$ are actual output and expected gross inflation in logs respectively and π and $y_t^\star$ are the inflation and output targets respectively. The output target is set equal to steady state output and the inflation target to the steady state rate of inflation. We use this specification in the study of the unconditional moments of the model in order to be consistent with the commonly held view that such a policy rule represents a good characterization of monetary policy.

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.

[4]As in the case of producers, all households who reoptimize their wage at time t choose the same wage. This is reflected in our notation as $W_t^\star$ does not depend on j.

1.6 The equilibrium

We now turn to the description of the equilibrium of the economy.

Definition 1 *An equilibrium of this economy is a sequence of prices* $\{\mathcal{P}_t\}_{t=0}^{\infty} = \{W_t, z_t, P_t, R_t, P_{it}, W_{jt}, i, j \in (0,1)\}_{t=0}^{\infty}$ *and a sequence of quantities* $\{\mathcal{Q}_t\}_{t=0}^{\infty} = \{\{\mathcal{Q}_t^H\}_{t=0}^{\infty}, \{\mathcal{Q}_t^F\}_{t=0}^{\infty}\}$ *with*

$$\begin{aligned} \{\mathcal{Q}_t^H\}_{t=0}^{\infty} &= \{x_t, i_t, B_t, k_{t+1}, n_t, M_t, u_t, h_{jt}; j \in (0,1)\} \\ \{\mathcal{Q}_t^H\}_{t=0}^{\infty} &= \{y_t, y_{it}, u_{it}k_{it}, n_{it}; i \in (0,1)\}_{t=0}^{\infty} \end{aligned}$$

such that:

(i) given a sequence of prices $\{\mathcal{P}_t\}_{t=0}^{\infty}$ *and a sequence of shocks,* $\{\mathcal{Q}_t^H\}_{t=0}^{\infty}$ *is a solution to the representative household's problem;*

(ii) given a sequence of prices $\{\mathcal{P}_t\}_{t=0}^{\infty}$ *and a sequence of shocks,* $\{\mathcal{Q}_t^F\}_{t=0}^{\infty}$ *is a solution to the representative firms' problem;*

(iii) given a sequence of quantities $\{\mathcal{Q}_t\}_{t=0}^{\infty}$ *and a sequence of shocks,* $\{\mathcal{P}_t\}_{t=0}^{\infty}$ *clears the markets*

$$y_t = c_t + i_t + g_t + a(u_t)k_t \tag{17}$$

$$n_t = \int_0^1 n_{it}\,di \tag{18}$$

$$k_t = \int_0^1 k_{it}\,di \tag{19}$$

$$n_h = h_t \tag{20}$$

$$g_t = \tau_t \tag{21}$$

and the money market.

(iv) Prices satisfy (5) and (6).

(v) Wages satisfy (13) and (14).

2 Parametrization

For comparison purposes, the parametrization of the model relies heavily on Christiano, Eichenbaum and Evans, 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.[5] The parameters are reported in table 1.

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

β, the discount factor is set such that households discount the future at a 5% annual rate, implying β equals 0.988. The parametrization of preferences follows Christiano et al., 2005. More precisely, we set $\vartheta = 0.65$, $\sigma_h = 1$ and $\sigma_m = 10.5$.

We set θ to 0.85, implying that the markup rate on goods is about 18%, which roughly corresponds to the average markup rate estimated by Christiano et al. 2005. α, the elasticity of the production function to physical capital, is set such that the model reproduces the US labor share — defined as the ratio of labor compensation to GDP — during the sample period (0.575). θ_w is borrowed from Christiano et al.

Table 1: Calibration: Benchmark case

Preferences		
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
Technology		
Markup on labor bundle	θ_w	0.950
Capital elasticity of intermediate output	α	0.281
Parameter of markup	θ	0.850
Depreciation rate	δ	0.025
Capital adjustment costs parameter	φ	2.500
Probability of price resetting	γ	0.250/0.500
Probability of wage resetting	γ_w	1.000/0.300
Shocks and policy parameters		
Persistence of technology shock	ρ_a	0.950
Standard deviation of technology shock	σ_a	0.008
Persistence of government spending shock	ρ_g	0.970
Volatility of government spending shock	σ_g	0.020
Persistence of money growth	ρ_μ	0.500
Volatility of money shock	σ_μ	0.007
Steady state money supply growth (gross)	μ	1.012
Inflation coefficient in Taylor rule	k_p	1.500
Output gap coefficient in Taylor rule	k_y	0.150
Persistence in interest rate rule	ρ	0.750
Share of government spending	g/y	0.200

The quarterly depreciation rate, δ, is set equal to 0.025. θ in the benchmark case is set such that the level of markup in the steady state is 15%. The accumulation function $\Phi(i_t, i_{t-1}, k_t)$ is assumed to take the following form

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

As in Christiano et al., 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 theories of accumulation frictions. Setting $\omega = 1$ we recover the specification used in Christiano et al., 2005, where investment is subject to adjustment costs. Setting $\omega = 0$, we obtain the standard capital adjustment costs specification. In both cases, we set $\varphi = 2.5$. The capital utilization function $a(u_t)$ satisfies $a(1) = 0$, $a''(1)/a'(1) = 1/\sigma_a$. $\sigma_a = 100$.

