Housing and the Redistributive Effects of Monetary Policy *

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April 29, 2019

Abstract

We study monetary policy in the framework of a large OLG model, with different skill classes and endogenous housing choice subject to down payment constraints. We investigate how household heterogeneity affects the ability of the central bank to stabilize the economy if business cycles are driven by aggregate demand shocks. Special attention is paid to the structure of debt, whether it is short-term (variable interest rate) or long-term (fixed interest rate), nominal or real.

We find that household heterogeneity limits the possibilities of monetary stabilization policy. Under demand shocks, aggressive monetary policy reduces the fluctuations of detrended output and inflation, but it stabilizes individual welfare only when debt is long-term. This is because monetary policy has long-lasting effects on the distribution of wealth. If the central bank stabilizes inflation, it stabilizes output fluctuations almost perfectly at business cycle frequencies, but not at lower frequencies.

JEL classification: E24, E32, E58
Keywords: Housing, monetary policy, redistribution, heterogeneous agents

*We are grateful to seminar participants in Oslo, Vienna, Marrakech, at NYUAD, Geneva, Bratislva and Bordeaux for helpful remarks and discussions. We thank Keith Kuester, Gabe Lee and Roman Sustek for discussions and extensive comments on an earlier draft of the paper. The usual disclaimer applies.

1 Introduction

Through changes in the nominal interest rate, monetary policy redistributes wealth between lenders and borrowers of nominal assets. Indirectly it redistributes between the owners of all other assets, for example houses, by affecting the prices of those assets. Heterogeneity in households' asset position therefore matters for the monetary transmission mechanism, which is the topic of a fast growing literature. We contribute to this literature looking at the distributional effects of monetary policy from a somewhat different perspective: does household heterogeneity in asset positions limit the ability of the central bank to stabilize the economy against demand shocks? More specifically, we address two concerns. Does redistribution affect the macroeconomic aggregates in a way that counteracts the stabilization policy? Does redistribution increase instability at the household level, even if the aggregate economy gets stabilized?

To analyze these questions we build a general equilibrium model which combines three features that we think are important: the life-cycle structure of households, owner-occupied housing with a down payment constraint on mortgages, and differential access to asset markets across household types. The life-cycle structure together with a housing choice helps to generate a realistic degree of gross asset positions. For most middle class households, gross positions are primarily given by a house and a mortgage. Households hold a long position in housing, which is a long-lived real asset, and a short position in the form of a mortgage, which is denoted in nominal terms. Such a household can have a small net worth and nevertheless be heavily exposed to interest rate risk. This risk then depends on whether the mortgage has a variable interest rate (what we call a "short-term" asset) or a fixed interest rate ("long-term asset"). The firm side of the model has a standard New Keynesian structure with Calvo price rigidity, which makes it a type of HANK (Heterogeneous Agent New Keynesian) model.

We model the differential access to asset markets by assuming three types of households:

1. Low-skill hand-to-mouth consumers with a finite life, who live in rented housing and hold no assets. In old age, they live from the benefits of a pay-as-you-go pension system.

2. Middle class households with a finite life, who decide about rented versus owner-occupied housing, and save in bonds for retirement, in addition to the pension system.

3. A representative, infinitely lived dynasty of "capitalists", who all live in owner-occupied houses, own the firms as well as the rental houses.

Since the type of assets traded is essential for the redistributive effect of monetary policy, we study not only short-term versus long-term debt, but also nominal versus real (inflation indexed) debt. This gives four variants of the model, depending on whether bonds are short-term nominal, long-term nominal, short-term real or long-term real. Mostly for technical reasons, we have only one type of debt in any version of the model.[1] This may not be as restrictive as it sounds. The data (Bouyon 2017, Figure 2) show large variations in the rate of variable-rate mortgages across European countries, ranging between 15 percent in Germany and almost 100 percent in Spain (until 2012). This suggests that the choice between fixed and variable rate is more determined by institutional factors in each country than by individual portfolio considerations.

Our main finding is that household heterogeneity makes monetary stabilization policy harder. This is true even if the economy is only hit by demand shocks, and the demand shocks are modeled such that simultaneous stabilization of both inflation and output (a version of the so-called "divine coincidence", cf. Blanchard and Galí (2007)) is possible in the representative household version of the model. More specifically, we find that the policy trade-offs are roughly the same in the benchmark model as in a representative agent version of the model, as long as they are measured in terms of second moments of *detrended* variables. In particular, the "divine coincidence" continues to hold approximately for detrended variables. However, it fails significantly if we also consider fluctuations at lower than business cycle frequencies, for reasons different from the ones already noted in the literature (Alves 2014). These fluctuations have strong effects on fluctuations in welfare. For example, strict inflation targeting reduces the variability of lifetime welfare if assets are long-term, but not if they are short-term. Interest rate smoothing reduces the variability of lifetime welfare. Underlying these findings is the fact that demand shocks, similar to monetary policy shocks, generate substantial redistribution between different cohorts and household types. This redistribution depends on the type of bond traded as well as on the concrete policy rule. Again, household heterogeneity and asset type have a small impact on the impulse responses of aggregate output and inflation to both shocks, much smaller than the width of the confidence bands in the empirical estimates of these impulses responses. However, some significant differences arise if one considers total fluctuations, not just fluctuations of conventionally detrended variables.

That the redistribution channel has such a limited effect on macroeconomic aggregates at business cycle frequencies may be the consequence of some crucial model assumptions. With several dimensions of heterogeneity, the effects of redistribution become very complex, and we want to clarify the discussion by abstracting from some potentially important mechanisms. In contrast to Kaplan, Moll, and Violante (2018), who stress the importance of fiscal policy, we reduce the role of fiscal policy to a minimum: there is no government debt, the government only runs a pay-as-you-go pension system. We do not assume any trading frictions in our model for physical capital or housing, so we do not generate the "rich hand-to-mouth con-

[1] To study monetary policy, we need a quarterly model period. With an economic life of 60 years, we have 240 cohorts, and in total the model has more than 1400 variables, so that we solve the model by linearization. The approximate solution is therefore of the certainty-equivalence type, and we cannot study portfolio choice among different types of financial assets such as short-term versus long-term debt.

sumers" that play a prominent role in their model. We also abstract from financial frictions that would give a role to the net worth of entrepreneurs in investment, a mechanism that is prominent since Carlstrom and Fuerst (1997).

Although we do not try to compute optimal policy, several policy implications emerge from our analysis. Fighting inflation aggressively is the right policy against demand shocks if long-term debt positions, such as mortgages, have fixed rather than variable interest rates, because this reduces the distributional impact of nominal interest rate movements. With variable interest rates, aggressive monetary policy generates large random redistributions. Regulatory changes that motivate banks and households to move towards fixed rate mortgages are therefore welcome from a monetary policy point of view. Since we find that the stabilization of macroeconomic aggregates does not go hand in hand with the stabilization of individual utility or welfare, our results raise the question of what is the exact objective of monetary policy.

1.1 Related Literature

The redistributive consequences of inflation are first described in Doepke and Schneider (2006a), where the effects of inflation through the channel of nominal assets are studied. 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. Our model replicates this empirical feature. For an extensive empirical study for the euro area countries see Adam and Zhu (2016). A theoretical model motivated by these observations is presented in Doepke and Schneider (2006b), where the redistribution by inflation is modeled exogenously.

Following up on these empirical findings, there is now a growing literature on the monetary transmission mechanism in the presence of heterogeneous agents. The model in the literature that is closest to ours is probably Garriga, Kydland, and Šustek (2017). This is a model of monetary policy with two types of households, house owners and capital owners. Like us, they analyze different mortgage types, namely fixed and adjustable rate mortgages. The authors consider a standard monetary policy shock as well as a shock to the target level. Their model has a more elaborate treatment of mortgages and down payment constraints. Redistribution happens between house and capital owners. In contrast, most of the redistribution in our model takes place between middle class households of different ages. The main focus of our analysis is not the transmission of monetary shocks, but the ability of monetary policy to insulate the economy from demand shocks. To the best of our knowledge, this differentiates our paper from all the papers in this literature. The empirical importance of the mortgage type was driven home by Di Maggio, Kermani, Keys, Piskorski, Ramcharan, Seru, and Yao

(2017), who find that a reduction in interest rate has much stronger effects on consumption (mostly on durables) when mortgages are adjustable-rate.

Our paper fits into the HANK (Heterogeneous Agent New Keynesian) literature pioneered by Kaplan, Moll, and Violante (2018). Our model is somewhat orthogonal to theirs in that we have features that they miss (finite lifetime, large gross positions with housing and mortgages), but abstract from features that they stress as important such as fiscal policy. Perhaps the key difference to their model as well as the model of Luetticke (2018) is that real assets are "illiquid" in our model only at the aggregate level, in the form of capital adjustment costs, but costlessly tradeable at the individual level. This is clearly unrealistic for housing, but not so unrealistic for stocks. In the other papers, individual trades are subject to adjustment costs, which makes them illiquid at an individual level. For this reason, the redistribution channel that we highlight here is substantially different from the mechanisms stressed in those two papers. Interestingly, Luetticke (2018) also finds that the output response to a monetary shock is similar to the representative agent model, also the composition between consumption and investment changes substantially. As for fiscal policy and redistribution, a recent paper by Cloyne and Surico (2017) shows that tax changes, which can be interpreted as shocks to liquidity constraints, affect people differently, whether or not they have a mortgage.

