Housing and the Redistributive Effects of Monetary Policy *

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PRELIMINARY VERSION

Abstract

We study the redistributive effects of monetary policy in the framework of a large OLG model, with endogenous housing choice, downpayment constraints, and different types of shocks. We pay special attention to the structure of debt, whether it is short-term or long-term, nominal or real. We find that monetary policy shocks have long-lasting effects on the inter-generational wealth distribution. While the debt structure only has a mild effect on aggregate statistics, it matters a lot for how different types of shocks under different monetary policy regimes affect the distribution.

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1 Introduction

In the presence of nominal contracts, inflation causes a redistribution between creditors and debtors. Typical losers of inflation are old rich households who hold a lot of their wealth in the form of nominal bonds. They are also those who gain from an increase in interest rates, when the central bank reacts. Typical winners of inflation are households with fixed-rate mortgages Doepke and Schneider (2006b, Doepke and Schneider (2006a). Households with flexible-rate mortgages lose from increases in interest rates. This means that monetary policy, next to its stabilizing effect on the economy, can have important redistributional consequences, although these are not at the focus of the policy makers. These redistributions will in turn affect the aggregate economy, because people react differently to shocks, given their asset position.

This heterogeneity among agents requires a new look at a number of old questions, for example, how aggressive should monetary policy be and should central banks smooth interest rates? This paper aims at doing this, as it assesses the distributional effects of shocks, for different asset structures. These effects do not just depend on the households net worth, but on their gross positions in different assets. Since owner occupied housing is the most important asset for the majority of households, we think that housing choice is an essential feature of a model asking questions about redistribution. Consider a young household with a house and the resulting mortgage, which implies little net worth, but a long position in a real asset (the house) and a short position in a nominal asset (mortgage). A reduction in real payments via inflation will be beneficial. These effects will be smaller, when the interest rate is locked in at the current rate, i.e. under a fixed rate mortgage as opposed to an adjustable rate mortgage. The structure of the mortgage differs among countries; while in the US fixed rate mortgages (the nominal interest rate is fixed for several years) are prevalent, in the UK, for example, the adjustable rate mortgage (the nominal rate is adjusted every year as a function of some money market rate) is more common. Contracts also differ in terms of indexation, meaning that some mortgages are tied to a price index, to protect each side against inflationary effects (about 20 % of mortgages in the UK). We therefore pay special attention to the structure of debt contracts: short-term versus long-term, and nominal versus real (inflation protected).

We study these issues in the framework of a stochastic OLG model with incomplete markets and age dependent productivity. There are two types of households, workers and capitalists. Workers have finite lifetime, they save for retirement through housing wealth and bonds, additional to their public pension payments. Capitalists are modelled as a representative, infinitely lived dynasty. They earn some labor income and get capital income from physical capital, firm ownership, by renting houses to the workers and holding bonds. Introducing capitalists into the model serves two purposes. First, it allows for a more realistic calibration. In this way we can account for the fact that most households do not have much financial assets. Second, the representative capitalist owns the firms. The marginal utility of the representative capitalist defines the stochastic discount factor to discount cash flows, which gives a well-defined objective function for the firm.

The production side has a standard New Keynesian structure with Calvo price rigidity. Households can rent or buy houses. There are no transaction costs or liquidity constraints. We then consider a variety of shocks, under different asset structures, and vary the reaction of the central bank, modelled via a Taylor rule.

The main conclusions are the following. First, monetary policy has large and very long-lasting effects on the wealth distribution. Second, monetary policy shocks create particularly large redistribution if debt contracts are short-term and nominal. With long-term real contracts, effects are small. With short-term real or long-term nominal contracts, the effects are in between the other two cases. Third, monetary policy with a standard Taylor rule ($\gamma_\pi = 1.5$) reduces the redistribution effect of demand shocks, compared to a lax monetary policy ($\gamma_\pi = 1{:}1$). The stabilizing effects of monetary policy therefore apply not only to aggregates, but also to the wealth distribution. Fourth, interest rate smoothing slightly reduces the redistribution effect of a demand shock if contracts are long-term nominal, but not if they are long-term nominal.

It is clear that our model is stylized in many ways. It is a strict life-cycle model without bequests. There is no intra-cohort heterogeneity. Housing choice is continuous and not subject to transaction costs. Furthermore, the model is solved by linearization, so that the approximate solution is of the certainty-equivalence type.[1] We therefore want to stress that our model does not provide a plausible "calibration" of wealth and asset inequality; economic inequality has many dimensions, and we capture only a few aspects of it.[2] Nevertheless, we think that the model provides a relevant numerical example, because it generates meaningful heterogeneity of asset positions, with a clear interpretation related to the life cycle of households. Households differ in their asset positions for many other reasons but life-cycle considerations. Since our main conclusions have clear intuitions, we hope that they hold in more general settings. This is an important area for future research.

1.1 Related Literature

The redistributive consequences of inflation are first described in Doepke and Schneider (2006b). They study the effects of inflation through the channel of nominal assets. The biggest beneficiary of inflation is the government, since it usually has a relatively large and negative asset position. Next to the government, young households gain from surprise inflation, while elderly households lose. This is because younger households are usually more indebted, either by student loans or mortgages, and thus inflation reduces their real debt

[1] To study monetary policy, we need a quarterly model period. With an economic life of 60 years, we have 240 cohorts. All in all our model has more than 1400 variables, and any other solution method but linearization would be very complicated.

[2] Notice that for the questions addressed here, it is not just the distribution of net wealth that matters, but the distribution of the whole portfolio holdings of households, a much more complicated object.

burden. A theoretical model motivated by these observations is presented in Doepke and Schneider (2006a), where the redistribution by inflation is modelled exogenously.

Following Doepke and Schneider (2006b), there are more and more papers studying the distributional effects of monetary policy both from a theoretical and an empirical perspective. Albanesi (2007) studies inflation in a political economy setup and finds that inflation is positively related to the degree of inequality. Williamson (2008) finds persistent non-neutralities in the distribution of consumption due to an increase in the money supply, along with inefficient allocation of goods. Brunnermeier and Sannikov (2012) study the effects of monetary policy on financial constraints and stability, an issue which has gained a lot of public interest during the recent Great Recession. They draw attention to the fact that a decline in the mortgage rate, which first leads to lower mortgage payments for the household sector, then leads to higher house prices and bigger mortgages. Dobbs et al. (2013) study the redistributive implications of the low interest rates, which can be viewed as a consequence of low inflation rates and economic turmoil.

For our calibration, we also draw on the literature that looks at housing choice over the business cycle (e.g Iacoviello (2002). or the standard textbook by Gali (2008)), and housing choice over the life-cycle Yang (2006, Iacoviello and Pavan (2013, Fernndez-Villaverde and Krueger (2011).

The following papers are most directly related to the results of our analysis. Cloyne et al. (2015) find, with a structural VAR analysis on UK data, that a contractionary monetary policy shock has a strong negative effect on consumption only for households with a mortgage. The effect is strongest for durables, as one would expect. In Gornemann et al. (2014), agents differ with respect to employment status and productivity in a Mortensen-Pissarides style labor market. They find that a contractionary monetary policy shock increases inequality. It hurts wealth-poor households much more than the rich. Auclert (2015) stresses the fact that the redistributive effects of monetary policy depend on the maturity structure of bonds and mortages.

2 The Model

2.1 Overview

There are two types of households: workers households and capitalits. Capitalists form an infinitely lived, representative dynasty. The economic life of workers is 60 years. With a quarterly model period, this means there are 240 cohorts of worker households. They retire after 160 periods. Assuming they start adult life at age 20, they retire at age 60 and die at age 80.

Worker households can save in two types of assets: bonds and houses. They also obtain housing services from rented houses; the decision of renting versus owning is endogenous.

Furthermore, they are forced to participate in a public PAYGO pension system.

Capitalists can save in bonds, houses (owner-occupied as well as houses rent out to workers), physical capital and firms. The firms earn positive profits due to imperfect competition, and distribute the profits to the capitalists.

2.2 Bonds

We will pay special attention in this paper to the type of bond that is traded, whether it is short-term or long-term, and whether it is nominal or real (inflation protected). We cannot model asset choice here, so in each variant of the model there is only one type of bond available. To ensure tractability, we use a bond with stochastic maturity (cf. eg. Krause and Moyen (2013)), which allows to vary maturity with only one type of bond. The following formulation nests all the possibilities. We assume that in period t, one unit of the bond carried from period $t-1$ earns a return

$$(\mu + r^B)v_t^B + (1-\mu)p_t^B \tag{1}$$

Here, p_t^B denotes the price of the bond, r^B is the nominal coupon of the bond, μ is the fraction of the bond that matures each period, and the variable v^B denotes the real over the nominal value of the bond. If $\mu = 1$, it is a one period bond; a ten-year bond can be approximated by $\mu = 0.025$, so that each quarter, 1/40 of the bond matures. The real-to-nominal ratio v^B follows the dynamic equation

$$\log(v_t^B) = \log(v_{t-1}^B) - \chi \log(\pi_t/\pi^*) \tag{2}$$

where χ measures the degree of "nominalness" of the bond: if $\chi = 0$, then inflation does not affect the real value of the bond, which means that it is a real bond. If $\chi = 1$, inflation reduces the nominal value of the bond one by one, so it is a purely nominal bond. We only consider these two extreme cases, but intermediate cases are possible.

