

**Persistency and Money Demand Distortions in a
Stochastic DGE Model with Sticky Prices
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Discussion Paper No. 103-02

ISSN 1433-058x

Persistency and Money Demand Distortions in a Stochastic DGE Model with Sticky Prices and Capital

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February 2002, revised May 5th, 2003

Abstract

This paper considers the implications of adding capital as a factor of production in a stochastic DGE model with sticky prices for the effects of money growth shocks. Particular attention is given to the role of money demand and to the form of the utility function. I consider cash-in-advance- (CIA) as well as money-in-the-utility-function- (MIU) models, with CRRA and GHH preferences, to evaluate their ability to generate persistence. It is shown that even in a MIU-model with a GHH utility function and a high elasticity of labor supply with respect to the real wage the additional intertemporal substitution channel opened through capital accumulation does have a significant dampening influence on the persistence effects of monetary shocks. In a CIA-setup with GHH preferences the model can generate the liquidity effect. A multiplicatively separable CRRA utility function in the MIU-model cannot account for the observed persistent reactions of inflation and output either.

JEL classification: E52

Keywords: Monetary Policy, New Neoclassical Synthesis, Sticky Prices, Persistency, Real Business Cycle

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1 Introduction

Can monetary shocks generate persistent responses of inflation and output? This question has been addressed in a battery of papers in the last few years. The most prominent paper is the one of [4, Chari/Kehoe/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.

Very recently [5, Christiano/Eichenbaum/Evans (2001)] have developed a 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 capacity 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.

[8, Dotsey/King (2001)] stress the importance of variable capacity utilization as well. They demonstrate that persistence is possible even in a sticky price model that features labor supply variability through changes in employment and incorporates produced inputs as intermediate goods. All these three ingredients together produce a flat reaction of real marginal costs to a money growth shock. In turn this reduces the extent of price adjustments of the firms. Unfortunately this gradual adjustment of the price level is responsible for the rise in the nominal interest rate: the model does not display the liquidity effect.

Intermediates also play an important role in the work of [16, Huang/Liu/Phaneuf (2000)] as well as [24, Linnemann (2000)]. The former also evaluate the performance of staggered wage models in relation to staggered price models. They conclude that their staggered wage model with intermediates can generate more persistence than a respective price model. Intermediates in general cause a trade off between inflation and output persistence: autocorrelations of output rise while those of inflation decrease. Especially staggered prices *and* wages are needed to produce a weak but slightly positive response of the real wage to a monetary shock, as is observed empirically.

[25, Maußner (2000)] has proposed a model with wage staggering augmented by adjustment costs of employment and prices at the firm level.

This model delivers the best results in a variant with small adjustment costs of labor while otherwise responses are even too strong.

[6, Dib/Phaneuf (2001)] discuss a similar model as Maußner but with price staggering instead of wage staggering. In a variant of the model with a nominal rigidity through costly price adjustment and a real rigidity through adjusting the labor input output, hours and real wages show a persistent reaction to a monetary shock. Moreover, the model can explain the decline in hours worked after a productivity shock, as observed in US postwar data.

In this paper special attention is given to the role of the implied money demand function for the persistency effects of money growth shocks. To do so cash-in-advance- (CIA) as well as money-in-the-utility-function- (MIU) models are proposed. These models are augmented by capital accumulation considerations. In contrast to models without capital the specific form of the utility function and the implied elasticity of labor supply with respect to the real wage play a minor role. The intertemporal substitution channel opened up by capital accumulation leads to very strong reactions of the firm's real marginal cost even in a MIU-model with GHH preferences and a high labor supply elasticity. Interestingly the CIA-model can display the liquidity effect under GHH preferences: a falling nominal interest rate. Under benchmark parameter values a CIA-economy generally displays more persistency than a MIU-world. Overall the results show that persistent output and inflation responses to money growth shocks cannot be explained in an economy with capital. Even an interest rate sensitive money demand together with a low real marginal cost elasticity cannot account for the observed reactions either.

Unfortunately it is not possible to study disaggregated variables because this leads to theoretical difficulties with respect to the aggregation of the production functions (no perfect aggregation possible) and also to computational problems concerning the uniqueness of the model solution (sunspots and multiple equilibria). So a symmetric equilibrium will be considered.

The paper is organized as follows: Section 2 describes in detail the different models, the steady state and the calibration. In section 3 impulse responses are discussed for the CIA- and the MIU-model. Section 4 concludes and gives some suggestions for future research.

2 The Models

2.1 The Household

The representative household is assumed to have preferences over consumption (c_t) and leisure ($1 - n_t$). I consider two different sets of functions under two different setups. In the one setup, CIA-models are considered while in the other MIU-models are evaluated. Both will be calculated through for special utility functions. Since they differ for the setups they will be discussed separately below. The first momentary utility function considered under CIA is the one used by [22, King/Wolman (1999)] and is given by

$$u(c_t, n_t, a_t) = \frac{\left[c_t - \frac{a_t \theta}{1+\gamma} n_t^{1+\gamma} \right]^{1-\sigma} - 1}{1 - \sigma} \quad (1)$$

Here a_t is a preference shock that also acts like a productivity shock. θ and γ are positive parameters. σ governs the degree of risk aversion. This function is familiar from the analysis of [14, Greenwood/Hercowitz/Huffman (1988)] and accordingly labeled GHH preferences. It has the special property that hours worked only depend upon the real wage and not upon consumption (no wealth effects).

The second utility function analyzed under CIA is the standard CRRA function used in many Real Business Cycle models. ζ measures the relative weight of consumption for the representative agent.

$$u(c_t, n_t, a_t) = \frac{\left[a_t c_t^\zeta (1 - n_t)^{1-\zeta} \right]^{1-\sigma} - 1}{1 - \sigma} \quad (2)$$

Under a MIU-specification the corresponding GHH function to (1) is given by

$$u\left(c_t, \frac{M_t}{P_t}, n_t, a_t\right) = \frac{\left[\left(\eta c_t^\nu + (1 - \eta) \left(\frac{M_t}{P_t} \right)^\nu \right)^{\frac{1}{\nu}} - \frac{a_t \theta}{1+\gamma} n_t^{1+\gamma} \right]^{1-\sigma} - 1}{1 - \sigma} \quad (3)$$

The MIU-specification was - among others - proposed by [26, Sidrauski (1967)]. Consumers are supposed to have preferences over real money balances M_t/P_t since they facilitate transactions. They are introduced using

a CES function together with consumption. This expression replaces the consumption term in (1). η is a share parameter and ν will be shown to determine the interest elasticity of the implied money demand function. In case of CRRA preferences the specification in the CES form is embedded in a Cobb-Douglas structure with labor where ζ again acts as a weighting parameter.

$$u\left(c_t, \frac{M_t}{P_t}, n_t, a_t\right) = \frac{\left[a_t \left(\eta c_t^\nu + (1 - \eta) \left(\frac{M_t}{P_t} \right)^\nu \right)^{\frac{\zeta}{\nu}} (1 - n_t)^{1 - \zeta} \right]^{1 - \sigma}}{1 - \sigma} - 1 \quad (4)$$

Note that for $\nu = \eta = 1$ this collapses to the CIA-specification of utility. The nonseparability here makes it possible to consider the influence of the money demand distortions on the dynamic evolution of consumption, labor and capital.

The household's budget has to be modified in comparison to a pure labor economy since it can now invest i_t units of the final good to augment the capital stock k_t . It also receives factor payments $z_t k_{t-1}$ for supplying capital to intermediate goods producing firms. The new constraint is therefore given by

$$c_t + i_t + \frac{M_t}{P_t} + \frac{B_t}{P_t} = w_t n_t + z_t k_{t-1} + \frac{M_{t-1}}{P_t} + (1 + R_{t-1}) \frac{B_{t-1}}{P_t} + \frac{M_t^s}{P_t} \quad (5)$$

where z_t denotes the real return on capital. The uses of wealth are real consumption c_t , holdings of real money balances M_t/P_t and real bonds B_t/P_t . The household has several sources of his wealth. It earns money working in the market at the real wage rate w_t ($w_t n_t$) and can spend its money holdings carried over from the previous period (M_{t-1}/P_t). There are also previous period bond holdings including the interest on them $(1 + R_{t-1})(B_{t-1}/P_t)$.¹ Finally the household receives a monetary transfer M_t^s from the government or the monetary authority, respectively. This transfer is equal to the change in money balances, i.e.

$$M_t^s = M_t - M_{t-1} \quad (6)$$

¹The household also receives profits from the intermediate goods firms. Since these profits will be zero in the equilibrium they are not explicitly included in the budget constraint here.

Regarding utility function (1) and (2) the household faces a cash-in-advance constraint. It can consume only out of cash balances it has received before. This condition is therefore given by

$$P_t c_t \leq M_{t-1} + M_t^s \quad (7)$$

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

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

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. Because this equation cannot be explicitly solved for i_t a third Lagrange multiplier (θ_t) has to be introduced into the optimization problem of the household. The Lagrangian in case of utility function (1) and (2) (index $H1$) (CIA-model) is then given by:

$$\begin{aligned} L_{H1} = & E_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_t, n_t, a_t) \right. \\ & + \sum_{t=0}^{\infty} \beta^t \lambda_t \left(z_t k_{t-1} + w_t n_t + m_{t-1} \frac{P_{t-1}}{P_t} + m_t^s \right. \\ & \quad \left. \left. + (1 + R_{t-1}) b_{t-1} \frac{P_{t-1}}{P_t} - c_t - i_t - m_t - b_t \right) \right. \\ & + \sum_{t=0}^{\infty} \beta^t \Omega_t \left(m_{t-1} \frac{P_{t-1}}{P_t} + m_t^s - c_t \right) \\ & \left. + \sum_{t=0}^{\infty} \beta^t \theta_t \left((1 - \delta) k_{t-1} + \phi \left(\frac{i_t}{k_{t-1}} \right) k_{t-1} - k_t \right) \right] \quad (9) \end{aligned}$$

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 for an interior solution are reported below.

$$\frac{\partial L_{H1}}{\partial c_t} = \beta^t \frac{\partial u(c_t, n_t, a_t)}{\partial c_t} - \beta^t \lambda_t - \beta^t \Omega_t = 0 \quad (10)$$

$$\frac{\partial L_{H1}}{\partial n_t} = \beta^t \frac{\partial u(c_t, n_t, a_t)}{\partial n_t} + \beta^t \lambda_t w_t = 0 \quad (11)$$

$$\frac{\partial L_{H1}}{\partial i_t} = -\beta^t \lambda_t + \beta^t \theta_t \phi' \left(\frac{i_t}{k_{t-1}} \right) \left(\frac{1}{k_{t-1}} \right) k_{t-1} = 0 \quad (12)$$

$$\begin{aligned} \frac{\partial L_{H1}}{\partial k_t} = & E_t \beta^{t+1} \lambda_{t+1} z_{t+1} - \beta^t \theta_t + E_t \beta^{t+1} \theta_{t+1} \left[(1 - \delta) \right. \\ & \left. + \phi \left(\frac{i_{t+1}}{k_t} \right) + \phi' \left(\frac{i_{t+1}}{k_t} \right) \left(-\frac{i_{t+1}}{k_t^2} \right) k_t \right] = 0 \end{aligned} \quad (13)$$

$$\frac{\partial L_{H1}}{\partial m_t} = -\beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1} \frac{P_t}{P_{t+1}} + E_t \beta^{t+1} \Omega_{t+1} \frac{P_t}{P_{t+1}} = 0 \quad (14)$$

$$\frac{\partial L_{H1}}{\partial b_t} = -\beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1} (1 + R_t) \frac{P_t}{P_{t+1}} = 0 \quad (15)$$

The derivatives with respect to λ_t and Ω_t are omitted since they are equal to the intertemporal budget constraint and the cash-in-advance constraint, respectively. 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 that these conditions result from the more general Kuhn-Tucker conditions assuming that all variables and multipliers are strictly positive. This implies especially that - given $\Omega_t > 0$ - the CIA-constraint is always binding and that the nominal interest rate R_t is positive. Otherwise (14) and (15) will not be compatible. In addition the household's optimal choices must also satisfy the transversality conditions:

$$\lim_{t \rightarrow \infty} \beta^t \lambda_t x_t = 0 \quad \text{for } x = m, b, k \quad (16)$$

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 distorted here by the cash-in-advance constraint. The real wage is now given by

$$w_t = -\frac{1}{\beta} \frac{\frac{\partial u(c_t, n_t, a_t)}{\partial n_t}}{\frac{\partial u(c_{t+1}, n_{t+1}, a_{t+1})}{\partial c_{t+1}}} \frac{P_{t+1}}{P_t} \quad (17)$$

This equation can be derived by eliminating Ω_t in the efficiency condition for consumption using the efficiency condition for money. Note the different timing of the marginal utility of consumption and labor which alters the dynamic evolution of w_t . There is also a direct influence of inflation on the real wage.

The efficiency condition for bond holdings establishes a relation between the nominal interest rate and the price level. Rearranging terms yields

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

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

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

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

In case of the MIU-model the CIA-constraint is dropped since money demand will be determined endogenously through the derivative with respect to m_t . In this case m_t shows up in the utility function, of course. So the Lagrangian (index $H2$) will be given by

$$\begin{aligned} L_{H2} = & E_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_t, m_t, n_t, a_t) \right. \\ & + \sum_{t=0}^{\infty} \beta^t \lambda_t \left(z_t k_{t-1} + w_t n_t + m_{t-1} \frac{P_{t-1}}{P_t} + m_t^s \right. \\ & \left. \left. + (1 + R_{t-1}) b_{t-1} \frac{P_{t-1}}{P_t} - c_t - i_t - m_t - b_t \right) \right. \\ & \left. + \sum_{t=0}^{\infty} \beta^t \theta_t \left((1 - \delta) k_{t-1} + \phi \left(\frac{i_t}{k_{t-1}} \right) k_{t-1} - k_t \right) \right] \quad (20) \end{aligned}$$

In order to compare both setups the first order conditions are again reported.

$$\frac{\partial L_{H2}}{\partial c_t} = \beta^t \frac{\partial u(c_t, m_t, n_t, a_t)}{\partial c_t} - \beta^t \lambda_t = 0 \quad (21)$$

$$\frac{\partial L_{H2}}{\partial n_t} = \beta^t \frac{\partial u(c_t, m_t, n_t, a_t)}{\partial n_t} + \beta^t \lambda_t w_t = 0 \quad (22)$$

$$\frac{\partial L_{H2}}{\partial i_t} = -\beta^t \lambda_t + \beta^t \theta_t \phi' \left(\frac{i_t}{k_{t-1}} \right) \left(\frac{1}{k_{t-1}} \right) k_{t-1} = 0 \quad (23)$$

$$\begin{aligned} \frac{\partial L_{H2}}{\partial k_t} &= E_t \beta^{t+1} \lambda_{t+1} z_{t+1} - \beta^t \theta_t + E_t \beta^{t+1} \theta_{t+1} \left[(1 - \delta) \right. \\ &\quad \left. + \phi \left(\frac{i_{t+1}}{k_t} \right) + \phi' \left(\frac{i_{t+1}}{k_t} \right) \left(-\frac{i_{t+1}}{k_t^2} \right) k_t \right] = 0 \end{aligned} \quad (24)$$

$$\frac{\partial L_{H2}}{\partial m_t} = \beta^t \frac{\partial u(c_t, m_t, n_t, a_t)}{\partial m_t} - \beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1} \frac{P_t}{P_{t+1}} = 0 \quad (25)$$

$$\frac{\partial L_{H2}}{\partial b_t} = -\beta^t \lambda_t + E_t \beta^{t+1} \lambda_{t+1} (1 + R_t) \frac{P_t}{P_{t+1}} = 0 \quad (26)$$

The derivatives with respect to n_t and b_t are essentially the same as for $H1$. As before, P_0, k_0, M_0 and B_0 are given and the transversality conditions hold. In the consumption Euler equation the influence of the second Lagrange multiplier Ω_t disappears whereas 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:

$$\frac{\partial u(c_t, m_t, n_t, a_t)}{\partial m_t} = \frac{\partial u(c_t, m_t, n_t, a_t)}{\partial c_t} \frac{R_t}{1 + R_t} \quad (27)$$

This specification allows to estimate an empirical money demand function. A detailed description will be presented in the calibration section. For the Taylor approximations see Appendix A.