Another paper that can be considered as complementary to ours is Gornemann, Kuester, and Nakajima (2016). While we focus on the role of the life cycle and housing choice, their model features infinitely lived households with heterogeneous skill levels facing unemployment risks. They study the output-inflation stabilization trade-off under a mixture of aggregate shocks. We focus on stabilizing demand shocks, where the relevant trade-off is not output versus inflation, but rather the stabilization of aggregates versus the stability of individual welfare.

Auclert (2015) decomposes the effects of monetary policy in what stems from the revaluation of nominal assets and the change in real assets and liabilities (which include consumption and wage income). A major result of Auclert, which is in line with our model is that longer maturities insure the agents better against unhedged interest rate exposure, which in the language of our model means that longer maturity structures or lower degree of asset nominality leads to lower variances in the consumption responses to a shock. Also for us the indirect effects brought about by heterogeneity are large, although the aggregate remains relatively unaffected. A central feature of Auclert's analysis are the UREs, the unhedged interest rate exposures, which he argues are the most important measure when talking about redistributive effects of monetary policy. UREs are defined as difference between maturing assets and liabilities. It will remain true in our model, that when households hold short term bonds where the entire value matures each period, redistributive effects tend to be larger.

A main difference of our paper to other general equilibrium models in this literature is the assumption of life cycle households.[2] Using US data, Wong (2018) finds that the bulk

[2]Existing life cycle NK models focus on other questions, such rational asset price bubbles (Gali 2014; Gali

of the consumption response to a monetary policy shock comes from young households. Our model is in line with these findings. She also shows that the consumption response is greater for households that refinance their mortgage after a decrease in interest rates. In our model, all households readjust their mortgage after a shock, since there are no adjustment costs to doing this.

A paper that focuses on the redistributive effects of inflation in a life cycle model is Doepke, Schneider, and Selezneva (2015). In this paper the authors identify the asset positions from the Survey of Consumer finances, and calculate how various inflation shocks (anticipated versus unanticipated) affect the real wealth of agents. They find that unexpected inflation generates large losses for older households who hold positions in long-term nominal assets, and large gains for middle-class homeowners with outstanding mortgages. They do not study the causes of inflation, but rather feed the distributional effects into a life cycle model, by directly altering the assets of each cohort, and then study the aggregate implications in the housing market. Our model generates similar redistribution effects as theirs, but our focus is on what this means for monetary policy.

Brunnermeier and Sannikov (2012) go a step further than the rest of the literature by emphasizing not only the redistribution of wealth, but also the redistribution of risk, with important consequences for financial stability. This is something we cannot do in our large model solved by linearization, which only gives certainty equivalence policies.

Our model is in a certain way similar to TANK (two-agent New Keynesian) models. Debortoli and Gali (2017) show that many of the insights about aggregate dynamics from the HANK model already emerges with only two types of agents, one being always constrained while the other is unconstrained. We add to this the life cycle and the housing component as well as a third type of household, but the linearized solution of our model shares with TANK the feature that households are either always constrained or always unconstrained. Another paper that employs a similar structure of a capitalist getting the firms profit and a worker getting the work remuneration is From a technical point of view, our model is similar to Heer and Scharrer (2018), who also uses a big scale OLG model and solve it by linearization around the steady state. The study the redistributive effects of fiscal policy and find that debt-financing can harm old and retired households, by reducing economic activity and thus the price of capital held by the elders. Finally, our model relates to the literature on housing over the life cycle, cf. for example Iacoviello and Pavan (2013). We use the results form this literature to inform our calibration in several ways.

The plan of the paper is as follows. Section 2 presents the model. In Section 3, we discuss the calibration and what this implies for the steady state of the model. After analzing the monetary transmission mechanism in Section 4, we turn in Section 5 to the main results of the paper, about the stabilizing role of monetary policy in an economy facing demand shocks. Section 6 concludes.

2017) or long-run real interest rates (Eggertsson and Mehrotra 2017).

2 The Model

2.1 Overview

Our model economy is inhabited by three types of agents: poor households, middle class households, and capitalists. While the first two are assumed to be households with a finite life cycle, capitalists are modeled as a representative infinitely lived dynasty.

The three types of agents differ in their labor productivity, the assets that they can invest in, and the housing options available to them. Poor households are excluded from asset markets and live in rental housing, the middle class chooses between owner-occupied and rental housing, and save or dis-save in bonds. Both types participate in a pay-as-you-go pension system. Capitalists own the houses they live in as well as the rental houses, trade bonds with the middle class and the central bank, and own all the firms. They hold most of the wealth in the economy.

The firm side is New Keynesian, where firms face monopolistic competition subject to Calvo pricing. The central bank conducts monetary policy according to a Taylor Rule. We introduce two types of shocks into the model. To study the monetary transmission mechanism, we consider a monetary policy shock, as is standard in the New Keynesian literature. To analyze the ability of monetary policy to stabilize the economy, we assume that the economy is hit by demand shocks.

Next we discuss firms and households in greater detail.

2.2 Firms

2.2.1 Final good producers

Production in the economy takes place in a final goods sector with monopolistic competition and pricing of the Calvo (1983) type. Each firm produces a differentiated good, using a Cobb-Douglas gross production function with capital and labor as inputs, subject to a fixed cost of production $\bar{\kappa}$. Net production is then

$$Y_t = F(K_{t-1}, L_t) = K_{t-1}^{\alpha} L_t^{1-\alpha} - \bar{\kappa}$$

The fixed cost will be chosen such that firms make zero profit in steady state.

Factor markets are assumed to be frictionless, therefore the optimal combination of production factors implies

$$\frac{r_t^K}{F_K(K_{t-1}, L_t)} = \frac{w_t}{F_L(K_{t-1}, L_t)} \equiv RMC_t \tag{1}$$

with RMC denoting real marginal costs. The pricing problem of the firm is standard. Under Calvo pricing, the first order condition for a price-setting firm is

$$\mathbb{E}_t \sum_{k=0}^{\infty} \theta^k Q_{t,t+k} Y_{t+k|t} \left(P_t^* - Y_{t+k|t} \frac{\varepsilon}{\varepsilon - 1} P_{t+k} RMC_{t+k} \right) = 0 \tag{2}$$

where P_t^* denotes the optimal price of a price-setting firm, θ is the probability of not changing the price, and ϵ is the demand elasticity. $Q_{t,t+k}$ is the nominal stochastic discount factor given in Equ. (24) below. As usual, linearization around the zero-inflation steady state leads to the following dynamic equation for inflation:

$$\pi_t = \hat{\beta}\mathbb{E}_t\pi_{t+1} + (1 - \hat{\beta}\theta)\frac{(1-\theta)\log RMC_t}{\theta \log RMC^*} \tag{3}$$

2.2.2 Investment and housing sector

We assume that new capital goods and new houses are produced by competitive firms under constant returns to scale subject to convex adjustment costs on the stock of these variables. Defining the investment ratio for physical capital as

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

we assume that capital evolves as

$$K_t = (1-\delta)K_{t-1} + \Phi(\iota_t^K, \phi_K)K_{t-1} \tag{4}$$

where

$$\Phi(\iota, \phi) = \iota - \frac{(\iota - \delta)^2}{\phi\delta}$$

Adjustment costs as well as marginal adjustment costs are zero in steady state, where the investment ratio is equal to the depreciation rate. This implies the standard Q-theory of investment, where the value of installed capital in equilibrium is given by

$$p_t^K = 1/\Phi_I(\iota_t^K, \phi_K) \tag{5}$$

The housing sector is analogous. Defining $\iota_t^H = \frac{I_t^H}{H_{t-1}}$, the law of motion is

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

and the price of housing is $p_t^H = 1/\Phi_I(\iota_t^H, \phi_H)$.

2.3 Households

Before describing each household type in detail, we discuss four important elements of the household problem, each of which applies to several household types: the different types of bonds, wage rigidity, demand shocks and demographics.

2.3.1 Bonds

Next to owner-occupied housing, middle class households have access to one financial asset, which we call a bond.A short position in the bond we will interpret as a mortgage, because borrowing is restricted to a constant fraction of the value of owned housing. Although in each variant of the model there is only one type of bond available, we model bonds in a more general way than usual, allowing for different maturities as well as for a distinction between nominal and real (inflation-protected) bonds. For tractability, we model maturity such that each period a constant fraction of the bond matures, as has been used already in the literature (e.g. Krause and Moyen (2013)).

In each case, denote by p_t^B the real price of the bond and by v_t^B the real face value of the bond, which means that both are expressed in terms of the consumption good. We normalize the nominal bond so as to have a face value of one monetary unit, so that v_t^B is the inverse of the nominal price of consumption. The real face value of a nominal bound is eroded each period by inflation, $v_t^B = v_{t-1}^B/\pi_t$. If each period the fraction μ of the bond matures, the gross return of a bond then has three components, all expressed in real terms: μv_t^B, the value of the principal that is paid back; $r^B v_t^B$, the coupon rate r^B paid on the face value; and $(1-\mu)p_t^B$, the market value of the part of the bond that has not matured. A real bond is defined such that the face value is inflation adjusted, that means $v_t^B = v_{t-1}^B$. Everything else is the same as in the nominal case.

