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Habit Persistence in Consumption in a Sticky Price Model of the Business Cycle*

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Abstract

This paper examines the role of habit persistence in consumption in explaining persistent responses of inflation and output to money growth shocks. A monetary stochastic dynamic general equilibrium (DGE) model with a money-in-the-utility-function (MIU-) setup is augmented by habit formation in consumption and evaluated for both Taylor and Calvo price staggering. It is shown that in the benchmark Taylor price staggering model consumption displays a persistent response while the volatility falls short empirical estimates. The reaction of most other aggregates including output, inflation and prices is counterfactually cyclical. Investment, labor hours and the real wage are too strongly correlated with output. In the benchmark Calvo price staggering model consumption is hump-shaped. Most variables are persistent and consumption shows a higher standard deviation. In sum, habit persistence in consumption improves the model outcome with respect to consumption's reaction while Calvo staggering improves the ability of a DGE model to explain persistent reactions of the other macroeconomic aggregates to money growth shocks.

JEL classification: E52

Keywords: Monetary Policy, New Neoclassical Synthesis, Sticky Prices, Transmission Mechanism, Habit Persistence

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1 Introduction

Can money growth shocks generate persistent responses of inflation and output? This question has been addressed in a number of papers in the last few years. The most prominent paper is the one of Chari, Kehoe and McGrattan (2000) who conclude that standard models with staggered prices generate only a positive output reaction for the time of exogenous price stickiness. Several attempts have been made to challenge this result.

Recently Christiano, Eichenbaum and Evans (2003) have developed a stochastic DGE model that is capable of generating the observed persistence of monetary shocks in US data. With an average duration of two to three quarters wage contracts are the critical nominal friction, not price contracts. If inertia in inflation and output persistence is the main goal to match then they show that variable capital utilization is most important. To explain the reaction of all variables they include habit persistence in consumption as well as adjustment costs in investment. It should be noted that these authors use a limited information econometric strategy that is not yet common in the literature so that the results are difficult to compare to existing studies.

The problem with this approach is that it is difficult to disentangle the specific role of several model components in generating persistent output responses. The authors do perform some sensitivity analysis but they do it by dropping only one or two model features while maintaining the other building blocks. But it would be interesting to study the implications of habit formation in consumption in a simple sticky price model in isolation. This is done in this paper. It turns out that habit formation in consumption only improves the response of consumption to a monetary policy shock. Under Taylor price staggering output and inflation responses are very strong on impact and are cyclical thereafter. The business cycle properties do not match well empirical estimates. With Calvo price staggering, however, all variables are persistent and display reasonable autocorrelations. Thus, it is important how to model sticky prices in a monetary DGE model of the business cycle.

Bouakez, Cardia and Ruge-Murcia (2002) have estimated a similar model to the one presented here using US data. In addition to habit formation they consider the influence of adjustment costs of capital on the persistence of output after a money growth shock. They conclude that both features give rise to a hump-shaped response of output to a money growth shock. This result cannot be supported. While consumption shows a hump under Calvo staggering output does not. This could probably be due to the way capital adjustment costs are modeled. Different results are also possible because these authors estimate the model while it is calibrated here.

McCallum and Nelson (1999) incorporate habit formation in an open economy model of nominal income targeting and find an important role for increasing the ability to match quarterly US data.

Auray, Collard and Fève (2002) consider habit formation in conjunction with a cash-in-advance (CIA-) model to explain the liquidity effect. They show that high enough habit persistence can generate a falling nominal interest rate after a positive money growth shock but that it leads also to real indeterminacy. In the model at hand the nominal rate rises. The difference may be due to the fact that these authors do not incorporate sticky prices. In a related paper Auray, Collard and Fève (2004) show that in a MIU-model there is always determinacy of the equilibrium.

The paper is organized as follows: Section 2 describes in detail the models, the steady state and the calibration. In Section 3 impulse responses are discussed while Section 4 gives results for the business cycle properties of the models. Section 5 concludes and gives some suggestions for future research.

2 The Models

The economy is assumed to consist of a representative household, a finished goods producing firm, intermediate goods producing firms and a monetary authority. The household faces the problem of maximizing life-time utility given an intertemporal budget constraint. The finished goods firm produces the final good which will be consumed by the household using the intermediate goods as inputs. It operates under perfect competition. The intermediate goods firms work with a Cobb-Douglas technology using labor and capital as inputs and operate under monopolistic competition. Their pricing units optimally set the price for two periods. This problem will be either solved as in Taylor (1980) – which will be labeled Taylor staggering – or as in Calvo (1983), accordingly labeled Calvo staggering. Monetary policy is assumed to be exogenous and given by a stochastic process of the money growth rate. It is the source of disturbance to which the economy reacts optimally. Business cycles thus arise as optimal responses of households and firms to shocks to the money growth rate.

2.1 The Household

The representative household is assumed to have preferences over consumption (c_t), leisure $(1 - n_t)$ (where n_t is labor) and real money balances M_t/P_t since they facilitate transactions. This MIU-specification was - among others - proposed by Sidrauski (1967). Here I use the simplest specification in a separable form – an additively separable constant relative risk aversion (CRRA) function – since a more complicated nonseparable variant does not enhance much - if at all - the persistence effects of money growth shocks in standard sticky price models. A MIU-setup is used because there is the problem of real indeterminacy in CIA-models with habit persistence, see Auray, Collard and Fève (2002) and the discussion above.

$$u\left(c_t, c_{t-1}, \frac{M_t}{P_t}, n_t\right) = \frac{1}{1-\sigma}\left[\left(\frac{c_t}{c_{t-1}^b}\right)^{1-\sigma} + \gamma\left(1-n_t\right)^{1-\sigma} + \left(\frac{M_t}{P_t}\right)^{1-\sigma}\right] \quad (1)$$

As usual σ governs the degree of risk aversion. γ is a positive parameter while b is a measure for the degree of habit persistence. Lagged consumption c_{t-1} is the habit reference level while b indexes the importance of this reference level relative to current consumption. With $b = 0$ the standard model with actual consumption c_t only results, but with $b = 1$ only consumption relative to previous consumption matters. This can be seen more clearly when rewriting the consumption term as

$$\left(\frac{c_t}{c_{t-1}^b}\right) = \left(\frac{c_t}{c_{t-1}} c_{t-1}^{1-b}\right) \quad (2)$$

Now with $b = 1$ the second term with lagged consumption has no influence any more so that the *level* of c_{t-1} does not matter. b cannot exceed 1 because otherwise steady state utility would be falling in consumption.[1]

This formulation of habit persistence neglects the possibility of memory in the habit reference level. Fuhrer (2000) considers the more general case introducing a new variable S_t for the reference level replacing c_{t-1} in (1). He assumes then that S_t evolves according to

$$S_t = \rho S_{t-1} + (1-\rho)\, c_{t-1} \quad (3)$$

With $\rho = 0$ only last period's consumption matters while for higher ρ past period's consumption levels become more and more important. Using this

[1] McCallum and Nelson (1999) also use this formulation for modeling habit persistence.

formulation leads to a very complex Euler equation which will not be used in this paper (see e.g. Fuhrer (2000), p. 371).

Some authors (e.g. Christiano, Eichenbaum and Evans (2003)) consider the difference in consumption levels in the utility function, not the ratio. So the term corresponding to (2) looks like

$$c_t - hc_{t-1} \tag{4}$$

Deaton (1992) shows that this is a special case of the Fuhrer (2000) formulation where h captures both the influence of b and ρ. It is the result when setting $\rho = 1$ so that there is no 'depreciation' of the habit reference level. In the model considered here persistence in habits does not have a great influence on the dynamics so it will not be used.[2]

The budget constraint is given by

$$\begin{aligned} & P_t c_t + P_t i_t + M_t + B_t \\ = \; & P_t w_t n_t + P_t z_t k_{t-1} + M_{t-1} + (1 + R_{t-1}) B_{t-1} + \Xi_t + M_t^s \end{aligned} \tag{5}$$

where

$$\Xi_t = \int_0^1 \Xi_{j,t} dj \tag{6}$$

are the nominal profits of the intermediate goods producing firms. The household can invest i_t units of the final good to augment the capital stock k_t. Further it can decide how much to consume (c_t) and how much real money balances M_t/P_t and real bonds B_t/P_t to hold. The household has a labor income $w_t n_t$ working in the market at the real wage rate w_t and can spend its money holdings carried over from the previous period (M_{t-1}/P_t). It also receives factor payments $z_t k_{t-1}$ for supplying capital to intermediate goods producing firms where z_t denotes the real return on capital. There are also previous period bond holdings including the interest on them $(1 + R_{t-1})(B_{t-1}/P_t)$. Finally, the household receives a monetary transfer M_t^s from the monetary authority and the profits form the intermediate goods firms Ξ_t, respectively. This transfer is equal to the change in money balances, i.e.

$$M_t^s = M_t - M_{t-1} \tag{7}$$

[2]See Deaton (1992), p. 30.

The capital stock increases according to the following law of motion:

$$k_t = (1-\delta)\,k_{t-1} + \phi\left(\frac{i_t}{k_{t-1}}\right)k_{t-1} \tag{8}$$

There are costs of adjusting the capital stock which are captured by the ϕ function. δ is the rate of depreciation. The detailed properties will be discussed in the calibration subsection.[3] Because this equation cannot be explicitly solved for i_t a second Lagrange multiplier (θ_t) has to be introduced into the optimization problem of the household. The Lagrangian is then given by:

$$\begin{aligned} L &= E_0\Bigg[\sum_{t=0}^{\infty}\beta^t u\left(c_t, c_{t-1}, m_t, n_t\right) \\ &+ \sum_{t=0}^{\infty}\beta^t\lambda_t\Bigg(z_t k_{t-1} + w_t n_t + m_{t-1}\frac{P_{t-1}}{P_t} + \frac{\Xi_t}{P_t} + m_t^s \\ &\quad + (1+R_{t-1})\,b_{t-1}\frac{P_{t-1}}{P_t} - c_t - i_t - m_t - b_t\Bigg) \\ &+ \sum_{t=0}^{\infty}\beta^t\theta_t\left((1-\delta)\,k_{t-1} + \phi\left(\frac{i_t}{k_{t-1}}\right)k_{t-1} - k_t\right)\Bigg] \end{aligned} \tag{9}$$

Here small variables indicate real quantities, i.e. for example $m_t = M_t/P_t$. Households optimize over c_t, n_t, i_t, k_t, m_t and b_t taking prices and the initial values of the price level P_0 and the capital stock k_0 as well as the outstanding stocks of money M_0 and bonds B_0 as given. The first order conditions are reported below.

$$\frac{\partial L}{\partial c_t} = \beta^t\frac{\partial u\left(c_t, c_{t-1}, m_t, n_t\right)}{\partial c_t} + \beta^{t+1}\frac{\partial u\left(c_{t+1}, c_t, m_{t+1}, n_{t+1}\right)}{\partial c_t} - \beta^t\lambda_t = 0 \tag{10}$$

$$\frac{\partial L}{\partial n_t} = \beta^t\frac{\partial u\left(c_t, c_{t-1}, m_t, n_t\right)}{\partial n_t} + \beta^t\lambda_t w_t = 0 \tag{11}$$

$$\frac{\partial L}{\partial i_t} = -\beta^t\lambda_t + \beta^t\theta_t\phi'\left(\frac{i_t}{k_{t-1}}\right)\left(\frac{1}{k_{t-1}}\right)k_{t-1} = 0 \tag{12}$$

[3]Bouakez, Cardia and Ruge-Murcia (2002), p. 4, assume a quadratic and strictly convex adjustment cost function.

$$\frac{\partial L}{\partial k_t} = E_t\beta^{t+1}\lambda_{t+1}z_{t+1} - \beta^t\theta_t + E_t\beta^{t+1}\theta_{t+1}\Bigg[(1-\delta) + \phi\left(\frac{i_{t+1}}{k_t}\right) + \phi'\left(\frac{i_{t+1}}{k_t}\right)\left(-\frac{i_{t+1}}{k_t^2}\right)k_t\Bigg] = 0 \tag{13}$$

$$\frac{\partial L}{\partial m_t} = \beta^t\frac{\partial u\left(c_t, c_{t-1}, m_t, n_t\right)}{\partial m_t} - \beta^t\lambda_t + E_t\beta^{t+1}\lambda_{t+1}\frac{P_t}{P_{t+1}} = 0 \tag{14}$$

$$\frac{\partial L}{\partial b_t} = -\beta^t\lambda_t + E_t\beta^{t+1}\lambda_{t+1}\left(1+R_t\right)\frac{P_t}{P_{t+1}} = 0 \tag{15}$$

