Housing and the Redistributive Effects of Monetary Policy *

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PRELIMINARY AND INCOMPLETE!

Abstract

How do the effects of shocks to an economy depend on the underlying asset structure? We study the redistributive effects of monetary policy in the framework of a large Overlapping Generations model, with endogenous housing choice, an endogenous down-payment constraint, and different types of shocks. The findings of the recent literature on redistribution and monetary policy are confirmed by our model, however we extend the analysis along an important dimension. We pay special attention to the structure (short-term versus long-term, nominal versus real) of assets and debt. Our results suggest that monetary policy has sizeable and long lasting effects on wealth distribution and consumption and that agents are affected differently according to the asset position they are holding. Inflation protected long term assets regularly provides better insurance against shocks, than their short-term nominal counterparts, which are subject to inflation. However, an economy equipped with real-long-term bonds has different implications for the aggregate economy and the monetary policy conducted by the central bank. House prices fluctuate more, when the economy is facing demand shocks, because housing and the other assets exhibit now similar characteristics, thus limiting the possibilities of insurance. Little movement of aggregate variables is masking strong effects on individual cohorts, which are mitigated by being adverse: while one set of agents increases their housing position after a shock, another fraction has to reduce their housing services in response. Monetary Policy should also consider the redistributive effects it induces, and how this depends on the underlying asset structure of the economy.

JEL classification: E21, D91, H31, E24, E32, E58

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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. These contracts may also vary among the dimension of indexation, meaning the mortgage is indexed by a price index, to protect each side against inflationary/deflationary effects (not very common, about 20 /policy greatly depend on the type of contract.

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.

Four main conclusions emerge

- 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, the redistributive effects of monetary policy depend on the asset structure and on the type of shock. For example a strict Taylor rule ($\gamma_\pi = 3$) reduces the redistribution effect of demand shocks when assets are long-run and nominal, but not when they are short-run nominal.
- 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. We therefore want to stress that our model does not provide a "realistic" calibration of wealth and asset inequality; economic inequality has many dimensions, and we capture only a few aspects of it.4 Nevertheless, we think that the models provides a relevant numerical example, because it generates a meaningful heterogeneity of asset positions, which has a clear interpretation, because it is 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.

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[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.

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1.1 Related Literature

The redistributive consequences of inflation are first described in Doepke and Schneider (2006a). 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 burden. A theoretical model motivated by these observations is presented in Doepke and Schneider (2006b), where the redistribution by inflation is modelled exogenously.

Following Doepke and Schneider (2006a), 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, the leads to higher house prices and bigger mortgages. Dobbs et al. (2013) studies 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. Surico 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.

[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.

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

Capitalists can save in terms of physical capital (they run the firms), housing and nominal bonds. Workers cannot trade firm ownership or capital, they only save in the form of housing or bonds. The economic life of workers is 60 years. With a quarterly model period, this means there are 240 cohorts of worker households. There are two types of households: workers households and capitalists. Capitalists form an infinitely lived, representative dynasty. Workers live for 240 periods, retire after 160 periods. With the time period being a quarter, and assuming they start adult life at age 20, they retire at 60 and die at 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

Stochastic maturity is used in Macro models to ensure tractability (cf. eg. Krause and Moyen (2013)), as one does not have to carry on the prices of the bond as state variables. We will pay special attention in this paper to the type of bond that is used, whether it is short-term or long-term, and whether it is nominal or real (inflation protected).

The following stylized formulation nests all the possibilities. We assume that in period t, one unit of the bond carried from period $t-1$ gets 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 If $\mu = 0.025$, 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, so 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.

Here real marginal cost is given by

$$RMC_t = \alpha^{-\alpha}(1-\alpha)^{\alpha-1} w_t^{1-\alpha} (r_t^K)^{\alpha}/z_t \tag{10}$$

Furthermore, we have allowed for a markup shock:

$$z_{\mu_t} = \rho_\mu z_{\mu_{t-1}} + \varepsilon_t^\mu \tag{11}$$

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

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

and the borrowing constraint

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

The first constraint, which is described in equation is a budget constraint, where The LHS of the budget constraint 12 represents the spending of cohort i in period t. It buys bonds at price p^B_t, 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, after which it receives a pension payments ψ_t, which are 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), and prevent the household from implausible high levels of debt, relative to its assets.

It is worth stressing that we model the housing choice in a very stylized way. 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.

For the utility function of the worker household we choose

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

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 important differences to that of worker households. First, they get the whole profits of the production sector, which equals output minus wage payments 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 capitalists are given by $-B_t$, since they are the ones who hold to counterbalance to the aggregated bonds of the workers.

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 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.