Two important implications come out right here. First, the real wage rate will be determined by the usual marginal rate of substitution between consumption and labor, in contrast to the additional dynamics in the CIA-model (see (17)). Second, the implied money demand function is independent of the specific form of the monetary transfer M_t^s and, in addition, it depends directly upon the nominal interest rate (see (27)).

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 [7, Dixit/Stiglitz (1977)] with $\epsilon > 1$.

$$y_t = \left(\int_0^1 y_{j,t}^{(\epsilon-1)/\epsilon} dj \right)^{\epsilon/(\epsilon-1)} \quad (28)$$

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

$$\max_{y_{j,t}} \left[P_t y_t - \int_0^1 P_{j,t} y_{j,t} dj \right] \text{ s.t. } y_t = \left(\int_0^1 y_{j,t}^{(\epsilon-1)/\epsilon} dj \right)^{\epsilon/(\epsilon-1)} \quad (29)$$

The first order conditions for each good j imply

$$y_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\epsilon} y_t \quad (30)$$

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

$$P_t = \left(\int_0^1 P_{j,t}^{(1-\epsilon)} dj \right)^{1/(1-\epsilon)} \quad (31)$$

In case that prices are fixed for just two periods and assuming that all price adjusting producers in a given period choose the same price the consumption aggregate can be written as

$$y_t = y(y_{0,t}, y_{1,t}) = \left(\frac{1}{2} y_{0,t}^{(\epsilon-1)/\epsilon} + \frac{1}{2} y_{1,t}^{(\epsilon-1)/\epsilon} \right)^{\epsilon/(\epsilon-1)} \quad (32)$$

where $y_{j,t}$ can then be interpreted as the quantity of a good produced in period t whose price was set in period $t-j$. Similarly in the two period price setting case to be explored in detail in the next section the price equation simplifies. 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 at time t and is given by

$$P_t = \left(\frac{1}{2} P_{0,t}^{1-\epsilon} + \frac{1}{2} P_{1,t}^{1-\epsilon} \right)^{1/(1-\epsilon)} \quad (33)$$

2.3 The Intermediate Goods Producing Firm

Intermediate good firms can be considered to consist of a producing and a pricing unit. The producing unit operates under a Cobb-Douglas-technology which is subject to an aggregate random productivity shock a_t .

$$y_{j,t} = a_t n_{j,t}^\alpha k_{j,t-1}^{1-\alpha} \quad (34)$$

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. Those who do not adjust their prices in a given period can be interpreted as passive while those who do adjust do so optimally.

The pricing unit sets prices to maximize the present discounted value of profits.² This can only be done after the producing unit has determined the cost function. In models with capital the problem is given by

$$\begin{aligned} \min_{n_{j,t}, k_{j,t-1}} & [P_{j,t} w_{j,t} n_{j,t} + P_{j,t} z_{j,t} k_{j,t-1}] \\ \text{s.t.} & \quad y_{j,t} = a_t n_{j,t}^\alpha k_{j,t-1}^{1-\alpha} \end{aligned} \quad (35)$$

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:

$$P_{j,t} w_{j,t} = \Psi_{j,t} \alpha a_t n_{j,t}^{\alpha-1} k_{j,t-1}^{1-\alpha} \quad (36)$$

$$P_{j,t} z_{j,t} = \Psi_{j,t} (1 - \alpha) a_t n_{j,t}^\alpha k_{j,t-1}^{-\alpha} \quad (37)$$

²The model deviates in this respect from the standard textbook model in which profits are maximized over the quantity.

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

$$P_{j,t} = P_t, w_{j,t} = w_t, z_{j,t} = z_t, n_{j,t} = n_t, k_{j,t-1} = k_{t-1} \text{ for all } t \quad (38)$$

So (36) and (37) hold with all j 's eliminated.

The pricing unit of the firm maximizes profits by choosing the optimal price. Define the relative price by $p_{j,t} = P_{j,t}/P_t$. Because the production functions are homogenous of degree one real profit $\xi_{j,t}$ for a firm of type j is equal to

$$\xi_{j,t} = \xi(p_{j,t}, y_t, \psi_t) = p_{j,t}y_{j,t} - \psi_t y_{j,t} \quad (39)$$

Using the demand function for the intermediate goods ($y_{j,t} = p_{j,t}^{-\epsilon} y_t$) the profit function can be rewritten as

$$\xi_{j,t} = \xi(p_{j,t}, y_t, \psi_t) = y_{j,t}(p_{j,t} - \psi_t) = p_{j,t}^{-\epsilon} y_t (p_{j,t} - \psi_t) \quad (40)$$

In the case in which prices are not sticky the firm can just set prices on a period by period basis optimizing the profit function (40) with respect to $p_{j,t}$. The result of this exercise would be that relative prices will have to be set according to

$$p_{j,t} = \frac{\epsilon}{\epsilon - 1} \psi_t \quad (41)$$

But 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 $t + 1$ ($\Pi_{t+1} = P_{t+1}/P_t$).

$$p_{1,t+1} = \frac{p_{0,t}}{\Pi_{t+1}} \quad (42)$$

If there is positive inflation, $p_{1,t+1}$ will fall because nominal prices are fixed for two periods. As the nominal price in period t is defined by $P_{0,t}$ and in period $t + 1$ by $P_{1,t+1}$, one has $P_{0,t} = P_{1,t+1}$, so that $p_{0,t} = P_{0,t}/P_t$ and $p_{1,t+1} = P_{1,t+1}/P_{t+1} = (P_{0,t}/P_t)(P_t/P_{t+1})$ which is what is stated in (42). So 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

$$\begin{aligned} \max_{p_{0,t}} E_t \left[\xi(p_{0,t}, y_t, \psi_t) + \beta \frac{\lambda_{t+1}}{\lambda_t} \xi(p_{1,t+1}, y_{t+1}, \psi_{t+1}) \right] \\ \text{s.t. } p_{1,t+1} = \frac{p_{0,t}}{\Pi_{t+1}} \end{aligned} \quad (43)$$

The term λ_{t+1}/λ_t is equal to the ratio of future to current marginal utility of labor and the respective real wage ratio (derived in the household's optimization problem) and considered to be - in conjunction with β - the appropriate discount factor for real profits. This is a consequence of the assumption that households own the production factors labor and capital and rent them to the firms. They also own a diversified portfolio of claims to the profits earned by the firms. λ_t can be used to determine the present value of profits.³ The efficiency condition for this problem is given by

$$0 = \frac{\partial \xi(p_{0,t}, y_t, \psi_t)}{\partial p_{0,t}} + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{\partial \xi(p_{1,t+1}, y_{t+1}, \psi_{t+1})}{\partial p_{1,t+1}} \frac{1}{\Pi_{t+1}} \right) \quad (44)$$

Multiplying this equation by $p_{0,t}$ and λ_t produces a more symmetric form of the efficiency condition that will be more convenient to derive the model solution later.

$$0 = \lambda_t p_{0,t} \frac{\partial \xi(p_{0,t}, y_t, \psi_t)}{\partial p_{0,t}} + \beta E_t \left(\lambda_{t+1} p_{1,t+1} \frac{\partial \xi(p_{1,t+1}, y_{t+1}, \psi_{t+1})}{\partial p_{1,t+1}} \right) \quad (45)$$

Using (40) one can solve this condition for the optimal price to be set in period t which corresponds to the optimal price in case that prices are flexible derived before. This yields a forward-looking form of the price equation and is in that respect similar to the one in [27, Taylor (1980)].

$$p_{0,t} = \frac{\epsilon}{\epsilon - 1} \frac{\lambda_t y_t \psi_t + \beta E_t \lambda_{t+1} (P_{t+1}/P_t)^\epsilon y_{t+1} \psi_{t+1}}{\lambda_t y_t + \beta E_t \lambda_{t+1} (P_{t+1}/P_t)^{\epsilon-1} y_{t+1}} \quad (46)$$

The optimal relative price $p_{0,t}$ depends upon the current and future real marginal costs, the gross inflation rate, current and future consumption as well as today's and tomorrow's interest rates (through the influence of the

³More details on this can be found in [10, Dotsey/King/Wolman (1999)], p. 659-665 as well as in [9, Dotsey/King/Wolman (1997)], p. 9-13.

λ -terms). It is thus fundamentally different from the one derived under fully flexible prices on a period-by-period basis (see (41)). (46) can be manipulated in a way that yields a form which is exactly equal to the one studied in [28, Walsh (1998)], p. 197, when using (18) for the interest rate factor. To derive the Taylor approximation in the Appendix it is useful to write (46) as

$$P_{0,t} = \frac{\epsilon}{\epsilon - 1} \frac{\lambda_t P_t^\epsilon y_t \psi_t + \beta E_t \lambda_{t+1} P_{t+1}^\epsilon y_{t+1} \psi_{t+1}}{\lambda_t P_t^{\epsilon-1} y_t + \beta E_t \lambda_{t+1} P_{t+1}^{\epsilon-1} y_{t+1}} \quad (47)$$

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

$$y_t = c_t + i_t \quad (48)$$

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 .⁴

Substituting M_t^s in the CIA-constraint - holding with equality - allows to derive an implicit money demand function in the CIA-model.

$$M_t = P_t c_t \quad (49)$$

It is essentially a quantity theoretic type of money demand. It is important to stress that it depends crucially upon the form of the monetary transfer M_t^s . [2, Carlstrom/Fuerst (1998)] include bond holdings in their CIA-constraint. Using this specification, including bond holdings also in M_t^s , leads to multiple equilibria.

In the MIU-model the efficiency condition for money determines the money demand function, of course.

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

$$\mu_t = \frac{1}{\psi_t} \quad (50)$$

⁴See [11, Flodén (2000)], p. 1413. He argues that bonds are introduced to determine the nominal interest rate.

Note that the optimal price $P_{0,t}$ is left in the model as a variable. It is not eliminated and combined with the price level to obtain a New Keynesian Phillips-curve as in some papers in the literature (see for example [1, Brückner/Schabert (2001)]). This makes it possible to analyze the behavior of optimal prices, the price level and inflation separately.

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 assumed. To achieve persistent but non permanent effects the level of money follows an AR(2)-process which implies that the growth rate follows an AR(1)-process. That means for the level of money

$$\widehat{M}_t = (1 + \rho_{M_2}) \widehat{M}_{t-1} - \rho_{M_2} \widehat{M}_{t-2} + \epsilon_{M_t} \quad (51)$$

whereas for the growth rate one gets

$$\widehat{M}_t - \widehat{M}_{t-1} = \rho_{M_2} (\widehat{M}_{t-1} - \widehat{M}_{t-2}) + \epsilon_{M_t} \quad (52)$$

A hat ($\widehat{}$) represents the relative deviation of the respective variable from its steady state (see the Appendix). ϵ_{M_t} is an i.i.d. sequence of shocks that hit the growth rate.

This formulation is equivalent to the standard assumption that money grows at a factor g_t :

$$M_t = g_t M_{t-1} \quad (53)$$

Suppose \widehat{g}_t follows an AR(1)-process $\widehat{g}_t = \rho_{M_2} \widehat{g}_{t-1} + \epsilon_{M_t}$ then it is easy to show that (52) is valid. Note that inflation is zero in the steady state so also money growth is zero there ($g = 1$, see the next Section).

There is another shock in the model, namely the productivity shock a_t . As is clear from the utility functions this shock can also act as a taste shock. So one can easily analyze the model's impulse responses to a productivity and taste shock. Under these circumstances \widehat{a}_t follows an AR(1)-process

$$\widehat{a}_t = \rho_a \widehat{a}_{t-1} + \epsilon_{a_t} \quad (54)$$

with ϵ_{a_t} white noise.

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 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 (36) and the steady state for z it is possible to pin down k/n which amounts to

$$\frac{k}{n} = \left(\frac{r + \delta}{a} \frac{1}{1 - \alpha} \frac{1}{\psi} \right)^{-1/\alpha} \quad (55)$$

For the markup μ it follows $\mu = 1/\psi$ while ψ is determined by the steady state of the efficiency condition for maximizing profits, (46). This amounts to $\psi = (\epsilon - 1)/\epsilon$. This can be used to calculate w as well:

$$w = \psi a \alpha \left(\frac{k}{n} \right)^{1-\alpha} \quad (56)$$

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

$$\frac{y}{n} = a \left(\frac{k}{n} \right)^{1-\alpha} \quad (57)$$

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

$$\frac{i}{y} = \left(\frac{i}{k} \frac{k}{n} \right) / \left(\frac{y}{n} \right) \quad (58)$$

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

$$\frac{c}{y} = -\frac{i}{y} + 1 \quad (59)$$

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.

In case of the CIA-model (17) is used to pin down the preference parameter, which is either θ or ζ . In case of utility function (1) $\theta = \beta w/(an^\gamma)$ whereas for (2) $\zeta = c/[\beta(w - wn) + c]$.

For the MIU-model with CRRA preferences the marginal rate of substitution between consumption and labor can also be used to calculate the preference parameter ζ .⁵ Using (27) the ratio of m over c depends only upon β, η and ν .

$$m = c \left[\frac{\eta}{1 - \eta} (1 - \beta) \right]^{\frac{1}{\nu-1}} \quad (60)$$

In turn ζ can be determined as a function of these parameters and c, w and n .

$$\zeta = \frac{c}{(1 - n)\Theta} \left[w + \frac{c}{1 - n}\Theta \right]^{-1} \quad (61)$$

with

$$\Theta = 1 + (1 - \beta)^{\frac{\nu}{\nu-1}} \left(\frac{\eta}{1 - \eta} \right)^{\frac{1}{\nu-1}} \quad (62)$$

In the MIU-model with GHH preferences m is also given by (60). Then θ changes to

$$\theta = \frac{1}{\mu} \frac{1}{n^\gamma} \left[c^\nu \left(\eta + (1 - \eta) \left((1 - \beta) \frac{\eta}{1 - \eta} \right)^{\frac{\nu}{\nu-1}} \right) \right]^{\frac{1-\nu}{\nu}} \eta c^{\nu-1} \quad (63)$$

2.7 Calibration

To compute impulse responses the parameters of the model have to be calibrated. Some parameters depend upon the specific utility function used so it is useful to look at first at the parameters which are independent of these.