The derivative with respect to λ_t is omitted since it is equal to the intertemporal budget constraint. The derivative with respect to θ_t is not reported again since it is given by the capital accumulation condition stated above. ϕ' denotes the derivative of the ϕ-function with respect to the investment to capital ratio which is regarded as one argument. Note the different consumption Euler equation. Due to habit formation the marginal utility of consumption enters two times indicating the influence of last period's consumption on today's utility. In addition the household's optimal choices must also satisfy the transversality conditions:

$$\lim_{t\to\infty}\beta^t\lambda_t x_t = 0 \qquad \text{for } x = m, b, k \tag{16}$$

The familiar result that the first two efficiency conditions imply the equality of the marginal rate of substitution between consumption and labor and the real wage is altered here through the influence of habit formation in consumption. The real wage is now given by

$$w_t = -\frac{\frac{\partial u(c_t,c_{t-1},m_t,n_t)}{\partial n_t}}{\frac{\partial u(c_t,c_{t-1},m_t,n_t)}{\partial c_t} + \beta\frac{\partial u(c_{t+1},c_t,m_{t+1},n_{t+1})}{\partial c_t}} \tag{17}$$

Note that the marginal utility of consumption enters twice in the denominator which alters the dynamic evolution of w_t.
The efficiency condition for bond holdings establishes a relation between the nominal interest rate and the price level. Rearranging terms yields

$$(1+R_t) = \frac{\lambda_t}{\lambda_{t+1}}\frac{1}{\beta}\frac{P_{t+1}}{P_t} \tag{18}$$

Supposed the Fisher equation is valid the real interest rate r_t is implicitly defined as

$$(1+r_t) = \frac{\lambda_t}{\lambda_{t+1}}\frac{1}{\beta} \tag{19}$$

because P_{t+1}/P_t equals one plus the rate of expected inflation which is approximated by the ex-post-inflation rate.

In the efficiency condition for money the marginal utility of real balances has to be considered. This derivative determines the endogenous money demand function. Combining the optimum conditions for consumption, bonds and money yields the following equation:

$$\begin{aligned}\frac{\partial u\left(c_t, c_{t-1}, m_t, n_t\right)}{\partial m_t} &= \left[\frac{\partial u\left(c_t, c_{t-1}, m_t, n_t\right)}{\partial c_t}\right.\\ &\quad \left.+\beta\frac{\partial u\left(c_{t+1}, c_t, m_{t+1}, n_{t+1}\right)}{\partial c_t}\right]\frac{R_t}{1+R_t} \qquad (20)\end{aligned}$$

In principal this specification allows to estimate an empirical money demand function. But this approach will not be pursued here since the dynamic structure involves consumption at three different points in time, a specification normally not considered to be appropriate for the estimation of an empirical money demand function. In addition the utility function (1) has been chosen such that there is no need for an estimation of further parameters. There is no parameter on real money balances and γ can be determined endogenously.

2.2 The Finished Goods Producing Firm

The firm producing the final good y_t in the economy uses $y_{j,t}$ units of each intermediate good $j \in [0,1]$ purchased at price $P_{j,t}$ to produce y_t units of the finished good. The production function is assumed to be a CES aggregator as in Dixit and Stiglitz (1977) with $\epsilon > 1$.

$$y_t = \left(\int_0^1 y_{j,t}^{(\epsilon-1)/\epsilon} dj\right)^{\epsilon/(\epsilon-1)} \qquad (21)$$

The firm maximizes its profits over $y_{j,t}$ given the above production function and given the price P_t. So the problem can be written as

$$\max_{y_{j,t}} \left[P_t y_t - \int_0^1 P_{j,t} y_{j,t} dj\right] \text{ s.t. } \quad y_t = \left(\int_0^1 y_{j,t}^{(\epsilon-1)/\epsilon} dj\right)^{\epsilon/(\epsilon-1)} \qquad (22)$$

The first order conditions for each good j imply

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon} y_t \qquad (23)$$

where $-\epsilon$ measures the constant price elasticity of demand for each good j. Since the firm operates under perfect competition it does not make any profits. Inserting the demand function into the profit function and imposing the zero profit condition reveals that the only price P_t that is consistent with this requirement is given by

$$P_t = \left(\int_0^1 P_{j,t}^{(1-\epsilon)} dj \right)^{1/(1-\epsilon)} \tag{24}$$

2.3 The Intermediate Goods Producing Firm

Intermediate goods firms can be considered to consist of a producing and a pricing unit. The producing unit is the same for both contract schemes and it will be presented in the next subsection. The pricing unit operates differently for Taylor and Calvo staggering and will thus be discussed separately in the following subsections.

2.3.1 The Producing Unit

The producing unit operates under a Cobb-Douglas-technology which is subject to an aggregate random productivity shock a_t.

$$y_{j,t} = a_t n_{j,t}^{\alpha} k_{j,t-1}^{1-\alpha} \tag{25}$$

Here $n_{j,t}$ is the labor input employed in period t by a firm who set the price in period $t-j$, similarly $k_{j,t-1}$ is the capital stock, and $0 < \alpha < 1$ is labor's share.

The producing unit chooses labor and capital to minimize costs. In models with capital the problem is given by

$$\begin{aligned} &\min_{n_{j,t},k_{j,t-1}} \left[P_{j,t} w_{j,t} n_{j,t} + P_{j,t} z_{j,t} k_{j,t-1} \right] \\ &\text{s.t.} \quad y_{j,t} = a_t n_{j,t}^{\alpha} k_{j,t-1}^{1-\alpha} \end{aligned} \tag{26}$$

It is useful for further calculations to define nominal marginal cost as $\Psi_{j,t}$ which is equal to the Lagrange multiplier in the cost minimization problem stated above. The efficiency conditions are the following:

$$P_{j,t} w_{j,t} = \Psi_{j,t} \alpha a_t n_{j,t}^{\alpha-1} k_{j,t-1}^{1-\alpha} \tag{27}$$

$$P_{j,t} z_{j,t} = \Psi_{j,t} (1-\alpha) a_t n_{j,t}^{\alpha} k_{j,t-1}^{-\alpha} \tag{28}$$

In a symmetric equilibrium all choices of the producing unit of the firms are the same so that

$$P_{j,t} = P_t, w_{j,t} = w_t, z_{j,t} = z_t, \Psi_{j,t} = \Psi_t, n_{j,t} = n_t, k_{j,t-1} = k_{t-1} \text{ for all } t \quad (29)$$

So (27) and (28) hold with all j's eliminated.

2.3.2 The Pricing Unit under Taylor Staggering

The pricing unit sets prices to maximize the present discounted value of profits. Those firms who do not adjust their prices in a given period can be interpreted as passive while those who do adjust do so optimally. Define the relative price by $p_{j,t} = P_{j,t}/P_t$. Because the production functions are homogenous of degree one real profit $\xi_{j,t} = \Xi_{j,t}/P_t$ for a firm of type j is equal to

$$\xi_{j,t} = \xi\left(p_{j,t}, y_t, \psi_t\right) = p_{j,t}y_{j,t} - \psi_t y_{j,t} \quad (30)$$

where $\psi_t = \Psi_t/P_t$ is real marginal cost. Using the demand function for the intermediate goods $\left(y_{j,t} = p_{j,t}^{-\epsilon}y_t\right)$ the profit function can be rewritten as

$$\xi_{j,t} = \xi\left(p_{j,t}, y_t, \psi_t\right) = y_{j,t}\left(p_{j,t} - \psi_t\right) = p_{j,t}^{-\epsilon}y_t\left(p_{j,t} - \psi_t\right) \quad (31)$$

When prices are fixed for two periods the firm has to take into account the effect of the price chosen in period t on current and future profits. The price in period $t+1$ will be affected by the gross inflation rate Π_{t+1} between t and $t+1$ ($\Pi_{t+1} = P_{t+1}/P_t$).

$$p_{1,t+1} = \frac{p_{0,t}}{\Pi_{t+1}} \quad (32)$$

The optimal relative price has to balance the effects due to inflation between profits today and tomorrow. This intertemporal maximization problem is formally given by

$$\begin{aligned} &\max_{p_{0,t}} E_t\left[\xi\left(p_{0,t}, y_t, \psi_t\right) + \beta\frac{\lambda_{t+1}}{\lambda_t}\xi\left(p_{1,t+1}, y_{t+1}, \psi_{t+1}\right)\right] \\ &\text{s.t.} \quad p_{1,t+1} = \frac{p_{0,t}}{\Pi_{t+1}} \end{aligned} \quad (33)$$

The term $\beta\lambda_{t+1}/\lambda_t$ is the appropriate discount factor for real profits.[4] Solving the efficiency condition for the optimal price to be set in period t using (31)

[4]See Dotsey, King and Wolman (1999), p. 659-665 as well as Dotsey, King and Wolman (1997), p. 9-13 for details.

yields a forward-looking form of the price equation which is in that respect similar to the one in Taylor (1980).

$$P_{0,t} = \frac{\epsilon}{\epsilon - 1} \frac{\lambda_t P_t^{\epsilon} y_t \psi_t + \beta E_t \lambda_{t+1} P_{t+1}^{\epsilon} y_{t+1} \psi_{t+1}}{\lambda_t P_t^{\epsilon-1} y_t + \beta E_t \lambda_{t+1} P_{t+1}^{\epsilon-1} y_{t+1}} \tag{34}$$

The optimal price $P_{0,t}$ depends upon the current and future real marginal costs, current and future price levels and output as well as today's and tomorrow's interest rates captured by the λ's.

With prices set for two periods half of the firms adjust their price in period t and half do not. Moreover all adjusting firms choose the same price. Then $P_{j,t}$ is the nominal price at time t of any good whose price was set j periods ago and P_t is the price index (24) at time t and is given by

$$P_t = \left(\frac{1}{2} P_{0,t}^{1-\epsilon} + \frac{1}{2} P_{1,t}^{1-\epsilon} \right)^{1/(1-\epsilon)} \tag{35}$$

2.3.3 The Pricing Unit under Calvo Staggering

Under Calvo pricing there exists a constant probability φ that firms are not able to change their price so that $P_{j,t} = P_{j,t-1}$.[5] With a probability of $1 - \varphi$ firms may reset their price independent of the time foregone since the last change in prices. Real profits can again be written as in (31) but it is useful to use the nominal prices as profits have to be evaluated s periods in the future.

$$\xi_{j,t+s} = \xi \left(p_{j,t+s}, y_{t+s}, \psi_{t+s} \right) = y_{j,t+s} \left(\frac{P_{j,t+s}}{P_{t+s}} - \psi_{t+s} \right) \tag{36}$$

The demand functions for the intermediate goods in period $t+s$ are given by

$$y_{j,t+s} = P_{j,t+s}^{-\epsilon} P_{t+s}^{\epsilon} y_{t+s} = P_{0,t}^{-\epsilon} P_{t+s}^{\epsilon} y_{t+s} \tag{37}$$

The last equality holds because the price $P_{j,t} = P_{0,t}$ has not been changed for s periods. Inserting these demand functions into the profit function yields

$$\xi_{j,t+s} = P_{0,t}^{1-\epsilon} P_{t+s}^{\epsilon-1} y_{t+s} - \psi_{t+s} P_{0,t}^{-\epsilon} P_{t+s}^{\epsilon} y_{t+s} \tag{38}$$

[5] Some authors assume an indexation rule for these firms so that $P_{j,t} = \bar{\Pi} P_{j,t-1}$ where $\bar{\Pi}$ is the inflation factor, see e.g. Kim (2003). Others like Christiano, Eichenbaum and Evans (2003) propose an indexation rule that allows for a variable gross inflation rate Π_{t-1} to account for inertia in inflation. Since in the model here inflation is zero at the steady state these extensions are not considered.