All the cases are therefore nested in the formula for the real gross return of a bond in period t

$$R_t^B = (\mu + r^B)v_t^B + (1-\mu)p_t^B \tag{6}$$

with the updating formula for the real face value

$$\log(v_t^B) = \log(v_{t-1}^B) - \chi \log(\pi_t/\pi^*) \tag{7}$$

The parameter χ measures the "nominality" of the bound: $\chi = 1$ characterizes a nominal bond and $\chi = 0$ a real bond. Intermediate values of χ are possible, but we do not consider them here.

The first order conditions of the linearized solution imply that all financial assets have the same expected rate of return. This implies

$$1 + R_t = \mathbb{E}_t \left[\frac{(\mu + r^B)v_{t+1}^B + (1-\mu)p_{t+1}^B}{p_t^B} \pi_{t+1} \right] \tag{8}$$

where R_t denotes the short-term nominal interest rate that is set by the monetary authority (cf. Section 2.4.3). In the case $\mu = 1$ and $\chi = 1$, Equ. (8) reduces to the familiar formula $p_t^B = \frac{(1+r^B)v_t^B}{1+R_t}$. Notice that this case is equivalent to a mortgage with variable interest rate, if this interest rate is equal to R_t in each period, and assuming the same downpayment constraint, cf. Equ. 17 below. We are just modeling the mortgage as being refinanced every period. We approximate fixed-rate mortgages by $\mu = 0.025$, which means a 10 percent repayment rate per year, and a coupon rate equal to the steady state interest rate.

2.3.2 Wage rigidity

New Keynesian models where prices are rigid but wages are flexible have the well known problem that profits become counter-cyclical, which is at odds with the data. It is therefore common in the literature to introduce wage as well as price rigidity. We avoid the usual Calvo wage setting, because we have a large number of heterogeneous agents, and proceed with a simple short-cut. We replace the first order condition $w_t^h = \frac{u_{l,t}^h}{u_{c,t}^h}$ of any household h by

$$w_t^h = \left(w_{stst}^h\right)^{\rho_W} \left(\mu_W \frac{u_{l,t}^h}{u_{c,t}^h}\right)^{1-\rho_W} \tag{9}$$

where w_{stst}^h denotes the steady state wage for household h, and ρ_W measures the degree of wage rigidity. μ_W is the wage markup over the marginal disutility of labor, to make sure that workers gain from an increase in labor demand even when wages are rigid. We set this parameter to $\mu_W = 1/0.9$. The formula (9) has the desired effect of allowing labor to fluctuate strongly with small variations in the real wage, without implying a large income elasticity of labor supply.

2.3.3 Demand shocks

Under the label "demand shocks", many different shocks can be found in the literature, especially in medium-sized DSGE such as Smets and Wouters (2007). We model demand shocks such that they satisfy three criteria:

1. They generate the aggregate pattern usually attributed to demand shocks, in particular the procyclical behavior of consumption, investment and inflation.

2. In a representative agent version of the model, or in a model without redistribution effects, the monetary authority can perfectly stabilize both output and inflation, a property that we refer to as "divine coincidence" (Blanchard and Galí 2007).[3]

3. From a welfare perspective, it is desirable to stabilize these fluctuations.

We therefore model the demand shock as a wedge in the household Euler equations.[4] To satisfy criterion 2 above, two conditions must be met. First, the wedge affects the Euler

[3] Blanchard and Galí (2007) coined the term "divine coincidence" in a model with supply-side fluctuations, where monetary policy simultaneously stabilizes inflation and the welfare-relevant output gap. In our model with constant productivity, we take the deviations from steady state as the output gap, since the fluctuations of the flexible-price allocation have no optimality properties in our incomplete-markets OLG model.

[4] This is very similar to the shock ϵ^b in (Smets and Wouters 2007, page 589), which "represents a wedge between the interest rate controlled by the central bank and the return on assets held by the households."

equation relating to bonds, but not the equations of housing or capital investment. This is distinct from a shock to the discount factor which affects all Euler equations. The latter cannot be completely offset by a change in the interest rate, because the difference between the return on bonds and on capital would trigger a change in investment. Second, the bond through which monetary policy is conducted, is not traded in equilibrium, as is the case in a representative agent model. This avoids wealth effects coming from the change in the bond return. To satisfy criterion 3, we interpret the wedge in the Euler equations as a distortion, not as a true change in preferences, in which case it would not be clear what monetary policy should do. Concretely, one can think of this distortion as induced by a tax that is immediately rebated lump sum to the cohort that pays the tax. The monetary authority should undo this distortion by interest rate policy if it can do so.

This is a very special and admittedly stylized way of modeling a demand shock, but it serves to isolate the redistribution channel of monetary policy, and the mechanisms that we describe in Section 5 would be active under other forms of demand shocks as well. In the heterogeneous agent model, the interest rate changes cause redistributions between households that hold a long position and those who hold a short position in bonds, thereby affecting aggregate demand. If business cycles are driven by the demand shock only, the deviations from perfect stabilization can be attributed to the redistribution channel, and not, for example, to wage rigidity, which prevents perfect stabilization in Blanchard and Galí (2007).

We assume the demand shock follows an AR(1) process:

$$D_t = \rho_D D_{t-1} + \epsilon_t^D$$

It will affect the Euler equations that refer to bonds, cf. Equs. (19) and (23) below.

2.3.4 Demographics of worker households

Workers are assumed to live for 60 years, which we interpret as adult live from age 20 to age 80. Since the model period is a quarter, the model age ranges from $s = 1$ to $s = I = 240$. Households work for the first 40 years of their live, and retire after age $s = I_R = 160$.

The lifetime profile of individual labor productivity of poor households is denoted by ζ_s for $s = 1, \ldots, I_R$. For middle class households, this profile is shifted up by a constant factor $\bar{\zeta}$ such that their individual productivity is given by $\bar{\zeta}\zeta_s$.

2.3.5 Poor households

We identify "poor" households as the lowest two deciles of the net wealth distribution. According to the data (SCF 2013), the median poor household has negative net worth over all age bins (cf. Table 5 in Appendix A). It does not live in owner-occupied housing, except for one age class (Table 7), and net financial assets are almost always negative (Table 6). We therefore model this class of agents as hand-to-mouth consumers, who live in rented housing and have no access to asset markets. Their income is given by

$$\tilde{y}_{s,t} = \begin{cases} w_t \tilde{l}_{s,t} \zeta_s & \text{for } s = 1, \dots, I_R \\ \psi_t & \text{for } s = I_R + 1 \dots, I \end{cases} \tag{10}$$

After retirement, they receive a lump sum pension benefit ψ_t. Notice that variables related to poor households are written with a tilde, such as $\tilde{x}$, while variables related to capitalists are written with a hat, such as $\cap x$,

The poor households' optimization problem is therefore reduced to a sequence of static labor-leisure-housing choices. With the utility function

$$u(c, l, h^R) = \log(c_t) + \eta \log(1 - l_t) + \eta_H \log(h_t^R) \tag{11}$$

subject to the budget constraint

$$r_t^H \tilde{h}_{s,t}^R + \tilde{c}_{s,t} = \tilde{y}_{s,t} \tag{12}$$

this leads to the following first order condition for consumption versus housing

$$\frac{\tilde{h}_{s,t}}{\tilde{c}_{s,t}} = \frac{\eta_H}{r_{s,t}^H} \tag{13}$$

Applying the rigid wage equation (9), we get the following first order condition for labor supply of working age households:

$$\eta \frac{c_{s,t}}{1 - l_{s,t}} = \bar{w} \left(\frac{w_t}{\bar{w}} \right)^{1/(1-\rho_W)} \zeta_s \tag{14}$$

In (14), the marginal rate of substitution varies one for one with labor productivity ζ_s, but more elastically w.r.t. cyclical wage fluctuations w_t in case $\rho_W > 0$. With flexible wages ($\rho_W = 0$), Equs. (12)–(14) imply constant labor supply, which is a consequence of log utility, were income and substitution effect exactly cancel. With wage rigidity, labor supply is still constant over the life cycle, for any given aggregate wage w_t, but responds positively to cyclical fluctuations in the wage.

2.3.6 Middle Class Households

The representative household of each middle class cohort owns a part and rents the remaining part of its housing. It can save in bonds, and borrow up to a certain limit against owned housing. A household born at time $t - 1$ solves

$$\max \mathbb{E}_t \sum_{s=1}^{I} \beta^s u(c_{s,t+s}, l_{s,t+s}, h_{s,t+s}^O, h_{s,t+s}^R) + \beta^I MUB \cdot R_{t+I}^B b_{I,t+I} \tag{15}$$

subject to the per period the budget constraint

$$p_t^B b_{s,t} + p_t^H \left(h_{s,t}^O - (1 - \delta_H) h_{s-1,t-1}^O \right) + c_{s,t} + r_t^H h_{s,t}^R = \\ (1 - \tau) w_t \zeta_s l_{s,t} + \mathcal{I}_s^R \psi_t + (1 - \mathcal{I}_s^R) \omega_{s,t} + R_t^B b_{s-1,t-1} \tag{16}$$

and the borrowing constraint

$$v_t^B b_{s,t} \geq -\nu \mathbb{E}_t p_{t+1}^H h_{s,t}^O \tag{17}$$

In (15), households receive a constant marginal utility from bequests MUB, which leads to a bequest $\Omega_t = R_{t+I}^B b_{I,t+I}$. This bequest Ω_t is then distributed evenly among working age middle class cohorts, such that their bequest is $\omega_{s,t} = \Omega_t / I_R$. The left hand side of the budget constraint (16) represents the spending of cohort s in period t. It buys bonds at price p_t^B, purchases new owned housing $h_{s,t}^O$, rents housing $h_{s,t}^R$ and consumes $c_{s,t}$. The right hand side gives the available resources of household at the beginning of period t, which consists of labor income, pension income (if the person is retired), bequests and the return on last period's bond holdings $b_{s,t-1}$ as described in Section 2.3.1. Here w_t is the hourly wage and ζ_s is the age-dependent idiosyncratic productivity of the household. The indicator function $\mathcal{I}_s^R$ is one if the household is retired.