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

⁵Remember that this ratio is not the same as (17) but the standard formula which results from combining the efficiency conditions for consumption and labor.

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 [23, 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 10.⁶ 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 in all models. For GHH preferences γ has to be specified. To make results comparable to the CRRA utility function γ is set to 1.3 which implies the same elasticity of labor supply with respect to the real wage. In the sensitivity analysis the value will be changed to 0.1. The implied value of θ under CIA is 34.7155.

Using the CRRA preference specification under CIA the parameter ζ can be calculated using equation (17) which implies $\zeta = 0.3617$, a value that is reasonably in line with other studies.

In the MIU-model, both for CRRA and GHH preferences, the parameters ν and η are calibrated by estimating an empirical money demand function the form of which is implied by the efficiency conditions of the household. This functional form is obtained by solving (27) for m_t and taking logarithms:

$$\ln m_t = \frac{1}{\nu - 1} \ln \frac{\eta}{1 - \eta} + \frac{1}{\nu - 1} \ln \left(\frac{R_t}{1 + R_t} \right) + \ln c_t \quad (64)$$

Estimates of [4, Chari/Kehoe/McGrattan (2000)] reveal that $\eta = 0.94$ and $\nu = -1.56$. They use US data from Citibase covering 1960:1-1995:4 regressing the log of consumption velocity on the log of the interest rate variable $R_t/(1 + R_t)$. Since the paper focuses on the qualitative results of the model the money demand function is not estimated for specific German or other data. For CRRA utility the implied value of ζ changes slightly to 0.3593 while m/c is equal to 2.06. Under GHH preferences $\theta = 35.2827$.

As this model considers the role of capital accumulation several other technological parameters have to be calibrated. The most common one is the

⁶In contrast to the well known basic neoclassical model of [17, King/Plosser/Rebelo (1988)] there is no escape from specifying parameters such as a at the steady state. The system cannot be reduced until only deep parameters remain to be calibrated.

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 -0.5.⁷ This value is also used in [21, King/Wolman (1996)]. The presence of adjustment costs of capital dampens the volatility of investment 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 exogenous money growth process $\rho_{M_2} = 0.5$ is used. As the focus of the paper is on persistency of money 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 [18, King/Plosser/Rebelo (1990)] which allows for singularities in the system matrix of the reduced model. The theoretical background of this algorithm is developed in [20, King/Watson (1999)] whereas computational aspects and the implementation are discussed in [19, King/Watson (1997)].

3.1 CIA-model

Because results differ it is useful to subdivide this subsection in two further sections containing results for the GHH preferences and for the standard CRRA utility function.

3.1.1 GHH Preferences

Here the impulse responses of the model variables to a 1% shock to the money growth rate will be discussed. Figures 1-4 display the reaction of selected variables to this shock. A striking feature of all responses is their cyclical pattern. The rise of output on impact is followed by an immediate decline in the second period which is again followed by a rise. There is no persistence at all. The impact effect on consumption is hardly positive. Investment reacts stronger than output while the reaction of labor is counterfactually stronger than that of output. Note that there are no permanent effects, although the graphs seem to support this conclusion. The very long lasting effects - output

⁷It can be shown that this elasticity is given by $-\phi''/\phi' \cdot (i/k)$.

is 0.01% above steady state even 40 quarters after the shock - is due to the very slow adjustment of the capital stock to its equilibrium value. The real marginal cost curve cannot be labeled flat. The capital stock displays also a cyclical reaction. The real return on capital \hat{z}_t rises sharply and mirrors the behavior of the capital stock. Real wages and the markup are also cyclical.

Price adjusting intermediate goods firms raise their prices strongly so that prices reach immediately their new equilibrium value. In the second period after the shock they go down and then approach the new steady state cyclically from below. As the other firms do the same later the price level goes up. As the initial rise in \hat{P}_t is nearly as strong as the rise in money due to the shock real money balances hardly rise on impact and decline afterwards. The inflationary peak is in the first period. Remarkably this model is able to generate a declining nominal interest rate although it rises in the second period and then remains positive through time.

Figures 5-8 show the results for $\gamma = 0.1$. Using this value together with $\sigma = 2$ produces a solution with multiple equilibria. In order to circumvent this problem σ is changed to 1 implying the special log-linear case. In a model with capital the elasticity of real marginal cost with respect to output is still equal to γ although production depends on the amount of capital used. Surprisingly the variables show overall no enhanced persistence as it was the case in the labor only economy. There is only a dampening effect on the cyclical reaction: the number of humps and dips goes down.⁸ This is especially the case for output and consumption which display a smoother adjustment to the steady state. Still this adjustment is from below what is not observed empirically. Consumption and real money balances even decline on impact now. Note that prices overshoot, a feature that also occurred in the labor economy for a high value for the elasticity of labor supply with respect to the real wage, a low γ .

It can be concluded that the intertemporal substitution channel that is opened up by capital accumulation works together with the quantity theoretic money demand function to compensate the effects of a low elasticity of real marginal costs. Adding capital enhances the role played by the money demand function in dampening persistence.

⁸Partly this can be also due the smaller value for the relative risk aversion. But see the discussion of the results for the MIU-model later.

3.1.2 CRRA Preferences

Comparing the results for CRRA preferences in Figures 9-12 with those under GHH utility immediately reveals first that the impulse responses are less cyclical. A second difference concerns the response of output and investment which is weaker under CRRA while consumption and labor react stronger. Especially consumption rises on impact. Third, the nominal interest rate rises again persistently so the model does not display the liquidity effect. Forth, the capital stock shows a smoother behavior and returns a bit faster back to steady state. Real money balances also clearly rise on impact now.

Prices react a lot weaker. The price reaction is smoother and more persistent under CRRA than under GHH in a CIA-model. Investment stays above steady state all the time, in contrast to the GHH case. Overall, the impulse responses for CRRA preferences show more persistence than those in the GHH case. Again, as is the case in a labor only economy, in a CIA-economy there is more persistency under CRRA so that the form of the utility function matters. Even a high value for the labor supply elasticity in the GHH model cannot account for higher degrees of persistence.

3.2 MIU-Model

Again this section is divided in two subsections considering GHH and CRRA preferences separately.

3.2.1 GHH Preferences

Figures 13-16 show the results for GHH preferences. Compared to the CIA-model especially output, consumption and labor hours show a stronger initial reaction. But some variables also display a weaker response, for example the real interest rate and the capital stock. The initial output response is stronger than the reaction of investment while labor reacts even stronger than output which is certainly counterfactual. Consumption rises more than output, something which is also not observed empirically. The nominal interest now rises again but does not show a persistent reaction. The decline in real money balances is very pronounced because prices overshoot very strongly. This causes inflation to peak in the first period. Overall the cyclicity is enhanced in the MIU-model compared with the CIA-setup. A very low value of the risk aversion parameter σ creates extremely cyclical impulse responses

with humps and dips for several periods. On the other hand high values of σ dampen the peaks and troughs.⁹

Figures 17-20 show the results for the model variant with a low value for γ ($=0.1$). The immediate impression from these figures is the loss of cyclicity. Now there is at most one pronounced peak or trough before the variable returns back to steady state.¹⁰ A second difference concerns the strength of the response: especially output, investment, consumption and labor show a stronger initial reaction while the real wage, real marginal costs, the markup and the return on capital react weaker. Prices do not overshoot that strong causing real money balances to decline weaker.

Two important things can be concluded from this exercise: First, in models with capital the role of the implied money demand function is weakened. In comparison to the results in [12, Gail (2001)] there is not more persistency in a CIA-model than in a MIU-setup under GHH preferences for comparable parameterizations. It obviously does not matter whether money demand is interest rate sensitive or not. Second, this result cannot be reversed for a low value of the elasticity of real marginal cost with respect to output. The intertemporal substitution possibilities which are available for the households through capital accumulation compensate completely the effect of a low value of γ .

3.2.2 CRRA Preferences

In Figures 21-24 the results for the MIU-model with CRRA preferences are presented. Compared to the GHH results all variables show less cyclicity. Consumption's and labor's initial response is weaker improving especially the volatility of consumption relative to output. Real money balances decline less because prices do not overshoot that strong. Varying σ does not affect the model outcome very much.

In comparison to the CIA-setup impulse responses are overall stronger initially, except those of prices and the nominal interest rate. The capital stock returns more quickly to the steady state while real money balances counterfactually fall now. Overall the CIA-model can generate a bit more

⁹This is not shown in the Figures. Results are available from the author upon request.

¹⁰In light of the results stated above and those in the previous section on the CIA-model with GHH preferences γ seems to be responsible for the loss of dips and humps. σ 's role in strengthening the peaks and troughs when being smaller seems to be compensated in the CIA-setup.

persistence than the MIU-setup. But the effect due to the implied money demand function is again not very strong if there is any effect at all. Here the same conclusion as for GHH utility holds. In a model with capital accumulation persistent responses of inflation and output to a money growth shock cannot be explained.

4 Conclusions

In light of the main question of the paper it must be concluded that persistent reactions of output and inflation to money growth shocks cannot be explained in sticky price models with capital. Even a MIU-model with GHH preferences and a low output elasticity of real marginal costs is not able to account for the observed persistency of the variables.

The interaction of an interest rate sensitive money demand function with a high labor supply elasticity in the MIU-model with GHH utility is obviously compensated by intertemporal links through capital accumulation. These effects are strong enough to outweigh those of the mechanisms responsible for generating a persistent output and inflation response in a labor only economy.

Price staggering seems to be insufficient to account for the stylized facts. This is probably different in open economy models. Recently [13, Ghironi (2002)] has shown that once openness is taken into account a sticky price model can generate endogenous output persistence.¹¹ This depends crucially on incomplete asset markets. But the models consider economies with labor as the only input factor in production. It would be interesting to generalize the model at hand to such a framework.

A Appendix

A.1 Household's Equations: CIA-model

The efficiency condition for consumption results in

$$\begin{aligned} & -D_1 u(c, n, a) \widehat{P}_{t+1} + nD_{12} u(c, n, a) \widehat{n}_{t+1} + cD_{11} u(c, n, a) \widehat{c}_{t+1} \quad (65) \\ = & D_1 u(c, n, a) \widehat{\lambda}_t - D_1 u(c, n, a) \widehat{P}_t - aD_{13} u(c, n, a) \widehat{a}_{t+1} \end{aligned}$$

¹¹See also [3, Cavallo/Ghironi (2002)].

using Ω_t from the derivative with respect to m_{t+1} .

A hat ($\widehat{\cdot}$) represents the relative deviation of the respective variable from its steady state ($\widehat{a}_t = (a_t - a) / a$). $D_i u(\cdot)$ denotes the first partial derivative of the u -function with respect to the i -th argument. Similarly $D_{ij} u(\cdot)$ denotes the partial derivative of $D_i u(\cdot)$ with respect to the j -th argument, all evaluated at the steady state. For labor one gets

$$0 = \quad nD_{22}u(c, n, a)\widehat{n}_t + cD_{21}u(c, n, a)\widehat{c}_t \quad (66)$$

$$\quad -D_2u(c, n, a)\widehat{\lambda}_t - D_2u(c, n, a)\widehat{w}_t + aD_{23}u(c, n, a)\widehat{a}_t$$

The cyclical behavior of money demand can be deduced from (49).

$$\widehat{M}_t = \widehat{c}_t + \widehat{P}_t \quad (67)$$

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

$$-\widehat{P}_{t+1} + \widehat{\lambda}_{t+1} = -\widehat{P}_t - \frac{R}{1+R}\widehat{R}_t + \widehat{\lambda}_t \quad (68)$$

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

$$\widehat{\lambda}_{t+1} = -\frac{r}{1+r}\widehat{r}_t + \widehat{\lambda}_t \quad (69)$$

Optimal investment is determined from the efficiency condition for i_t :

$$0 = -\widehat{\lambda}_t + \widehat{\theta}_t + \frac{\phi''}{\phi'} \frac{i}{k} \widehat{i}_t - \frac{\phi''}{\phi'} \frac{i}{k} \widehat{k}_{t-1} \quad (70)$$

The first order condition for capital implies:

$$\beta z \widehat{\lambda}_{t+1} + \beta z \widehat{z}_{t+1} + \beta(1-\delta)\widehat{\theta}_{t+1} - \beta \frac{\phi''}{\phi'} \frac{i}{k} \widehat{i}_{t+1} = -\beta \frac{\phi''}{\phi'} \frac{i}{k} \widehat{k}_t + \widehat{\theta}_t \quad (71)$$

Capital evolves over time according to

$$\widehat{k}_t = (1-\delta)\widehat{k}_{t-1} + \delta \widehat{i}_t \quad (72)$$

A.2 Household's Equations: MIU-Model

In the MIU-model the following three equations replace the first three in Appendix A.1. The approximation for consumption is then given by

$$\begin{aligned}
0 = & -mD_{12}u(c, m, n, a) \widehat{P}_t + nD_{13}u(c, m, n, a) \widehat{n}_t \\
& + cD_{11}u(c, m, n, a) \widehat{c}_t - D_1u(c, m, n, a) \widehat{\lambda}_t \\
& + mD_{12}u(c, m, n, a) \widehat{M}_t + aD_{14}u(c, m, n, a) \widehat{a}_t
\end{aligned} \tag{73}$$

The cyclical behavior of labor is determined by

$$\begin{aligned}
0 = & nD_{33}u(c, m, n, a) \widehat{n}_t + cD_{31}u(c, m, n, a) \widehat{c}_t \\
& - D_3u(c, m, n, a) \widehat{\lambda}_t - D_3u(c, m, n, a) \widehat{w}_t \\
& + mD_{32}u(c, m, n, a) \widehat{M}_t + aD_{34}u(c, m, n, a) \widehat{a}_t \\
& - mD_{32}u(c, m, n, a) \widehat{P}_t
\end{aligned} \tag{74}$$

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

$$\begin{aligned}
& \beta D_1u(c, m, n, a) \widehat{P}_{t+1} - \beta D_1u(c, m, n, a) \widehat{\lambda}_{t+1} \\
= & cD_{21}u(c, m, n, a) \widehat{c}_t + mD_{22}u(c, m, n, a) \widehat{M}_t \\
& + nD_{23}u(c, m, n, a) \widehat{n}_t - D_1u(c, m, n, a) \widehat{\lambda}_t \\
& + [\beta D_1u(c, m, n, a) - mD_{22}u(c, m, n, a)] \widehat{P}_t \\
& + aD_{24}u(c, m, n, a) \widehat{a}_t
\end{aligned} \tag{75}$$

The other equations stay the same.