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

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

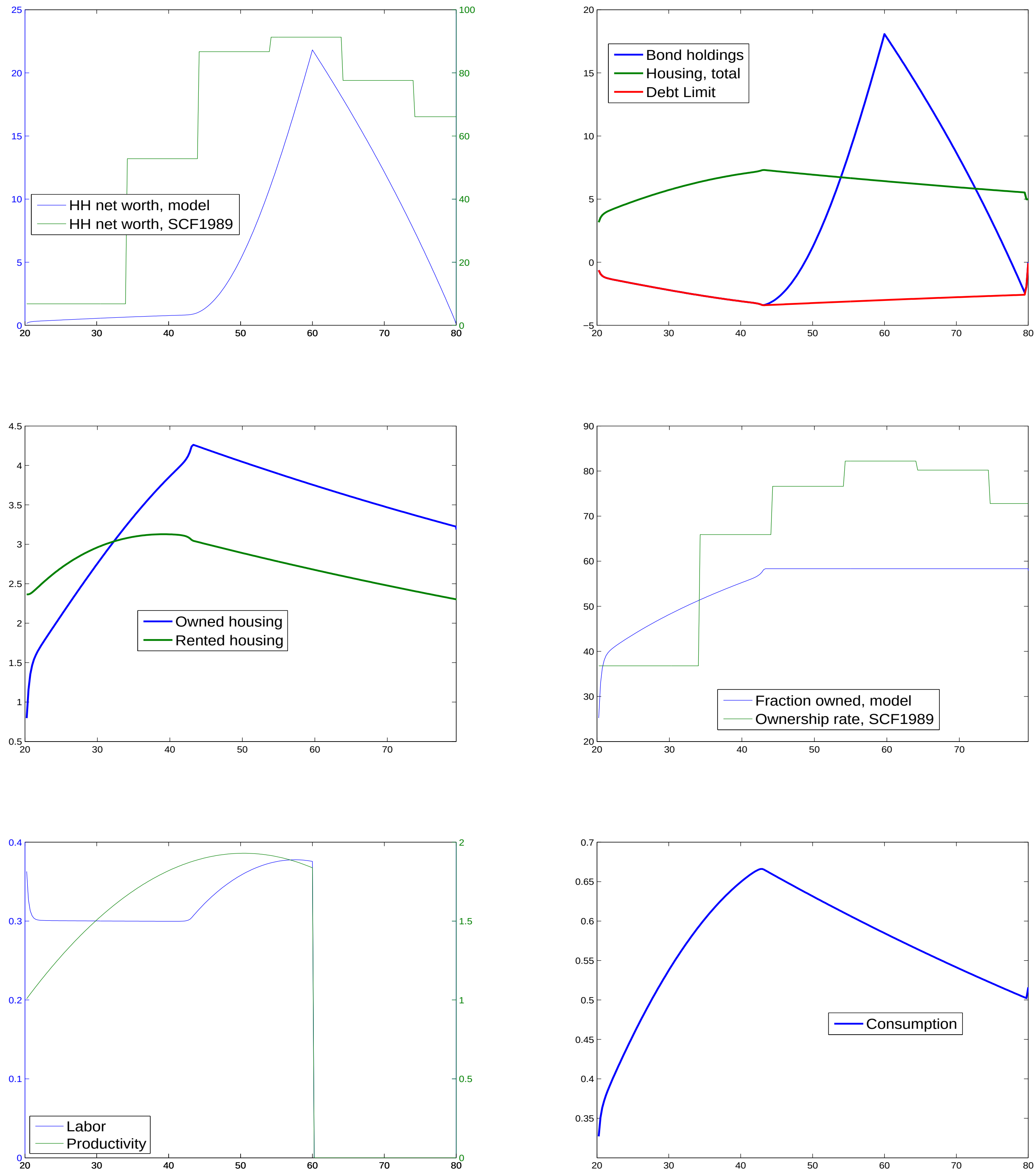


Figure 1: Lifecycle paths in steady state

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

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 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 to a contractionary monetary policy shock (shock to the Taylor rule) of 0.25 percentage points (1 percentage point at annualized rate) that lasts for one quarter. 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.