2.3 Firms

Production takes place in a final goods sector with monopolistic competition and Calvo pricing. Each firm uses a standard neoclassical production function

$$Y_t = F(z_t, K_{t-1}, L_t) \tag{3}$$

The exogenous process for total factor productivity follows.

$$\log(z_t) = \rho_Z \log(z_{t-1}) + \varepsilon_t^Z \tag{4}$$

Factor markets are assumed to be frictionless. The optimal combination of production factors then implies

$$w_t F_k(z_t, kl_t) = r_t^K F_L(z_t, kl_t) \tag{5}$$

As is standard in New Keynesian models of monetary policy, we assume nominal stickiness a la Calvo. The dynamic equation for inflation is

$$\pi_t = (\theta + (1-\theta)(P_t^* \pi_t)^{1-\varepsilon})^{1/(1-\varepsilon)} \tag{6}$$

where P_t^* denotes the optimal price of a price-setting firm. The first order condition for the optimal price is

$$V_{MC,t} = P_t^* V_{Y,t} \tag{7}$$

where

$$V_{Y,t} = Y_t + \theta(\hat{\beta}\hat{U}_{ct+1}/\hat{U}_{ct})/\pi_{t+1} V_{Y,t+1} \tag{8}$$

and

$$V_{MC,t} = (\varepsilon/(\varepsilon-1) + z_{\mu,t}) Y_t RMC_t + \theta(\hat{\beta}\hat{U}_{ct+1}/\hat{U}_{ct}) V_{MC,t+1} \tag{9}$$

Notice that the stochastic discount factor of firms depends on the marginal utility of consumption of the (representative) capitalists, because they are the firm owners. The term $z_{\mu,t}$ in (9) is interpreted as a markup shock, which is assumed to follow the exogenous process

$$z_{\mu,t} = \rho_\mu z_{\mu,t-1} + \varepsilon_t^\mu \tag{10}$$

Real marginal cost is given by

$$RMC_t = \alpha^{-\alpha}(1-\alpha)^{\alpha-1} w_t^{1-\alpha} (r_t^K)^\alpha / z_t \tag{11}$$

2.4 Worker households

A worker household born at s solves

$$\max \mathbb{E}_0 \sum_{i=0}^{T-1} \beta^i u(c_{i,s+i}, l_{i,s+i}, h^O_{i,s+i}, h^R_{i,s+i})$$

s.t. the budget constraint

$$\begin{aligned} p_t^B b_{i,t} + h^O_{i,t} p_t^H + c_{i,t} + r_t^H h^R_{i,t} = ((1-\tau) w_t \zeta_i l_{i,t} + \mathcal{I}_{Ri}\psi_t + \\ ((\mu + r^B) v_t^B + (1-\mu) p_t^B) b_{i,t-1} + (1-\delta_H) h^O_{i-1,t-1} p_t^H)) \end{aligned} \tag{12}$$

and the borrowing constraint

$$p_t^B b_{i,t} \geq -\nu \mathbb{E}_t p^H_{t+1} h^O_{i,t} \tag{13}$$

The LHS of the budget constraint (12) represents the spending of cohort i in period t. It buys bonds at price p_t^B, purchases the housing owned $h^O_{i,t}$, rents housing $h^R_{i,t}$ and consumes $c_{i,t}$. The RHS gives the available resources of household at the beginning of period t, which consists of labor income, pension income, the return on last period's bond holdings $b_{i,t-1}$ as described in Section 2.2, and the value of the house it bought last period, after depreciation. Here w_t is the hourly wage and ζ_i is the age-dependent idiosyncratic productivity of the household. The indicator function $\mathcal{I}_{Ri}$ is one if the household is retired, in which case it receives the pension payment ψ_t, financed via a payroll-tax τ.

The downpayment constraint (13) states that a household can only borrow up to the fraction ν (which is in the baseline calibration equal to 0.8) of the value of their house. So 20% of the mortgage of a house have to be financed by savings, prior to the purchase. When this constraint holds with equality, the household is constrained in its borrowing, since an extension of the borrowing would be desired but is not possible. The constraint will be binding for a significant part of the lifecycle (namely from 36 to 51). Our model of housing choice is stylized in two ways. First, the representative household of each cohort owns a part and rents the remaining part of its housing. This is the consequence of not modelling intra-cohort heterogeneity. Second, there are no adjustment costs to the housing choice of the cohort. Adjustment costs only arise in the production of housing, which generates fluctuations in the house price, cf. Sectoin 2.6.

For the utility function of the worker household we choose

$$\begin{aligned} U(c,l,h^R,h^O) =& \log(c_t) + \eta \log(1-l_t) \\ &+ \eta_H \log \left[\left((h_t^R)^{(\sigma-1)/\sigma} + \xi (h_t^O)^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)} \right] \end{aligned}$$

The parameter σ measures the elasticity of substitution between owned and rented housing.

The household first order conditions can be found in Appendix B.

2.5 Capitalists' budget constraint

Capitalists have the same period utility function as workers, except that they do not value rented housing. This gives

$$\hat{U}(\hat{c},\hat{l},\hat{h}^O) = \log(\hat{c}) + \eta log(LC - \hat{l}) + \eta_H \log(\hat{h}^O)$$

Being infinitly lived, they solve

$$\max \mathbb{E}_0 \sum_{i=0}^{\infty} \hat{\beta}^i u(\hat{c}_t, \hat{l}_t, \hat{h}_t^O)$$

subject to the budget constraint

$$\begin{aligned} & Y_t - I_t^K - w_t L_t^W + r_t^H H_t^R + p_t^B B_t + p_t^H (H_t - (1-\delta_H) H_{t-1}) - I_t^H \\ =& \hat{c}_t + p_t^H (\hat{h}_t^O + H_t^R - (1-\delta_H)(\hat{h}_{t-1}^O + H_{t-1}^R)) \\ &+ ((\mu + r^B) v_t^B + (1-\mu) p_t^B) B_{t-1} \end{aligned}$$

The budget constraint of the capitalist has some extra terms compared to that of worker households. First, they get the whole profits of the production sector, which equals output minus wage payments to workers minus investment into physical capital. They also invest into housing, and earn money from selling new houses to workers, and renting out the part of the housing stock which is not owner-occupied. Furthermore, capitalists have no borrowing constraints. Notice that the bond holdings of the capilists are given by $-B_t$, since they are the ones who borrow from the worker households.

2.6 Dynamics of real assets

Both capital and housing are subject to convex adjustment costs. Define investment ratio for physical capital as

$$\iota_t^K = \frac{I_t^K}{K_{t-1}} \tag{14}$$

Then the capital stock evolves according to

$$K_t = (1-\delta)K_{t-1} + \phi(\iota_t^K)K_{t-1} \tag{15}$$

Value of installed capital:

$$Q_t = 1/\phi_I(\iota_t^K) \tag{16}$$

The FOC for investment is

$$Q_t = (\hat{\beta}\hat{U}_{ct+1}/\hat{U}_{ct})(r_{t+1}^K + Q_{t+1}(1-\delta+\phi(\iota_{t+1}^K) - \iota_{t+1}^K\phi_I(\iota_{t+1}^K))) \tag{17}$$

The equations for housing are analogous: The Law of Motion is

$$H_t = (1-\delta_H + \phi(\iota_t^H))H_{t-1}$$

where

$$I_t^H = \iota_t^H H_{t-1}$$

The price of housing is then

$$p_t^H = 1/\phi_I(\iota_t^H) \tag{18}$$

The worker households' FOC for housing is

$$(U_H(c_{i,t}, l_{i,t}, h_{i,t}^R, h_{i,t}^H, \eta_{H,t}) = p_t^H U_{ci,t} + \beta(1-\delta_H)p_{t+1}^H U_{ci+1,t+1} \tag{19}$$

2.7 Closing the model

Effective labor supply of worker households is obtained by summing of labor efficiency times hours worked:

$$L_t^W = \sum_{i=1}^{T} \zeta_i l_{i,t}/T \tag{20}$$

Aggregates are converted into per-cohort values, dividing by T. Total labor input into production is then

$$L_t = L_t^W + \hat{L}_t \tag{21}$$

The labor efficiency of capitalists is normalized to 1.

The other aggregates over worker households are then defined as $B_t = \sum_{i=1}^{T} b_{i,t}/T$, $C_t = \sum_{i=1}^{T} c_{i,t}/T$, $H_t^R = \sum_{i=1}^{T} h_{i,t}^R/T$, $H_t^H = \sum_{i=1}^{T} h_{i,t}^H/T$. The aggregate resource constraint is then

$$Y_t = C_t + \hat{C}_t + I_t^K + I_t^H \tag{22}$$

The total housing stock is

$$H_t = H_t^R + H_t^H + \hat{H}_t \tag{23}$$

The budget constraint for the PAYGO pension system is

$$\psi_t = (\tau w_t L_t^W)\frac{240}{80} \tag{24}$$

Monetary policy follows the Taylor rule

$$\log(R_t/R^*) = \rho_R \log(R_{t-1}/R^*) + (1-\rho_R)\left(\gamma_\pi \log(\pi_t/\pi^*) + \gamma_y \log(Y_t/Y^*)\right) + z_{M,t} \tag{25}$$

The shock $z_{M,t}$ is assumed to be i.i.d.

3 Parameters Values and the Deterministic Steady State

Parameter values where chosen either following the literature or matching certain long-run averages in the data. Table 1 lists the parameter values for the benchmark calibration. Technology parameters are set to standard values. The discount factor of the capitalist is set so as to give a real interest rate of 4 percent annually. The discount factor of worker households, together with a social security tax of 15 percent on labor income, generates a saving pattern such that worker households hold 30 percent of non-housing wealth.

The value of housing in utility, η_H, serves to fix the amount of housing in the economy. A value $\xi = 1.2$ means a 20% efficiency gain from owner-occupied housing, following Iacoviello and Pavan (2013). This parameter is essential in determining the home ownership rate.