A.3 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.

$$0 = \frac{1}{2} \widehat{P}_{0,t} + \frac{1}{2} \widehat{P}_{0,t-1} - \widehat{P}_t \tag{76}$$

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

A.4 Intermediate Goods Firm's Equations

The optimum conditions of the cost minimization problem determine the real wage and the rental rate of capital (see (36) and (37)), with the j 's dropped of course.

$$0 = (\alpha - 1)\hat{n}_t + (1 - \alpha)\hat{k}_{t-1} + \hat{\psi}_t + \hat{a}_t - \hat{w}_t \quad (77)$$

$$0 = \alpha\hat{n}_t - \alpha\hat{k}_{t-1} + \hat{\psi}_t + \hat{a}_t - \hat{z}_t \quad (78)$$

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

$$0 = -\hat{y}_t + \alpha\hat{n}_t + (1 - \alpha)\hat{k}_{t-1} + \hat{a}_t \quad (79)$$

The condition for optimal two period pricing is given in (46). Its Taylor approximation can be written as

$$\begin{aligned} & \beta [\epsilon\psi - (\epsilon - 1)]\hat{\lambda}_{t+1} + \beta [\epsilon^2\psi - (\epsilon - 1)^2]\hat{P}_{t+1} + \beta [\epsilon\psi - (\epsilon - 1)]\hat{y}_{t+1} \\ & + \beta\epsilon\psi\hat{\psi}_{t+1} = (\epsilon - 1)(1 + \beta)\hat{P}_{0,t} + [(\epsilon - 1) - \epsilon\psi]\hat{\lambda}_t \\ & + [(\epsilon - 1)^2 - \epsilon^2\psi]\hat{P}_t + [(\epsilon - 1) - \epsilon\psi]\hat{y}_t - \epsilon\psi\hat{\psi}_t \end{aligned} \quad (80)$$

A.5 Market Clearing Conditions and Other Equations

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

$$0 = -\hat{y}_t + \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{i}_t \quad (81)$$

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

$$0 = \hat{\mu}_t + \hat{\psi}_t \quad (82)$$

A.6 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

$$0 = \widehat{M}_t - \widehat{g}_{M_t} \quad (83)$$

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:

$$0 = -\widehat{\Pi}_t + \widehat{P}_t - \widehat{P}_{t-1} \quad (84)$$

There are now 20 variables

$\widehat{c}_t, \widehat{i}_t, \widehat{y}_t, \widehat{\lambda}_t, \widehat{\theta}_t, \widehat{k}_t, \widehat{k}_{t-1}, \widehat{n}_t, \widehat{w}_t, \widehat{z}_t, \widehat{\mu}_t, \widehat{\psi}_t, \widehat{r}_t, \widehat{R}_t, \widehat{P}_t, \widehat{P}_{t-1}, \widehat{P}_{0,t}, \widehat{P}_{0,t-1}, \widehat{\Pi}_t, \widehat{M}_t$ but only 17 equations so three tautologies must be added to the model. These are

$$\widehat{P}_{0,t} = \widehat{P}_{0,t} \quad (85)$$

$$\widehat{P}_t = \widehat{P}_t \quad (86)$$

$$\widehat{k}_t = \widehat{k}_t \quad (87)$$

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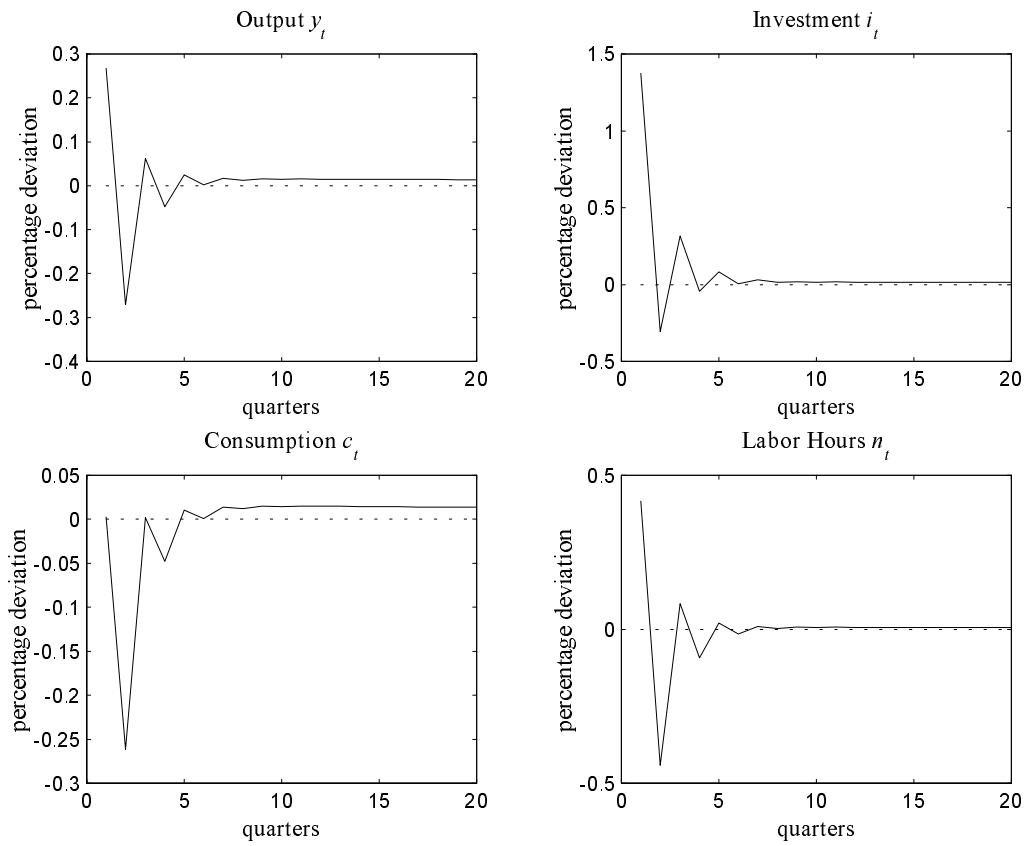


Figure 1: Impulse Response Functions for $\hat{y}_t, \hat{i}_t, \hat{c}_t, \hat{n}_t$, CIA-model, GHH preferences

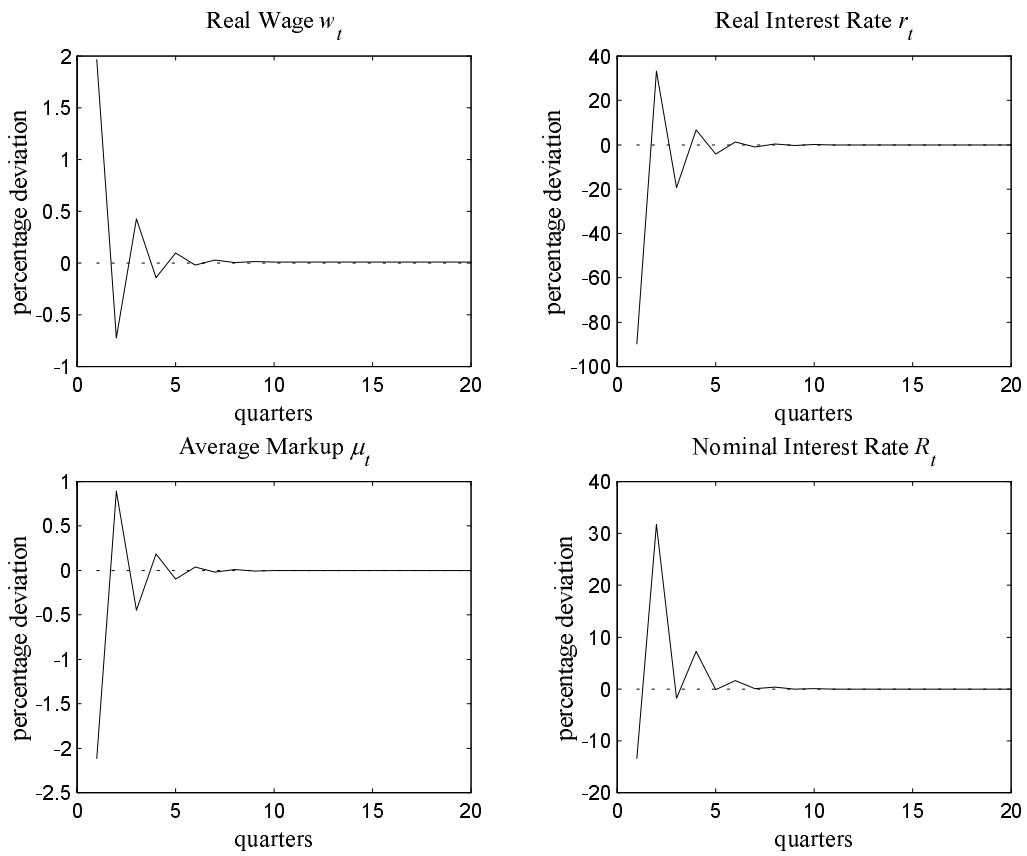


Figure 2: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, CIA-model, GHH preferences

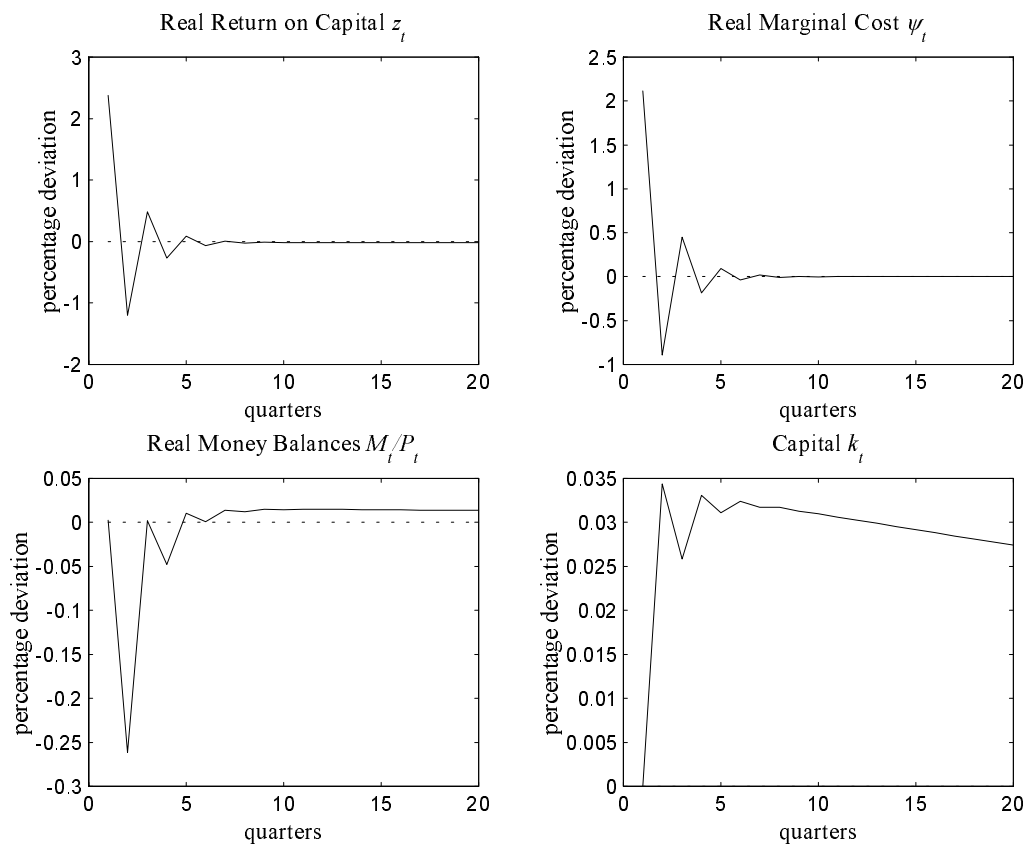


Figure 3: Impulse Response Functions for $\widehat{z}_t, \widehat{\psi}_t, \widehat{M}_t - \widehat{P}_t, \widehat{k}_t$, CIA-model, GHH preferences

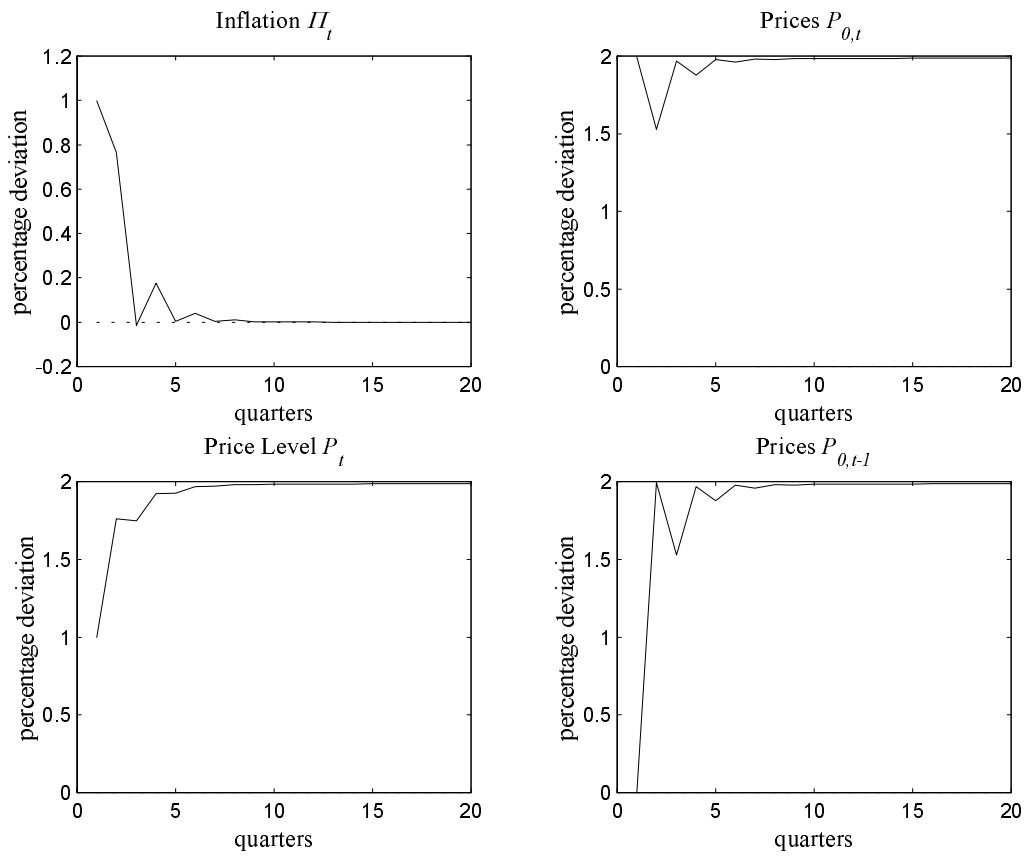


Figure 4: Impulse Response Functions for $\hat{\Pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{0,t-1}$, CIA-model, GHH preferences