The down payment constraint (17) relates the real face value of the bond to the expected real value of owned housing. It states that a household can only borrow up to the fraction ν of the value of their house. This parameter is commonly referred to as the Loan to Value Ratio (LTV). We set $\nu = 0.8$, which means that 20% of the mortgage of a house have to be financed by savings, prior to the purchase. Notice that we value $b_{s,t}$ on the lhs of (17) by its face value v_B rather than the market price p_B. This difference is important in the case of long-run nominal debt. Since the coupon payment of the bond is fixed to the steady state interest rate, variations in expected future interest rates do not affect the ability of households to repay debt of a given face value, and should therefore not affect the downpayment constraint, although the market price of the bond is decreasing in future interest rates. In contrast, a decrease in inflation increases the real value of future coupon payments and diminishes the ability of households to repay debt. The constraint should therefore be tightened, which happens through the increase in the real face value of debt. We therefore think that our formulation is a more appropriate approximation to the down payment constraints in real world contracts.[5] An important restriction of our linearized solution is that we cannot handle occasionally binding constraints. If the down payment constraint is binding for a certain age group in steady state, it is always binding for this age group, independent of the business cycle.

For the utility function of the middle class household we choose

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

The parameter σ measures the elasticity of substitution between owned and rented housing. The relative efficiency of owned housing ξ_s is supposed to capture the pros and cons of

[5] The downpayment constraint of real world mortgages is different from the formula 17 below, in this sense our approximation is rather stylized. See Garriga, Kydland, and Šustek (2017) for a more detailed representation of mortgages.

home ownership versus rental. The pros are reduced moral hazard, and the ability to make alterations and adjustments. The cons are reduced geographical flexibility, and capital risk. To match the observed pattern of the ownership rate, we postulate a linear relationship in age:

$$\xi_s = \bar{\xi} + \hat{\xi} \cdot s \tag{18}$$

The first order condition for labor supply is again given by (9). The first order conditions for asset choice are given by the following three expressions, the derivation of which can be found in Appendix B

$$u_{h^R_{i,t}} = r^H_t u_{ci,t} \tag{19}$$

$$u_{c_{i,t}} p^B_t = \beta(1 + D_t)\mathbb{E}_t \left[R^B_{t+1} u_{c_{i,t+1}}\right] \tag{20}$$

$$u_{c_{i,t}}[p^H_t - \frac{p^B_t}{v^B_t}\nu \mathbb{E} p^H_{t+1}] = u_{h^O_{i,t}} - \beta \mathbb{E}_t \left[u_{c_{i,t+1}} \left(\frac{R^B_{t+1}}{v^B_t}\nu \mathbb{E} p^H_{t+1} - (1 - \delta_H) p^H_{t+1}\right)\right] \tag{21}$$

As was described in Section 5, households face an aggregate demand shock D, which acts as a wedge between the returns of bonds and physical assets.

2.3.7 Capitalists

Capitalists own most of the real assets in the economy. They own the firms and thus are the beneficiaries of any profits accruing to them. Additional to their own housing, they own the houses which are rented out at rental rate r^H_t.

We assume the utility function of the capitalists takes the following form.

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

Being infinitely lived, they solve

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

subject to the budget constraint

$$Y_t - I^K_t - w_t L^W_t + r^H_t H^R_t + p^B_t B_t + p^H_t (H_t - (1 - \delta_H) H_{t-1}) - I^H_t + w_t \hat{l}_t + R^B_t \hat{B}_{t-1} + \frac{R_{t-1}}{\pi_t} B^{CB}_{t-1}$$
$$= \hat{c}_t + p^H_t (\hat{h}^O_t + H^R_t - (1 - \delta_H)(\hat{h}^O_{t-1} + H^R_{t-1})) + p^B_t \hat{B}_t + B^{CB}_t \tag{22}$$

The income of capitalists (lhs of 22) has the following components. They receive the profits of the production sector, which equals output minus wage payments minus investment into physical capital. They also earn money from renting out part of the housing stock to the other types of households, and they earn the profits of the housing and capital construction sectors. They receive labor income, and they receive the returns of their bond holdings, which in equilibrium are negative since they hold a short position. Notice that the bond holdings of the capitalists are given by $\hat{B}_t = -B_t$, since they hold the offsetting position to the bonds of workers. Additionally, they can invest in a one-period nominal bond issued by the Central Bank B_t^{CB} at the interest rate R_t. This bond, which in equilibrium is in zero net supply, is the channel via which the central bank conducts monetary policy, as capitalists need to be indifferent between holding these type of bonds and any other asset. Notice that capitalists do neither contribute nor benefit from the social security systems. They face no borrowing constraints. On the spending side, the distribute these resources between their consumption, purchases on their own housing and the housing that they rent out, and the two types of bonds.

The first order condition for labor supply is again given by (9). The first order conditions for asset choice are

$$\begin{aligned} \hat{U}_{\hat{h}_t^O} &= p_t^H \hat{U}_{\hat{c}_t} - \hat{\beta}(1-\delta_H)\mathbb{E}_t(p_{t+1}^H \hat{U}_{\hat{c}_{t+1}}) \\ \hat{U}_{\hat{c}_t}[p_t^H - r_t^H] &= \hat{\beta}(1-\delta_H)\mathbb{E}_t(p_{t+1}^H \hat{U}_{\hat{c}_{t+1}}) \\ \hat{U}_{\hat{c}_t} p_t^B &= \hat{\beta}(1+D_t)\mathbb{E}_t(R_{t+1}^B \hat{U}_{\hat{c}_{t+1}}) \\ \hat{U}_{\hat{c}_t} &= \hat{\beta}(1+D_t)\mathbb{E}_t\left(\frac{R_t}{\pi_{t+1}}\hat{U}_{\hat{c}_{t+1}}\right) \end{aligned} \tag{23}$$

Capitalists are affected by the demand shock D_t just like middle class households, which operates on the first order condition with respect to bonds. Since capitalists own the firms, the relevant nominal stochastic discount factor is

$$Q_{t,t+k} = \hat{\beta}^k \frac{\lambda_{t+k}}{\lambda_t} \frac{P_t}{P_{t+k}} \frac{\hat{U}_{\hat{c}_{t+k}}}{\hat{U}_{\hat{c}_t}} \tag{24}$$

2.4 Closing the model

2.4.1 Aggregate Variables

Define per capita (better: per cohort) labor input of poor and middle class households as

$$\tilde{L}_t = \sum_{s=1}^{I} \zeta_s \tilde{l}_{s,t}/I \tag{25}$$

$$L_t = \sum_{s=1}^{I} \bar{\zeta}\zeta_s l_{s,t}/I \tag{26}$$

$$\tag{27}$$

respectively. Total labor input is then

$$L_t = 0.2\tilde{L}_t + 0.7L_t + 0.1\hat{L}_t \tag{28}$$

Notice that the labor efficiency of capitalists is normalized to 1. Similarly for consumption

$$\tilde{C}_t = \sum_{s=1}^{I} \tilde{c}_{s,t}/I \tag{29}$$

$$C_t = \sum_{s=1}^{I} c_{s,t}/I \tag{30}$$

$$C_t = 0.2\tilde{C}_t + 0.7C_t + 0.1\hat{C}_t \tag{31}$$

Bonds held by workers are given by

$$B_t = 0.7\sum_{s=1}^{I} b_{s,t}/I$$

The bond position of capitalists is then $-B_t$. Rented and owner-occupied housing of workers is defined analogously to consumption, and then total housing given by

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

The aggregate resource constraint is

$$Y_t = C_t + \hat{C}_t + I_t^K + I_t^H \tag{32}$$

Finally, the total housing stock H is given by adding up total rental housing H^R, aggregate housing owned by the middle class H^H and the housing owned by the capitalists $\hat{H}$. Real GDP is defined as production Y_t plus the imputed value of housing rents, evaluated at steady state price r^{H*}:

$$GDP_t = Y_t + r_t^H H_t$$

2.4.2 Government

The government in this model has only a passive role. It takes the form of a pay-as-you-go pension system, which taxes the labor earnings of the workforce and rebates it lump sum and equally to all retired agents, which then receive an amount ψ_t in period t. We assume that benefits are indexed to the real wage:

$$\psi_t = \tau^* w_t \frac{0.2\tilde{L}^* + 0.7L^*}{0.9} \frac{I}{I - I_R}$$

Over the business cycle, the benefit level fluctuates with the wage, but not with the number of hours, therefore formula (2.4.2) contains L^*, not L_t. Then the payroll tax τ_t adjusts so as to balance the budget of the pension system:

$$\tau_t = \psi_t / \left[w_t \frac{0.2\tilde{L}_t + 0.7L_t}{0.9} \frac{I}{I - I_R} \right]$$

The adjustment factor on the right hand side of these equations accounts for the fact that labor input is measured per capita, but benefits are only received by the retirees.