The parameters relating to inflation and monetary policy are standard values in the literature. With these parameter values, we get a capital-output ratio of 2.069 (2.2 in Iacoviello & Pavan (2013), 2.5 in Garriga, Kydland and Šustek (2013)), a ratio of housing to output of 1.67 (1.4 in Iacoviello & Pavan (2013) ,1.8 in Iacoviello (2011)), a ratio of capital investment to output of 0.21 (0.2 in Iacoviello & Pavan (2013) ,0.16 in Garriga, Kydland and Šustek) and a ratio of housing investment to output of 0.085 (0.07 in Iacoviello & Pavan (2013) ,0.05 in Garriga, Kydland and Šustek). Our average homeownership rate is 69.7, compared to 64.8% in the data.

Let us now look at the life-cycle path of the cohort-specific variables, depicted in Figure 1. The median values of housing, debt (negative bond holdings), consumption and the home ownership rate all exhibit the hump shape over the lifecycle that is observed in the data (cf. Iacoviello and Pavan (2013, Figure 4) and Fernndez-Villaverde and Krueger (2011, Figures 2.2

Parameter	Target	Value
Technology and utility		
number of cohorts		$T = 240$
discount factor of capitalists		$\hat{\beta} = 0.96^{0.25}$
discount factor of workers	workers' bond holdings	$\beta = 0.9469^{0.25}$
output share of capital		$\alpha = 0.35$
depreciation rate for capital		$\delta = 1 - 0.9^{0.25}$
adjustment costs parameter capital		$\eta_I = 6$
weight of leisure in utility	labor supply	$\eta = 2.622$
labor endowment of capitalists	capitalist labor supply	$\bar{L} = 0.500921$
payroll tax		$\tau = 0.15$
Housing		
efficiency owner occupied housing		$\xi = 1.2$
depreciation rate for housing		$\delta_H = 1 - 0.95^{0.25}$
weight of housing in utility		$\bar{\eta}_H = 0.22$
adjustment costs parameter housing		$\eta_J = 4$
elasticity of subst. rental vs. owner		$\sigma = 2$
housing service from stock		$\nu = 0.04$
autocorrelation technology shock		$\rho_Z = 0.8^{0.25}$
autocorrelation housing utility shock		$\rho_H = 0.8^{0.25}$
monetary policy shock		$\rho_M = 0.0$
markup shock		$\rho_\mu = 0.0$
influence past interest rate		$\rho_R = 0.25^{0.25}$
Inflation and monetary policy		
steady state inflation		$\pi^* = 1$
Taylor rule parameter inflation		$\gamma_\pi = 1.5$
Taylor rule parameter output gap		$\gamma_y = 0.0$
demand elasticity		$\varepsilon = 7$
prob. keeping the price		$\theta = 0.75$

Table 1: Parameter values

and 2.7)). We replicate the data qualitatively, although there are substantial quantitative differences. Most notably, the homeownership varies more strongly in the data than in the model, and the strong increase in net worth starts earlier in the model than in the data. The life-cycle pattern of saving before retirement and quickly dissaving afterwards is exaggerated in the model compared to the data, largely because old households dissave slowly and leave substantial bequests. A better quantitative match of these life-cycle facts would require a substantially more complicated model.

Our pattern of hours worked is the same as the model of Iacoviello and Pavan (2013), but inverse to the data pattern reported there. This pattern is sensitive to the discount rate. Hours remains constant while the worker is borrowing constrained, which is a consequence of logarithmic utility.

We can do a further check on the model by comparing the nominal net positions in the data, taken from Doepke & Schneider (2006), and presented in Table 2, to our model results. Again, the model matches the data qualitatively, but not quantitatively. The middle group switches from a negative to a positive net position at around age 50. A negative net position in the model of 400% of net wealth is a consequence of the 20 percent downpayment requirement. These extreme values are not found in the data, because of intra-cohort heterogeneity.

US	≤ 34	35-44	45-54	55-64	65-74	¿ 74
Rich	-14	3.8	6.6	16.3	16.7	24.5
Middle	-114	- 31.6	-4.8	14	25.2	38.1
Poor	-36.6	-33.8	-5.5	7.5	17.5	26.4
Total	-42.6	-10.1	2.3	15.2	19.4	30.6
Model	-400	-400	3.8	80.8	77.8	40.2

Table 2: Nominal net position, percent of net worth

Let us finally look at the calibration of the "capitalists". Capitalists are identified the top 5% in terms of financial wealth. According to the Survey of Consumer Finances 2014, this group of households earn 20% of total wages and own 66% of financial wealth . This group owns 24% of owned Houses (percentage of wealth, not units), and 96% of them are home owners. In order to match these facts qualitatively, we target the aggregate value of bonds owned by worker households to 30% of capital; with this number, we also mimic the timing of when households switch from a negative to a positive net nominal asset position. Furthermore, we assume in our model that all capitalists are homeowners. In the calibration, their homes amount to 35% of total housing, and to 51% of owned housing; the discrepancy to the data comes from the fact that we use a homothetic utility function, which implies that they hold this high share of their wealth in the form of housing. Rather than going to more complicated utility functions, we choose to deviate from the data in this respect, because it

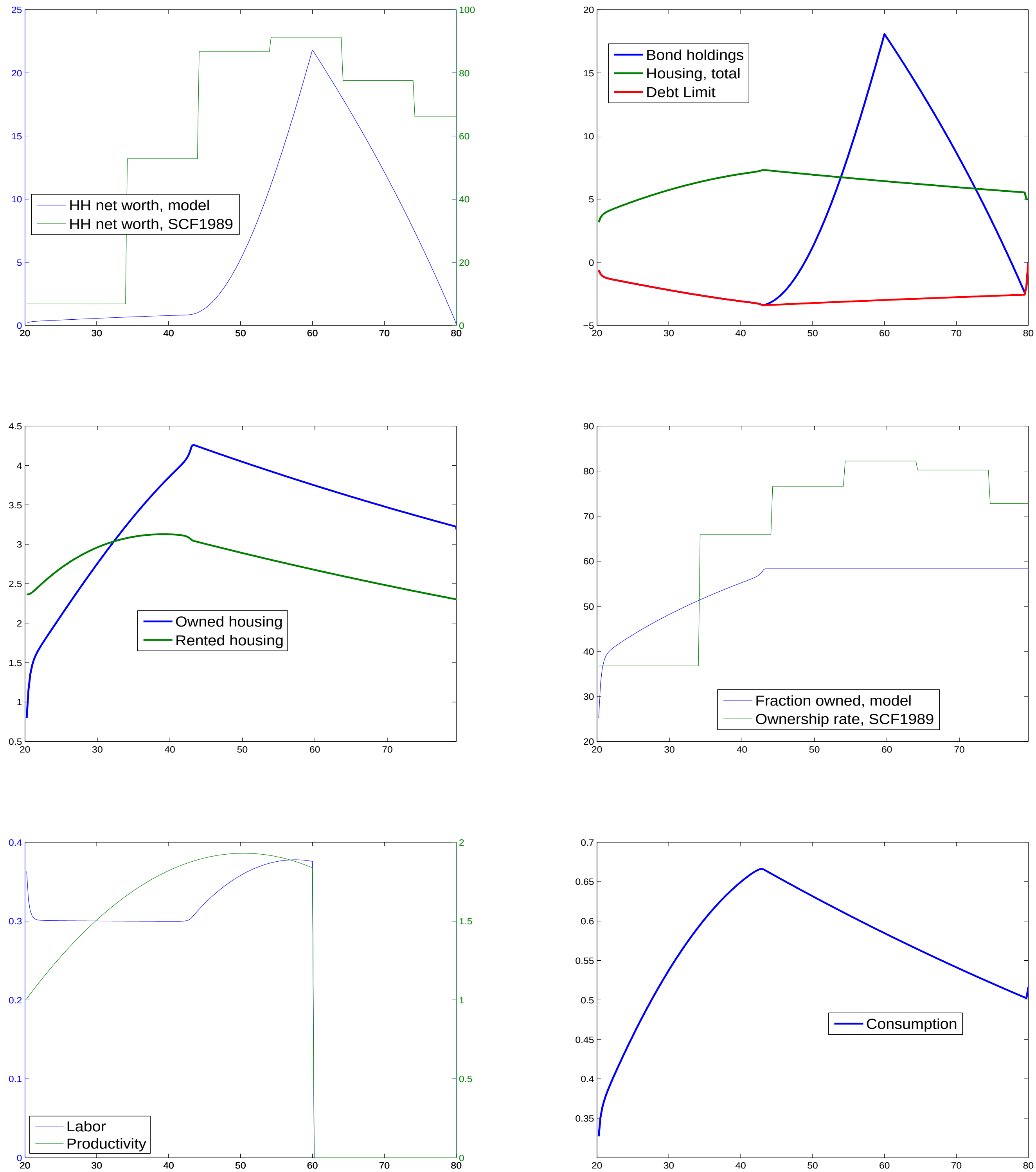


Figure 1: Lifecycle paths in steady state

will not essentially affect our conclusions. Likewise, we calibrate their share of the labor input (value weighted) to 10% rather than 20%; otherwise their share in housing would be even bigger.

4 Numerical Results

4.1 The Monetary Transmission Mechanism

The upper left panel of Figure 2 contains impulse response functions of price variables to a contractionary monetary policy shock (a shock to the Taylor rule) of 0.25 percentage points, (1 percentage point at annualized rate) that lasts for one quarter. For reference, impulse responses of the macroeconomic aggregates to different shocks are reported in Figure 7 in the appendix. Remember that monetary policy shocks are uncorrelated, but under the baseline policy, the central bank has an interest smoothing motive $\rho_R = 0.7$. The graph shows the typical picture of a contractionary monetary policy shock in a New Keynesian model: The nominal, and even more so the expected real short-term interest rate go up. Because of this contractionary effect, inflation goes down, and due to the immediate endogenous response of the central bank, the interest rate increases by less than the shock. Lower economic activity in terms of output lets the wage rate decline, as well as the house prices.