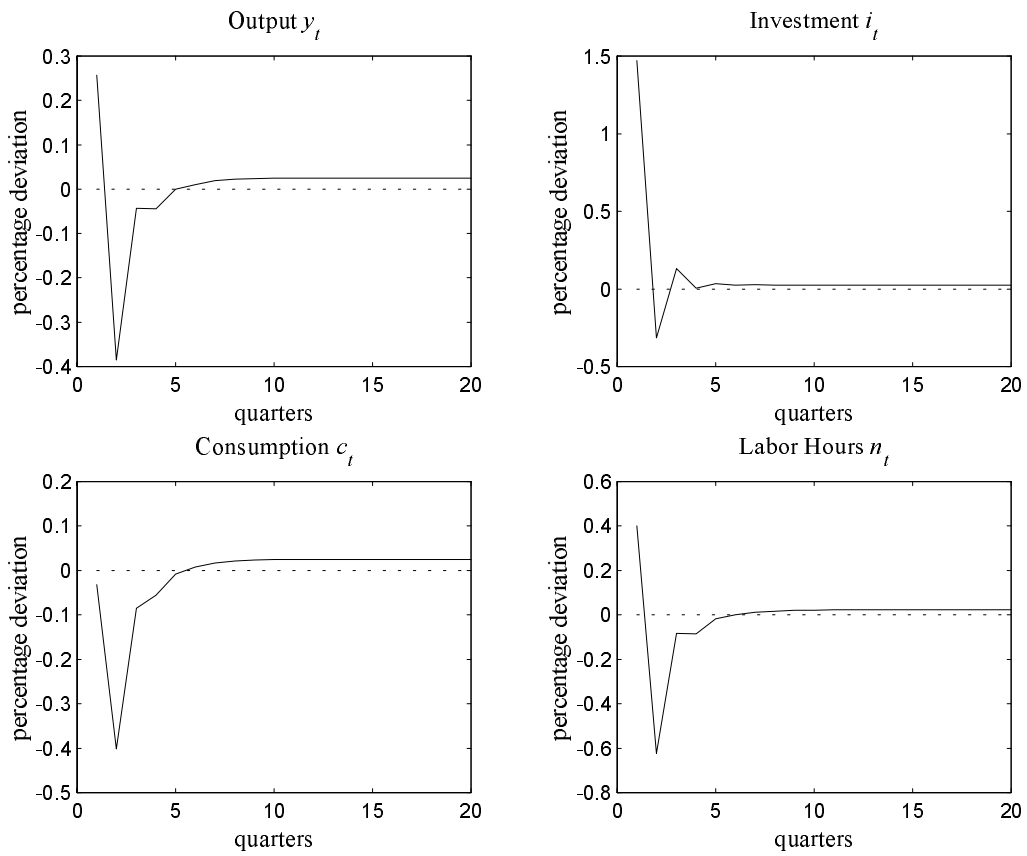


Figure 5: Impulse Response Functions for $\widehat{c}_{0,t}, \widehat{c}_{1,t}, \widehat{c}_t, \widehat{n}_t$, CIA-model, GHH preferences, high labor supply elasticity

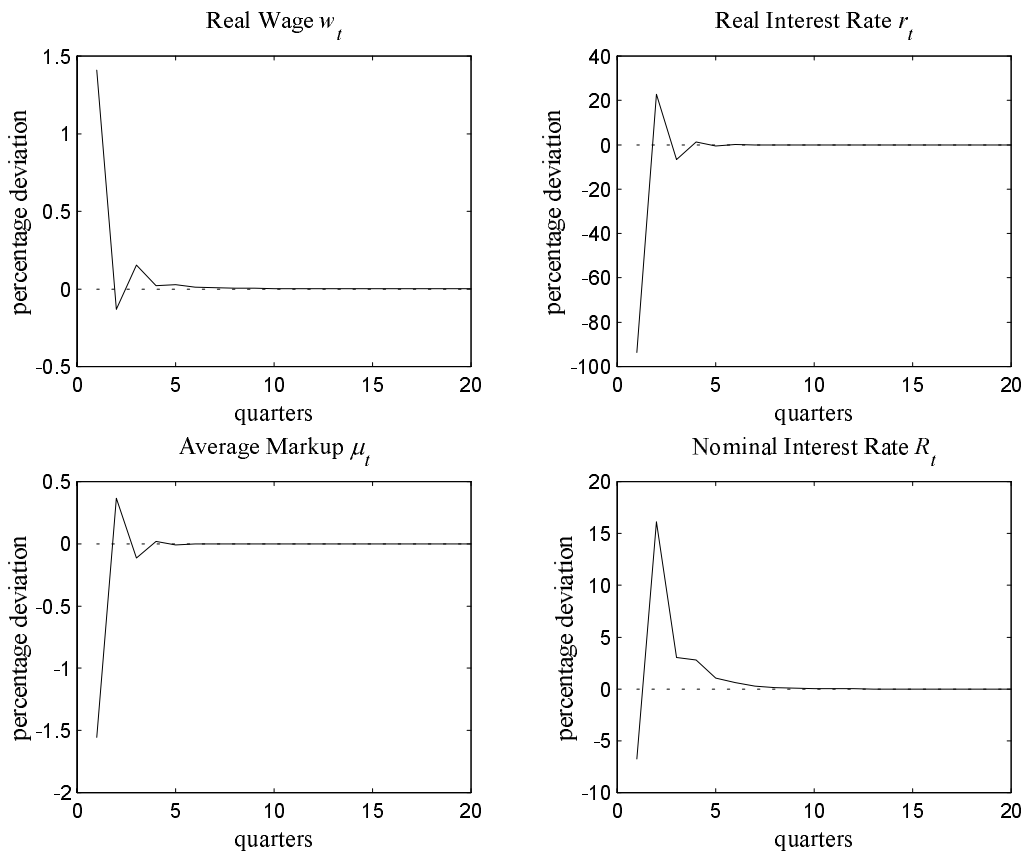


Figure 6: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, CIA-model, GHH preferences, high labor supply elasticity

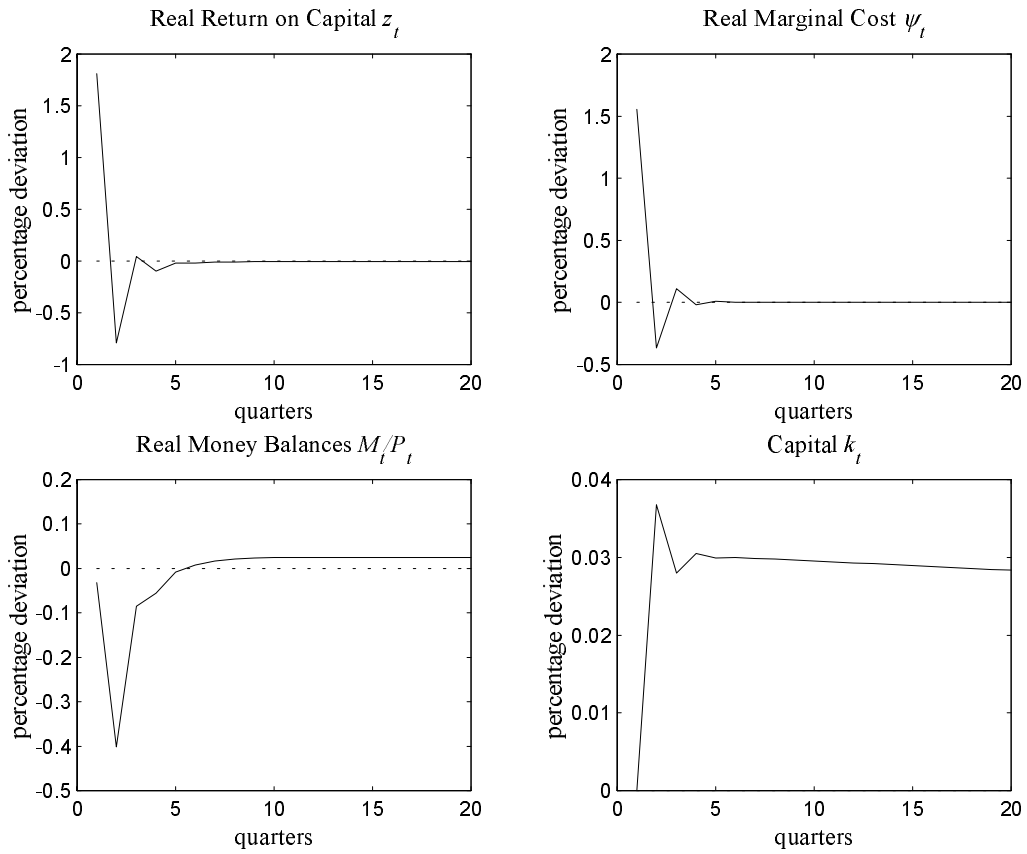


Figure 7: Impulse Response Functions for $\hat{n}_{0,t}$, $\hat{\psi}_t$, $\widehat{M}_t - \widehat{P}_t$, $\hat{n}_{1,t}$, CIA-model, GHH preferences, high labor supply elasticity

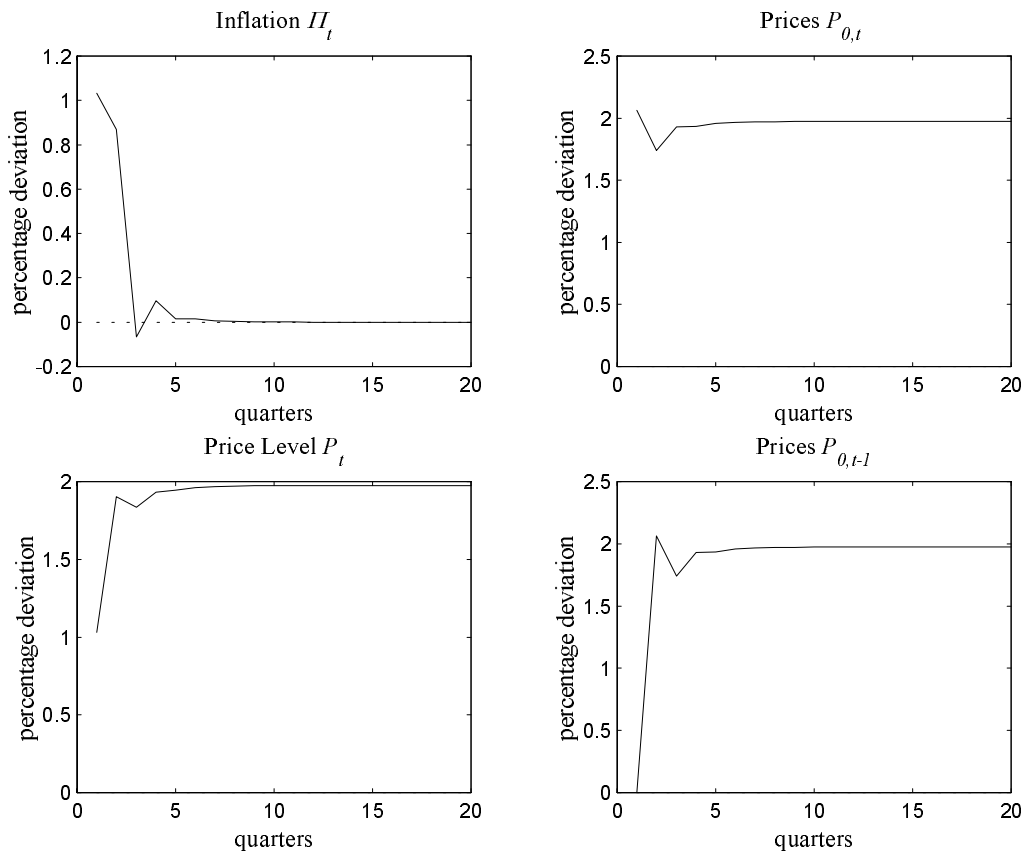


Figure 8: Impulse Response Functions for $\hat{\Pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{1,t}$, CIA-model, GHH preferences, high labor supply elasticity

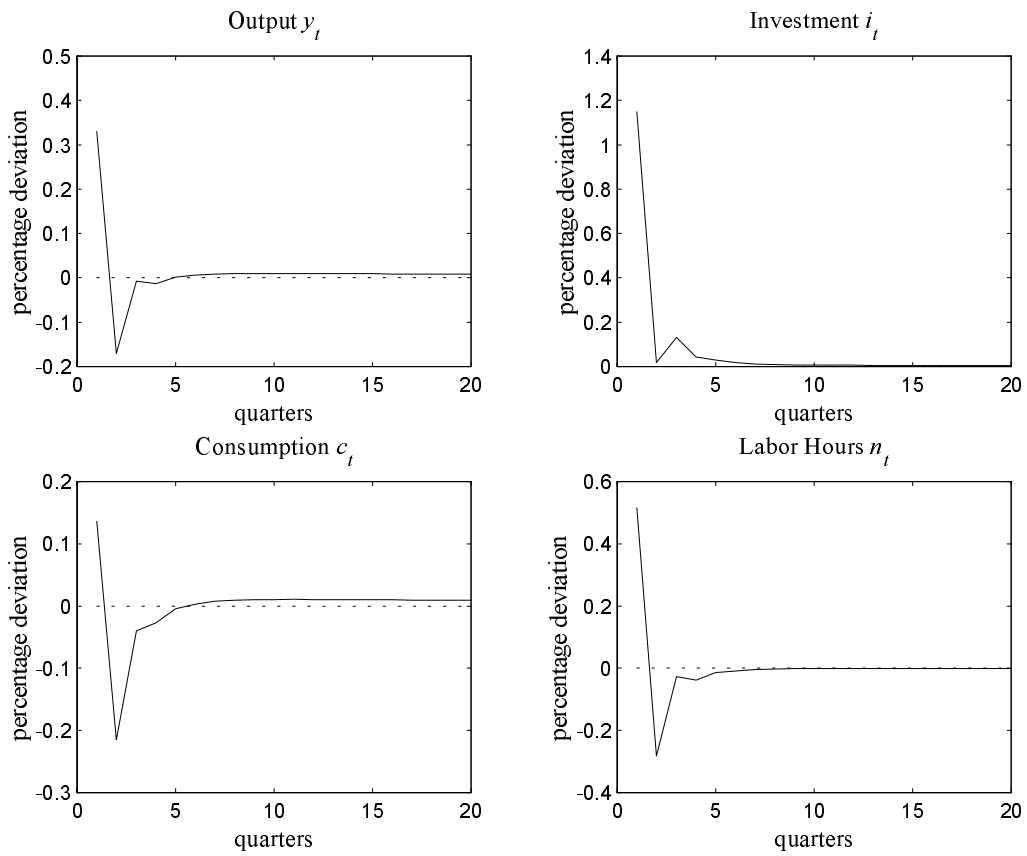


Figure 9: Impulse Response Functions for $\hat{y}_t, \hat{i}_t, \hat{c}_t, \hat{n}_t$, CIA-model, CRRA preferences