2.4.3 The Monetary Authority

Monetary Policy is implemented by controlling the interest rate on a one period nominal bond, which is offered to capitalists. This bond is not traded in equilibrium, but linked to the other assets via a no-arbitrage condition. Under the short-term nominal bond regime, this bond is identical to the bond traded with middle class households, but in other asset regimes it is not.

In the benchmark model, the central bank follows the Taylor rule

$$\log(R_t/R^*) = \rho_R \log(R_{t-1}/R^*) + \\ (1-\rho_R)\left(\gamma_\pi \log(\pi_t/\pi^*) + \gamma_y \log(Y_t/Y^*) + \gamma_H \log(p^H_{t+1}/p^{H^*})\right) + \epsilon^M_t \quad (33)$$

In general, we allow the interest rate react to inflation, to the output gap, and to deviations of the house price from its steady state. The shock ϵ^M_t is assumed to be i.i.d., but gets propagated by interest smoothing with parameter ρ_R.

Under strict inflation targeting, the nominal interest is chosen so as to get $\pi_t = 0$ always.

3 Calibration and Deterministic Steady State

The time period of the model is one quarter, and the economic lifetime of a worker agent is $I = 240$ quarters. In the data, we identify the three types of households according to their position in the net worth distribution of the survey of consumer finances 2013 (SCF). Poor households are the poorest 20 percent, middle class households are the next 70 percent, and capitalists are identified as the top 10 percent of households in terms of net worth.

Table 1 lists the parameter values for the benchmark calibration. The Cobb-Douglas parameter $\alpha = 0.36$ and the depreciation rates (3 percent annually for housing, 10 percent for other fixed investment) are standard. The adjustment cost parameters for capital and housing, $\phi_K = \phi_H = 8.5$, were chosen such that total investment responds twice as much as output to a monetary policy shock on impact. We have chosen the same adjustment cost parameter for capital and for housing. This understates the historical volatility of housing investment, which varies more than business investment, but also understates the volatility of house prices. Making housing investment more volatile would make house prices even more stable.

We take the parameters for age dependent productivity ζ from Hansen (1993), who finds that labor efficiency peaks around the age of 54. The labor productivity of poor households of the cohorts $s = 1, \ldots, I_R$ follows

$$\zeta_s = 1 + 0.061329\frac{i-0.5}{4} - 0.001011\left(\frac{i-0.5}{4}\right)^2 \quad (34)$$

Middle class households have the same profile ζ, but multiplied by the constant 2.093, so as to match the differences in average earnings between the two groups.

The discount factor of the capitalists gives a real interest rate of 4 percent annually. The discount factor of middle class households was set so as to match their average bond holdings, measured as a fraction of their average labor income. The weight of leisure in workers' utility function, η, was chosen such that hours worked, averaged over all workers and weighted by labor productivity, equals one third of the labor endowment. This is a common number in the RBC literature. For capitalists, the labor endowment and weight of leisure was chosen such that they work one third of their time in steady state and their effective labor supply is 10 percent of the total, in line with their share of the population. We estimate the size of bequests by the net worth of middle class households over the age of 80 in our data, and set the marginal utility of bequests to match this target. We assume that bequests are distributed equally across all non-retired cohorts, i.e. $\omega_t = \frac{\Omega_t}{160}$. The autocorrelation of the demand shock was set to 0.95. The standard deviation of the shock was chosen to match the standard deviation of detrended log GDP for US data 1984–2017, which is 1.21 percent.

The parameters for the relative efficiency of owned housing, $\bar{\xi}$ and $\hat{\xi}$, and the weight of housing in utility, η_H, were chosen jointly to match the average home value of the middle class, as well as two statistics of the ownership rate: the average over the life cycle, which is 73.7, and the value for the 20-25 years old, which 9 percent. The result is plausible: for the youngest cohort, renting is more efficient, but home ownership becomes more efficient with age. The housing weight for capitalists is set to $\eta_H/2$ which reflects the lower share of housing in their total wealth. The elasticity of substitution between rental and owned housing was set, somewhat arbitrarily to 3.0, assuming they are close substitutes.

We set the steady state payroll tax to 18 percent. This is higher than the current US payroll tax (around 12 percent) so as to include other sources of pension income. It results in a drop of log consumption of -0.28 at retirement for poor households. This is within the range of estimates in the literature.[6]

The parameters related to price stickiness and monetary policy are all standard in the literature. We are choosing a very high degree of wage rigidity, $\rho_W = 0.9$, to match the finding in Christiano and Evans (2005) that the maximum real wage response is about one fifth of the output response. Wage rigidity is a key determinant for the variability of inflation. Despite the strong degree of rigidity, the model still tends to exaggerate inflation in our main experiment, where fluctuations are generated by demand shocks. There the standard deviation of (annualized) inflation is about the same as that of output, while it is 64 percent in the US data since 1984, as measured by the GDP deflator.

[6] Aguiar and Hurst (2005) estimate a retirement dummy for log food consumption of -0.17. Bernheim, Skinner, and Weinberg (2001) find a change in log consumption of -0.24 after the first and -0.566 after the second year for the lowest wealth quartile. Aguiar and Hurst (2005) and Aguiar and Hurst (2013) point out that this is largely compensated by home production, but for our purpose it is market consumption that matters.

Parameter	Target	Symbol	Value
Technology			
production elasticity capital	output share of capital	α	0.360
depreciation rate for capital	$\frac{I}{K}$	δ	0.025
depreciation rate for housing	housing investment	δ_H	0.007
adjustment cost parameter capital	IR investment	ϕ_K	8.500
adjustment cost parameter housing	IR housing	ϕ_H	8.500
labor efficiency middle class	wage differential		2.093
Utility			
discount factor of capitalists	4 % ann. interest	$\hat{\beta}$	0.990
discount factor of workers	workers' bond holdings	β	0.984
weight of leisure middle class	labor supply	η	2.638
weight of leisure capitalists	labor supply	η	0.761
labor endowment capitalists	labor supply	$\bar{L}^C$	0.231
marg.util. bequest	size of bequests	MUB	1.282
autocorrelation demand shock		ρ_D	0.950
stand.dev. demand shock, percent	output volatility		0.175
Utility related to housing			
weight of housing in utility	housing wealth	$\bar{\eta}_H$	0.311
intercept efficiency owner occupied	path ownership rate	$\bar{\xi}$	0.217
slope efficiency owner occupied	path ownership rate	$\hat{\xi}$	0.017
elasticity of subst. rental vs. owner		σ	3.000
Taxes			
payroll tax	consumption old age	τ	0.180
Inflation and monetary policy			
steady state inflation		π^*	1.000
demand elasticity		ε	7.000
prob. keeping the price		θ	0.750
Taylor rule parameter inflation		γ_π	1.500
Taylor rule parameter output gap		γ_y	0.125
influence of past interest rate		ρ_R	0.700
wage rigidity	variability inflation	ρ_W	0.900

Table 1: Parameter values benchmark calibration

3.1 Steady State Results

Our capital and investment rates are comparable to the literature. The ratio of capital to annual GDP is around 2.2 in our model and the housing stock to GDP ratio is 2.1. The corresponding values are 2.2 and 1.4 in Iacoviello and Pavan (2013) or 1.75 and 1.3 in Garriga, Kydland, and Sustek (2013). The ratio of capital investment to output is 0.22 (0.2 in Iacoviello and Pavan (2013), 0.16 in Garriga, Kydland, and Sustek (2013)), and for housing investment the ratio is 0.06 (0.07 in Iacoviello and Pavan (2013), 0.05 in Garriga, Kydland, and Sustek (2013)). Notice that the housing stock in our calibration is somewhat higher than what is found in other studies, this is the consequence of the housing wealth in our SCF data. With a depreciation rate of 3 percent annually, this nevertheless translates into a realistic housing investment rate.

Figure 1 depicts some life cycle paths in the deterministic steady state for worker households. We have used the productivity values from Hansen (1993) for both poor and middle class households, and these numbers still fit the data relatively well. Our linear trend for housing efficiency in (34) gives an almost perfect fit for the home ownership rate. We have a somewhat larger discrepancy with the mean data in terms of financial wealth of the middle class. Our model somewhat overstates the amplitude of the life cycle path of assets, compared to the median holdings of each cohort. We have not tried to dampen this pattern. Overstating the inequality over the life cycle partially compensates for the lack of intra-cohort inequality. Taking a cross-section over the whole economy, our model still underestimates inequality in earnings, net worth and financial wealth, cf. Table 2. Notice that the Gini coefficient can be larger than 1 if some households hold negative wealth, which many households do with financial assets. The slow dissaving of retired people is considered a puzzle in the microeconomics literature and varies between countries, see e.g. Nakajima and Telyukova (2016). In our model, it is generated by a strong bequest motive.