Now firms can reset their prices with a probability of $1-\varphi$. With probability φ they could not change their price so with a probability of φ^s their old price is still valid in a period s. But differently $P_{0,t}$ influences a firm j's profits as long as it cannot reoptimize its price. The probability that this occurs for s periods in given by φ^s. Accordingly the intertemporal profit maximization problem can be written as follows:

$$\max_{P_{0,t}} E_t \left[\sum_{s=0}^{\infty} (\beta\varphi)^s \frac{\lambda_{t+s}}{\lambda_t} \xi_{j,t+s} \right] \tag{39}$$

Intermediate goods firms maximize the present value of their profits as under Taylor staggering but now for an infinite horizon. In analogy to Taylor pricing $\beta^s \lambda_{t+s}/\lambda_t$ is the appropriate discount factor. Using (38) and rearranging the optimal reset price is given by

$$P_{0,t} = \frac{\epsilon}{\epsilon - 1} \frac{\sum\limits_{s=0}^{\infty} (\beta\varphi)^s E_t \lambda_{t+s} P_{t+s}^{\epsilon} y_{t+s} \psi_{t+s}}{\sum\limits_{s=0}^{\infty} (\beta\varphi)^s E_t \lambda_{t+s} P_{t+s}^{\epsilon-1} y_{t+s}} \tag{40}$$

Using the pricing rule for non-adjusting firms $P_{j,t} = P_{j,t-1}$ the price level (24) can be written as follows[6]

$$P_t = \left[\varphi P_{t-1}^{1-\epsilon} + (1-\varphi) P_{0,t}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \tag{41}$$

One can now combine the optimum condition and the price level equation to derive the so called New Keynesian Phillips curve **as a Taylor approximation**.[7]

$$\widehat{\pi}_t = (1-\varphi)(1-\beta\varphi)\varphi^{-1}\widehat{\psi}_t + \beta E_t \widehat{\pi}_{t+1} \tag{42}$$

This result is very important. Note that output, the optimal price and the Lagrange multiplier λ do not show up in this equation. It is the typical forward-looking Phillips curve where inflation $\widehat{\pi}_t$ depends on the expected inflation rate and on real marginal costs. Remember that Bouakez, Cardia and Ruge-Murcia (2002) also use this type of a New Keynesian Phillips curve.

[6] This requires very tedious algebra. See Calvo (1983).

[7] A formal derivation of this equation can be found in the appendix of Schabert (2001) and also in Walsh (2003), p. 263-266. The same formula is obtained in Christiano, Eichenbaum and Evans (2003) while Kim (2003) uses a different way to solve the dynamic system.

2.4 Market Clearing Conditions and Other Equations

The aggregate resource constraint is derived using the resource constraint of households, firms, the government and the monetary authority. Since there are neither government expenditures nor taxes in this model, this condition is given by

$$y_t = c_t + i_t \tag{43}$$

It is well known that models like the one at hand imply multiple equilibria and sunspots because bonds are not determined. To escape this problem the household budget constraint is dropped and bonds are set to zero: $b_t = 0$ for all t.

The markup μ_t is just the reciprocal of real marginal cost so that

$$\mu_t = \frac{1}{\psi_t} \tag{44}$$

2.5 The Monetary Authority

The model is closed by adding a monetary policy rule. Therefore an exogenous process for the money growth rate is considered. To achieve persistent but non permanent effects the level of money follows an AR(2)-process. Assume that money grows at a factor g_t:

$$M_t = g_t M_{t-1} \tag{45}$$

If $\widehat{g}_t$ follows an AR(1)-process $\widehat{g}_t = \rho_g \widehat{g}_{t-1} + \epsilon_{g_t}$ then money will follow an AR(2)-process.[8] As before ρ_g lies between 0 and 1 and ϵ_{g_t} is white noise. Remember that inflation is zero at the steady state so also money growth is zero there ($g = 1$).

The productivity shock a_t follows an AR(1)-process

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + \epsilon_{a_t} \tag{46}$$

with ϵ_{a_t} white noise and $0 < \rho_a < 1$.

[8] A hat ($\widehat{\ }$) represents the relative deviation of the respective variable from its steady state (see the Appendix).

2.6 The Steady State

Imposing the condition of constancy of the price level in the steady state ($P_t = P_{t-1} = P$) on the nominal interest rate equation reveals the familiar condition from RBC models that $\beta = 1/(1+R)$. In addition, as there is no steady state inflation, $R = r$. The two period price setting of the firms implies $P_0 = P_1$. Using this in the price index reveals that $P_0 = P_1 = P$. The capital accumulation equation tells us that $\phi(i/k) = \delta$ at the steady state. It is assumed that $\phi' = 1$ in the steady state to ensure that Tobin's q is equal to one ($q = 1/\phi'$). As a consequence of the requirement that the model with adjustment costs of capital should display the same steady state as the model without them i/k is equal to $\phi(i/k)$. Using this in the efficiency condition for capital it can be shown that the rental rate on capital is $z = r + \delta$ as in a standard RBC model. With the help of (27) and the steady state for z it is possible to pin down k/n which amounts to

$$\frac{k}{n} = \left(\frac{r+\delta}{a}\frac{1}{1-\alpha}\frac{1}{\psi}\right)^{-1/\alpha} \tag{47}$$

For the markup μ it follows $\mu = 1/\psi$ while ψ is determined by the steady state of the efficiency condition for maximizing profits, (34). This amounts to $\psi = (\epsilon - 1)/\epsilon$. This can be used to calculate w as well:

$$w = \psi a \alpha \left(\frac{k}{n}\right)^{1-\alpha} \tag{48}$$

The calculation of the steady state value of consumption is tedious because it takes quite a lot of steps. From the production function one knows that labor productivity is given by

$$\frac{y}{n} = a\left(\frac{k}{n}\right)^{1-\alpha} \tag{49}$$

This productivity can be combined with the investment to capital ratio to calculate the investment share:

$$\frac{i}{y} = \left(\frac{i}{k}\frac{k}{n}\right) / \left(\frac{y}{n}\right) \tag{50}$$

Now one can derive the consumption share using the aggregate resource constraint.

$$\frac{c}{y} = -\frac{i}{y} + 1 \tag{51}$$

To get the level of c the level of y and i have to be determined: $y = n \cdot y/n$, $i = y \cdot i/y$. Finally $c = y - i$ is the consumption steady state value.

The marginal rate of substitution (17) between consumption and labor can also be used to calculate the preference parameter γ.

$$\gamma = (1 - \beta b)\, c^{\sigma b - \sigma - b} w\, (1 - n)^{\sigma} \tag{52}$$

Using the efficiency condition for money m depends only upon β, b, c and σ and can be written as

$$m = (1 - \beta)^{-\frac{1}{\sigma}} (1 - \beta b)^{-\frac{1}{\sigma}} c^{\frac{\sigma + b - \sigma b}{b}} \tag{53}$$

2.7 Calibration

To compute impulse responses the parameters of the model have to be calibrated.

It is possible to either specify β or r exogenously. Here β will be set to 0.99 implying a value of r of about 0.0101 per quarter which is in line with other values used for the real interest rate in the literature. ψ and μ can be determined by fixing a value for the elasticity of the demand functions for the differentiated products. This elasticity being equal to 4 causes the static markup $\mu = \epsilon/(\epsilon - 1)$ to be 1.33 which is in line with the study of Linnemann (1999) about average markups. In order to determine the steady state real wage w the productivity shock a has to be specified, along with calculating k/n, see below. As there is no information available about that parameter it is arbitrarily set at 10. n is specified to be equal to 0.25 implying that agents work 25 % of their non-sleeping time.

In the benchmark case, σ, the parameter governing the degree of risk aversion, is set to 2. The value of b which measures the degree of habit persistence is set to 0.8 as in McCallum and Nelson (1999) in the benchmark case, implying a value for γ of 0.1483.

As this model considers the role of capital accumulation several other technological parameters have to be calibrated. The most common one is the depreciation rate δ which is set to 0.025 implying 10% depreciation per year. Labor's share α is 0.64 whereas the elasticity of Tobin's q with respect to i/k is set to -0.5.[9] This value is also used in King and Wolman (1996). The presence of adjustment costs of capital dampens the volatility of investment

[9] It can be shown that this elasticity is given by $-[\phi''/\phi' \cdot (i/k)]$.

and is a common feature in equilibrium business cycle models. Using r, δ, a, α and ψ the ratio k/n can be determined.

For the Calvo model the probability that firms can reset their price is given by $1-\varphi = 1/3$. The probability that a price is still in effect in a period s is given by $(1-\varphi)\,\varphi^s$ because with $1-\varphi$ the price was once set optimally. So the average duration is given by $(1-\varphi)\sum_{s=0}^{\infty} s\varphi^s = \varphi/\,(1-\varphi)$.[10] This implies an average duration of price contracts of 2. Thus prices are on average fixed the same period of time as in the Taylor pricing version of the model. For the exogenous money growth process $\rho_g = 0.5$ is used. As the focus of the paper is on the persistence effects of money growth shocks productivity shocks will not be considered. But they can be used to check whether the model displays reasonable impulse responses to technology shocks.

3 Impulse Response Functions

The solution is conducted using an extended version of the algorithm of King, Plosser and Rebelo (2002) which allows for singularities in the system matrix of the reduced model. This algorithm builds upon the Blanchard and Kahn (1980) approach for solving a system of linear stochastic difference equations. The theoretical background is developed in King and Watson (1999) whereas computational aspects and the implementation are discussed in King and Watson (2002). The results will be discussed using impulse responses. They are presented in the next two subsections.

3.1 Taylor Staggering

Figure 1 shows the reaction of output, investment, consumption and labor hours to a one percent shock to the money growth rate. The immediate impression is the cyclical responses of $\widehat{y}_t, \widehat{n}_t$ and $\widehat{i}_t$. They display almost no persistence at all. But consumption displays quite a persistent response although the magnitude is very small. Nevertheless the effects last for more than five periods. This is due to the habit formation in consumption. With the respective parameter b equal to 0.8 there is a sizeable influence of past period's consumption on today's utility so that households smooth their consumption expenditures. Using as a metric of persistence the ratio of the

[10] See Bénassy (2003), p. 12.

period $t+1$ reaction of a variable to the period t reaction as proposed by Andersen (2004) for two period contracts – defined as the contract multiplier in Huang and Liu (2002) – reveals a value of 0.42 for consumption.[11] Figure 2 mirrors the response of the real wage, the real interest rate, the markup and the nominal interest rate. Counterfactually the nominal rate rises so the model does not generate the liquidity effect. But this variable is quite persistent as opposed to the other three which are again cyclical. The strong rise in real marginal costs displayed in Figure 3 causes firms to raise prices very strongly. They overshoot their new equilibrium value considerably. This rise is stronger than the rise in money so real balances even fall and approach the steady state from below. The capital stock is hump-shaped but the magnitude of the increase is very small while nevertheless the effects are long lasting. Inflation does not show a hump but peaks in the first period, as shown in Figure 4.

Is there an intuition for this model result? To answer this question it is helpful to examine the dynamics of the real wage. Using (17) and inserting the marginal utilities of labor and consumption allows to derive the following equation:[12]

$$w_t = \frac{\gamma \left(1 - n_t\right)^{-\sigma}}{c_t^{-\sigma} c_{t-1}^{b(\sigma-1)} - \beta b c_{t+1}^{1-\sigma} c_t^{b(\sigma-1)-1}} \tag{54}$$

Now a positive money growth shock causes a rise in n since firms face higher demand and hire more workers. This leads to a rise in the numerator. The increase in consumption c_t leads to a decrease in the first term in the denominator whereas the second term decreases as long as $b < 1$ for $\sigma = 2$. But this second term is subtracted so that the overall effect is not definite. In addition there is an influence of future consumption c_{t+1} which increases as can be seen in Figure 1. This leads to a further decrease of the second term. c_{t-1} enters the first term but is unchanged in period t thus having no effect here. Overall as long as $b > 0$ the second term will dampen the decline of the numerator so that the rise of the real wage rate will be dampened as well. The impulse response of w_t reveals that the dampening effect is not very strong as the real wage deviates 1.25% from the steady state. As the money growth shock also leads to an increase in the demand for capital k

[11]The values of Andersen (2004) for output range between 0.55 and 0.87. A variable that is cyclical is not persistent at all in this definition. Note that Chari, Kehoe and McGrattan (2000) use a different definition of the contract multiplier.

[12]It should be kept in mind that w_t is also influenced from the production side.

the rental rate on capital z_t rises. This results in additional upward pressure on real marginal cost. $\widehat{\psi}_t$'s initial response is a 1.48% deviation from steady state.