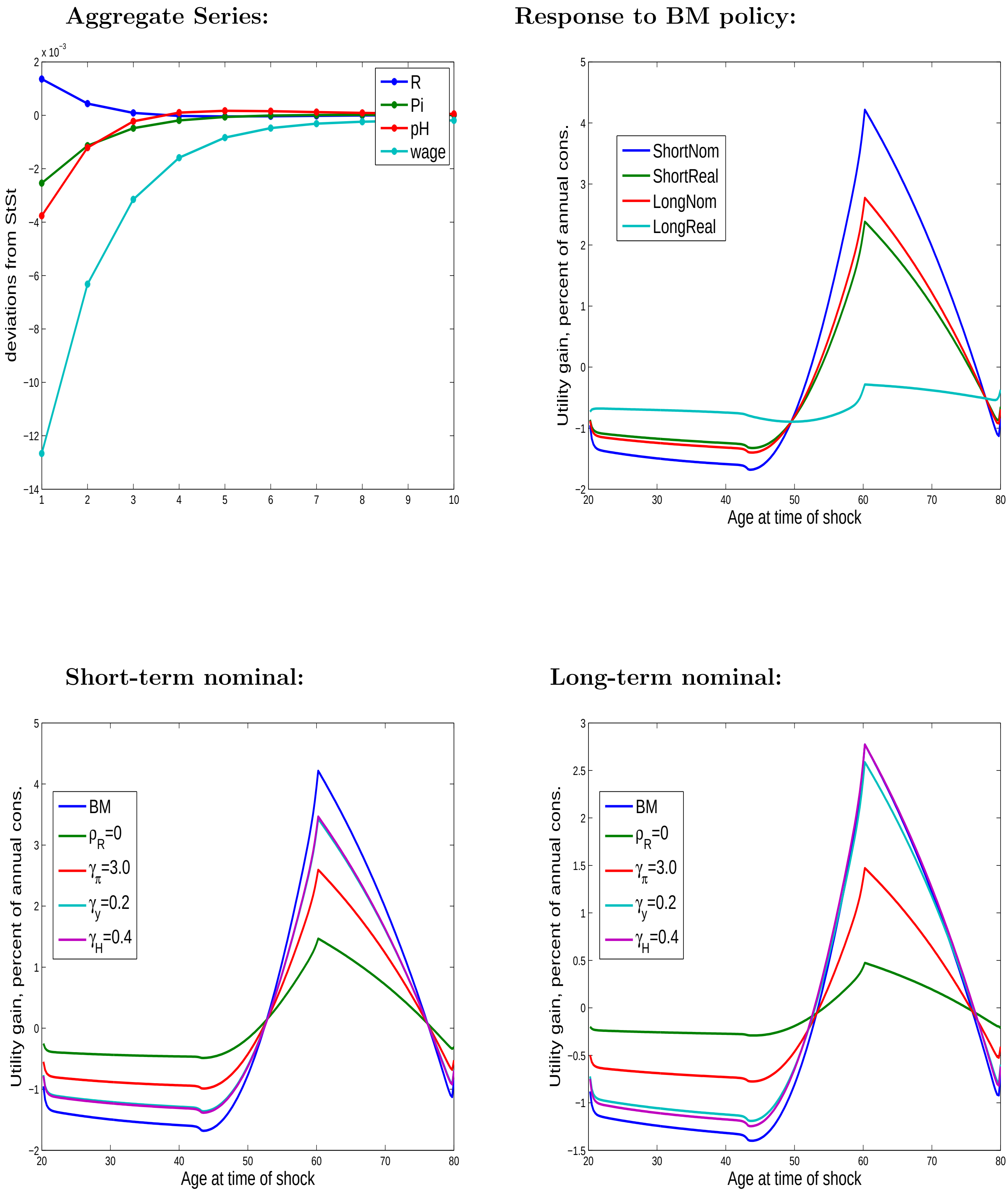


Figure 2: Impulse response to monetary policy shock

4.2 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 mortgage, 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 increase in 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 smaller gain. Conversely, home-owners with a mortgage do not suffer from 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 refinanced in the period where interest are high. Again, their gain is now smaller, compared to the case of short-term bonds. The opposite effect applies 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.

Four main conclusions emerge

- 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 stricter course against inflation ($\gamma_\pi = 3$) reduces variability in utility changes, compared to the baseline specification of the Taylor rule ($\gamma_\pi = 1.5$). The stabilizing effects of monetary policy therefore apply not only to aggregates, but also to individuals.
- While every sort of stronger reaction compared to the baseline Taylor rule brings variability down when the assets are short-term nominal, the picture is not so clear for long-term nominal bonds. This effect will be even more pronounced for the other shocks.

While the effect of a single shock is limited, it is clear that these effects build up over time and will amount in a significant variability of individual cohorts' consumption and assets.

4.3 The long-lasting effect on distribution

To gain an even 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 (everyone above the 92nd cohort (age 43), meaning 148 quarters to live) 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.