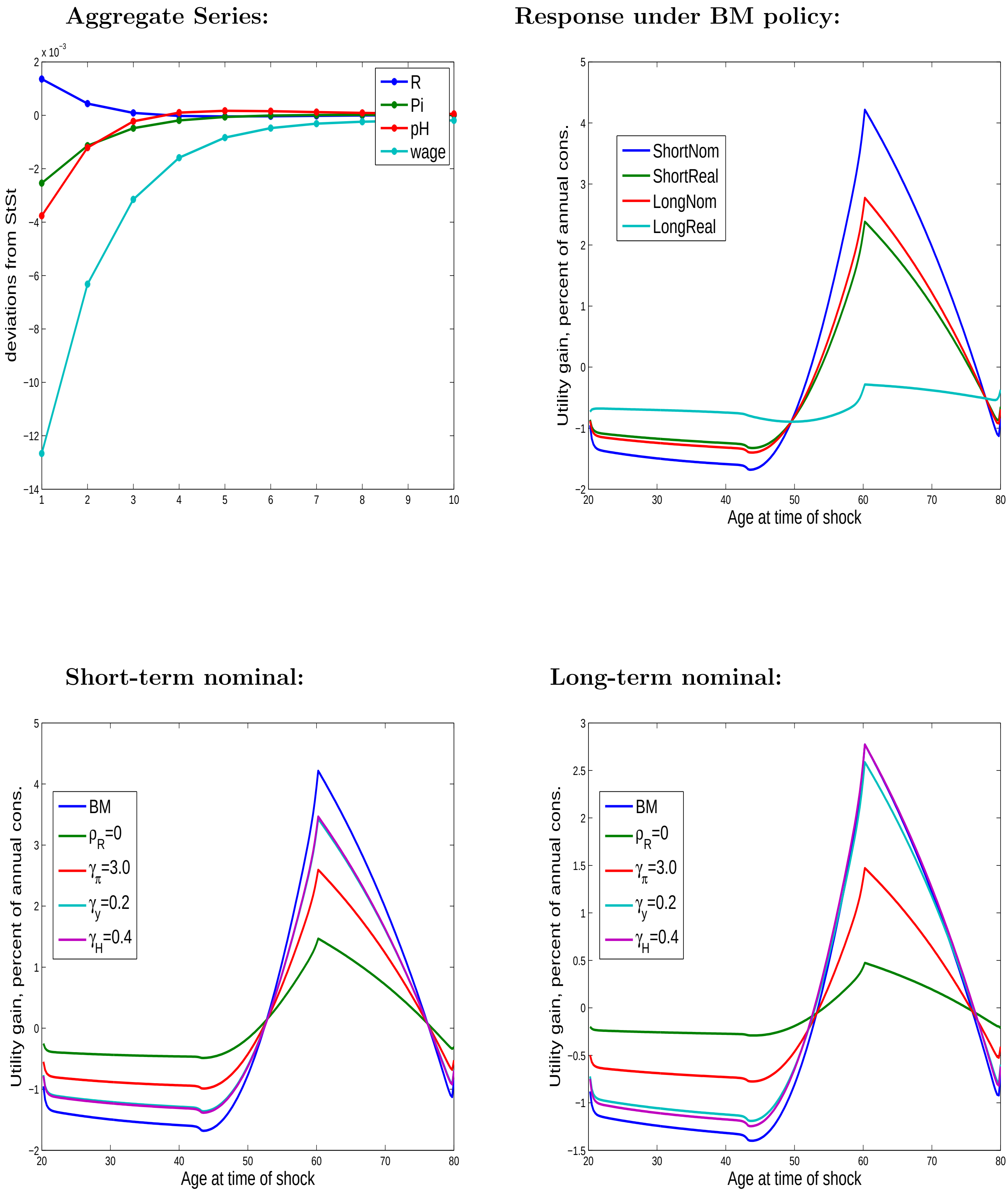


Figure 2: Impulse response to monetary policy shock

4.1.1 The effect of monetary shocks on welfare

The upper right panel of Figure 2 conveys the main message about the distributional effect of monetary policy shocks. In each case, the effect is measured in percent of annual consumption. For example, a value of 2 means that the household loses the equivalent of 2 percent of consumption during one year. Important is not whether a change in utility is positive or negative, because shocks have expectation zero, and a gain to a positive shock is outweighed by the loss in response to a negative shock. What matters is the absolute value of the utility change, because it indicates larger fluctuations of utility in response to a shock. In other words, we focus on second, not first moments.

Look first at the blue line, referring to the case of short-term nominal bonds. We see that the effects are large. A contractionary monetary policy shock of 0.25 percentage points that lasts for one quarter (1 percentage point at annualized rate) causes utility gains and losses of up to 4 percent of annual consumption. The shock damages households up to age around 54, while households shortly before and after retirement benefit. This pattern is not difficult to understand. First, home-owners suffer a wealth loss on impact, due to the reduction in the house price. If they hold a mortage, they also suffer from the decrease in current inflation, because they hold nominal debt. In contrast, households around the age of 60 hold a large positive position in the nominal asset. They benefit both from the increase in the nominal interest rate and from the decrease in inflation.

How does this picture change when bonds are still short-term, but inflation protected (real bonds)? The main difference is that bond holders now do not benefit from the decrease in inflation, and therefore enjoy a smaller gain. Conversely, home-owners with a mortgage do not suffer from a decrease in current inflation. Their utility loss is now smaller.

What is the effect of monetary shocks in a regime of long-term nominal bonds? Bond holders now benefit from reduced inflation, but they do not benefit much from the short-run increase in interest rates, because only a small part of their bonds mature and can be reinvested in the period when interest rates are high. Again, their gain is now smaller, compared to the case of short-term bonds. The opposite effect opplies to home owners: they still suffer reduced inflation, but not from the increase in interest rates, resulting in a smaller welfare loss for them.

Finally, let us look at the effect of monetary shocks under long-term real bonds. In this case, all household assets (bonds and houses) are long-term and real. In this case, households are largely insulated from monetary policy. Everybody suffers from the contraction of economic activity following a monetary policy shock, but there is not much direct effect from interest rates and inflation, so the loss is rather evenly spread, and very small compared to the case of nominal bonds.

The lower two panels of Figure 2 show how these effects change, when the central bank conducts monetary policy differently, i.e. the parameters of the Taylor Rule are changed. The qualitative conclusions are robust to these changes in the policy parameters. In particular, the conclusion that the effects are stronger under short-run nominal than under long-run nominal bonds appears to be robust across different specifications of the monetary policy rule.

4.1.2 The long-lasting effect on distribution

To gain a better understanding of how monetary shocks affects different cohorts, let us look at the change in the consumption profile of different cohorts, which are depicted in Figure 3. Each line in the panel follows a specific cohort; the length of the line shows the lifetime of this cohort remaining at the time of the shock. We consider cohorts in the range of 20 quarters to live (age of 75 years at time of shock) to 180 quarters to live (age 35). The upper panels show consumption, the lower panels show bond holdings. The left panels refer to the case of short-term nominal bonds, the right panels refer to the case of long-term real bonds.

In the upper left panel, we see that unconstrained cohorts (cohorts 99 and older are unconstrained) have the same consumption growth rate, determined by the expected real interest rate. Due to consumption smoothing, differences in consumption responses are not very big, but very persistent. Consumption of the younger cohorts is determined by the down-payment constraint. As their ability to smooth consumption is limited, consumption for them drops much more on impact. This is also reflected in the bond positions (lower left panel). The young households increase their bond holdings (more precisely, they reduce their debt), due to the tightening of the down-payment constraint. Other households smooth consumption by lowering their asset position. The differences in debt positions persists for many quarters.

The main conclusion from these figures is that changes in the wealth distribution are very persistent in this model.

4.2 The Effects of Demand Shocks Under Different Monetary Rules

The upper left panel of Figure 4 shows the response of prices to a negative demand shock. As one would expect, this is very similar to the response to a contractionary monetary policy shock, with the exception that the nominal interest rate and inflation are lower now, since there is no shock to the interest rate. Inflation, the nominal rate and the wage rate decrease. The price of housing first goes down, but recovers quickly, mainly reflecting the response of the real rate. The real rate goes down, but with some delay, due to interest rate smoothing.

The welfare consequences of a demand shock, however, are quite different from those of a monetary policy shock. While it is still true that households are best insured against a shock if they invest in long-term real assets, the largest welfare variations appear with long-run nominal assets. The households that are most affected by changes in inflation and interest rates are again the households with large nominal asset holdings, shortly before retirement. The response to a demand shock makes both inflation and the real rate decrease.