There are three important special cases to be considered in (54). The first is $\sigma = 1$ which implies log linear utility. This will eliminate c_{t+1} as well as c_{t-1} so that the real wage rate will be solely determined by current consumption.

$$w_t = \frac{\gamma (1 - n_t)^{-1}}{c_t^{-1} - \beta b c_t^{-1}} \tag{55}$$

The impulse responses are presented in Figure 5. The exercise has little effect on the wage rate (1.27% deviation) but a dramatic effect on consumption that is cyclical again as output, investment and labor. The reason for this is that with $\sigma = 1$ consumption from the previous period c_{t-1} drops out of the dynamic system. This essentially eliminates consumption habits and thus persistence from the model. Because the rental rate $\widehat{z}_t$ rises stronger now real marginal cost also show an increased reaction of 1.79% deviation. The second limiting case is $b = 0$ which would eliminate habit persistence from the model.

$$w_t = \frac{\gamma (1 - n_t)^{-1}}{c_t^{-1}} = \frac{\gamma c_t}{(1 - n_t)} \tag{56}$$

Figure 6 displays the results. Now the real wage response is strongest (1.41%) because the rise in labor and in consumption can exert fully their influence as in the MIU-model of the labor only economy. In (55) the factor $1-\beta b = 0.208$ dampens consumption's rise on w_t. Comparing Figures 5 and 6 reveals a stronger reaction of output, labor and consumption with log linear utility than without habit persistence. This confirms the characteristic of habit persistence to dampen consumption's reaction.

Finally, the third important special case is given by assigning b the highest possible value of 1 so that only the ratio of current to past consumption matters (see the discussion of the utility function above). In this case consumption is hump-shaped reaching a peak 12 periods after the shock (see Figure 7). The contract multiplier is now very high: 0.96. But note the very small value of the reaction: $\widehat{c}_t$ deviates only about 0.01 percent from steady state due to a 1 percent shock to money growth. It can be concluded that habit persistence improves only the response of consumption to a money growth shock in a model with Taylor price staggering.

3.2 Calvo Staggering

Figures 8 – 11 show the results for Calvo staggering. Note that the average length of price stickiness is the same as in the previous section under Taylor staggering. The results are very astonishing. Output, labor and investment show considerable persistence after a money growth shock. The contract multiplier for output is 0.73. Consumption even shows a hump and has a contract multiplier of 1.14. Real money balances increase and are persistent. The capital stock increase is higher than under Taylor pricing and the reaction is very smooth and long lasting. Unfortunately the model is again unable to account for the liquidity effect, the nominal interest rate rises.

Why are the dynamics here completely different? This question is of special interest because real marginal costs rise *stronger* than in a Taylor staggering model. $\widehat{\psi}_t$ deviates 2.16% from steady state in the initial period which is 46% higher here. Prices $\widehat{P}_{0,t}$ overshoot even stronger with a 2.61 percentage deviation from steady state, see Figure 11. But the price level shows a remarkable persistence, too, as this figure reveals. Since both models are exactly equal with the exception of the price setting rule the answer to the question must be found there. As stated above the New Keynesian Phillips curve is valid in the Calvo model only as a Taylor approximation. It is derived by approximating (40) at the steady state. In (40) there are several sums over an infinite horizon. It can be shown that during the approximation all Lagrange multipliers λ_{t+s}, all outputs y_{t+s} and all ψ_{t+s} except ψ_t cancel. This eliminates an enormous amount of dynamic interaction resulting in an equation in which solely the expected inflation rate and current real marginal costs show up. Comparing (42) with (34) immediately confirms this intuition. Taken together this leads to the results presented in the figures.

Kim (2003) tries to get more intuition by simplifying his models so that he can obtain analytical results. In these stripped down versions he can show that the autoregressive coefficient in the pricing equation (which is actually a first order difference equation) is negative leading to the oscillatory behavior in the Taylor staggering model. In contrast the respective coefficient in the Calvo model can be shown to be positive. In the Taylor version this parameter depends on $(1-n)/n$ and on the price elasticity of the demand for intermediate goods ϵ while in the Calvo setup it depends also on $(1-n)/n$ and on the probability that firms cannot adjust prices φ. He can demonstrate that the autoregressive coefficient in the Taylor model is *always* negative irrespective of the specific value of ϵ while in the Calvo staggering model it is *always* positive. This result is confirmed in the model at hand.

For log linear utility ($\sigma = 1$) consumption's reaction is no longer hump-shaped, see Figure 12. Thus the contract multiplier drops to 0.56 while the strength of the initial reaction rises to 1.08%. Output also reacts stronger while the contract multiplier falls to 0.55. The rental rate on capital rises even stronger while the real wage rate response is nearly unaffected. As a consequence $\widehat{\psi}_t$'s response is now 2.48% so that intermediate goods firm's optimal reset price shows an increased percentage deviation of 2.71% from steady state. For the second special case where $b = 0$ results are similar in nature to the Taylor staggering model but the responses are persistent. Again output, consumption and labor hours react weaker than under log linear utility. The real wage's initial response is strongest with a value of 2.00%. The contract multipliers do not change significantly. Finally, for $b = 1$ consumption is hump-shaped again with a very high contract multiplier of 1.56. But the magnitude of the initial reaction is quite small, only 0.026%, compare Figure 13.

4 Business Cycle Properties

In order to explore the implications for the business cycle properties one has to specify the standard deviation of the AR(1)-process for money growth. Here the value estimated in Cooley and Hansen (1995), p. 201, is used.[13] It implies a value of 0.0000792 for the variance σ_g^2. Table 1 shows the results for the Taylor staggering model with $b = 0.8$ after HP-filtering with $\lambda = 1600$.[14] $\sigma_{\widehat{x}}$ denotes the percentage standard deviation of $\widehat{x}$ whereas $\sigma_{\widehat{x}}/\sigma_{\widehat{y}}$ measures the respective standard deviation relative to that of output $\widehat{y}$. The next two columns report the autocorrelations for one and two lags of the respective aggregate. The remaining columns display the cross correlations with output. A variable $\widehat{x}$ is leading $\widehat{y}$ if the absolute value of the correlation $\rho\left(\widehat{x}_t, \widehat{y}_{t+i}\right)$ is highest for $i > 0$. Accordingly a variable $\widehat{x}$ is lagging $\widehat{y}$ if the absolute value of the correlation $\rho\left(\widehat{x}_t, \widehat{y}_{t+i}\right)$ has a maximum for $i < 0$. In case that this correlation is positive one speaks of a procyclical variable while it is

[13]It is not intended to take the model explicitly to the data because of its overwhelming simplicity. This justifies the use of Cooley and Hansen's parameter values.

[14]Note that all values in the tables have been rounded using the computer output. So it is possible that the relative standard deviations deliver a different value when using the values in the table.

Table 1: Moments in the Taylor Staggering Model

			autocorrelation		cross correlation of $\widehat{x}_t$ with $\widehat{y}$ in				
$\widehat{x}_t$	$\sigma_{\widehat{x}}$	$\sigma_{\widehat{x}}/\sigma_{\widehat{y}}$	1	2	$t-2$	$t-1$	t	$t+1$	$t+2$
$\widehat{y}_t$	0.34	1.00	-0.14	-0.02	-0.02	-0.14	1.00	-0.14	-0.02
$\widehat{i}_t$	1.42	4.14	-0.23	-0.04	-0.06	-0.25	0.99	-0.12	-0.01
$\widehat{c}_t$	0.10	0.29	0.28	0.06	0.10	0.26	0.90	-0.18	-0.08
$\widehat{n}_t$	0.54	1.59	-0.15	-0.03	-0.04	-0.16	0.99	-0.13	-0.01
$\widehat{w}_t$	1.09	3.19	-0.20	-0.04	-0.05	-0.22	0.99	-0.13	-0.01
$\widehat{\mu}_t$	1.29	3.78	-0.20	-0.04	0.05	0.21	-0.99	0.12	0.01
$\widehat{R}_t$	1.30	3.79	0.60	0.12	0.17	0.62	0.62	-0.13	-0.07
$\widehat{\psi}_t$	1.29	3.78	-0.20	-0.04	-0.05	-0.21	0.99	-0.12	-0.01
$\widehat{\Pi}_t$	1.26	3.67	0.35	-0.20	-0.21	0.61	0.69	-0.11	-0.04
$\widehat{P}_t$	2.17	6.33	0.83	0.54	0.31	0.43	0.07	-0.32	-0.26

called anticyclical if it is negative. If the maximum correlation occurs at lag 0 ($i = 0$) the variable is moving with the cycle. This table strenghtens the insights from the impulse response functions. First, the cyclical character of most variables is displayed in their negative autocorrelations, see e.g. output and investment. Second, investment, labor, the real wage and real marginal cost are nearly perfectly correlated with output whereas the correlations at leads and lags are negative. Third, the relative variability of consumption (0.29) is very low while also most absolute volatilities of the real variables are too small compared to empirical estimates. This applies especially to output and investment. In German data I found a percentage standard deviation of 1.42% for consumption and 1.55% for output, see Gail (1998), p. 52. The opposite is true for nominal variables such as the inflation rate which is by far too volatile. The same result concerns the price level. Empirical estimates of Maußner (1994), p. 19, for Germany reveal a relative volatility of the price level of 0.70 using the consumer price index and 0.58 when employing the GDP deflator. Fourth, only consumption and the nominal interest rate show a small portion of persistence since their autocorrelations are positive and well above 0.25 at the first lag.

In the limiting case with $b = 1$ the relative variability of consumption falls to 0.04 while the absolute value is only 0.01% (see also Figure 7). But the autocorrelations rise to 0.75 and 0.57 respectively. On the other hand investment is now 5.40 times as volatile as output which is by far too high. Labor's relative variability does not change. Finally, considering $b = 0$ worsens the performance of the model even more. Of course now consumption shows more variation, its relative volatility rises to 0.65. But the autocorrelations as well as the lead/lag correlations get negative while the contemporaneous correlation with output is perfect.

Table 2 shows the results for the Calvo staggering model after HP-filtering with $\lambda = 1600$. Now all aggregates are positively autocorrelated. Output's

Table 2: Moments in the Calvo Staggering Model

			autocorrelation		cross correlation of $\widehat{x}_t$ with $\widehat{y}$ in				
$\widehat{x}_t$	$\sigma_{\widehat{x}}$	$\sigma_{\widehat{x}}/\sigma_{\widehat{y}}$	1	2	$t-2$	$t-1$	t	$t+1$	$t+2$
$\widehat{y}_t$	0.66	1.00	0.55	0.22	0.22	0.55	1.00	0.55	0.22
$\widehat{i}_t$	2.16	3.30	0.42	0.10	0.03	0.36	0.97	0.58	0.27
$\widehat{c}_t$	0.34	0.51	0.75	0.41	0.49	0.79	0.93	0.46	0.12
$\widehat{n}_t$	1.03	1.57	0.54	0.21	0.19	0.52	1.00	0.57	0.25
$\widehat{w}_t$	1.72	2.63	0.47	0.14	0.10	0.43	0.99	0.57	0.26
$\widehat{\mu}_t$	2.09	3.19	0.48	0.15	-0.11	-0.44	-0.99	-0.58	-0.26
$\widehat{R}_t$	0.79	1.21	0.34	0.05	-0.03	0.26	0.94	0.57	0.29
$\widehat{\psi}_t$	2.09	3.19	0.48	0.15	0.11	0.44	0.99	0.58	0.26
$\widehat{\Pi}_t$	0.83	1.27	0.45	0.13	0.07	0.41	0.98	0.58	0.27
$\widehat{P}_t$	1.83	2.79	0.90	0.70	0.58	0.55	0.36	-0.08	-0.35

volatility nearly doubles to 0.66 still being smaller than empirical estimates but considerably higher than in the Taylor staggering model. Investment's relative variability is slightly reduced while labor fluctuates about as strong as before. Consumption approaches its empirical value of the standard deviation relative to output. The most striking difference concerns the cross correlations which rise very strongly: correlations at leads and lags are positive and the contemporaneous correlations are well above 0.90. Such high values are not observed empirically. In German data, consumption has a contemporaneous correlation of 0.62 and investment a correlation of 0.78 with output. The relative volatility of the price level and inflation fall approaching their empirical counterparts. Prices are now clearly lagging procyclically (0.58) – which is counterfactual – while the inflation rate is procyclical. Interestingly the standard deviation of real marginal costs rises by more than 60% compared to the Taylor model. Overall, the Calvo staggering model performs much better concerning the ability to match business cycle stylized

facts than the Taylor model.
Regarding the limiting case with $b = 1$ reveals that consumption's relative variability rises to 0.90 which matches the empirical counterpart of 0.92 for Germany quite well. But due the prolonged hump-shaped response consumption is now lagging output which is counterfactual. As output's standard deviation falls investment is again too volatile relative to output (5.21). Again labor's relative standard deviation is nearly unchanged. Eliminating habits in consumption ($b = 0$) causes output to be more volatile (0.80% compared to 0.66%) whereas consumption is now perfectly correlated with output because there is no hump-shaped response any more.