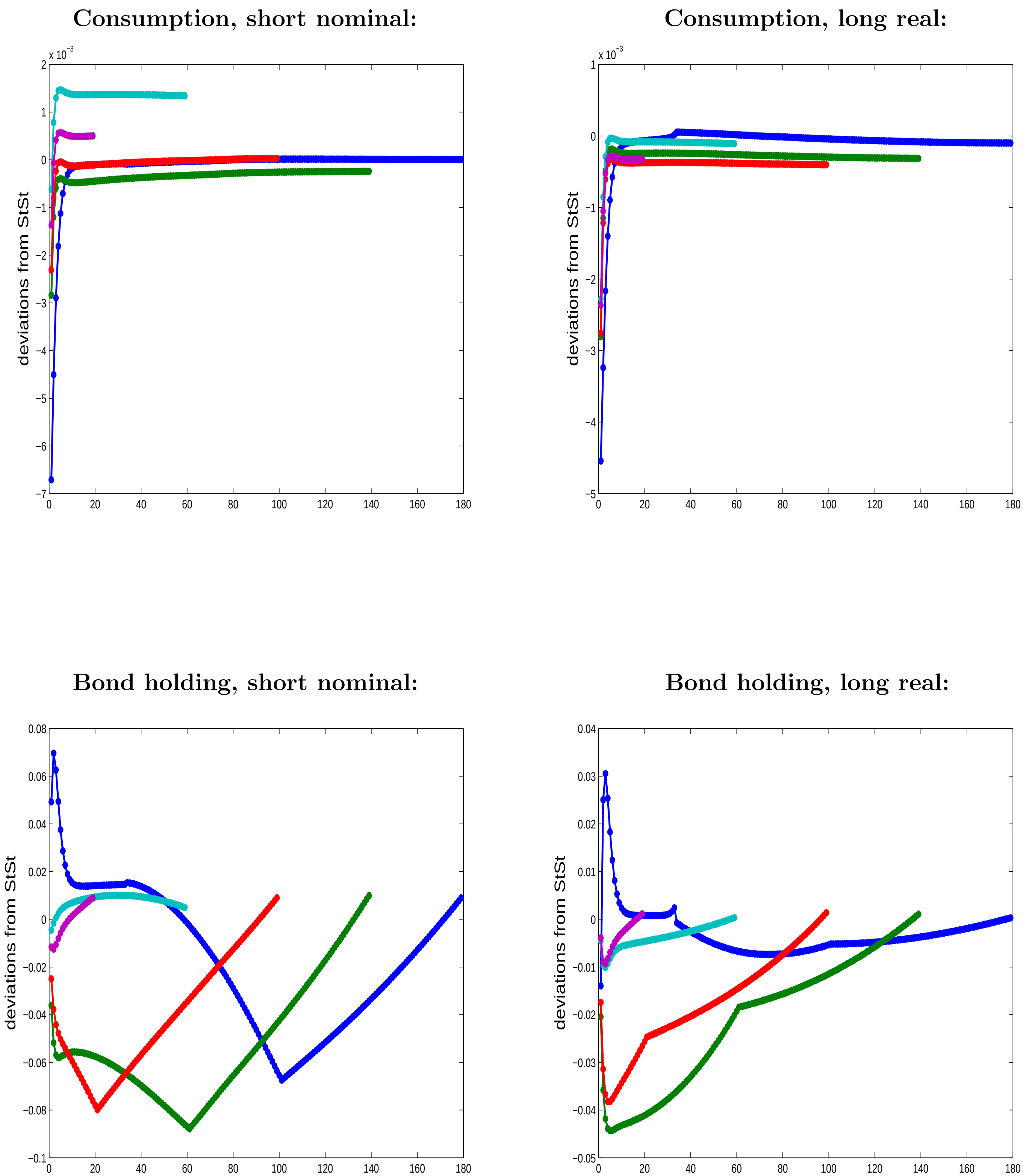


Figure 3: Impulse response to monetary shock

The main conclusion from these figures is that changes in the wealth distribution are very persistent in this model. Again keep in mind, while the effect of a single shock is limited, it is clear that these effects build up over time and will amount in a significant variability of individual cohorts' consumption and assets.

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, ($\gamma_\pi = 1.5$, $\rho_R = 0.7$, $\gamma_y = 0$), as well as three 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* shocks.

The results about the output-inflation trade-off confirm earlier 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. 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.

The most important results for an economy driven by *demand* shocks are:

- Under the benchmark policy, aggregate results depend little on the asset structure (with the exception, obviously, of the bond price, since the nature of the bond is different across asset structure).

- 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 and the same pattern holds for real bonds. The results do not provide much support for interest rate smoothing, since 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. This finding is consistent with the arguments put forward in (Boehm and House 2014), wehre the authors argue that "(w)hen the output gap and inflation are observed without error, it is typically best to adopt infinitely aggressive responses to output and inflation i.e., the optimal coeficients on inflation and output are arbitrarily large." This holds true in our model, although there is a slight increase in volatility of inflation when bonds are long term nominal.

	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

- 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. We consider this is a "consistency check" of our model and the literature: under demand shocks, aggressive monetary policy is clearly stabilizing.
- Output targeting ($\gamma_y = 0.2$) mostly has a stabilizing effect, but this is not true for inflation and the nominal interest rate under long-term nominal bonds.
- Including house prices in the Taylor Rule succeeds in reducing house price volatility, but increases the variance of inflation. The intuition for this is that by reacting to house prices, the volatility of the interest rate goes up, which in turn affects inflation volatility.

How do results change when we consider *markup* shocks instead:

- Again, the asset structure matters little under the baseline policy.
- Now there is a clear tradeoff between inflation and output variability, with respect to the γ_π parameter. The stricter course against inflation reduces the variability of inflation, at the cost of higher output variance. This effect is also there for output stabilization ($\gamma_y = 0.2$)
- Abandoning interest rate smoothing in this case leads to overall higher volatilities across all asset structures.
- Introducing house prices in the Taylor rule has virtually the same effect as targeting the output gap, as the last two columns of table 4 are almost identical.

	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

4.5 The Effect of Demand Shocks Under Different Monetary Rules

We not turn to the analysis of the demand and the markup shock in greater detail. The upper left panel of Figure 4 shows the response of prices to a demand shock. As one would expect, both inflation and the nominal rate increase, as well as the wage rate. Smets and Wouters (2007) The price of housing first goes up, but then reduces, because of the increase in the real rate, which sets in with some delay, due to interest rate smoothing. The upper right panel gives a broadly similar message as in the case of a monetary policy shock: if households invest in long-term real assets, they are much better insured against demand shocks. The case of long-term nominal assets gives the largest variations in lifetime utility.

The lower panels show that the standard Taylor rule $\gamma_\pi = 1.5$ leads to much smaller variations in utility, than lax monetary policy, both under short-term and long-term nominal bonds. This confirms the basic view that monetary policy insulates the economy from demand fluctuations. In our economy, this is true for the large majority of cohorts. The more subtle question is whether interest rate smoothing (the benchmark, $\rho_R = 0.7$), with a lagged response of the nominal interest rate, yields advantages in this respect.

4.6 The effects of a technology shock

The upper left panel of Figure 5 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 for some quarters after the shock. The increase in housing demand also causes a rise in the price of houses.