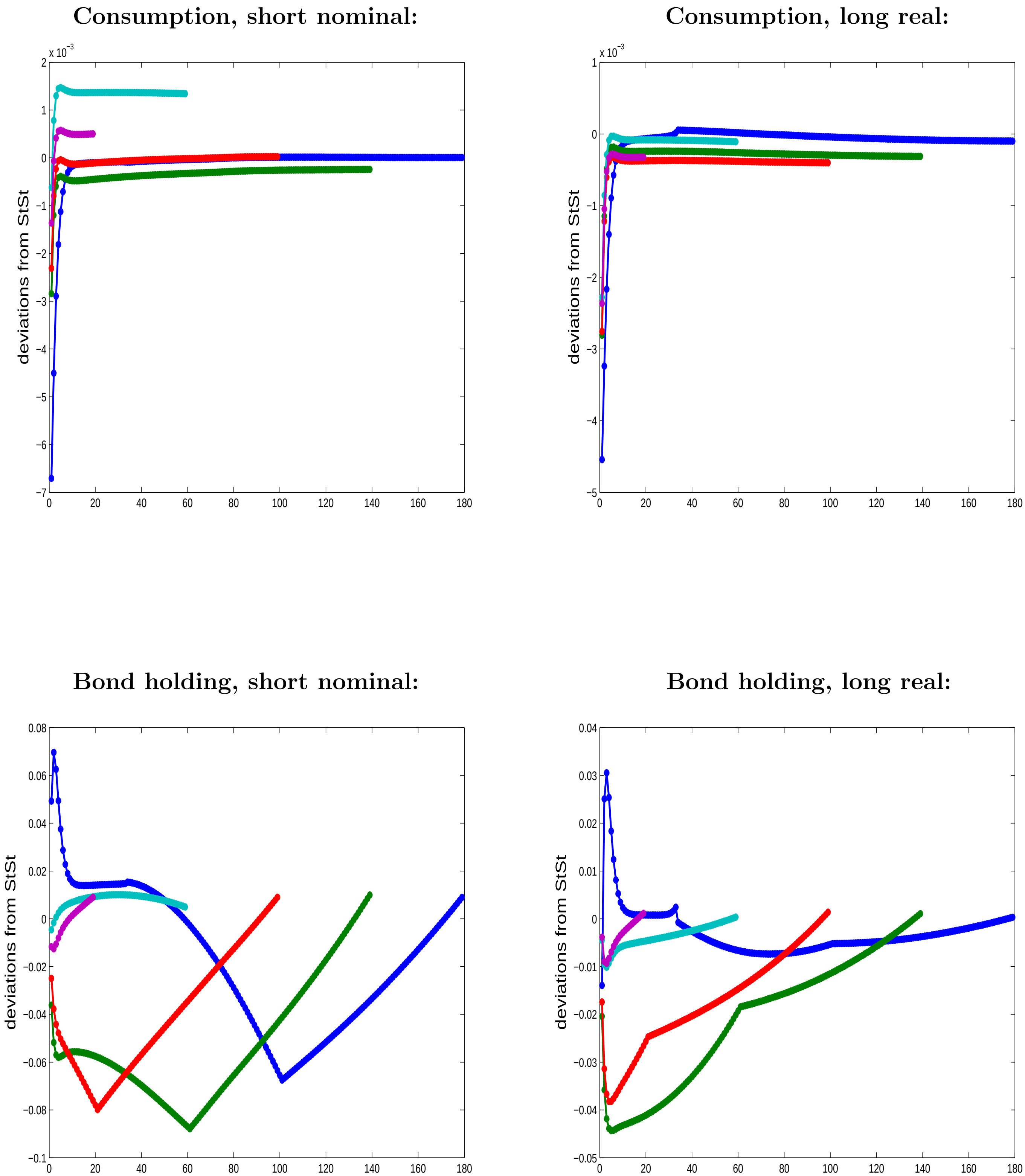


Figure 3: Impulse response to monetary shock

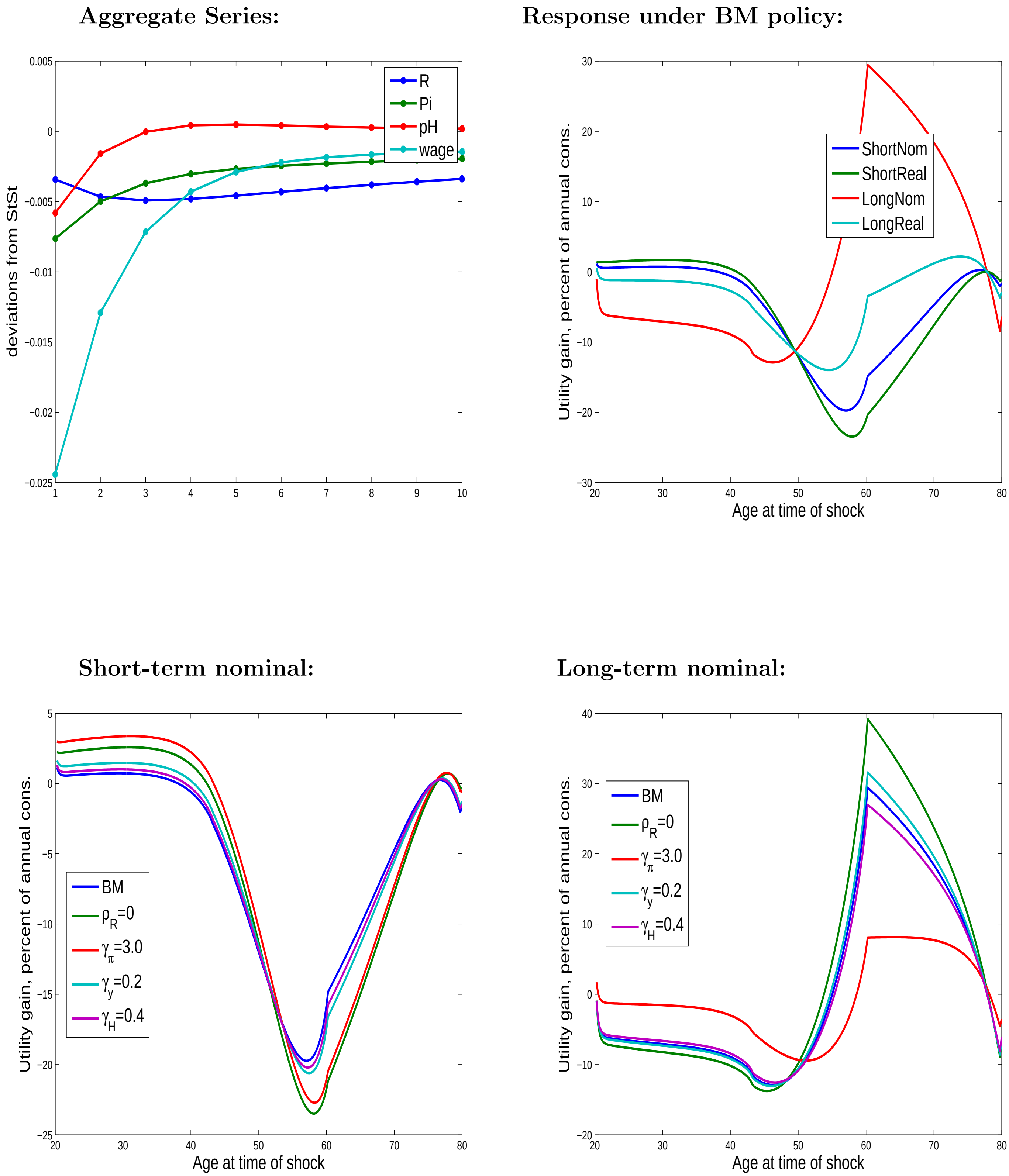


Figure 4: Impulse response to demand shock

The reduction in inflation benefits long-run bond holders. The reduction in the real rate perjudicates short-term bond holders. The absolute size of the first effect is bigger than the second one, because the overall change in inflation is bigger than the change in the real rate, in absolute terms.

The lower panels contain an important message: aggressive monetary policy ($\gamma_\pi = 3$) reduces the variability of welfare under long-term, but not short-term nominal assets. The intuition is simple. With short-term nominal assets, fighting inflation aggressively is costly because households are negatively affected by the short-term fluctuations in real interest rates that are implied by this policy. With long-term nominal assets, households are largely protected against fluctuations in the nominal rate, and mostly care about the variability of inflation, which is reduced by aggressive monetary policy. This is a new insight that is not revealed by looking at aggregate fluctuations: as we will see in the next subsection, aggressive monetary policy reduces the variability of both output and inflation, no matter what the asset structure is.

4.3 The Effects of Markup Shocks Under Different Monetary Rules

The upper left panel of Figure 5 shows the response of prices to a markup shock. We have set the shock persistence to zero, nevertheless most variables show a rather persistent response to the shock. The exception is inflation, which increases for one period, but is more than offset by the reaction of the central bank in the subsequent period. House prices and wages decrease persistently, because of the overall decrease in economic activity.

Although the shock is i.i.d., it is now a good idea for the central bank to smooth interest rates. Not doing so ($\rho_R = 0$) leads to higher variance of utility changes. Also fighting the inflation stronger increases this uncertainty, although this effect is mitigated when the bonds are long term, because a smaller fraction of bonds has to be rolled over at the higher interest rate.

4.4 The Output-Inflation Tradeoff

Table 3 lists statistics for 6 aggregate variables, conditional on the assumption that all fluctuations are caused by *demand* shocks. We report results for the benchmark Taylor rule, ($\gamma_\pi = 1.5$, $\rho_R = 0.7$, $\gamma_y = 0$, $\gamma_H = 0$) as well as four alternatives, where in each case one of those parameters is varied. We show all results for the four combinations of asset structures, nominal versus real, and long- vs. short-run. For each asset structure, the size of the shock was normalized such that the standard deviation of output is 1 under the benchmark Taylor rule. In brackets, we show the correlation with output. The variables we report are GDP (Y), nominal interest rate (R), inflation (Π), the ex-post real interest rate ($Rreal$), and the percentage changes in the price of bonds (Δp^B), and housing (Δp^H). Table 4 provides the same information conditional on the assumption that all fluctuations are caused by *markup*