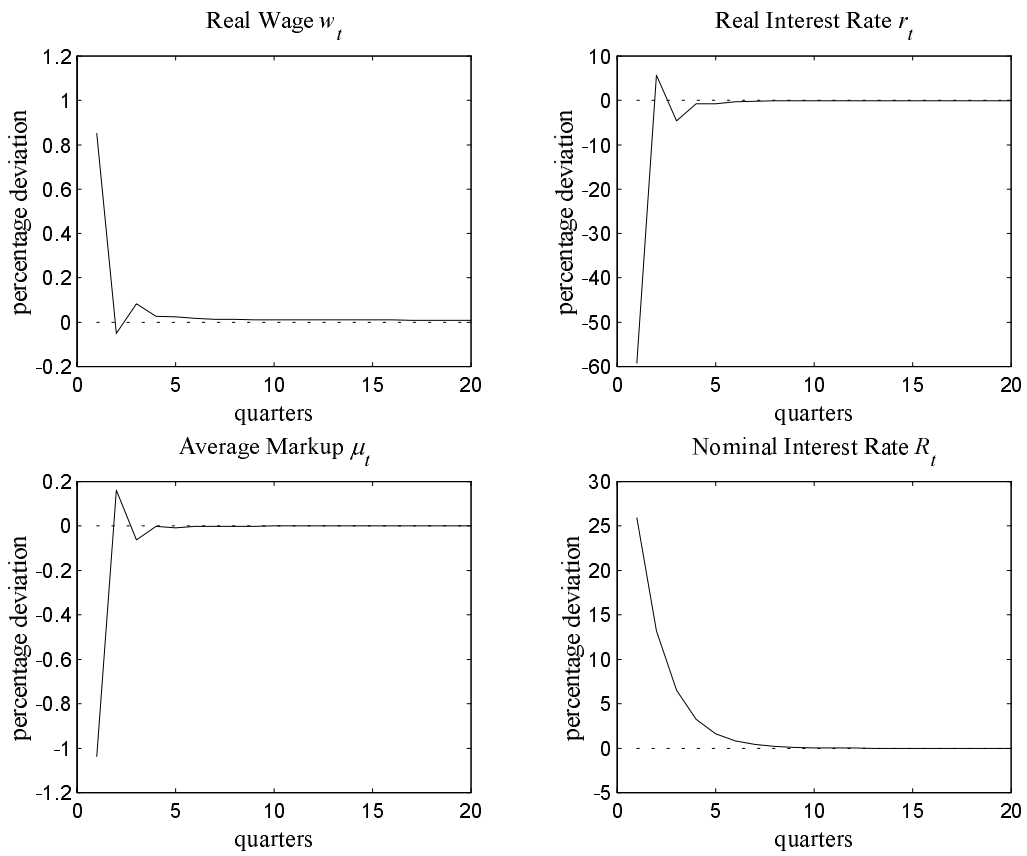


Figure 10: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, CIA-model, CRRA preferences

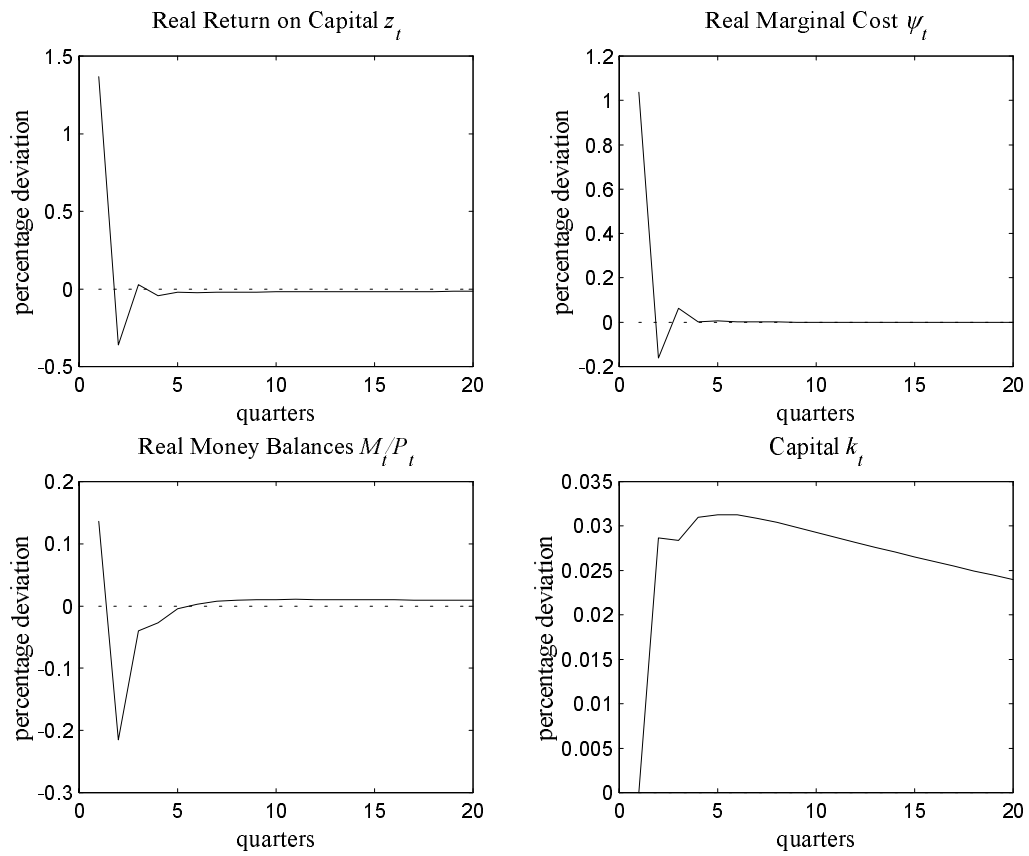


Figure 11: Impulse Response Functions for $\hat{z}_t, \hat{\psi}_t, \hat{M}_t - \hat{P}_t, \hat{k}_t$, CIA-model, CRRA preferences

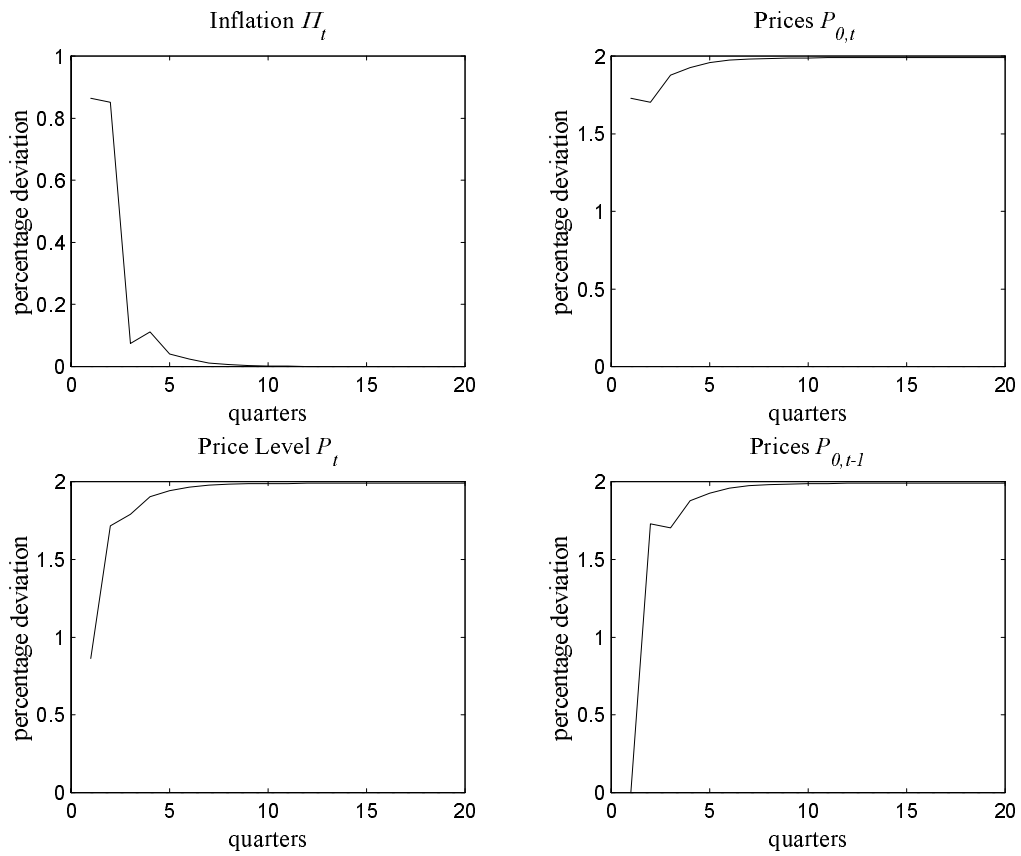


Figure 12: Impulse Response Functions for $\hat{\pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{0,t-1}$, CIA-model, CRRA preferences

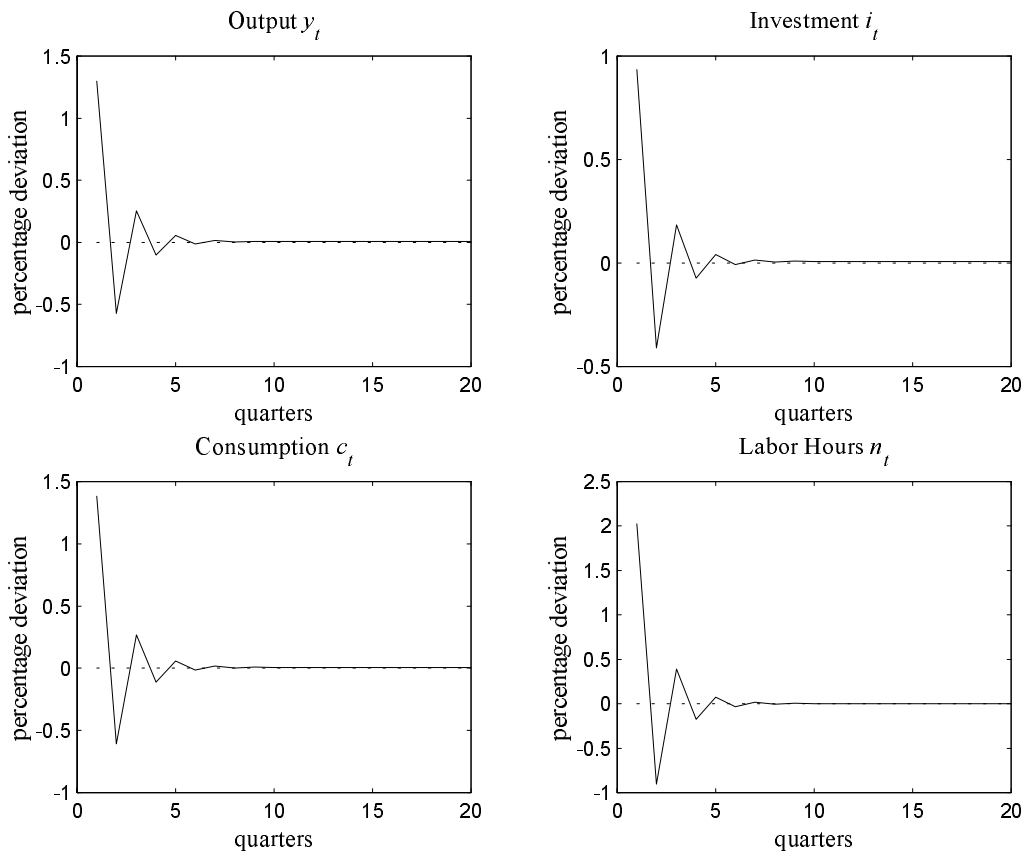


Figure 13: Impulse Response Functions for $\hat{y}_t, \hat{i}_t, \hat{c}_t, \hat{n}_t$, MIU-model, GHH preferences

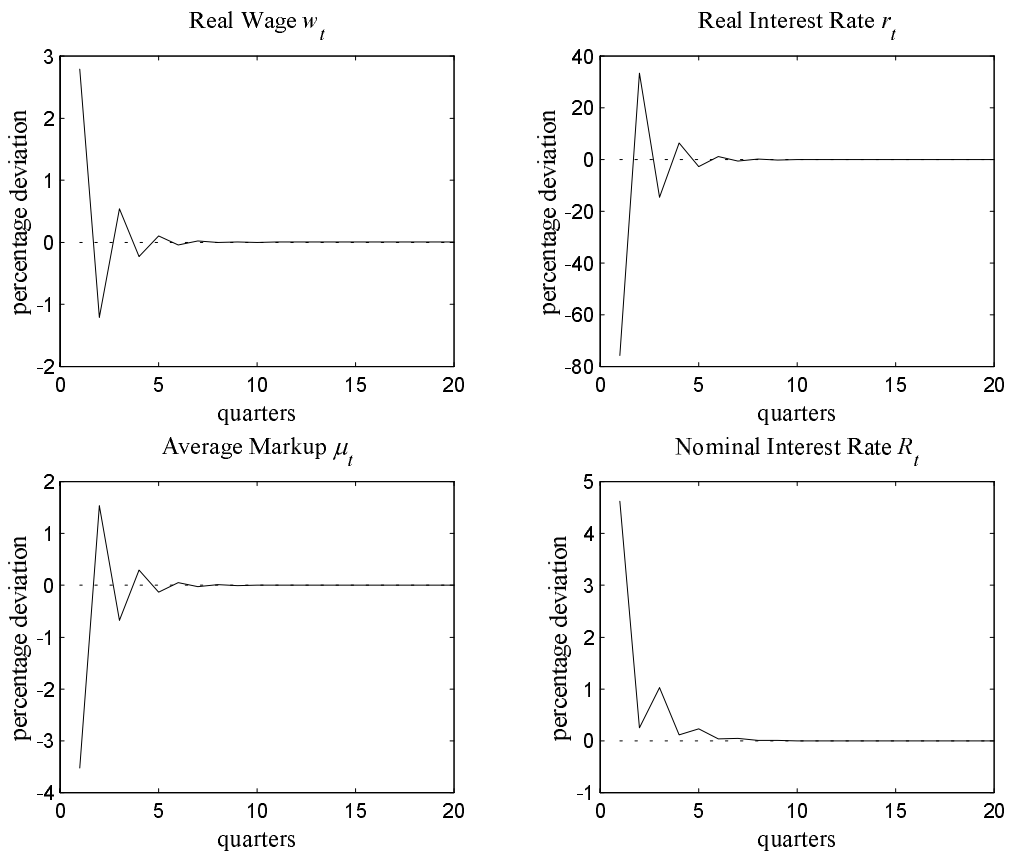


Figure 14: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, MIU-model, GHH preferences