The upper right panel of Figure 5 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. The economic intuition behind this is that while a positive technology shocks makes most people in the economy better of (although it does not necessarily "lift all boats"),

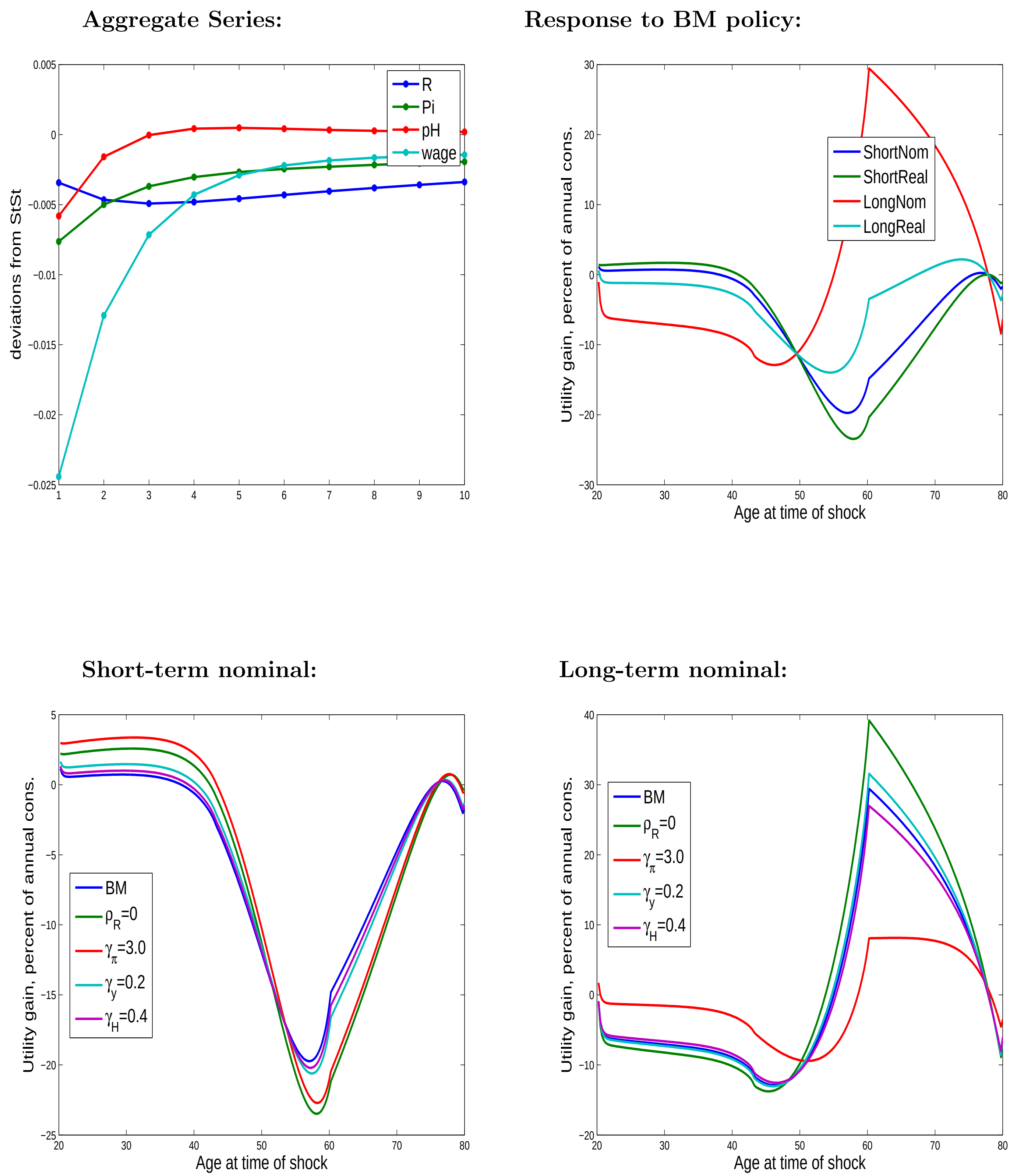
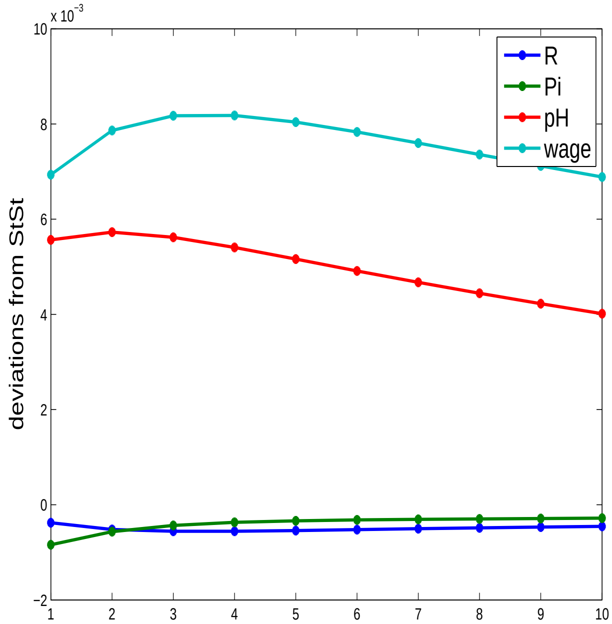
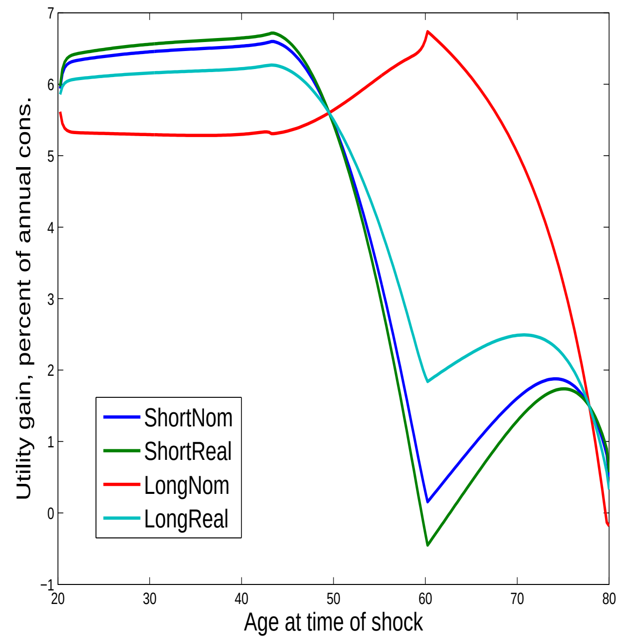