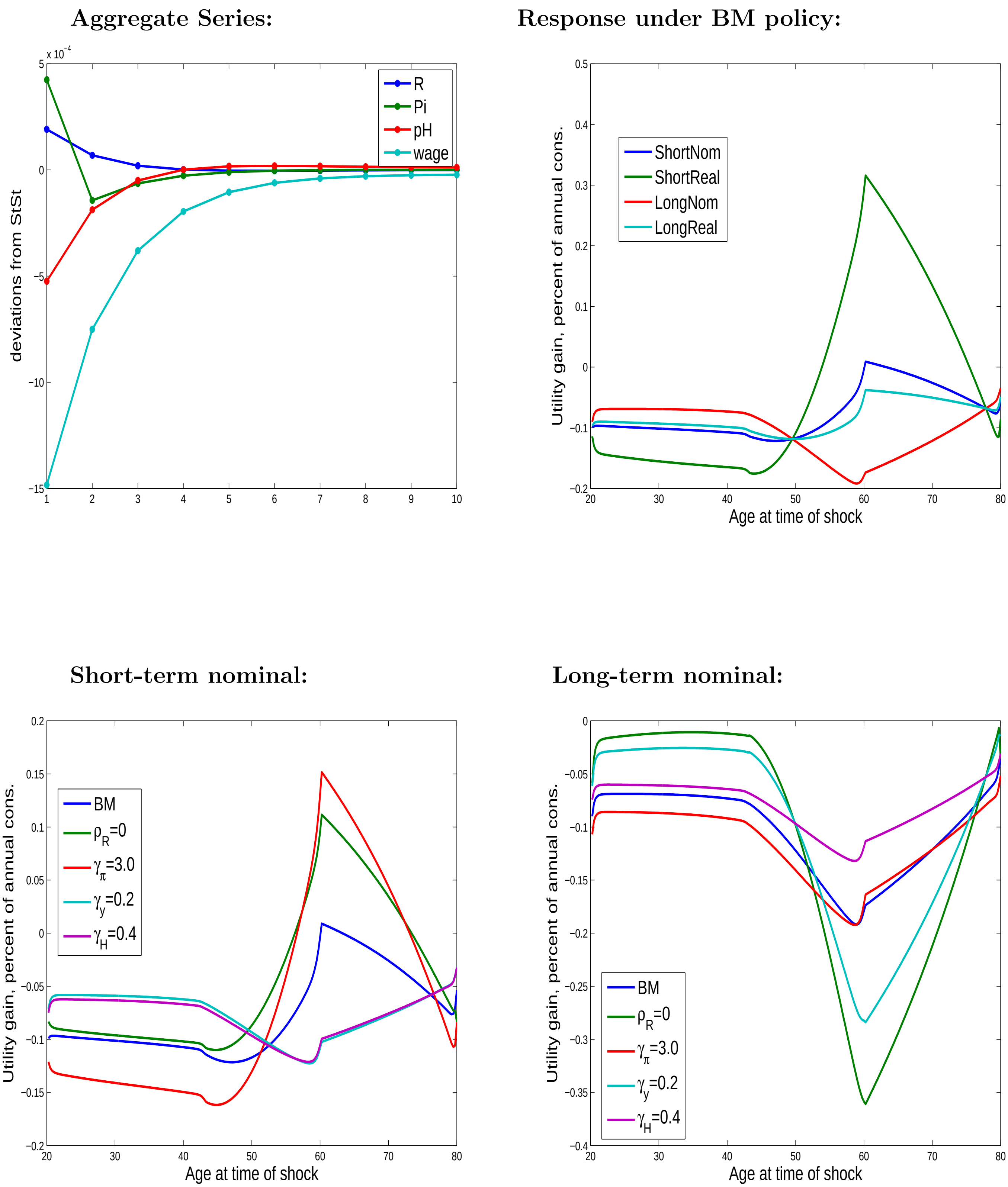


Figure 5: Impulse response to markup shock

shocks.

The findings about the output-inflation trade-off confirm standard results. With demand shocks, there seems to be no trade-off. A more aggressive policy ($\gamma_\pi = 3$ versus $\gamma_\pi = 1.5$) reduces the volatility of both output and inflation. Actually, with demand shocks, stricter monetary policy ($\gamma_\pi = 3$) increases variances of all variables under all asset structures (with the exception of Δp^B under real long-run assets). If the economy is driven by markup shocks, a stricter stand against inflation is successful in reducing the variance of inflation, but increases the variance of output; this means, there is a trade-off. We take these results as a "consistency check" of our model and the literature.

Let us now look in more detail at the results under the benchmark policy, in economy driven by demand shocks, It appears that aggregate results depend little on the asset structure, with the obvious exception of the bond price dynamics. This is simply because bonds are a different type of asset under different asset structures.

This is not true under the policy without interest rate smoothing ($\rho_R = 0$). For example, house prices fluctuate much more with long-run nominal bonds than with short-run nominal bonds. The results in Table 3 do not provide much support for interest rate smoothing. Without smoothing ($\rho_R = 0$), there is significantly less output variation, with only a comparatively small increase in inflation variation. This output-inflation trade-off holds under all bond-structures.

The results in the last two columns are not surprising. Output targeting ($\gamma_y = 0.2$) has always a stabilizing effect on ouput, but an ambiguous effect on inflation. Including house prices in the Taylor Rule succeeds in reducing house price volatility, but increases the variance of inflation in most cases.

Results change in some important ways when we consider markup shocks. Now there is a clear tradeoff between inflation and output variability when varying the parameter γ_π. The stricter course against inflation reduces the variability of inflation, at the cost of higher output variance. Most interestingly, under markup shocks there is a clear reason for interest rate smoothing. Without smoothing ($\rho_R = 0$), volatilities are higher across all asset structures. This is a case where the aggregete statistics and the redistributional effect of policies might well lead to opposite policy conclusions. With long-run nominal assets, we have seen in Figure 5 that markup shocks have much less redistributional effects if the central bank adopts interest rate smoothing.

4.5 The Effects of Technology Shocks

The upper left panel of Figure 6 shows the typical response of prices to a positive technology shock in New Keynesian models. The increase in productivity makes wages go up and the real marginal cost go down, which reduces inflation, and induces the central bank to reduce the nominal interest rate. This further boosts production and thus wages continue to increase

	BM	$\rho_R = 0$	$\gamma_\pi = 3.0$	$\gamma_y = 0.2$	$\gamma_H = 0.4$
Short-run nominal assets					
Y	1.00 (1.00)	0.43 (1.00)	0.40 (1.00)	0.80 (1.00)	0.88 (1.00)
R	1.47 (0.52)	1.91 (0.92)	0.92 (0.57)	1.38 (0.57)	1.58 (0.57)
Π	1.15 (0.84)	1.27 (0.92)	0.37 (0.85)	0.99 (0.84)	1.20 (0.83)
$Rreal$	0.92 (-0.54)	0.83 (0.66)	0.69 (0.06)	0.84 (-0.38)	0.89 (-0.45)
Δp^B	1.36 (-0.93)	1.52 (-0.79)	0.52 (-0.93)	1.18 (-0.94)	1.40 (-0.93)
Δp^H	0.65 (0.44)	0.06 (-0.07)	0.24 (0.39)	0.50 (0.43)	0.55 (0.43)
Long-run nominal assets					
Y	1.00 (1.00)	0.28 (1.00)	0.34 (1.00)	0.86 (1.00)	0.96 (1.00)
R	1.42 (0.15)	2.08 (-0.40)	0.94 (-0.17)	1.54 (0.09)	1.38 (0.25)
Π	1.19 (0.62)	1.39 (-0.40)	0.41 (0.36)	1.22 (0.50)	1.16 (0.70)
$Rreal$	1.04 (-0.87)	1.11 (-0.22)	0.74 (-0.77)	1.02 (-0.87)	1.03 (-0.84)
Δp^B	6.02 (-0.94)	7.95 (0.09)	3.75 (-0.89)	6.38 (-0.93)	5.75 (-0.94)
Δp^H	0.50 (0.37)	0.56 (0.05)	0.14 (-0.22)	0.39 (0.27)	0.46 (0.36)
Short-run real assets					
Y	1.00 (1.00)	0.46 (1.00)	0.41 (1.00)	0.79 (1.00)	0.87 (1.00)
R	1.45 (0.56)	1.87 (0.91)	0.91 (0.60)	1.35 (0.61)	1.59 (0.61)
Π	1.13 (0.86)	1.25 (0.91)	0.36 (0.86)	0.95 (0.85)	1.20 (0.84)
$Rreal$	0.89 (-0.48)	0.80 (0.66)	0.67 (0.10)	0.81 (-0.31)	0.86 (-0.38)
Δp^B	0.27 (0.11)	0.23 (-0.06)	0.12 (-0.59)	0.20 (-0.04)	0.23 (0.02)
Δp^H	0.66 (0.43)	0.03 (-0.16)	0.25 (0.38)	0.51 (0.41)	0.55 (0.42)
Long-run real assets					
Y	1.00 (1.00)	0.26 (1.00)	0.33 (1.00)	0.80 (1.00)	0.90 (1.00)
R	1.50 (0.44)	2.01 (0.93)	0.97 (0.15)	1.46 (0.45)	1.56 (0.47)
Π	1.19 (0.80)	1.34 (0.93)	0.41 (0.62)	1.08 (0.77)	1.21 (0.79)
$Rreal$	0.98 (-0.65)	0.93 (0.62)	0.75 (-0.49)	0.91 (-0.57)	0.96 (-0.60)
Δp^B	2.21 (-0.91)	2.86 (-0.06)	2.58 (-0.97)	2.32 (-0.91)	2.27 (-0.90)
Δp^H	0.62 (0.45)	0.22 (0.01)	0.16 (0.19)	0.48 (0.43)	0.54 (0.44)