The stochastic technology shock, $a_t = \log(A_t/\overline{A})$, is assumed to follow a stationary AR(1) process of the form

$$a_t = \rho_a a_{t-1} + \varepsilon_{a,t}$$

with $|\rho_a| < 1$ and $\varepsilon_{a,t} \rightsquigarrow \mathcal{N}(0, \sigma_a^2)$. We set $\rho_a = 0.95$ and $\sigma_a = 0.008$.

The government spending shock[6] is assumed to follow an AR(1) process

$$\log(g_t) = \rho_g \log(g_{t-1}) + (1 - \rho_g) \log(\overline{g}) + \varepsilon_{g,t}$$

with $|\rho_g| < 1$ and $\varepsilon_{g,t} \sim \mathcal{N}(0, \sigma_g^2)$. The persistence parameter is set to, ρ_g, of 0.97 and the standard deviation of innovations is $\sigma_g = 0.02$. The government spending to output ratio is set to 0.20.

When the monetary authorities are assumed to use an exogenous money supply rule, gross money growth evolves according to

$$\mu_t = (1 - \rho_\mu)\overline{\mu} + \rho_\mu \mu_{t-1} + \epsilon_{\mu t}$$

where $|\rho_m| < 1$, $\overline{\mu} = E(\mu_t)$ and $\epsilon_{\mu t}$ is a gaussian white noise process with mean 0 and standard deviation σ_μ. The nominal growth of the economy, $\overline{\mu}$, is set such that the average quarterly rate of inflation over the period is $\overline{\pi} = 1.2\%$ per quarter. Direct estimation of this AR(1) process yields $\rho_\mu = 0.5$ and $\sigma_\mu = 0.007$.

When an HTM rule is assumed, we use the values of $\rho_r = 0.75$, $k_\pi = 1.5$ and $k_y = 0.15$ suggested in the literature (see Galí, 2003).

We investigate two alternative settings for nominal rigidities. In the first one, only prices are sticky and wages are flexible. In this situation, we set the probability of price resetting, γ, to 0.25, implying that the average length of price contracts is about 4 quarters. In the second setting both prices and wages are sticky. We follow Christiano et al. and set $\gamma = 0.50$ and $\gamma_w = 0.30$, implying that prices are reset on average every semester, while it takes 3 quarters on average to reset wages.

A methodological point should be made clear at this point. Our approach uses fixed parameter values across experiments (model versions) and seeks to uncover the features of the model

[6] The –logarithm of the– government expenditure series is first detrended using a linear trend.

that play the critical role for the inertial responses observed following a monetary shock. An alternative would be to either re-estimate the parameters within each subversion of the model used. Or to allow for calibrated values to vary across model versions in order to give each particular version a better chance to match the data. We think that pursuing any of these two alternatives would completely miss the point. First, we are not interested in running a general race across different specifications (as Smets and Wouters do) so there is no reason to fine tune the model (by varying the structural parameters) in order to get the best performing –overall- version for each specification. The issue addressed in this paper is not what the best overall model is but rather what is needed in order to produce inertia. Second, a model can only be useful if its parameters are structural, so one cannot justify varying these parameters across experiments. And third, our approach is the only genuinely ceteris paribus approach for the task at hand. Allowing parameter values to change together with the model feature investigated could only serve to obscure the analysis.

3 The results

The model is log–linearized around its deterministic steady state and then solved. The presentation of the results is organized as follows. We first deal with the case of nominal price and then of nominal wage rigidity. For each type of nominal rigidity we present results from the standard version of the NK model (full rationality) with various real rigidities (variable capital utilization, habit persistence, investment adjustment costs, predetermined expenditure). We then repeat the same analysis under the assumption that the firms (workers) who do not set prices (wages) optimally use the backward indexation scheme of Christiano et al. 2005. We report both the IRFs to a monetary shock and the unconditional moments.

3.1 Nominal price rigidity

3.1.1 Standard version

Figure 1 shows the IRF of output, inflation, the nominal and the real interest rate to a monetary shock in the presence of an individual real rigidity; and figure 2 when all rigidities are combined together. For instance, the second row of figure 1 gives the response of output, inflation and the interest rates to a one standard deviation monetary shock when the only rigidity present is capacity utilization. The top panel of table 2 gives the unconditional moments of the model (an appendix available at www.vwi.ch/amakro/res gives a more detailed picture of unconditional moments as a function of individual model features).

What are the main patterns of interest? First, the model fails to generate inflation inertia independent of the type(s) of real rigidity considered. Second, output inertia does not obtain under any single real rigidity but emerges when all of them are combined together. Third, investment adjustment costs are the only feature that can help the model produce a liquidity effect. And forth, the model does not have overall satisfactory performance as far as unconditional moments are concerned. For instance, investment is not volatile enough and inflation is too volatile. A major weakness of the model is to be found in its implication of strong countercyclicality in the real and nominal interest rate.