5 Conclusions

Adding habit persistence in consumption to a monetary stochastic dynamic general equilibrium model with Taylor price staggering does not enhance very much the ability to account for persistent effects of money growth shocks. It is only the behavior of consumption that can be improved. For a model version with Calvo price staggering habits give rise to a hump-shaped response of consumption even in the benchmark model. All aggregates show a persistent reaction to a shock to the money growth rate. This confirms results in Bouakez, Cardia and Ruge-Murcia (2002) who consider a similar model with quadratic adjustment costs of capital and Calvo pricing. Thus it can be concluded that it is necessary to have habit formation in consumption together with price staggering in the spirit of Calvo to account for empirically observed impulse responses. However, the performance of the model concerning business stylized facts is only partly successful. While empirical autocorrelations and some relative volatilities are matched quite well cross correlations with output are generally too high.

The model presented here can also be extended to include wage staggering as another nominal rigidity. It would be particularly interesting to investigate the interaction with sticky prices to account for inflation and output persistence. In addition the inclusion of variable capital utilization could further enhance persistence, as suggested by Christiano, Eichenbaum and Evans (2003).

The analysis of wage staggering is of particular interest since Woodford has recently shown that 'allowing for wage stickiness does not matter all that much, if the goal is simply to construct a positive model of the co-movement of inflation and output, and the way that both can be affected by monetary policy'.[15] This gives a justification to neglect wage staggering in positive stochastic dynamic general equilibrium models and casts some doubt on the role some authors give to sticky wages.

A Appendix

A.1 Household's Equations

The efficiency condition for consumption results in

$$\begin{aligned} & (1-\sigma)\,\beta b c^{\sigma b-b-\sigma}\widehat{c}_{t+1} \\ = \; & \left[-\sigma-\beta b\,(\sigma b-b-1)\right] c^{\sigma b-b-\sigma}\widehat{c}_t + b\,(\sigma-1)\,c^{\sigma b-b-\sigma}\widehat{c}_{t-1} \\ & -(1-\beta b)\,c^{\sigma b-b-\sigma}\widehat{\lambda}_t \end{aligned} \tag{57}$$

A hat ($\widehat{\ }$) represents the relative deviation of the respective variable from its steady state ($\widehat{c}_t = (c_t - c)/c$).
The cyclical behavior of labor is determined by

$$\begin{aligned} 0 = \; & -n\gamma\sigma\,(1-n)^{-\sigma-1}\,\widehat{n}_t \\ & +\gamma\,(1-n)^{-\sigma}\,\widehat{\lambda}_t + \gamma\,(1-n)^{-\sigma}\,\widehat{w}_t \end{aligned} \tag{58}$$

The efficiency condition for money determines the respective demand function. So one gets

$$\begin{aligned} & \beta\,(1-\beta b)\,c^{\sigma b-b-\sigma}\,\widehat{P}_{t+1} - \beta\,(1-\beta b)\,c^{\sigma b-b-\sigma}\widehat{\lambda}_{t+1} \\ = \; & -\sigma m^{-\sigma}\widehat{M}_t \\ & -(1-\beta b)\,c^{\sigma b-b-\sigma}\widehat{\lambda}_t \\ & +\left[\beta\,(1-\beta b)\,c^{\sigma b-b-\sigma} + \sigma m^{-\sigma}\right]\widehat{P}_t \end{aligned} \tag{59}$$

The nominal interest rate follows, according to (18),

$$-\widehat{P}_{t+1} + \widehat{\lambda}_{t+1} = -\widehat{P}_t - \frac{R}{1+R}\widehat{R}_t + \widehat{\lambda}_t \tag{60}$$

[15] See Woodford (2003), p. 235.

in the approximated form, with R (respective r for the real rate) as the steady state values. The real rate r_t was deduced via the Fisher equation (see (19)) so that the approximated equation is given by

$$\widehat{\lambda}_{t+1} = -\frac{r}{1+r}\widehat{r}_t + \widehat{\lambda}_t \tag{61}$$

Optimal investment is determined from the efficiency condition for i_t:

$$0 = -\widehat{\lambda}_t + \widehat{\theta}_t + \frac{\phi''}{\phi'}\frac{i}{k}\widehat{i}_t - \frac{\phi''}{\phi'}\frac{i}{k}\widehat{k}_{t-1} \tag{62}$$

The first order condition for capital implies:

$$\beta z\widehat{\lambda}_{t+1} + \beta z\widehat{z}_{t+1} + \beta\left(1-\delta\right)\widehat{\theta}_{t+1} - \beta\frac{\phi''}{\phi'}\frac{i}{k}\frac{i}{k}\widehat{i}_{t+1} = -\beta\frac{\phi''}{\phi'}\frac{i}{k}\frac{i}{k}\widehat{k}_t + \widehat{\theta}_t \tag{63}$$

Capital evolves over time according to

$$\widehat{k}_t = \left(1-\delta\right)\widehat{k}_{t-1} + \delta\widehat{i}_t \tag{64}$$

A.2 Finished Goods Firm's Equations

Since the focus is on a symmetric equilibrium the only equation that remains for the finished goods firm is the price index. In case of the Taylor model it is given by

$$0 = \frac{1}{2}\widehat{P}_{0,t} + \frac{1}{2}\widehat{P}_{0,t-1} - \widehat{P}_t \tag{65}$$

In order to avoid too many variables $\widehat{P}_{1,t}$ is dropped and replaced by $\widehat{P}_{0,t-1}$.

Under Calvo pricing the price level is given by (41) so that the Taylor approximation reads

$$0 = \frac{1}{1-\varphi}\widehat{P}_t - \frac{\varphi}{1-\varphi}\widehat{P}_{t-1} - \widehat{P}_{0,t} \tag{66}$$

A.3 Intermediate Goods Firm's Equations

A.3.1 The Producing Unit

The optimum conditions of the cost minimization problem determine the real wage and the rental rate of capital (see (27) and(28)), with the j's dropped of course.

$$
\begin{aligned}
0 &= (\alpha - 1)\,\widehat{n}_t + (1-\alpha)\,\widehat{k}_{t-1} + \widehat{\psi}_t + \widehat{a}_t - \widehat{w}_t && (67)\\
0 &= \alpha\widehat{n}_t - \alpha\widehat{k}_{t-1} + \widehat{\psi}_t + \widehat{a}_t - \widehat{z}_t && (68)
\end{aligned}
$$

The production function is given by the Cobb-Douglas-functions of the intermediate goods firms and valid in aggregate variables.

$$
0 = -\widehat{y}_t + \alpha\widehat{n}_t + (1-\alpha)\,\widehat{k}_{t-1} + \widehat{a}_t \tag{69}
$$

A.3.2 The Pricing Unit under Taylor Staggering

The condition for optimal two period pricing is given in (34). Its Taylor approximation can be written as

$$
\begin{aligned}
&\beta\left[\epsilon\psi - (\epsilon-1)\right]\widehat{\lambda}_{t+1} + \beta\left[\epsilon^2\psi - (\epsilon-1)^2\right]\widehat{P}_{t+1} + \beta\left[\epsilon\psi - (\epsilon-1)\right]\widehat{y}_{t+1}\\
&+\beta\epsilon\psi\widehat{\psi}_{t+1} = (\epsilon-1)\,(1+\beta)\,\widehat{P}_{0,t} + \left[(\epsilon-1) - \epsilon\psi\right]\widehat{\lambda}_t \qquad (70)\\
&+\left[(\epsilon-1)^2 - \epsilon^2\psi\right]\widehat{P}_t + \left[(\epsilon-1) - \epsilon\psi\right]\widehat{y}_t - \epsilon\psi\widehat{\psi}_t
\end{aligned}
$$

A.3.3 The Pricing Unit under Calvo Staggering

As stated in the main text the approximation of (40) yields the New Keynesian Phillips curve and is given by

$$
\widehat{\pi}_t = (1-\varphi)\,(1-\beta\varphi)\,\varphi^{-1}\widehat{\psi}_t + \beta E_t\widehat{\pi}_{t+1} \tag{71}
$$

A.4 Market Clearing Conditions and Other Equations

The Taylor expansion of the aggregate market clearing condition is given by

$$
0 = -\widehat{y}_t + \frac{c}{y}\widehat{c}_t + \frac{i}{y}\widehat{i}_t \tag{72}
$$

The markup μ_t is determined by the ratio of price over nominal marginal cost ($\mu = P/(P\psi)$ and as there is no steady state inflation it follows that $\mu_t = 1/\psi_t$. So the Taylor approximation can be written as

$$
0 = \widehat{\mu}_t + \widehat{\psi}_t \tag{73}
$$

A.5 The Monetary Authority and Further Equations

To close the model one needs to assume some exogenous process for money supply. Here it will be assumed that money $\widehat{M_t}$ follows an AR(2)-process (see the discussion in the main text). This implies that the growth rate of $\widehat{M_t}$ follows an AR(1)-process. In order to model this properly one has to add the equation

$$0 = \widehat{M_t} - \widehat{g}_{M_t} \tag{74}$$

where $\widehat{g}_{M_t}$ is the exogenous stochastic process that will have the same characteristics as $\widehat{M_t}$.

As it is interesting to study the implications for the inflation rate Π this equation is further added to the system:

$$0 = -\widehat{\Pi}_t + \widehat{P}_t - \widehat{P}_{t-1} \tag{75}$$

In the model with Taylor staggering there are now 21 variables $\widehat{c}_t, \widehat{c}_{t-1}, \widehat{i}_t, \widehat{y}_t, \widehat{\lambda}_t, \widehat{\theta}_t, \widehat{k}_t, \widehat{k}_{t-1}, \widehat{n}_t, \widehat{w}_t, \widehat{z}_t, \widehat{\mu}_t, \widehat{\psi}_t, \widehat{r}_t, \widehat{R}_t, \widehat{P}_t, \widehat{P}_{t-1}, \widehat{P}_{0,t}, \widehat{P}_{0,t-1}, \widehat{\Pi}_t, \widehat{M_t}$ but only 17 equations so four tautologies must be added to the model. These are

$$\begin{aligned} \widehat{P}_{0,t} &= \widehat{P}_{0,t} && (76) \\ \widehat{P}_t &= \widehat{P}_t && (77) \\ \widehat{k}_t &= \widehat{k}_t && (78) \\ \widehat{c}_t &= \widehat{c}_t && (79) \end{aligned}$$

In the Calvo pricing model there are only 20 variables since $\widehat{P}_{0,t-1}$ does not show up. So only three tautologies must be added to the model. These are given by

$$\begin{aligned} \widehat{P}_t &= \widehat{P}_t && (80) \\ \widehat{k}_t &= \widehat{k}_t && (81) \\ \widehat{c}_t &= \widehat{c}_t && (82) \end{aligned}$$

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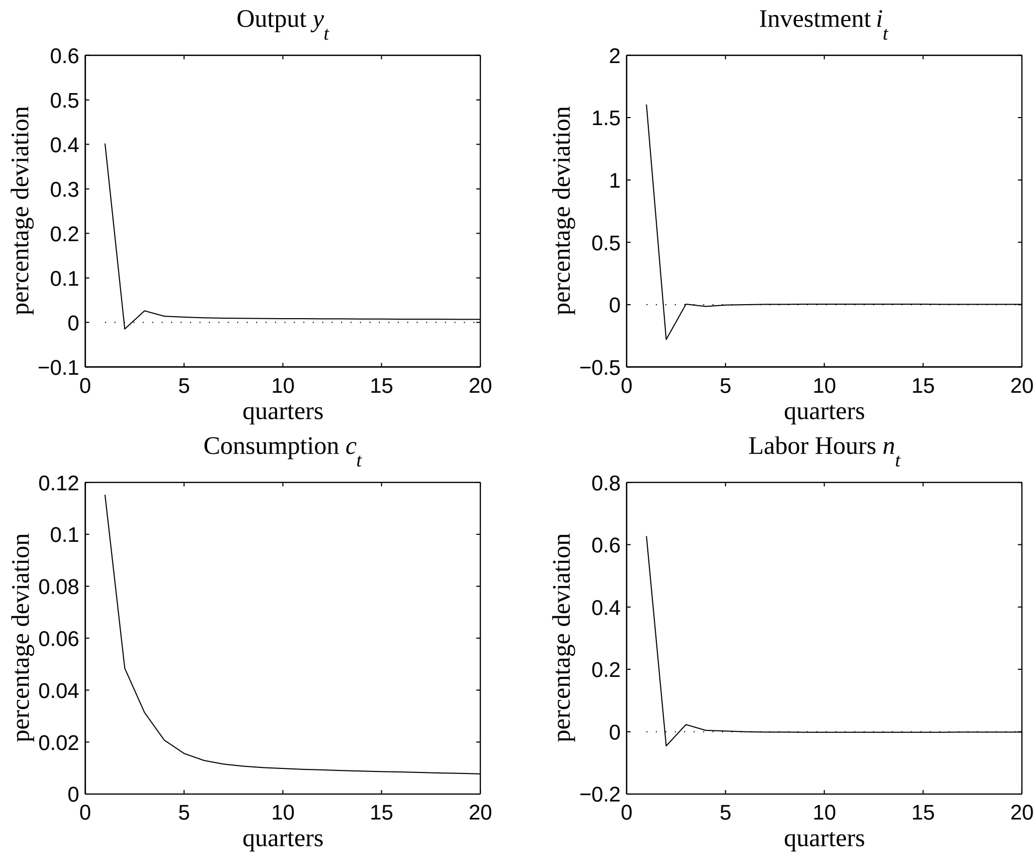