	Financial assets	Net worth	Earnings
Data	1.41	0.85	0.65
Model	1.10	0.73	0.44

Table 2: Gini coefficients

The middle right panel summarizes the information about assets in the model. Middle class households start out at their borrowing constraint and accumulate bigger housing and bigger debts over time. Before the age of 50, they leave the borrowing constraint and start to accumulate savings for retirement. Their assets peak at the time of retirement, after which they run down the assets until the bequest motive is met at the period of 80.

Consumption (lower left panel) exhibits the hump shape commonly found in life cycle models (see e.g. Fernández-Villaverde and Krueger (2011)), and for poor households also the drop at the time of retirement. In contrast, middle class households smooth out their

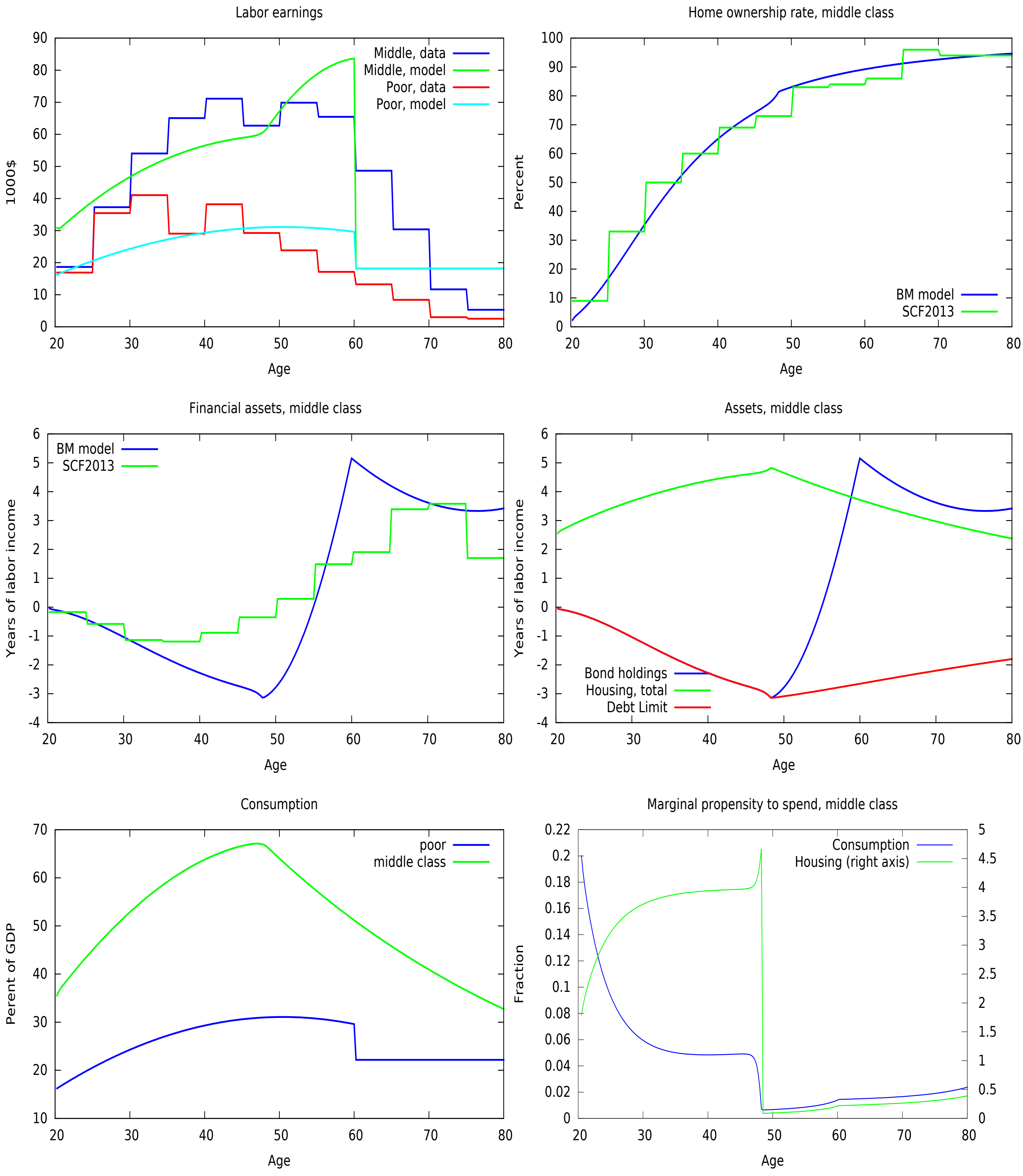

Figure 1: Life cycle paths in Steady State

consumption over the whole unconstrained part of their life cycle. They tend to consume early, since they are less patient then capitalits, but face the borrowing constraint in the first part of their life.

The blue line in the lower right panel shows the marginal propensity to consume (consumption goods and rental housing). Since the MPC is falling while both earnings and net worth are rising until retirement, this picture qualitatively fits the empirical findings in Auclert (2017, Figure 2). The green line shows the marginal propensity to buy new homes. This number is large: since households are constrained, a dollar saved allows to buy another four dollars of housing. The expansion in demand stemming from these households is therefore much greater than what the MPC suggests. This mechanism is potentially very important, but it is not present in current HANK models (Kaplan, Moll, and Violante 2018; Bayer, Luetticke, Pham-Dao, and Tjaden 2019) where the borrowing limit is independent of the holdings of illiqid assets. Empirically, it should show up not in the behavior of households who already have a home and a mortgage, but in the behavior of new buyers, who either buy a bigger home or buy earlier.

4 The Monetary Transmission Mechanism

Figure 2 contains impulse response functions to an expansionary monetary policy shock of 0.25 percentage points (1 percentage point at annualized rate) which lasts for one quarter. Remember that monetary policy shocks are uncorrelated, but under the baseline policy, the central bank has an interest smoothing motive, $\rho_R = 0.7$. Responses are shown for inflation and the nominal interest rate, as well as for the four big macroeconomic aggregates (output, consumption, investment and housing investment), and wages and house prices. In each case, there are four lines for the four different asset regimes, and for comparison, a fifth line for the representative agent (RA) version of the economy.[7] Obviously, the difference in aggregate responses across asset regimes are rather small, at least compared to the width of the confidence intervals in empirical estimates of the MP transition mechanism. Even the differences to the RA model are only moderate. The graph shows the typical picture of an expansionary monetary policy shock in a New Keynesian model: The nominal, and even more so the expected real short-term interest rates go down. Because of this expansionary effect, inflation goes up, and due to the immediate endogenous response of the central bank, the interest rate decreases by less than the shock. All the four macroeconomic aggregates jump up on impact due to the interest rate decrease. The increase in housing investment also leads to a increase in house prices, and the increase in economic activity raises the real wage. The effect on real wages is small because of wage rigidity. This dampens the reaction of real

[7] The RA economy consists of capitalists only. It uses the same calibration as the benchmark model, and was obtained by setting the weight of the worker household to zero. Notice that capitalists have a lower utility of housing.