We have also studied the performance of the model under the assumption that the agents observe the growth rate of the money supply with a one period lag. Figure **??** in the appendix shows that the informational lag (together with real rigidities) does not help in producing a hump in inflation.

The conclusion we draw from these findings is that real rigidities alone can only offer limited help to the NK model with sticky prices. No specification of the model can account for inflation inertia.

3.1.2 Indexation to lagged inflation

We repeat the analysis under the assumption that those firms who do not set prices optimally follow the price indexation rule described in section 1.2. The following patterns emerge (figure 3and bottom panel of table 2): First, the model can now generate inflation persistence. Lagged indexation is not sufficient for that, the model also needs to include investment adjustment costs. The same real rigidity is also responsible for a liquidity effect. The other real rigidities do not contribute to inflation inertia but all together they help generate inertial output dynamics. Predetermined expenditure is particularly important for the last pattern. And second, the model does not perform noticeably better relative to the standard version with regard to unconditional moments. The same weaknesses are observed, in particular with regard to the cyclical properties of the interest rates.

From these findings one can claim that the existence of the price indexation scheme is sina qua non for the ability of the Keynesian model to produce inflation inertia[7].

3.2 Nominal wage rigidity

3.2.1 Standard version

In Christiano et al, 2005 nominal wage rigidities are found to be the dominant source of nominal rigidity. In this section we repeat the preceding analysis using nominal wage in

[7]Peel and Minford, 2004, have argued that allowing the non optimizing agents to set their prices according to their rational expectation of inflation –rather than in a backward way– removes inflation inertia from the model.

place of price rigidity. Figure 5 and the top panel of table 3 show the main findings. The dynamic patterns are virtually identical to those obtained under price rigidity. No inflation inertia ever obtains no matter what type(s) of real rigidities are present. When all the real rigidities are combined together then the model produces hump shaped dynamics for output and a liquidity effect (due mostly to investment adjustment costs). The overall performance of the model as judged by the unconditional moments is worse relative to the case of price rigidities because of excessively large volatility. The strong countercyclicality in interest rates remains.

3.2.2 Indexation to lagged inflation

We repeat the analysis under the assumption that those agents who do not set wages optimally follow the price indexation scheme described in section 1.2. The results (figure 6 and bottom panel of table 3) are again virtually indistinguishable from the case of price rigidity. Namely, inflation inertia obtains following a monetary shock, thanks to the combination of lagged indexation and investment adjustment costs. The same combination is also responsible for inertia in output and a liquidity effect. The unconditional moments indicate too much volatility and the cyclical properties of interest rates remain very poor.

4 Conclusions

In this paper we have studied the role played by various type of real rigidities as well as the price setting mechanism in the new Keynesian model with nominal price or wage rigidities. In general, real rigidities cannot produce inertial behavior in the inflation rate following a monetary policy shock, unless there is a set of agents in the population that mechanically indexes its price to past price developments. When this is the case and in the presence also of investment adjustment costs the Keynesian model generates plausible dynamics not only for inflation but also for output and it also gives rise to a liquidity effect. The main drawback in this case is that the model does not perform well overall, as its unconditional moments diverge significantly from those in the data, in particular those pertaining to interest rates.

A clear and important challenge then lies ahead. We need to develop models which will enjoy the remarkable empirical success of the Christiano et al, 2005 and Smets and Wouters, 2003, models regarding dynamic properties. But at the same time, they should also perform better unconditionally and also rely less on features that are either untested (such as investment adjustment costs) or seem to be at variance with the empirical evidence (the price indexation scheme). While the models of Mankiw and Reis, 2002 and Collard and Dellas, 2004, have showed some promise with regard to some of these aspects, they are still a long way from serving as a successful alternative to the existing versions of the New Keynesian model.

References

Christiano, L.J., M. Eichenbaum, and C.L. Evans, 2005, Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy, *Journal of Political Economy*, 113, 1–45.

Chari, V., P. Kehoe, and E. McGrattan, 2000, Sticky Price Models of the Business Cycle, *Econometrica*, 68(5), 1151–1179.

Collard, F. and H. Dellas, 2004, The New Keynesian Model with Imperfect Information and Learning, mimeo, Bern University.

de Walque, G, Smets, F. and R. Wouters, 2005, Firm Specific Production Factors in a DSGE Model with Taylor Price Setting, mimeo.

Dhyne et al., 2005, Price Setting in the Euro Area, ECB working paper, No 524 (September)

Eichenbaum, M. and J. Fisher, 2004, Evaluating the Calvo Model of Sticky Prices, NBER wp 10617.

Galí, J., 2003, *New Perspectives on Monetary Policy, Inflation, and the Business Cycle*, in Advances in Economic Theory, edited by: M. Dewatripont, L. Hansen, and S. Turnovsky, Cambridge University Press, vol. III, pp. 151–197.