Figure 1: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $b = 0.8$, Taylor Staggering

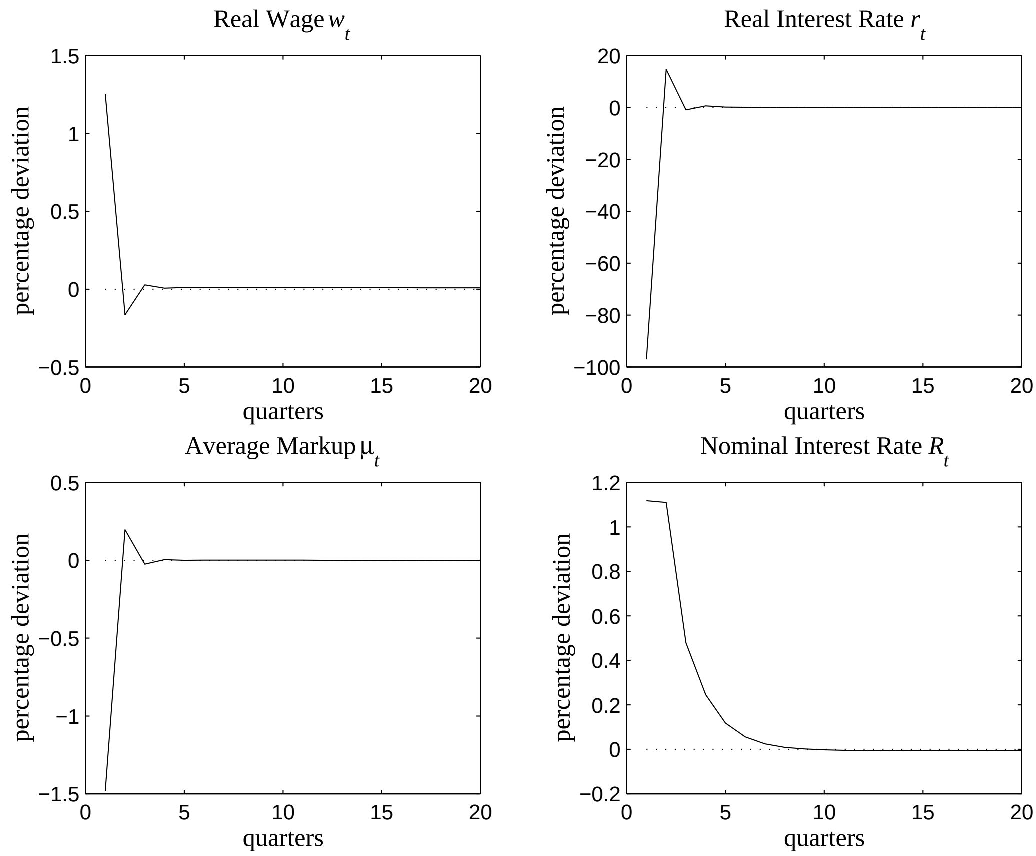

Figure 2: Impulse Response Functions for $\widehat{w}_t, \widehat{r}_t, \widehat{\mu}_t, \widehat{R}_t$ $b = 0.8$,
Taylor Staggering

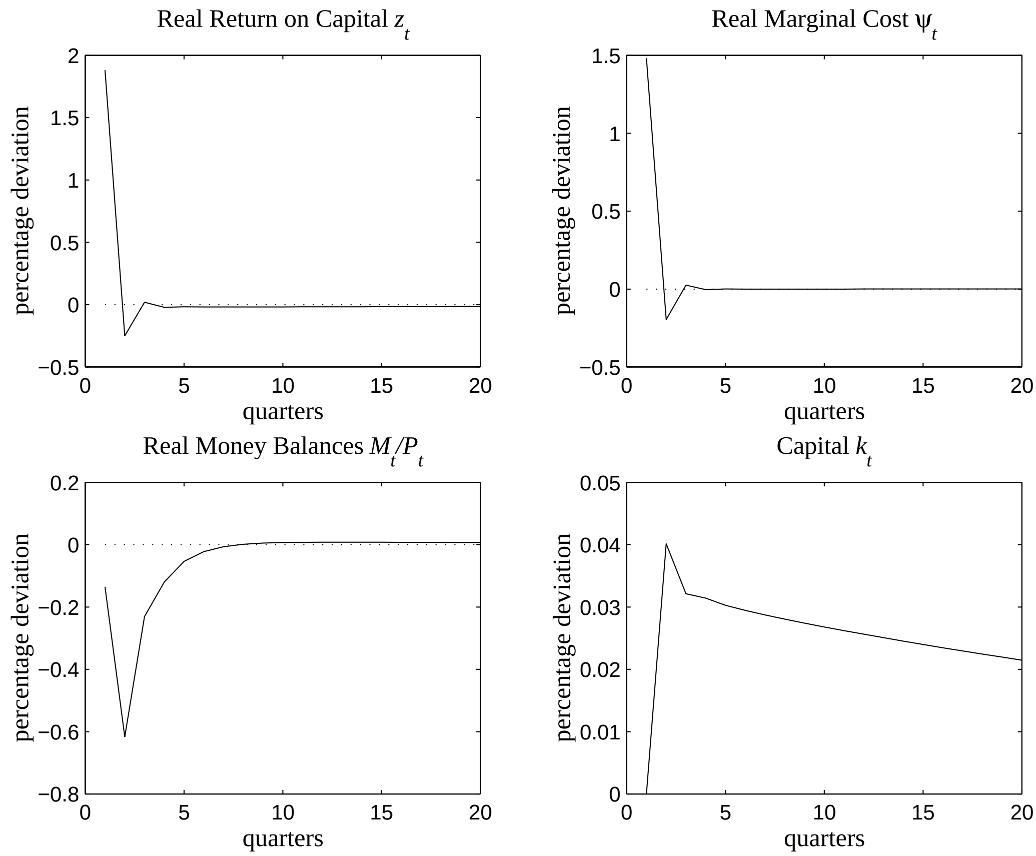

Figure 3: Impulse Response Functions for $\widehat{z}_t, \widehat{\psi}_t, \widehat{M_t} - \widehat{P}_t, \widehat{k}_t$ $b = 0.8$, Taylor Staggering

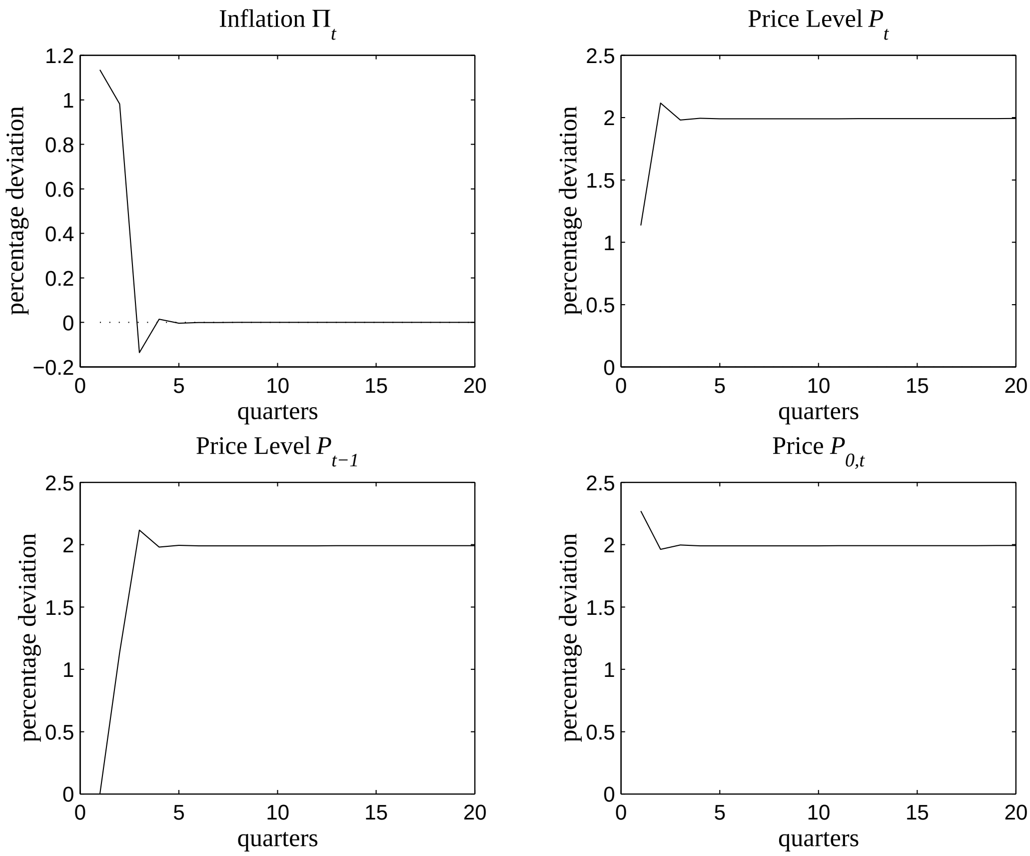

Figure 4: Impulse Response Functions for $\widehat{\Pi}_t$, $\widehat{P}_{0,t}$, $\widehat{P}_t$, $\widehat{P}_{0,t-1}$ $b = 0.8$, Taylor Staggering

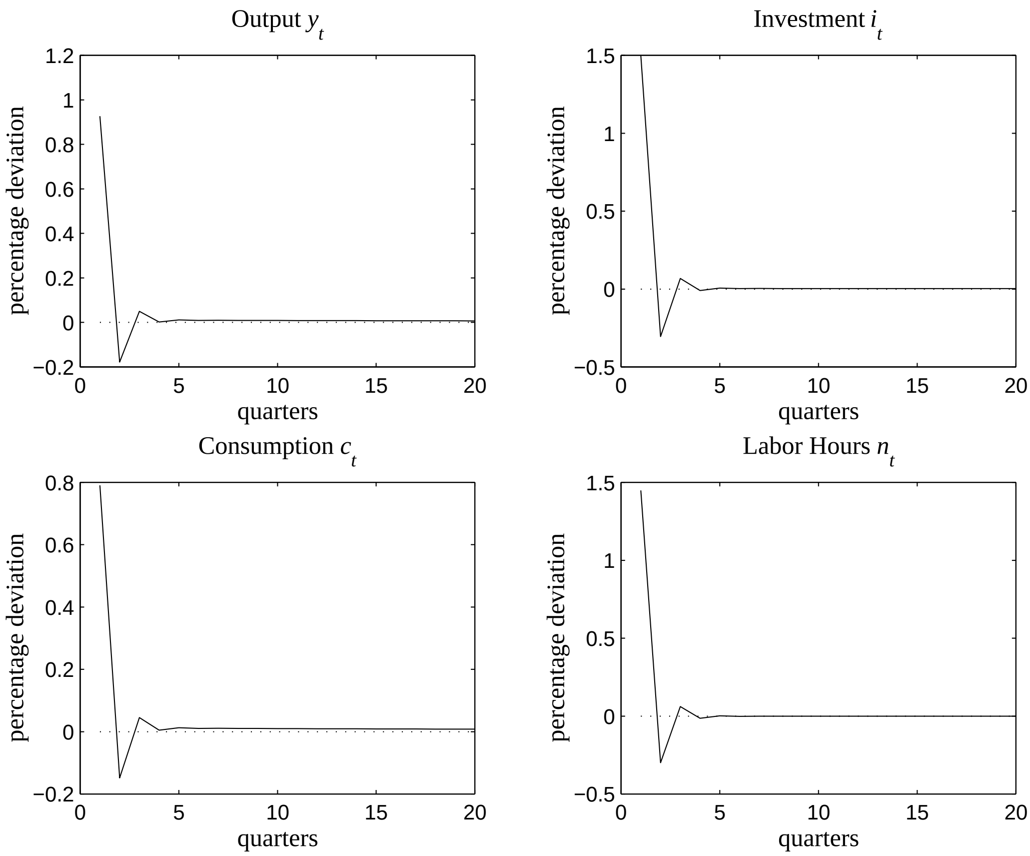

Figure 5: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $\sigma = 1$,
Taylor Staggering