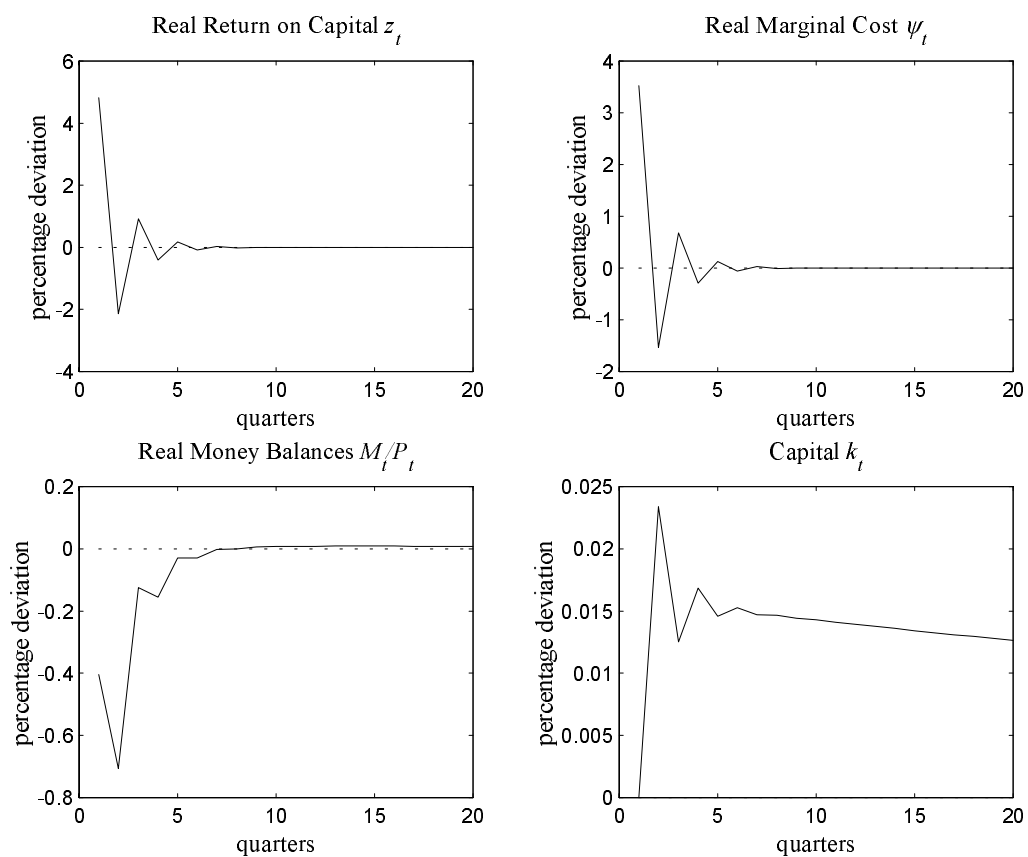


Figure 15: Impulse Response Functions for $\hat{z}_t, \hat{\psi}_t, \hat{M}_t - \hat{P}_t, \hat{k}_t$, MIU-model, GHH preferences

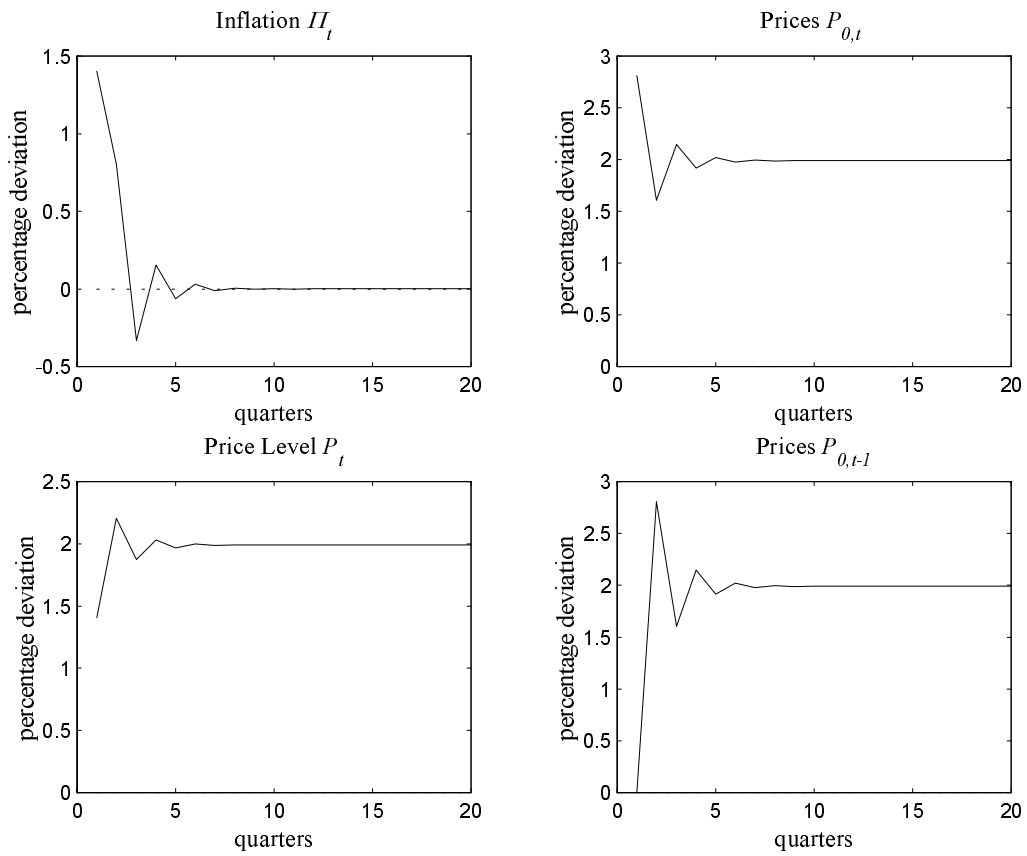


Figure 16: Impulse Response Functions for $\hat{\Pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{0,t-1}$, MIU-model, GHH preferences

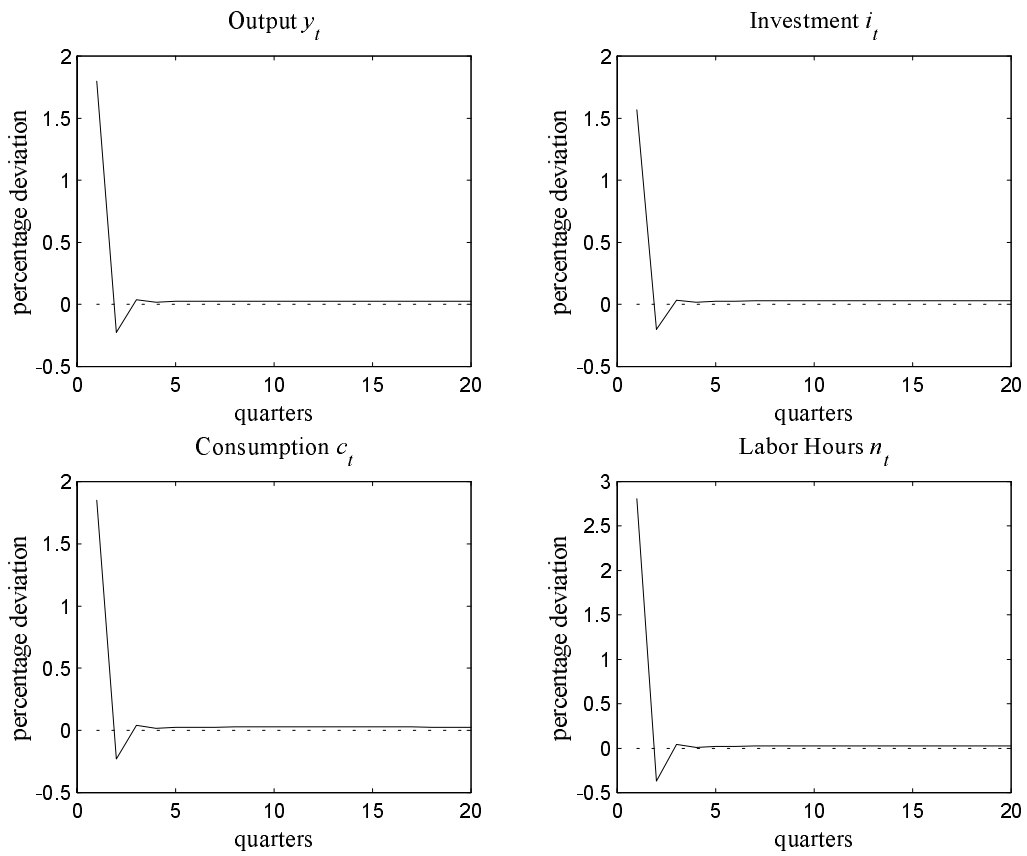


Figure 17: Impulse Response Functions for $\hat{c}_{0,t}$, $\hat{c}_{1,t}$, \hat{c}_t , \hat{n}_t , MIU-Model, GHH preferences, high labor supply elasticity

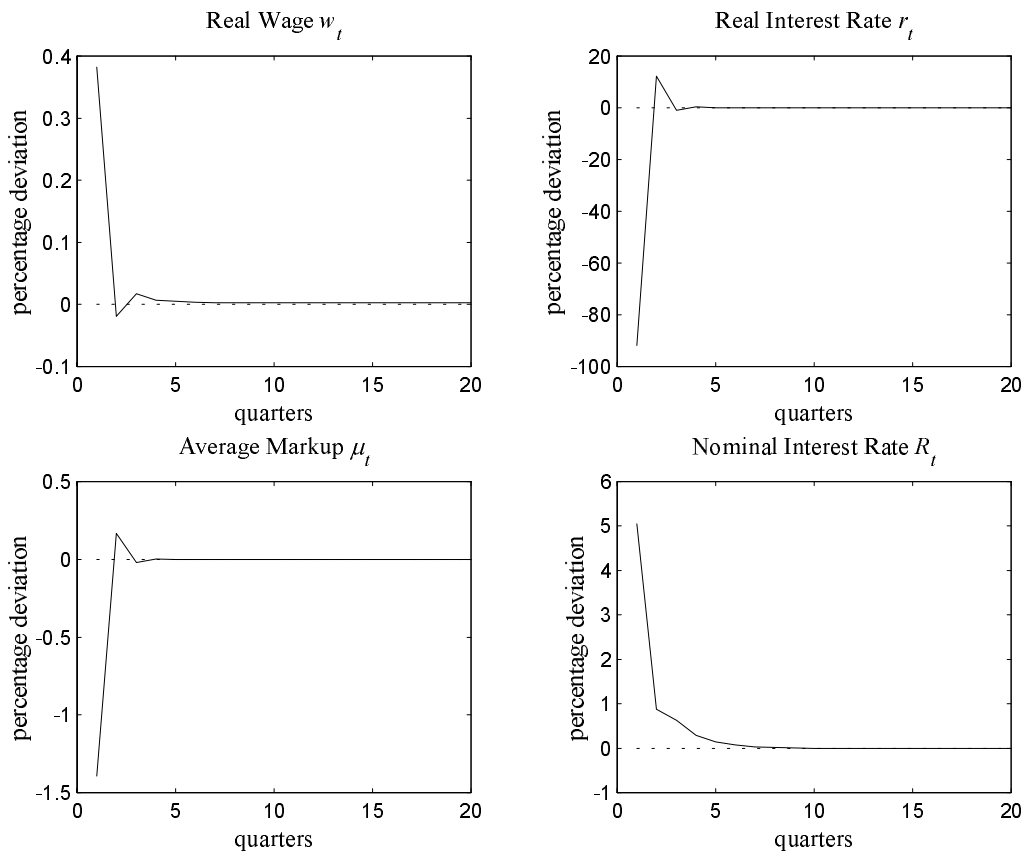


Figure 18: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, MIU-Model, GHH preferences, high labor supply elasticity

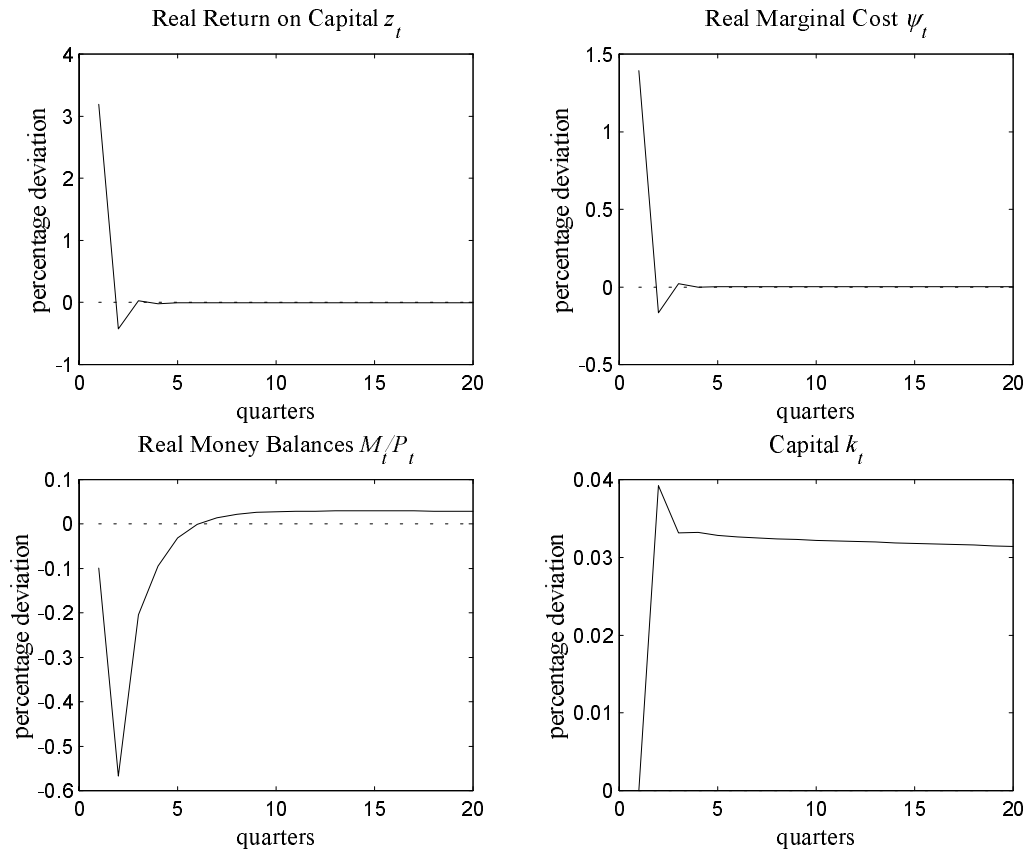


Figure 19: Impulse Response Functions for $\hat{n}_{0,t}$, $\hat{\psi}_t$, $\widehat{M}_t - \widehat{P}_t$, $\hat{n}_{1,t}$, MIU-Model, GHH preferences, high labor supply elasticity