Galí, J. and M. Gertler, 1999, Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics*, 44, pp. 195–222.

Mankiw, G. and R. Reis, 2002, Sticky Information versus Sticky Prices, *Quarterly Journal of Economics*, 117, pp. 1295–1328.

Minford, P. and D. Peel, 2003, Calvo Contracts - A Critique, mimeo.

Rotemberg, J. and M. Woodford, 1997, *An Optimization-based Econometric Framework for the Evaluation of Monetary Policy*, NBER Macroeconomics Annual, pp. 297–344.

Smets, F. and R. Wouters, 2003, An estimated Stochastic Dynamic General Equilibrium Model of the Euro Area, *Journal of European Economic Association*, 1, pp. 1123–1175.

Figure 1: Price rigidity, **full** rationality. Adding real rigidities to the basic NK model

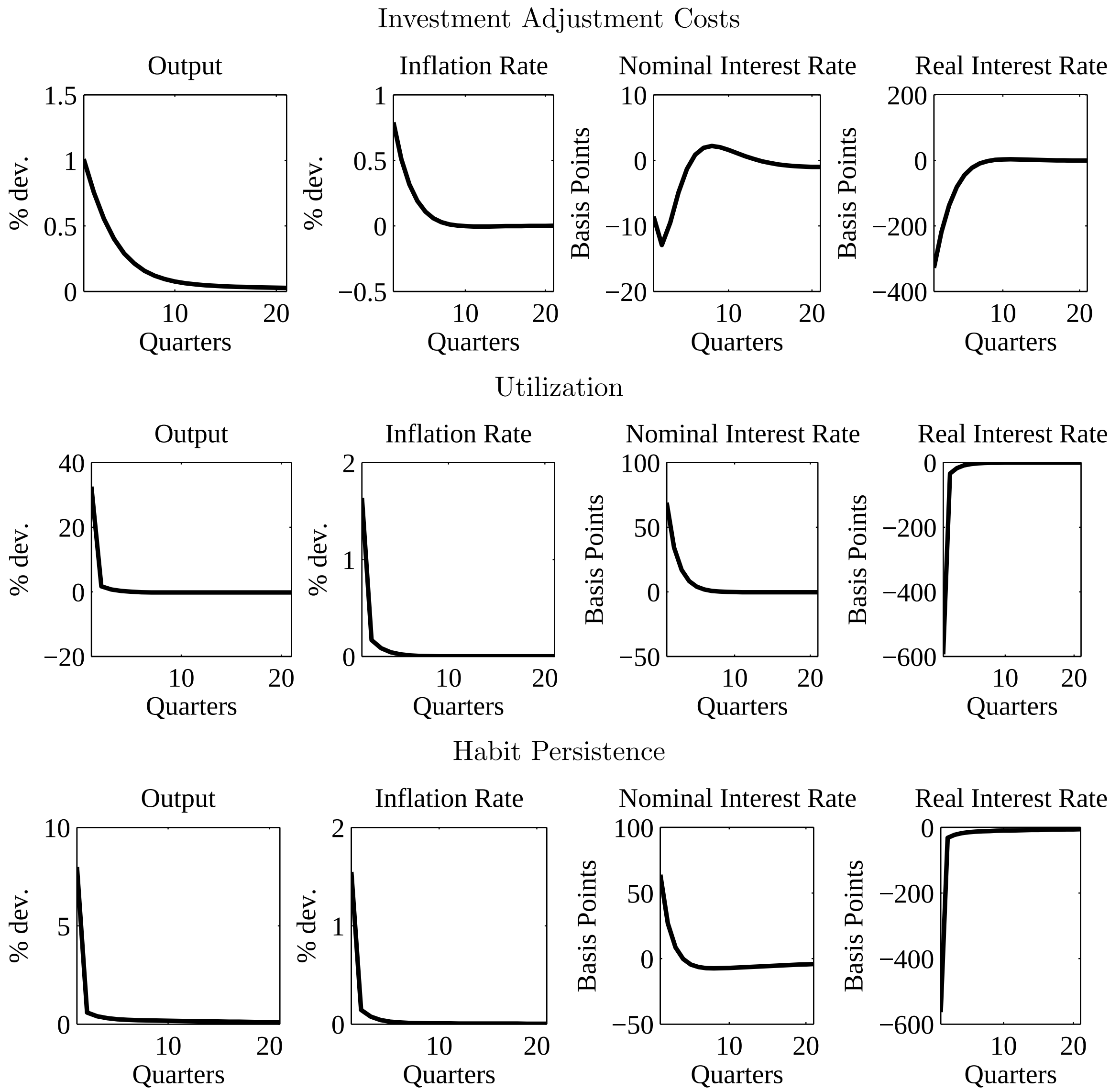

Figure 2: Price rigidity, **baseline version**. Combined effect of real rigidities