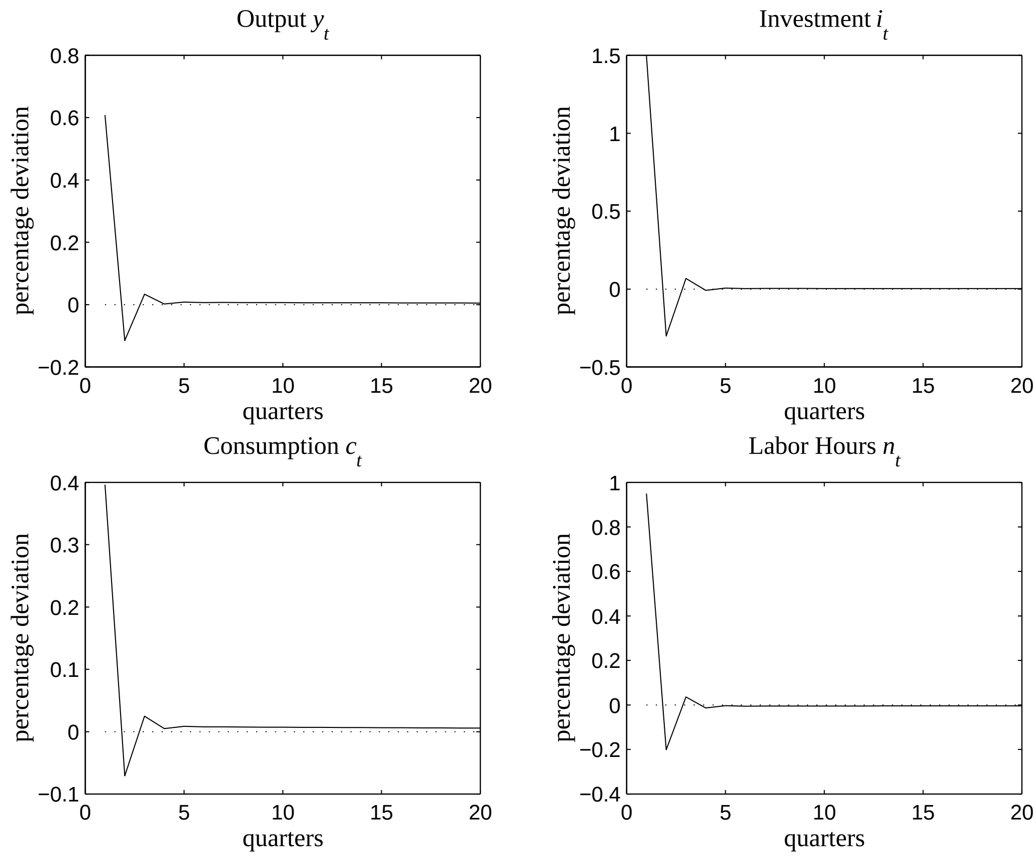

Figure 6: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $b = 0$, Taylor Staggering

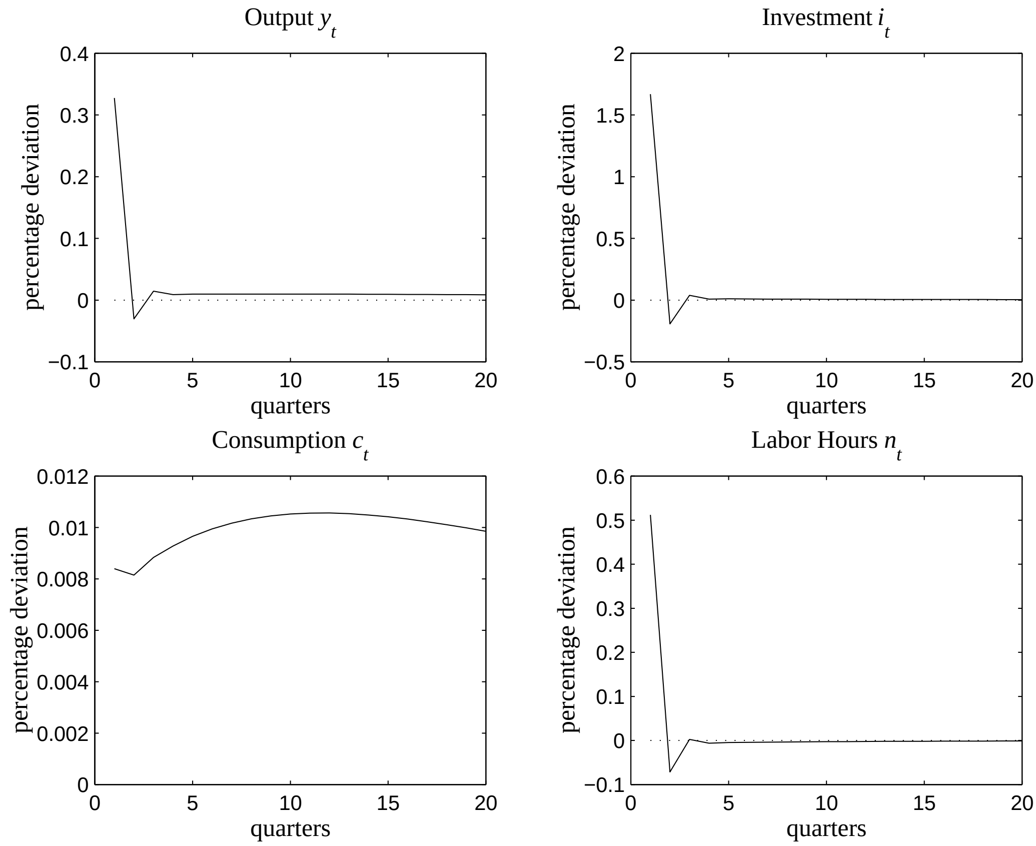

Figure 7: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $b = 1$,
Taylor Staggering

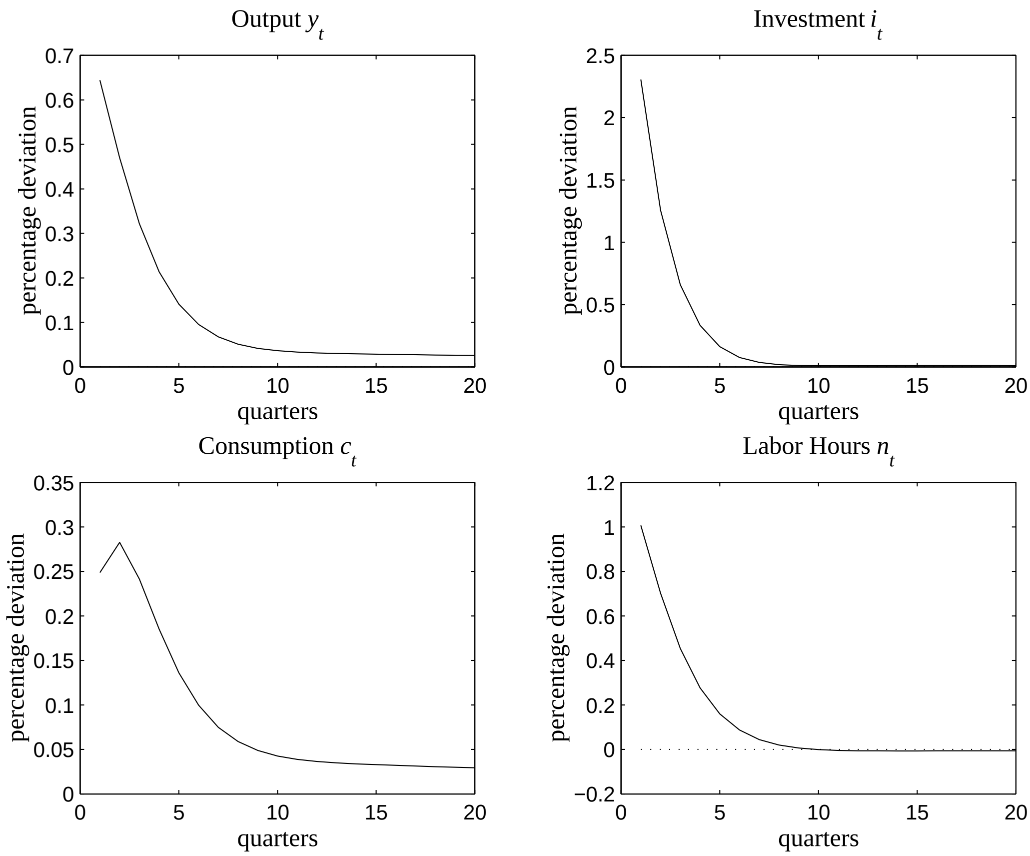

Figure 8: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $b = 0.8$,
Calvo Staggering

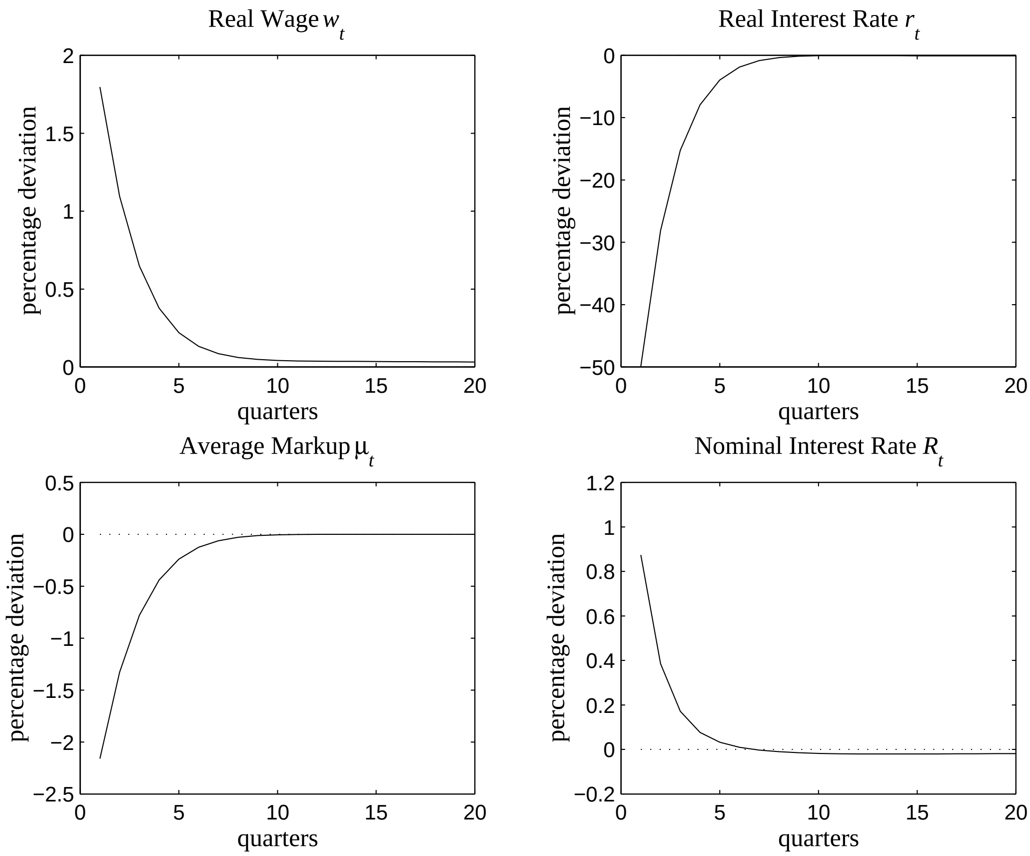

Figure 9: Impulse Response Functions for $\widehat{w}_t, \widehat{r}_t, \widehat{\mu}_t, \widehat{R}_t$ $b = 0.8$,
Calvo Staggering