Figure 4: Impulse response to demand shock

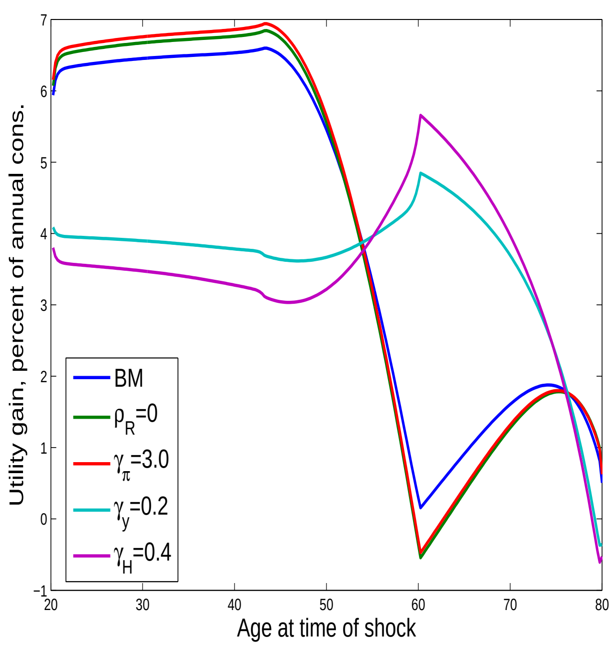
Aggregate Series:



Response to BM policy:



Short-term nominal:



Long-term nominal:

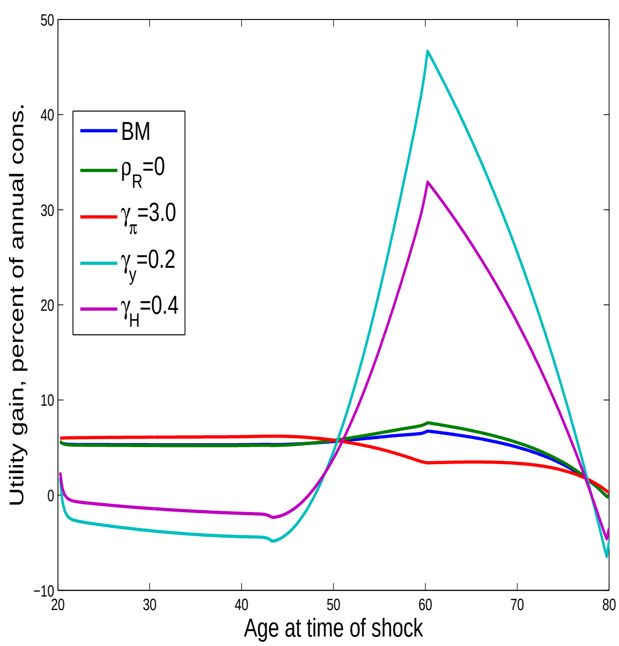


Figure 5: Impulse response to technology shock

the reaction of the central bank determines who wins and who loses, namely by setting the nominal interest rates. 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 5 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 4.5) are much more straightforward.

4.7 The effects of a markup shock

In response to a one period markup shock without propagation, inflation increases for one period, but is more than offset by the Central Bank's reaction in the subsequent period. However, house prices and wages decrease, because of the overall decrease in economic activity.

Since the aggregate effects are small in magnitude, also the changes in utility are small, but this is just because we consider a small shock, that raised the price level

Interest rate smoothing is now a good idea, as the rise in inflation is not permanent, so, abandoning it ($\rho_R = 0$) 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.