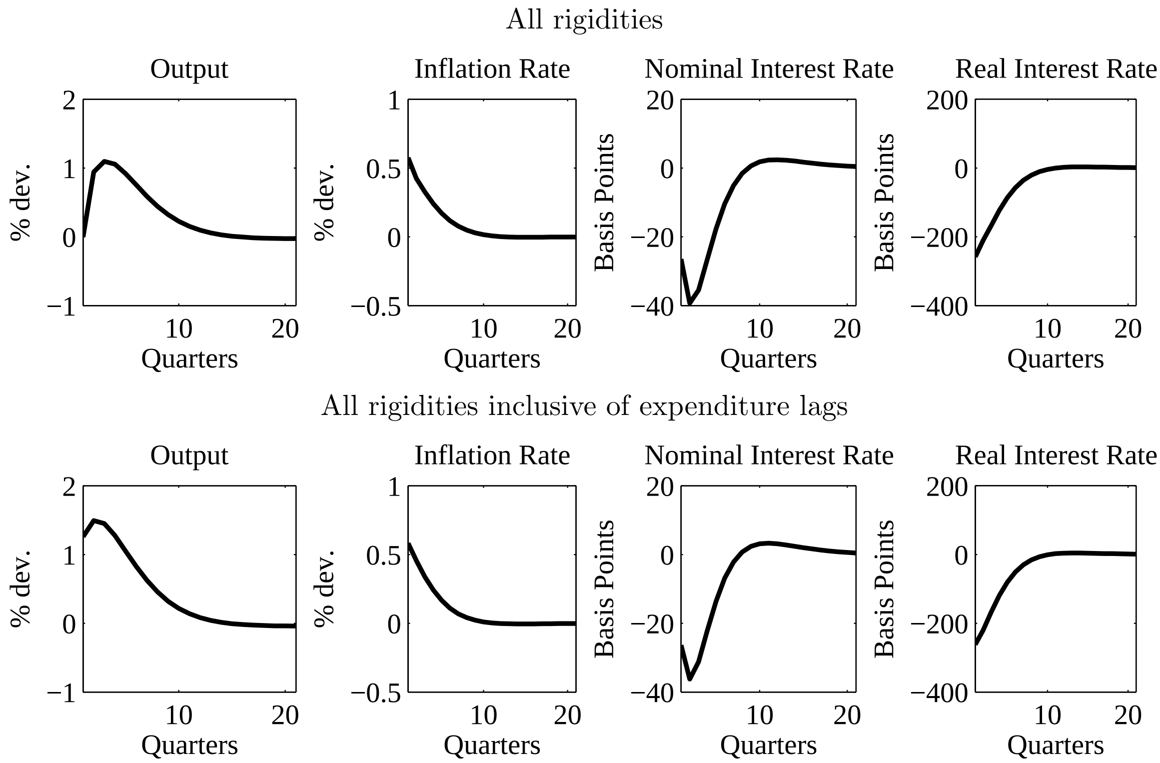

Figure 3: Price rigidity, **backward** indexation. Adding real rigidities

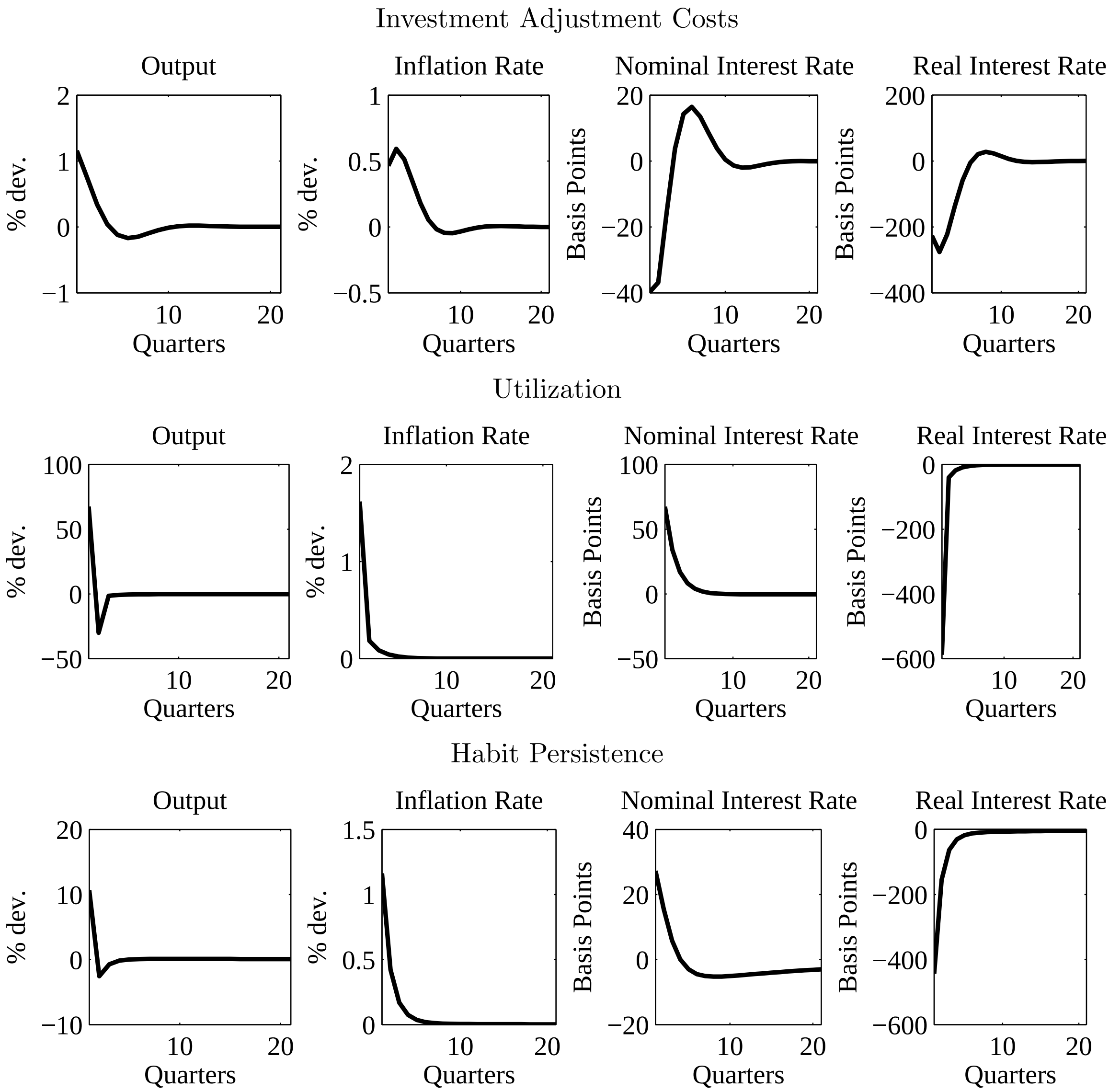

Figure 4: Price rigidity, **backward** indexation. Combined effects of real rigidities