Table 3: Demand shocks

	BM	$\rho_R = 0$	$\gamma_\pi = 3.0$	$\gamma_y = 0.2$	$\gamma_H = 0.4$
Short-run nominal assets					
Y	1.00 (1.00)	1.16 (1.00)	1.25 (1.00)	0.80 (1.00)	0.79 (1.00)
R	0.26 (-0.99)	0.94 (-1.00)	0.45 (-1.00)	0.25 (-0.99)	0.24 (-0.94)
Π	0.58 (-0.71)	0.63 (-1.00)	0.51 (-0.73)	0.65 (-0.81)	0.65 (-0.79)
$Rreal$	0.71 (0.42)	1.16 (0.55)	0.80 (0.28)	0.75 (0.58)	0.74 (0.57)
Δp^B	0.87 (0.65)	1.88 (0.84)	1.04 (0.65)	0.92 (0.73)	0.91 (0.71)
Δp^H	0.82 (0.51)	1.33 (0.68)	1.08 (0.54)	0.68 (0.52)	0.67 (0.52)
Long-run nominal assets					
Y	1.00 (1.00)	1.18 (1.00)	1.26 (1.00)	0.79 (1.00)	0.79 (1.00)
R	0.27 (-0.99)	0.99 (-1.00)	0.46 (-1.00)	0.26 (-0.99)	0.24 (-0.94)
Π	0.59 (-0.71)	0.66 (-1.00)	0.53 (-0.73)	0.67 (-0.81)	0.65 (-0.79)
$Rreal$	0.72 (0.42)	1.20 (0.55)	0.82 (0.27)	0.76 (0.57)	0.74 (0.57)
Δp^B	0.99 (0.60)	1.82 (0.83)	1.25 (0.61)	1.05 (0.70)	0.77 (0.58)
Δp^H	0.83 (0.51)	1.39 (0.69)	1.11 (0.54)	0.68 (0.52)	0.67 (0.52)
Short-run real assets					
Y	1.00 (1.00)	1.15 (1.00)	1.23 (1.00)	0.80 (1.00)	0.81 (1.00)
R	0.25 (-0.99)	0.90 (-0.99)	0.43 (-0.99)	0.23 (-0.99)	0.22 (-0.97)
Π	0.56 (-0.70)	0.60 (-0.99)	0.50 (-0.73)	0.63 (-0.80)	0.62 (-0.79)
$Rreal$	0.69 (0.43)	1.13 (0.54)	0.78 (0.29)	0.72 (0.58)	0.71 (0.58)
Δp^B	0.51 (0.54)	1.38 (0.70)	0.74 (0.57)	0.44 (0.55)	0.44 (0.54)
Δp^H	0.80 (0.51)	1.29 (0.68)	1.05 (0.54)	0.66 (0.52)	0.66 (0.52)
Long-run real assets					
Y	1.00 (1.00)	1.17 (1.00)	1.25 (1.00)	0.80 (1.00)	0.80 (1.00)
R	0.26 (-0.99)	0.95 (-1.00)	0.45 (-1.00)	0.24 (-0.99)	0.23 (-0.95)
Π	0.58 (-0.71)	0.64 (-1.00)	0.52 (-0.73)	0.65 (-0.81)	0.65 (-0.79)
$Rreal$	0.72 (0.42)	1.17 (0.55)	0.81 (0.27)	0.74 (0.58)	0.73 (0.57)
Δp^B	0.79 (0.50)	1.35 (0.68)	1.07 (0.53)	0.65 (0.52)	0.65 (0.51)
Δp^H	0.82 (0.51)	1.35 (0.69)	1.10 (0.54)	0.67 (0.52)	0.67 (0.52)

Table 4: Markup shocks

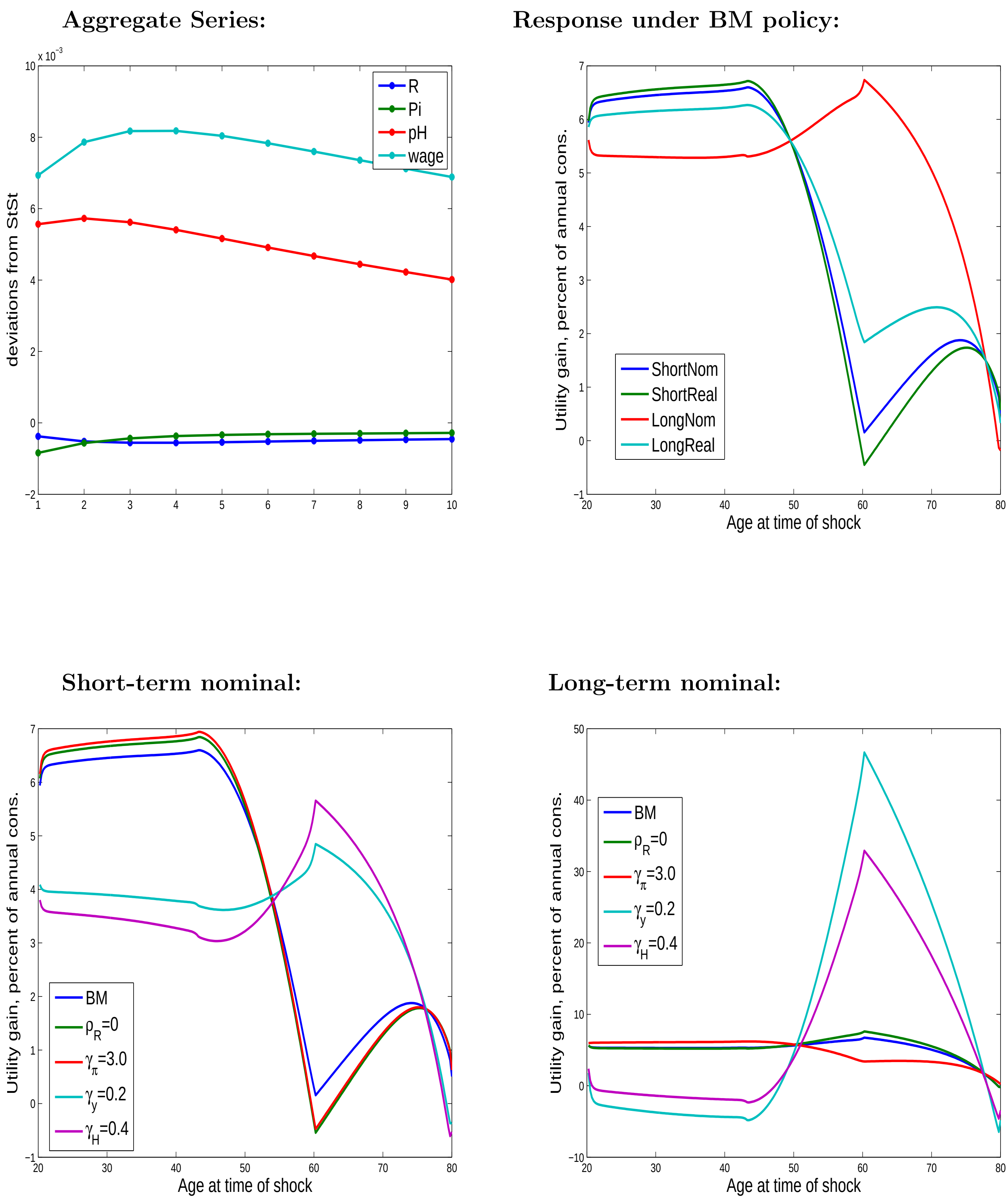


Figure 6: Impulse response to technology shock

for some quarters after the shock. The increase in housing demand leads to an increase in housing investment, higher adjustment costs and therefore a rise in the price of houses.

The upper right panel of Figure 6 shows the effect on household utility. Households which will continue in the labor market for many years take full advantage of the wage rise. Beyond the age of 50, this gain decreases, but notice that even retirees benefit from the wage rise through the public pension system. For a household at age 60, the slight reduction in the real interest rate more than offsets the gain through higher pensions, due to the large positive position in nominal assets. For households around age 75, which have already run down their wealth considerably, the pension effect dominates. With long term nominal bonds, households around the age of 60 do not care about the increase in the real rate that much, because the nominal interest rate will not adapt, so they also gain from the shock via a reduction in inflation and higher pensions.

The lower panels deliver one very interesting result: policies which seem to be distributing the shock relatively uniformly across age groups for short-term nominal assets (including house prices and the output gap into the Taylor rule) do not work well for long-term bonds, and vice versa. While a positive technology shocks makes almost everybody in the economy better of (although it does not necessarily "lift all boats"), the reaction of the central bank determines who wins wins most. When it increases the interest rate due to higher output ($\gamma_y = 0.2$) to prevent an overheating of the economy, or because of higher housing prices ($\gamma_H = 0.4$), this channel will be the main effect for households with extreme (positive and negative) bond positions. If it however decides to react stronger to the lowered inflation, this of course helps the debtors at the cost of the borrowers (age around 60 years), who still benefit from reduced inflation.

All in all, Figure 6 shows a rather complicated picture of the effect of monetary policy in different circumstances. It is not clear whether it is worthwhile to study all this in detail, because a simple Taylor rule as postulated in our model is probably not appropriate if technology shocks are the main driving force in the economy. The effects of monetary policy under demand shocks (cf. Section 4.2) are much more straightforward.

4.6 Comparison to empirical findings in the literature

Comparing our findings to the results presented in Adam and Zhu (2014), there are differences due to the methodology used. In their empirical study, the authors compute the Nominal Net Position (Nominal claims - Nominal liabilities) and normalize by net wealth, and use this measure as inflation exposure to asses redistributive questions. In our General Equilibrium Model, we incorporate the responses of the central bank and of the economy as a whole. Their results correspond to our equilibrium debt/bondholding. We get positive inflation exposure for young households, since they save up to overcome the downpayment-constraint. This is at odds with data for US and Canada, but qualitatively true for poor young households in the

Euro Area. Since we explicitly model the richest households as capitalists and those are not part of the households over the lifecycle, the rich households in the data are of little concern.

It is important to realize that both the net nominal and the net real positions are important, because monetary policy affects both the nominal and the real interest rate. The model outcome creates a pattern similar to Germany, where even the young households hold a sizeable positive nominal asset position, although the magnitudes are not right. The absence of a bequest motive causes the households in our model to run down their assets before they die, which is why the model predictions at the end of the lifecycle have to be taken with a grain of salt.