4.8 Comparison to empirical findings

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

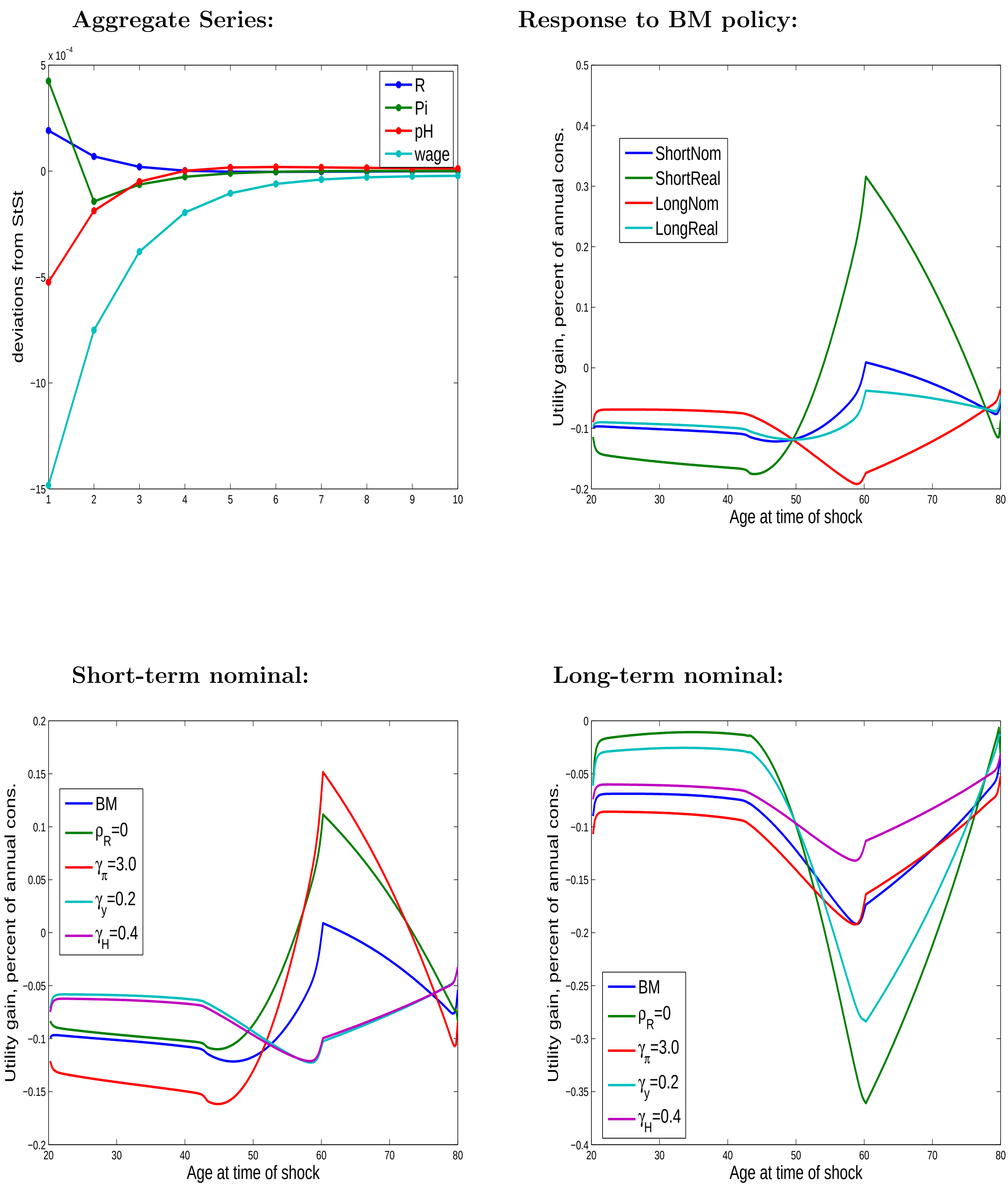


Figure 6: Impulse response to markup shock

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 (Surico, Ferreira, and Cloyne 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

Our analysis adds new dimensions to the redistributive effects of monetary policy, conducted by a Taylor rule, namely heterogeneity among agents and a variety of shocks. We find that the asset structure has little effect on the development of economic aggregates after a shock, but some implications for monetary policy parameters. It furthermore matters for the individual cohorts, as certain shocks combined with different asset structures, can result in adverse utility changes for specific cohorts.

Using real (inflation protected) assets commonly reduces the risk exposure, although there are exceptions from this rule (short term real assets for the markup shock).

Our results confirm evidence found previously by the literature on the redistributive effects of monetary policy, and opens up a new set of questions, concerning optimal monetary policy analysis, when combining our methodology with a model-economy in the presence several quantitatively calibrated shocks at once.

A Impulse responses

Figure 7 shows impulse responses of the big economic aggregates to the four types of shocks. As one would expect, an interest rate shock has a contractionary effect on all the aggregates. A contractionary

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

$$u_{c_{i,t}} p^H_t = u_{h^O_{i,t}} + \beta(1-\delta_H) \mathbb{E}_t \left[u_{c_{i+1,t+1}} p^H_{t+1} \right] \tag{30}$$

$$+ \frac{\nu}{p^B_t} \mathbb{E}_t p^H_{t+1} \left(p^B_t u_{c_{i,t}} - \beta \mathbb{E}_t \left[u_{c_{i+1,t+1}} R^B_{t+1} \right] \right) \tag{31}$$