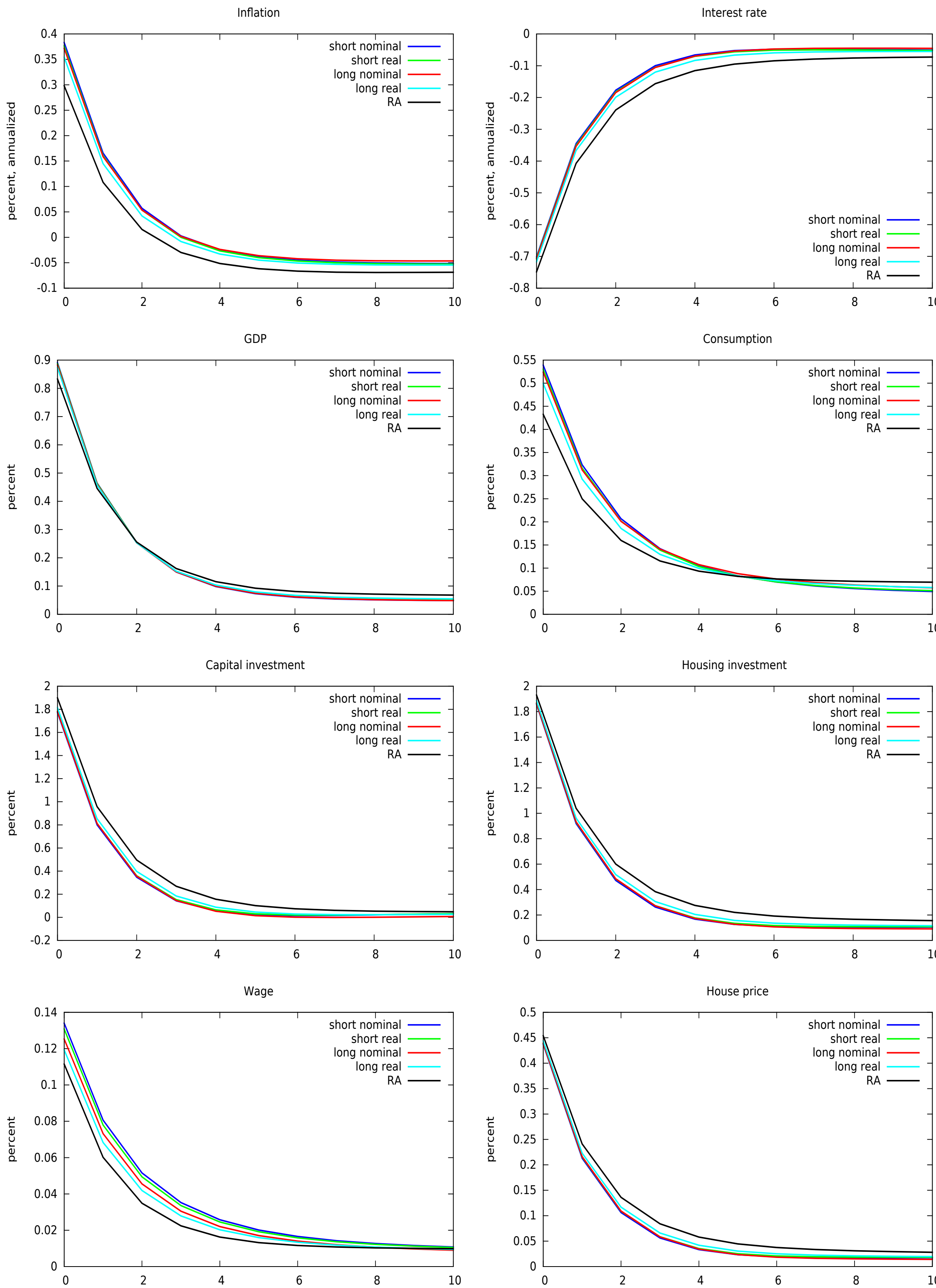

Figure 2: Impulse responses to monetary shock

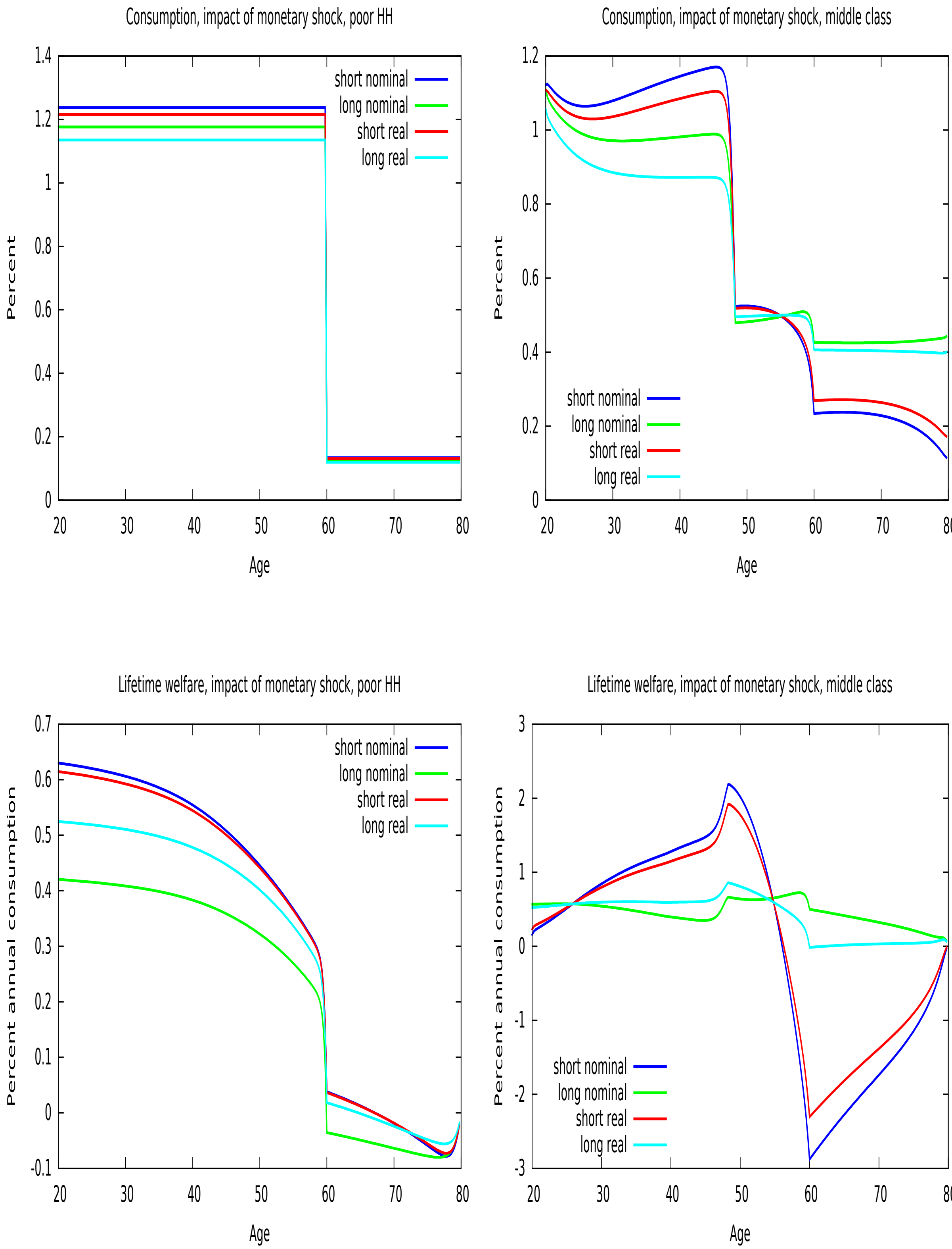

Figure 3: Impact effect of MP shock

marginal cost and inflation, in line with the empirical evidence for example in Christiano and Evans (2005).

Knowing the effect of monetary policy on prices, we can now analyze how it affects the different cohorts. The upper panels of Figure 3 display the effect of a monetary policy shock on the consumption of poor and middle class households, under different assumptions about the asset structure. With poor households, the consumption effect is the same for all working age households, and the same for all retired households. This is the consequence of hand-to-mouth behavior in combination with log utility. A more interesting picture arises for the middle class. Most young cohorts are constrained and can now increase consumption significantly. Middle age households are unconstrained and smooth consumption. Their response comes from an intertemporal substitution effect and a wealth effect that results both from their asset position (discussed below) and their labor earnings (or retirement income). Since the effect of the asset position is minimized with long-term real bonds, the corresponding line in the diagram approximately measures the effect from economic activity. The age pattern in the consumption response is in line with empirical findings in Wong (2018), where the response is strongest for young households and weakest for old households. Table 3 of that paper finds that the young contribute 72 percent of the total consumption response. Our model does not reproduce this rather extreme result, but it goes a long way in that direction. Although the consumption of the households of age 20 to 40 accounts for only 33 percent in steady state, it accounts for 50 percent of the reaction to a monetary policy shock.

The wealth effect of a monetary policy shock can be seen in the bottom panels of Figure 3.[8] 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. The effect on poor households (bottom left panel) is relatively small, both before and after retirement. These households own no assets, their welfare is only affected through the change in wages. The welfare effect on middle class households (bottom right panel) is big: an expansionary monetary policy shock of 0.25 percentage points which lasts for one quarter causes utility gains and losses of up to 3 percent of annual consumption. Gains and losses vary greatly across cohorts, being mostly driven by their asset positions.

To understand the welfare changes, notice first that the temporary increase in house prices does not seriously affect home owners. The house prices have only increased because the decrease in the expected real return on bonds requires an decrease in the expected return on housing in equilibrium. The current increase in market price, which appears as a capital gain in the books, is basically offset by the decrease in future returns on housing. One can also see it from a different angle: a temporary rise in the house price does not much affect households who hold on to the house for a long time. The wealth effect shold therefore be dominated by the nominal asset position. This is confirmed by the blue line in that panel, which shows the results for short-term nominal bonds. this line is the mirror image of the

[8] Section 5.4 explains how we compute welfare.

line of steady state bond holdings in Figure 1. Young households with a mortgage gain from the reduction in the real interest rate, while the biggest losers are households shortly before retirement, which hold a substantial amount of bonds. Of course, everybody gains from the expansion of economic activity following a monetary policy shock, but this effect is much smaller than the redistribution effects and rather evenly spread.

The asset regime matters for the distributional impact. When bonds are short-term nominal, households with a long position in bonds suffer both from the persistent decrease in the nominal interest rate and from the increase in inflation. They are insulated from the impact effect of inflation when bonds are short-term and real (inflation-protected), The welfare effects are minimized when bonds are long-term and inflation-protected, so that both bonds and houses are long-term and real, and variations in neither interest rates nor inflation affect households much. When bonds are long-term and nominal, households suffer little from the reduction in the nominal rate, because they have locked in the interest rate on their assets for ten years on average. They are still affected by inflation, but since the inflation response is small in our model due to wage rigidity, there is little difference between long-term nominal and real bonds.

The above analysis has revealed enormous differences in the consumption response and in the welfare consequences of monetary shocks, both between cohorts and between different asset regimes. It is remarkable that this makes so little difference for the aggregate variables. Nevertheless, we will see in the next section that heterogeneity and redistribution can have important consequences even for the aggregate.