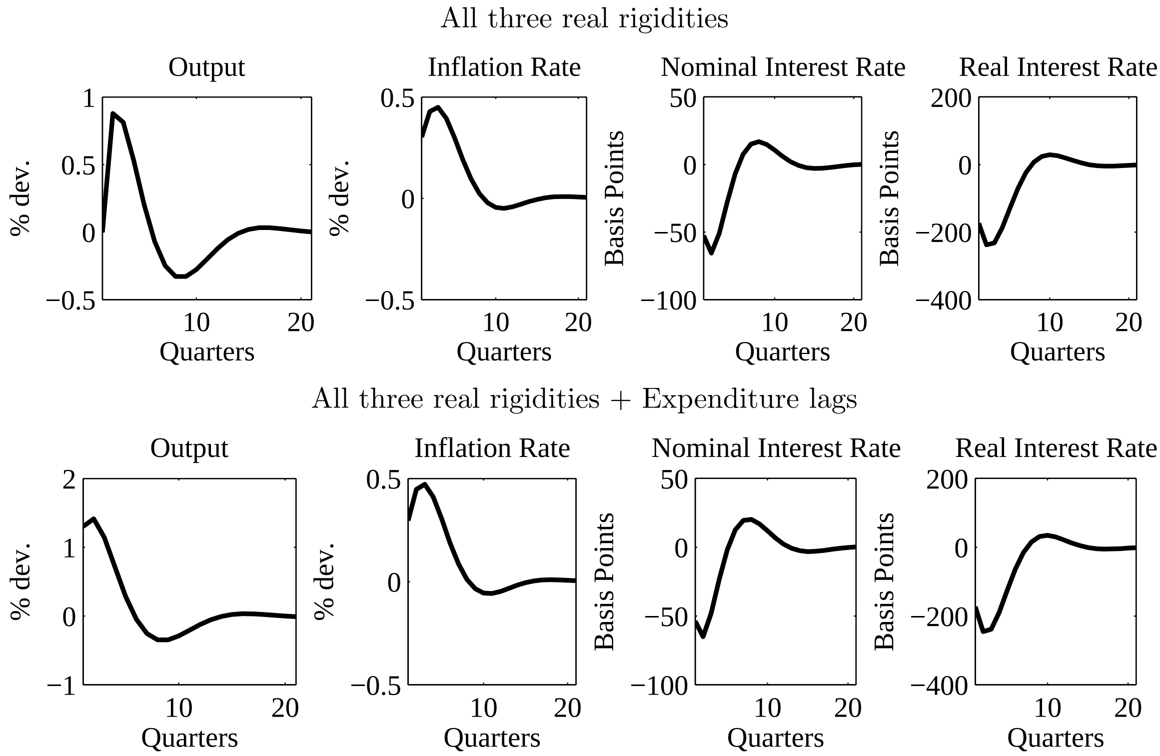

Table 2: Moments: Price rigidity

Var.	Std	Rel. Std.	$\rho(\cdot, y)$	$\rho(1)$	$\rho(2)$
All three real rigidities and expend. lags					
Baseline version					
y	2.02	1.00	1.00	0.88	0.67
c	0.76	0.38	0.84	0.88	0.65
i	4.62	2.28	0.88	0.93	0.79
h	1.79	0.89	0.69	0.61	0.33
π	0.53	0.26	0.43	0.55	0.27
R_{nom}	0.12	0.06	-0.50	0.84	0.54
R_{real}	0.61	0.30	-0.48	0.62	0.33
Backward indexation					
y	2.43	1.00	1.00	0.84	0.59
c	0.90	0.37	0.88	0.87	0.60
i	5.02	2.06	0.87	0.93	0.76
h	1.42	0.58	0.79	0.72	0.41
π	0.54	0.22	0.59	0.85	0.55
R_{nom}	0.19	0.08	-0.82	0.79	0.41
R_{real}	0.68	0.28	-0.70	0.83	0.51

Figure 5: Wage rigidity, **baseline version**. Adding real rigidities to the basic NK model