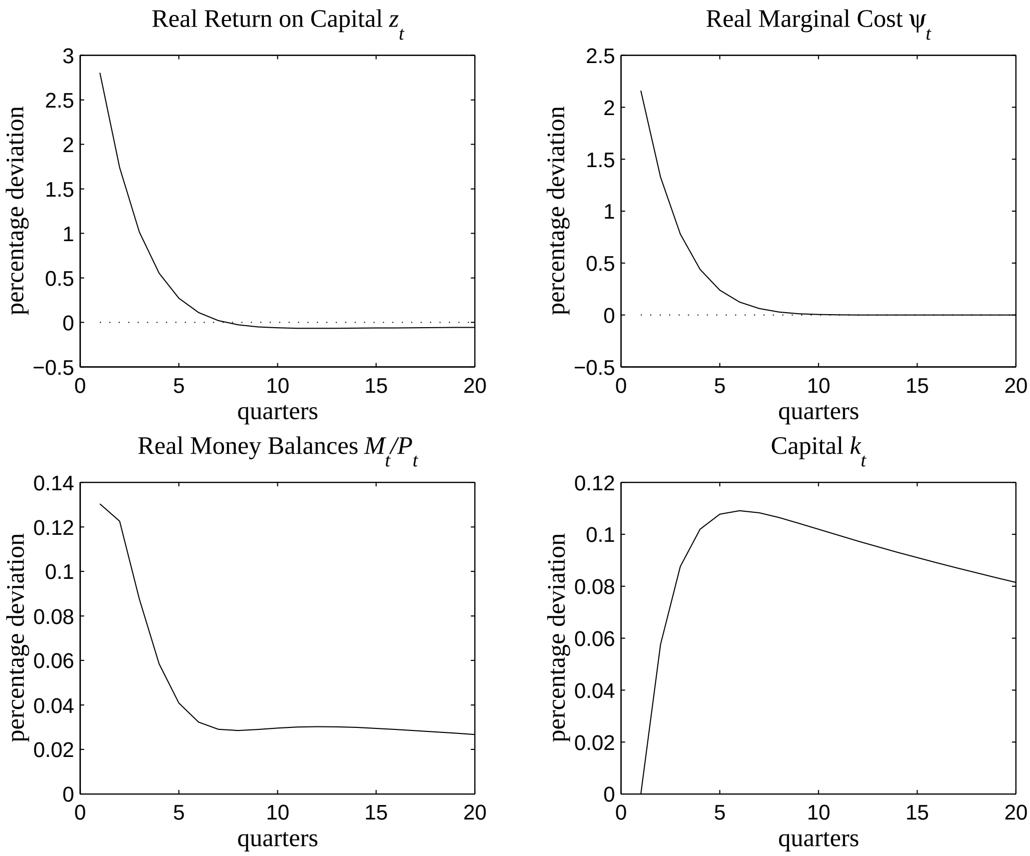

Figure 10: Impulse Response Functions for $\widehat{z}_t, \widehat{\psi}_t, \widehat{M}_t - \widehat{P}_t, \widehat{k}_t$ $b = 0.8$, Calvo Staggering

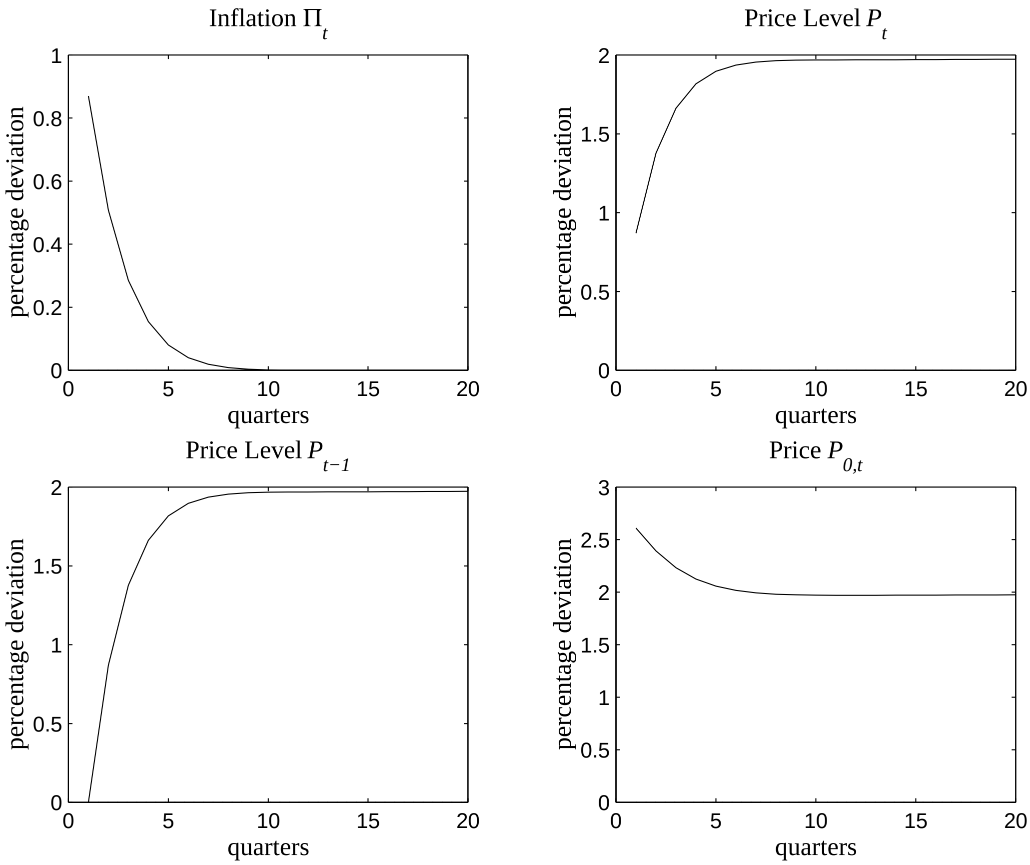

Figure 11: Impulse Response Functions for $\widehat{\Pi}_t$, $\widehat{P}_{0,t}$, $\widehat{P}_t$, $\widehat{P}_{t-1}$ $b = 0.8$, Calvo Staggering

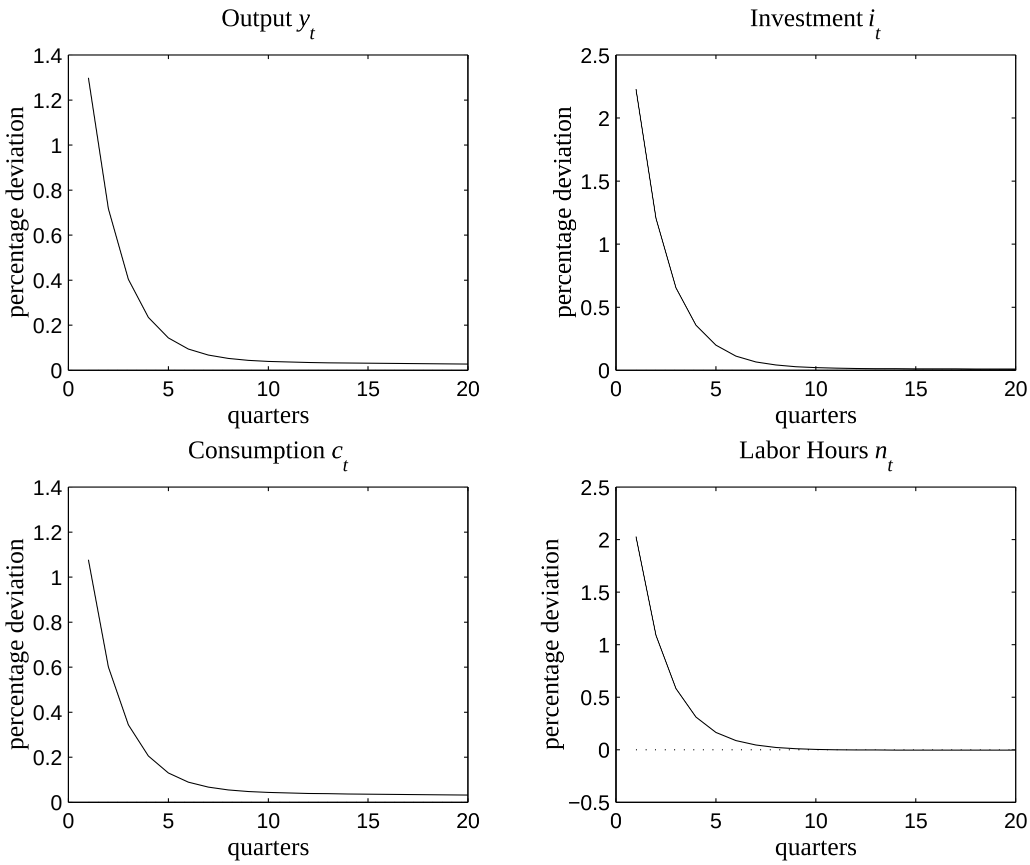

Figure 12: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $\sigma = 1$, Calvo Staggering

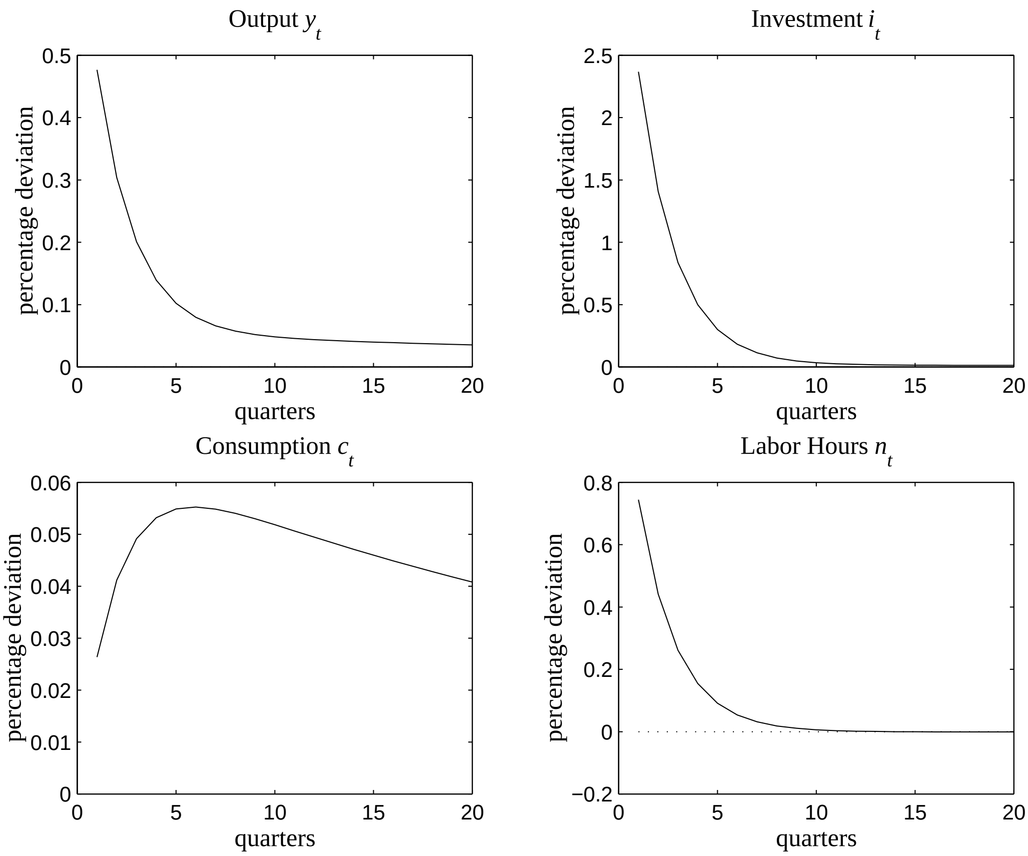

Figure 13: Impulse Response Functions for $\widehat{y}_t, \widehat{i}_t, \widehat{c}_t, \widehat{n}_t$, $b = 1$, Calvo Staggering

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42-93 **Klaus Schöler** und **Matthias Schlemper**, Oligopolistisches Marktverhalten der Banken

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44-93 **Andreas Pfingsten** and **Reiner Wolff**, Adverse Rybczynski Effects Generated from Scale Diseconomies

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