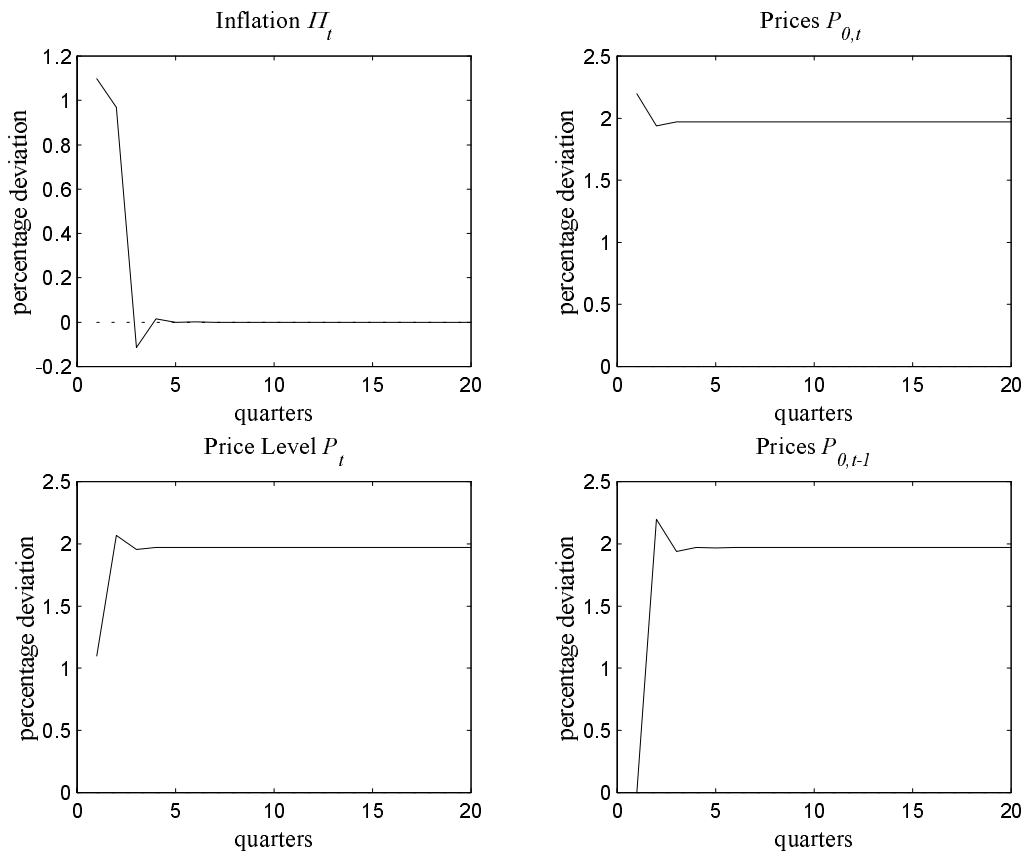


Figure 20: Impulse Response Functions for $\hat{\Pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{1,t}$, MIU-Model, GHH preferences, high labor supply elasticity

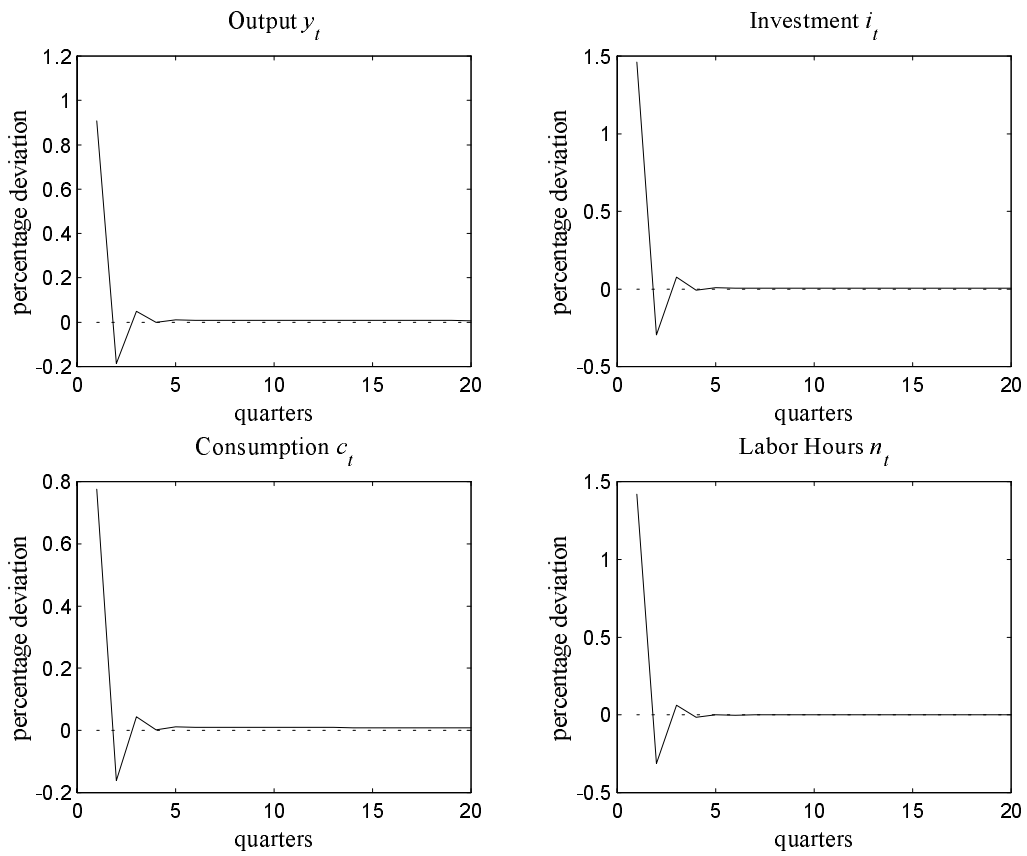


Figure 21: Impulse Response Functions for $\hat{y}_t, \hat{i}_t, \hat{c}_t, \hat{n}_t$, MIU-model, CRRA preferences

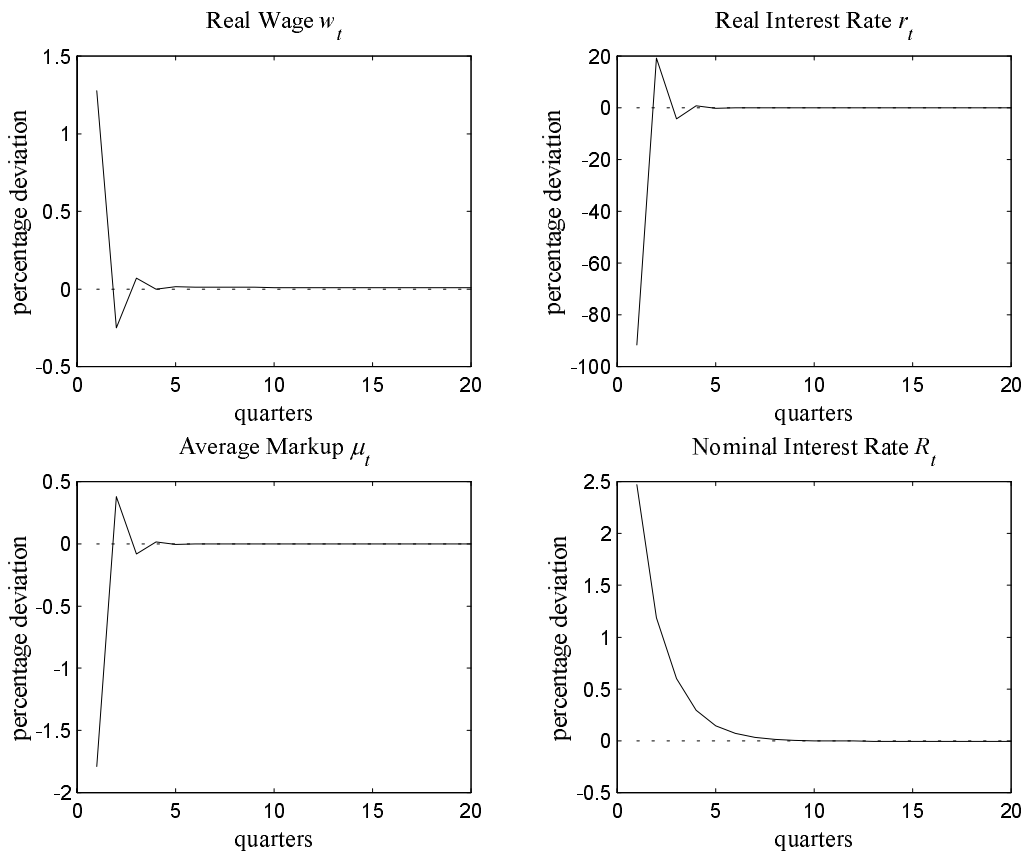


Figure 22: Impulse Response Functions for $\hat{w}_t, \hat{r}_t, \hat{\mu}_t, \hat{R}_t$, MIU-model, CRRA preferences

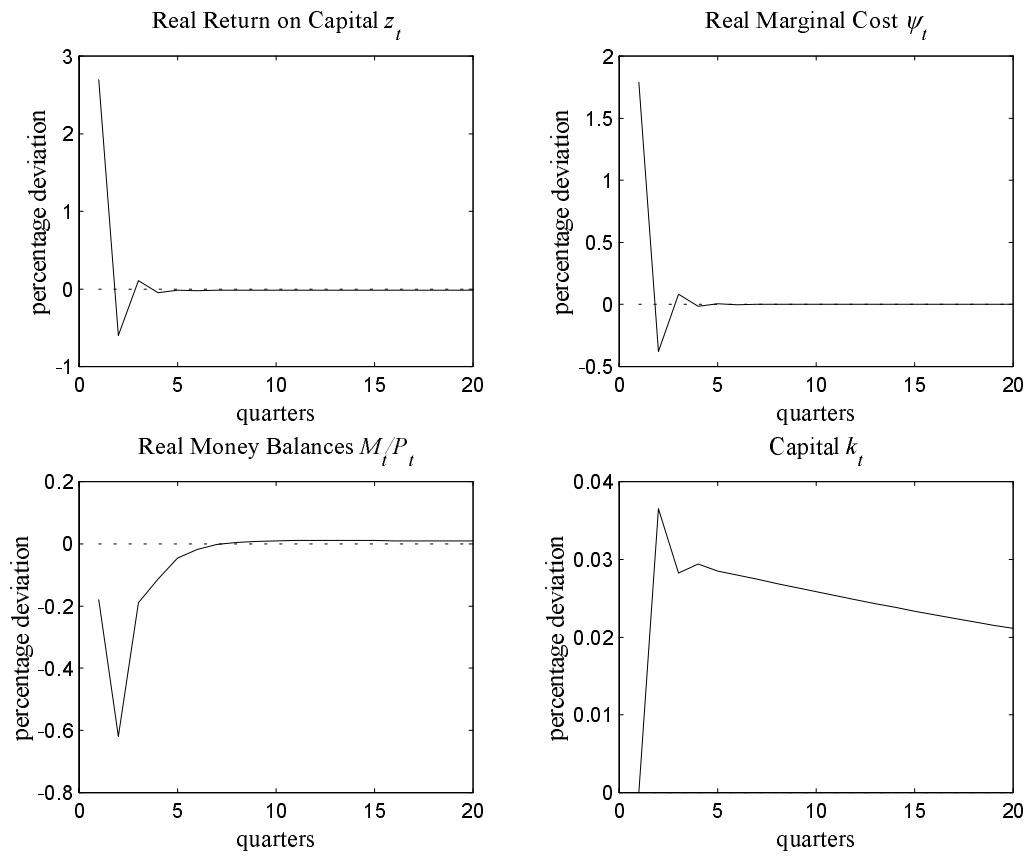


Figure 23: Impulse Response Functions for $\hat{z}_t, \hat{\psi}_t, \hat{M}_t - \hat{P}_t, \hat{k}_t$, MIU-model, CRRA preferences

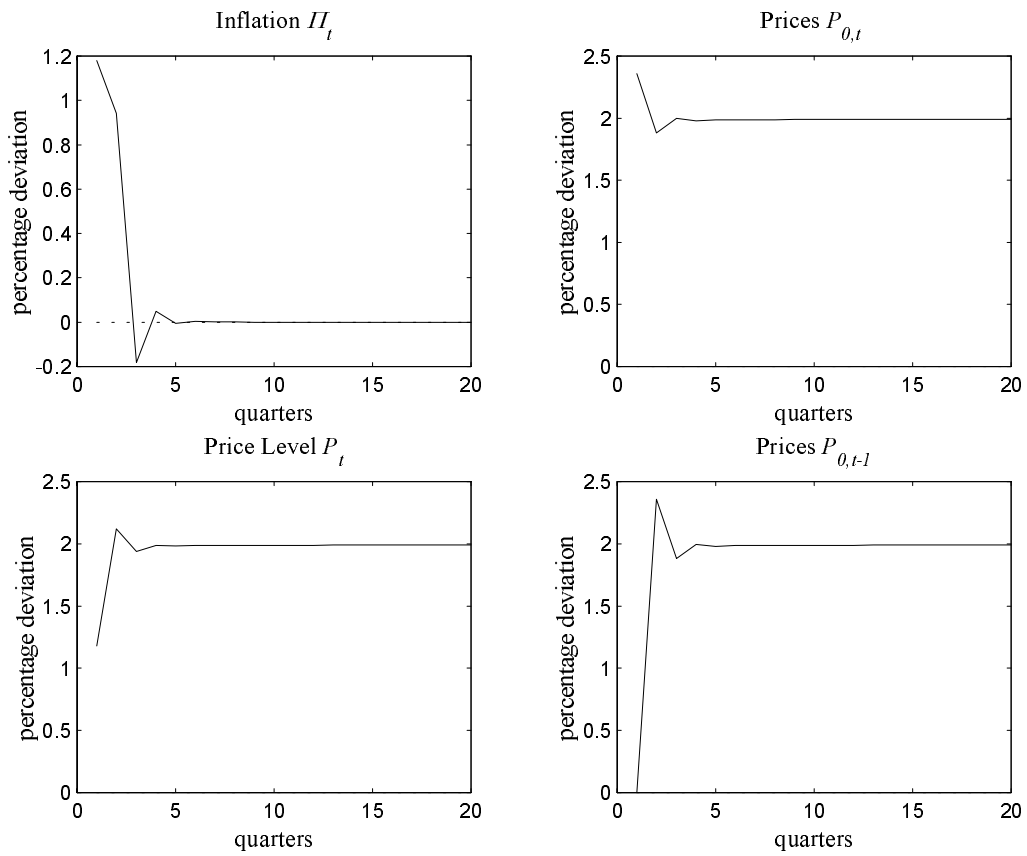


Figure 24: Impulse Response Functions for $\hat{\Pi}_t, \hat{P}_{0,t}, \hat{P}_t, \hat{P}_{0,t-1}$, MIU-model, CRRA preferences

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- 39-93 **Reiner Wolff**, Strategien der Investitionspolitik in einer Region: Der Fall des Wachstums mit konstanter Sektorstruktur
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- 95-01 **Thomas Christiaans**, Economic Growth, a Golden Rule of Thumb, and Learning by Doing
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- 101-02 **Karl-Josef Koch**, Beyond Balanced Growth: On the Analysis of Growth Trajectories
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- 103-02 **Michael Gail**, Persistency and Money Demand Distortions in a Stochastic DGE Model with Sticky Prices and Capital