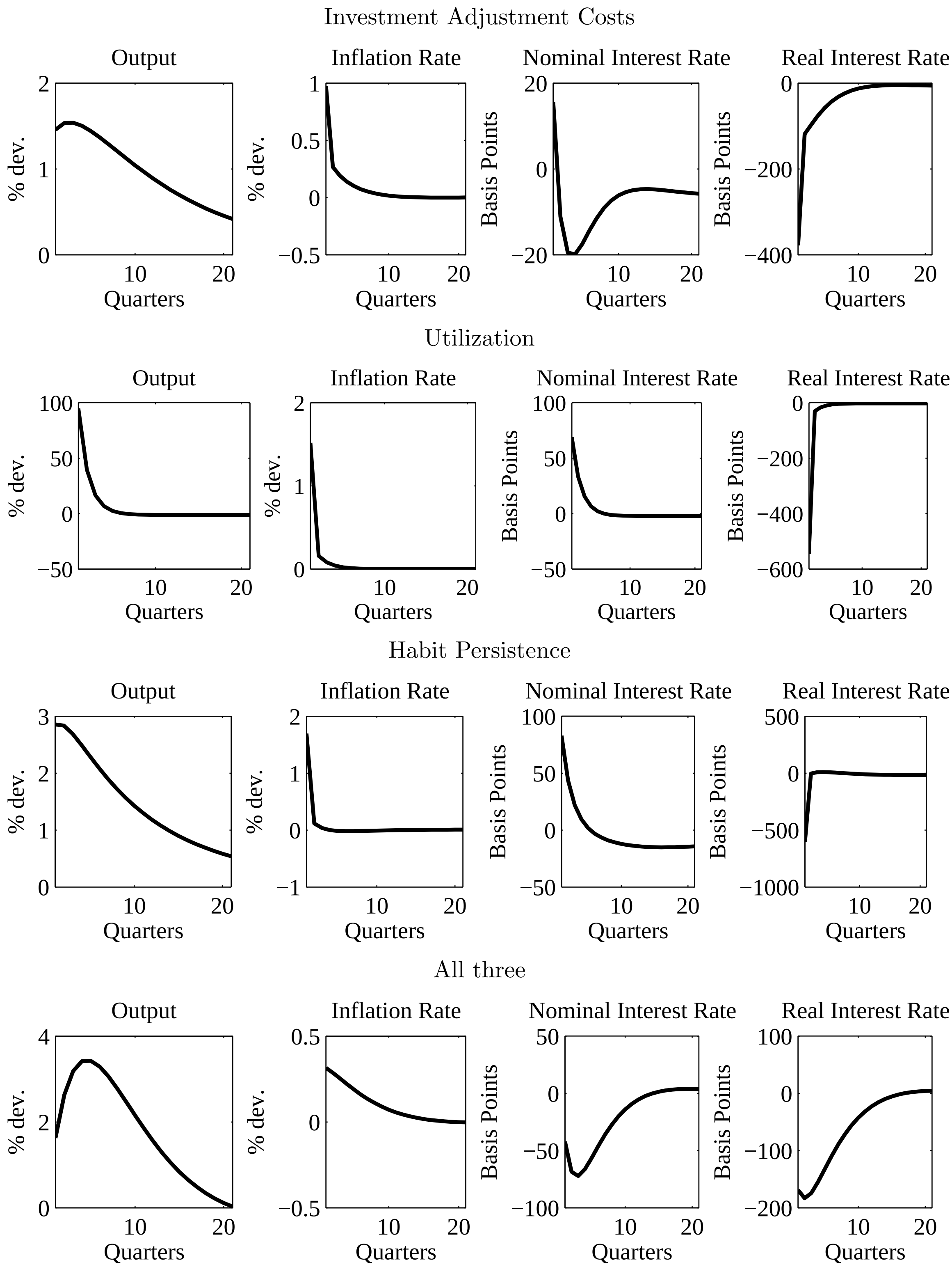

Figure 6: Wage rigidity, **backward** indexation. Adding real rigidities

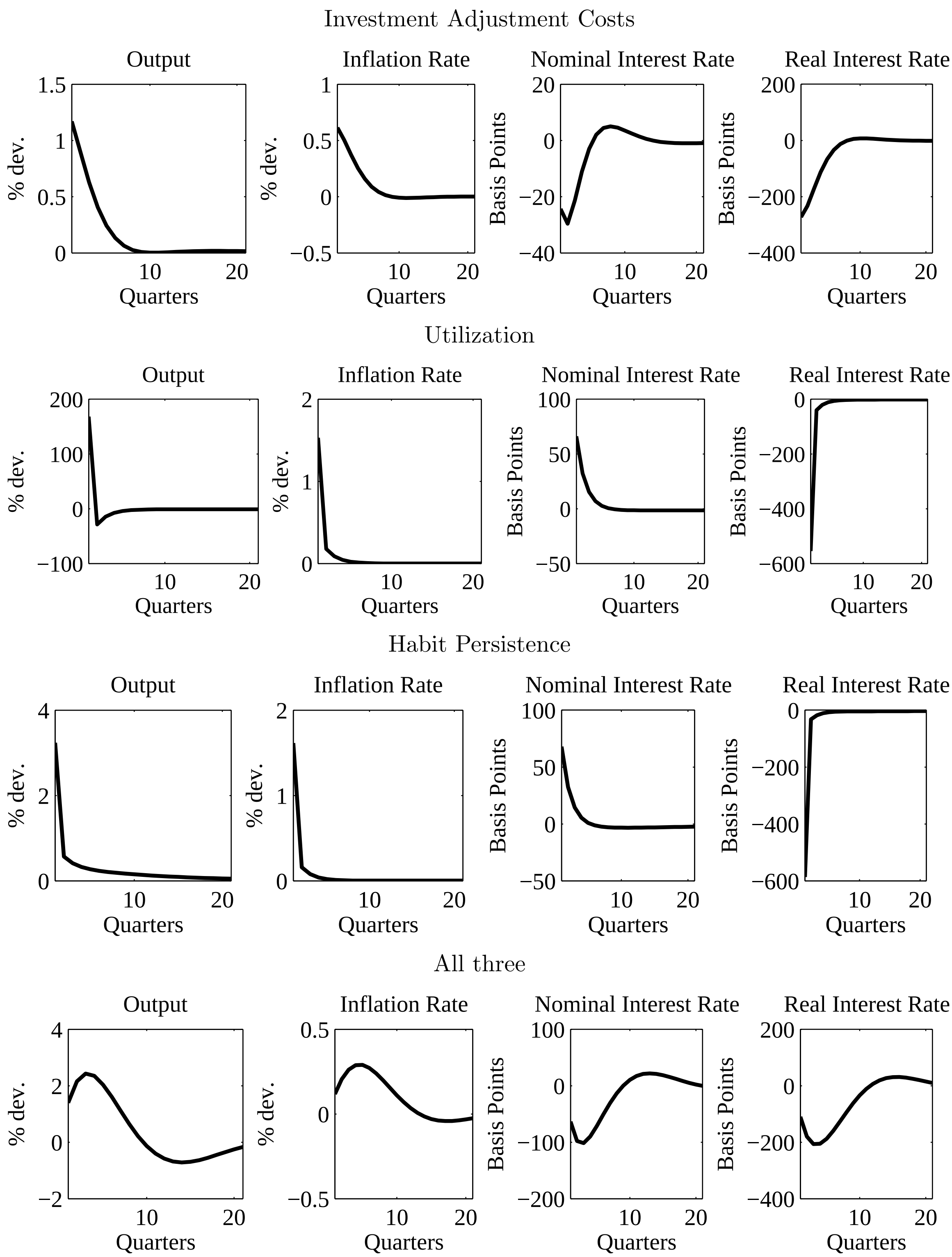

Table 3: Moments: Wage rigidity

Var.	Std	Rel. Std.	$\rho(\cdot, y)$	$\rho(1)$	$\rho(2)$
All three real rigidities and expend. lags					
Baseline version					
y	5.23	1.00	1.00	0.92	0.75
c	2.06	0.39	0.92	0.88	0.66
i	14.13	2.70	0.94	0.94	0.80
h	4.47	0.85	0.96	0.92	0.75
π	1.14	0.22	0.26	-0.03	-0.05
R_{nom}	0.33	0.06	-0.71	0.74	0.48
R_{real}	1.13	0.22	-0.47	0.11	0.06
Backward indexation					
y	10.58	1.00	1.00	0.93	0.76
c	4.24	0.40	0.96	0.91	0.72
i	27.89	2.64	0.96	0.94	0.79
h	9.52	0.90	0.99	0.93	0.77
π	1.29	0.12	0.08	0.67	0.38
R_{nom}	0.71	0.07	-0.97	0.92	0.73
R_{real}	1.47	0.14	-0.54	0.75	0.48

5 Appendix

Figure 7: Price rigidity, information lags, all real rigidities: The baseline model.