Our model also replicates the finding by Cloyne et al. (2015), where they write "(I)n response to an unanticipated change in interest rates, households with mortgage debt adjust their expenditure significantly, especially on durable goods, renters react to a lesser extent, and outright home-owners do not react at all." Their finding for UK data translates to the reactions in housing by our agents, and we see that constraint agents (up to cohort 92) react more strongly to a monetary policy shock than their one quarter older fellow people.

The result that long term nominal bonds protect better against monetary policy shocks is reminiscent of a result obtained in Calza, Monacelli, and Stracca (2013), where they find that consumption responses are stronger in countries where the adjustable rate mortgage is more prevalent, corresponding to our short term nominal bonds.

5 Conclusions

In this paper, we have taken a look at monetary policy under a new perspective. We analyze the distributional consequences of monetary policy, and hereby we focus on the role of housing choice and of the asset structure, that means, whether households save and borrow in the form of nominal or real, short-run or long-run bonds. Our framework is an OLG model, the relevant dimension of redistribution is therefore the redistribution across cohorts.

In general, we find that monetary policy has large and very long-lasting effects on the wealth distribution. The asset structure turns out to have only small effects on aggregate dynamics, but large effects on the distribution. Households are well insulated from monetary policy only if household assets and debt are in terms of long-run real (inflation protected) bonds, a case that is not relevant for current economies. Monetary policy shocks create particularly large redistribution if debt contracts are short-term and nominal. With long-term real contracts, effects are small. With short-term real or long-term nominal contracts, the effects are in between the other two cases.

A more detailed evaluation of monetary policy has to take a stand on which shocks are driving the economy. If demand shocks are the main driving force of business cycles, and if assets are long-term nominal, a more aggressive monetary policy does not only reduce aggregate fluctuations in output and prices, it also reduces the intergenerational redistribution of these shocks. In contrast, interest rate smoothing dampens the distributional effects of monetary policy if households are invested in long-run nominal bonds. This is true for both demand and markup shocks, although interest rate smoothing increases the variability of output in the case of demand shocks.

The results of this paper raise many questions. The following two seem most important to us. First, we have used a rather straightforward model with few frictions. It therefore remains to check whether the results hold up in a framework with all the bells and whistles of recent DSGE models. Second, we have imposed the asset structure exogenously on the economy. In each version of the model, there was only one type of bond available. This is a consequence of the high-dimensional model setup, which we have solved by linearization around the steady state. A rigorous nonlinear analysis of the model should check the implications of monetary policy for asset choice, and how this in turn affects the distribuutional consequences of these policies.

A Impulse responses

Figure 7 shows impulse responses of the big economic aggregates to the four types of shocks.

B First order conditions

We briefly discuss the first order conditions for the worker households, obtained from maximizing the utility function with respect to the budget constraint and the downpayment constraint.

The trade-off between consumption and leisure is

$$u_{l_{i,t}} = -(1-\tau)w_t \zeta_i u_{c_{i,t}} \tag{26}$$

Since the pension payment is lump sum, the social security tax at rate τ is purely distortive.

The trade-off between consumption and rental housing has no friction:

$$u_{h^R_{i,t}} = r^H_t u_{ci,t} \tag{27}$$

The consumption Euler equation is

$$u_{c_{i,t}} p^B_t \geq \beta \mathbb{E}_t \left[u_{c_{i+1,t+1}} R^B_{t+1} \right] \tag{28}$$

where the gross return to bonds is defined as

$$R^B_t \equiv ((\mu + r^B)v^B_t + (1-\mu)p^B_t) \tag{29}$$

If the downpayment constraint is not binding, (28) holds with equality.

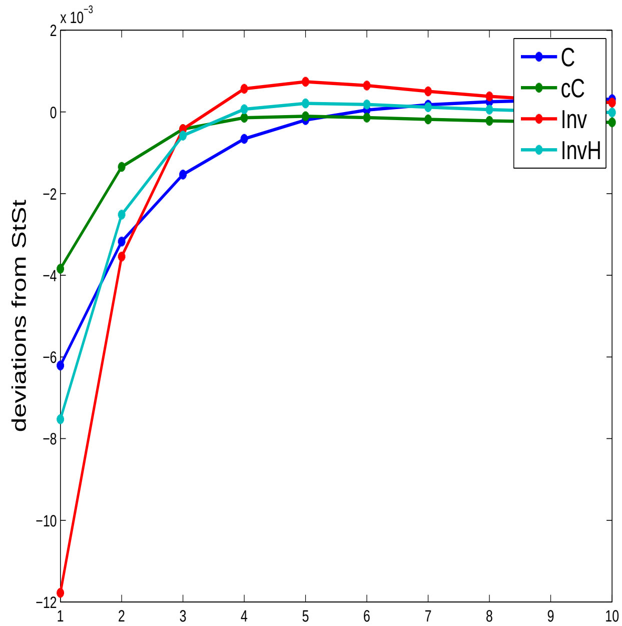
The first order condition for buying one more unit of owned housing is

$$u_{c_{i,t}} p_t^H = u_{h_{i,t}^O} + \beta(1-\delta_H)\mathbb{E}_t\left[u_{c_{i+1,t+1}} p_{t+1}^H\right] \tag{30}$$

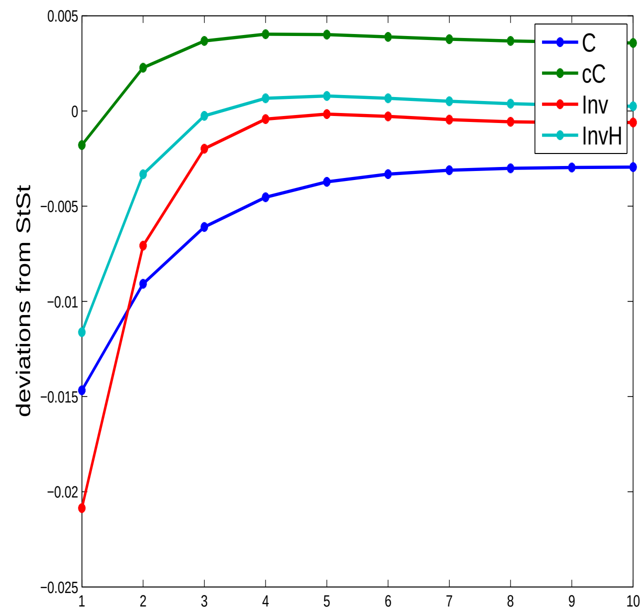
$$+ \frac{\nu}{p_t^B}\mathbb{E}_t p_{t+1}^H \left(p_t^B u_{c_{i,t}} - \beta\mathbb{E}_t\left[u_{c_{i+1,t+1}} R_{t+1}^B\right]\right) \tag{31}$$

The second line of (30) gives the utility gain arising from the fact that buying one unit of housing relaxes the borrowing constraint by $\nu\mathbb{E}_t p_{t+1}^H$. If (28) holds with equality, this part of (30) is zero.

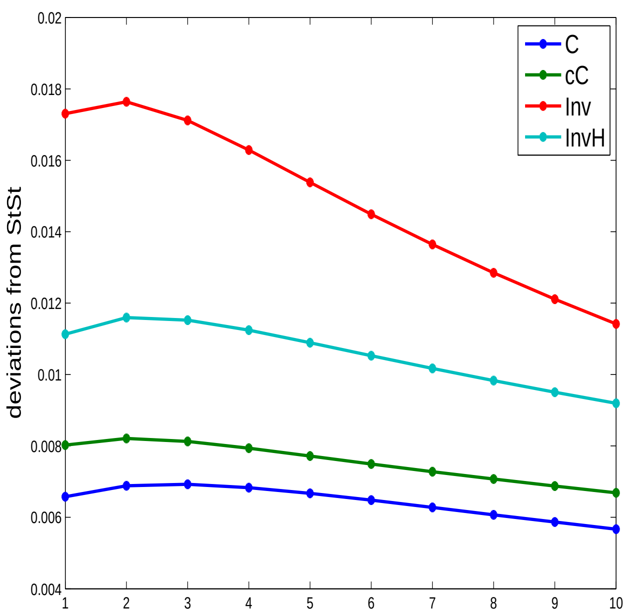
Monetary policy shock:



Demand shock:



Technology shock:



Markup shock:

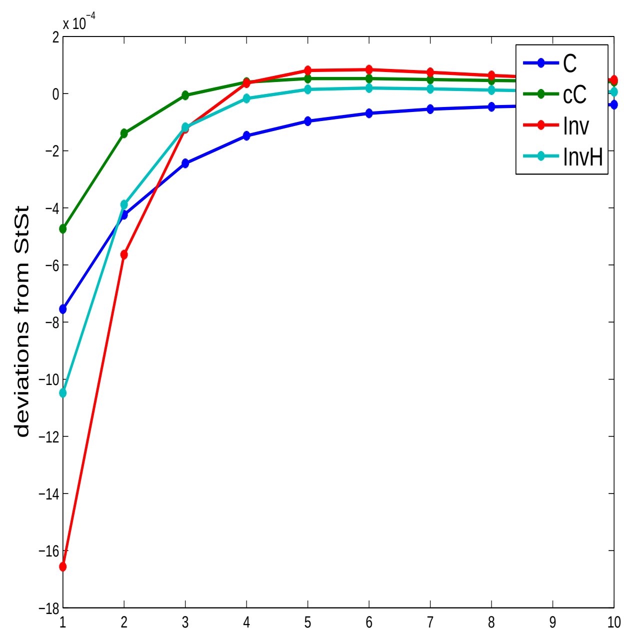


Figure 7: Impulse responses of aggregate variables

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