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

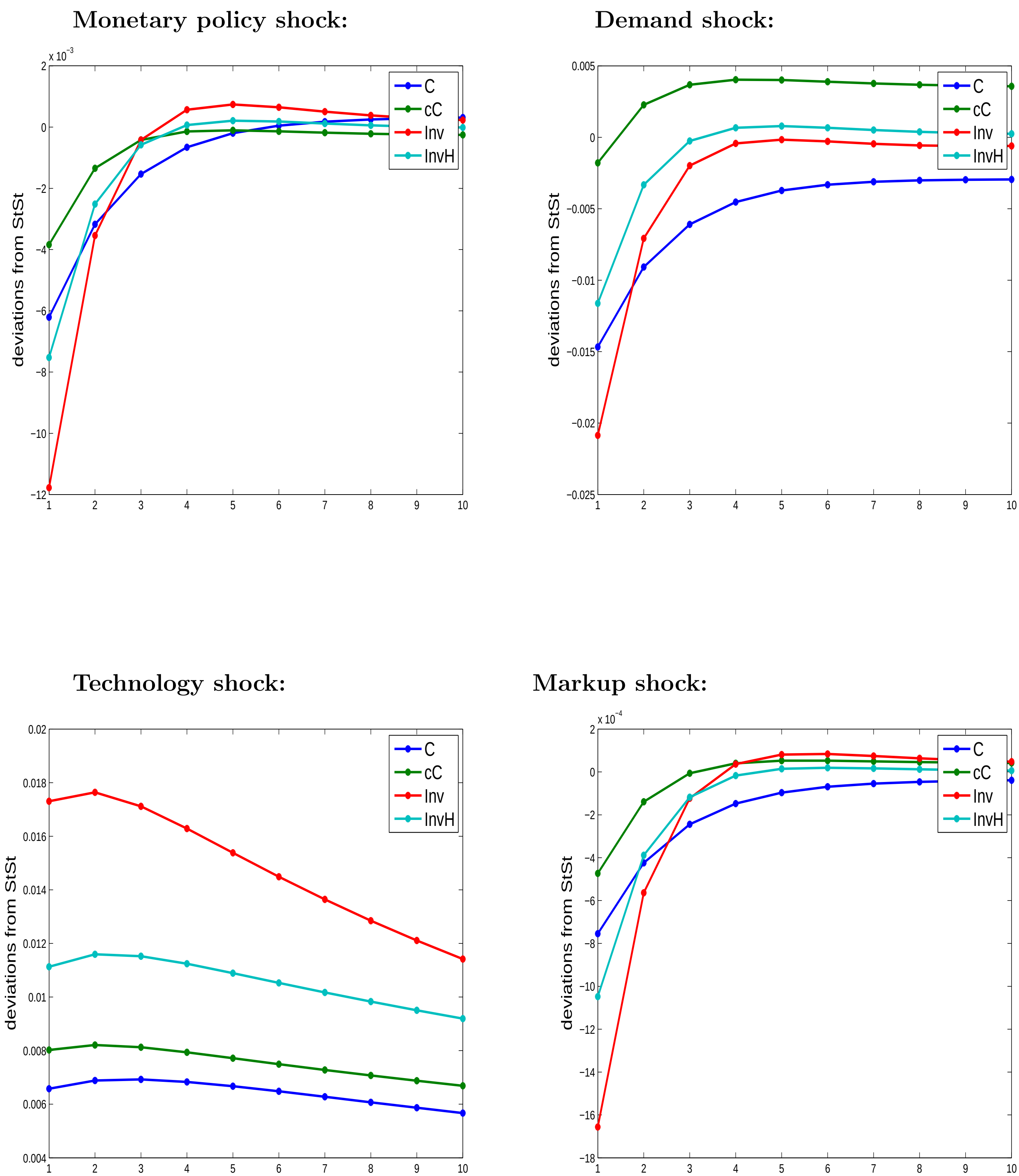


Figure 7: Impulse responses of aggregate variables

References

Adam, K. and J. Zhu (2014). Price Level Changes and the Redistribution of Nominal Wealth Across the Euro Area. Technical report.

Albanesi, S. (2007, May). Inflation and inequality. *Journal of Monetary Economics 54*(4), 1088–1114.

Auclert, A. (2015, Jannuary). Monetary Policy and the Redistribution Channel. *Jobmarket Paper*.

Boehm, C. E. and C. L. House (2014, June). Optimal Taylor Rules in New Keynesian Models. NBER Working Papers 20237, National Bureau of Economic Research, Inc.

Brunnermeier, M. K. and Y. Sannikov (2012). Redistributive monetary policy. *Proceedings - Economic Policy Symposium - Jackson Hole*, 331–384.

Calza, A., T. Monacelli, and L. Stracca (2013, 01). Housing Finance And Monetary Policy. *Journal of the European Economic Association 11*, 101–122.

Dobbs, R., S. Lund, T. Koller, and A. Shwayder (2013, November). QE and ultra-low interest rates: Distributional effects and risks. *McKinsey Global Institute, Discussion Paper*.

Doepke, M. and M. Schneider (2006a, December). Inflation and the Redistribution of Nominal Wealth. *Journal of Political Economy 114*(6), 1069–1097.

Doepke, M. and M. Schneider (2006b, June). Inflation as a Redistribution Shock: Effects on Aggregates and Welfare. NBER Working Papers 12319, National Bureau of Economic Research, Inc.

Fernndez-Villaverde, J. and D. Krueger (2011, November). Consumption And Saving Over The Life Cycle: How Important Are Consumer Durables? *Macroeconomic Dynamics 15*(05), 725–770.

Gali, J. (2008). *Monetary Policy, Inflation and the Business Cycle*. Princeton University Press.

Gornemann, N., K. Kuester, and M. Nakajima (2014). Doves for the Rich, Hawks for the Poor? Distributional Consequences of Monetary Policy. Technical report.

Iacoviello, M. (2002, October). House prices, borrowing constraints and monetary policy in the business cycle. Boston College Working Papers in Economics 542, Boston College Department of Economics.

Iacoviello, M. and M. Pavan (2013). Housing and debt over the life cycle and over the business cycle. *Journal of Monetary Economics 60*(2), 221–238.

Krause, M. U. and S. Moyen (2013). Public debt and changing inflation targets. Technical report.

Smets, F. and R. Wouters (2007, June). Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review 97*(3), 586–606.

Surico, P., C. Ferreira, and J. Cloyne (2015). Housing Debt and the Transmission of Monetary Policy. Technical report.

Williamson, S. D. (2008, September). Monetary policy and distribution. *Journal of Monetary Economics 55*(6), 1038–1053.

Yang, F. (2006). Consumption Over the Life Cycle: How Different is Housing? *Working Paper 635, Federal Reserve Bank of Minneapolis*.