5 Economic Stabilization in the Face of Demand Shocks

5.1 Impulse Responses

We now analyze the implications of household heterogeneity for what is arguably the main task of monetary policy, namely stabilizing the economy in the face of demand shocks. Figures 4 presents impulse responses to an expansionary demand shock. The graphs show that our shock has the properties that we usually expect from a "demand shock": output, inflation, consumption and investment all go up on impact. Only housing investment goes down, as a consequence of the monetary policy reaction, which counteracts the demand shock by an increase in the nominal interest rate. The key difference between monetary and demand shocks is the behavior of interest rates, going in the same direction as inflation in the case of a demand shock, while going in the opposition direction in the case of a monetary shock. We now notice somewhat stronger differences between the different asset regimes, and a stronger difference to the representative agent benchmark, in particular with respect to housing. To understand these responses, the upper panels of Figure 5 report consumption and welfare effects for middle class households. The welfare consequences of a demand shock are quite different from those

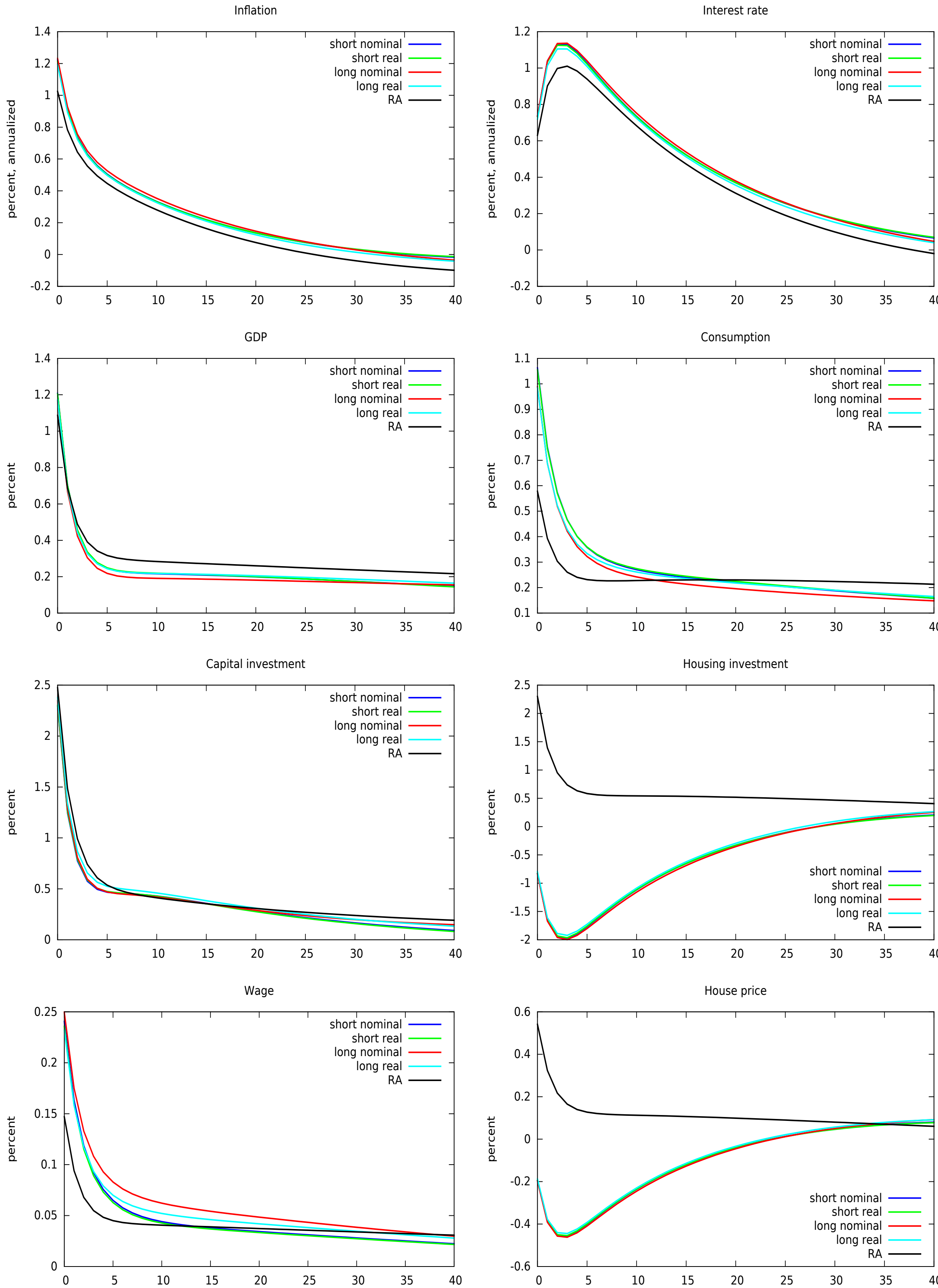

Figure 4: Impulse responses to demand shock

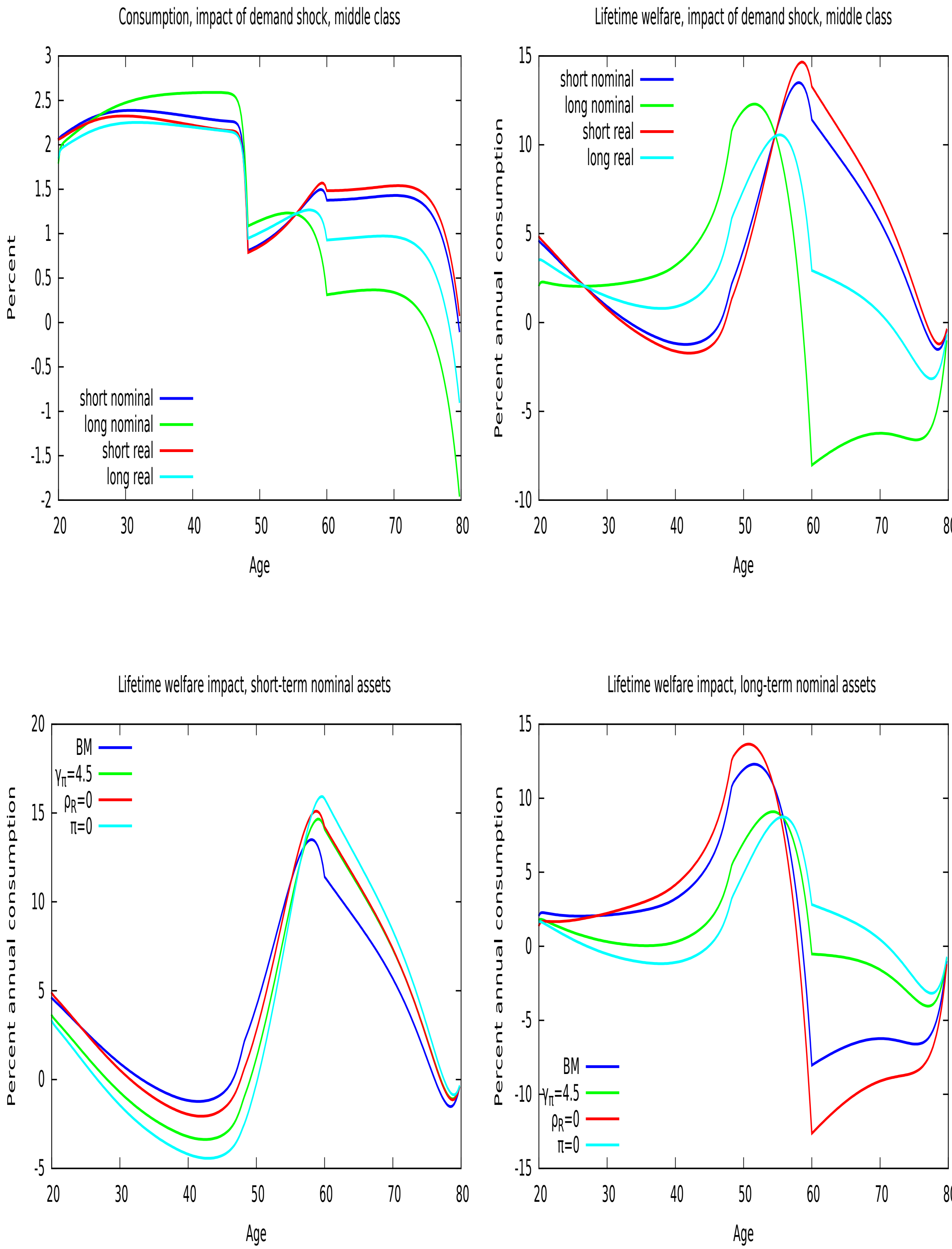

Figure 5: Impact effect of demand shock

of a monetary policy shock, mainly because of a stronger inflation response. Households are best insured against a shock if they invest in long-term real assets, but large welfare variations appear with long-run nominal assets. The response to a demand shock makes both inflation and the real rate increase. The increase in inflation hurts long-run bond holders. The increase in the real rate benefits short-term bond holders.

The lower panels contain an important message: aggressive monetary policy ($\gamma_\pi = 4.5$) reduces the variability of welfare under long-term, but not under short-term nominal assets. The intuition is clear. 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. Keep in mind that what matters here 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. Important 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.

5.2 Policy Trade-offs

A central topic in the theory of monetary policy is the trade-off between output stabilization and inflation stabilization. In the textbook model (cf. for example Clarida, Galí, and Gertler (1999)) this trade-off arises in the face of cost-push shocks, but not in the case of demand shocks. In the latter case, the monetary authority can perfectly stabilize both output and inflation. We focus on demand shocks, to see whether this favorable situation continues to hold. 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, which is characterized by ($\gamma_\pi = 1.5$, $\rho_R = 0.7$, $\gamma_y = 0.125$ and $\gamma_H = 0$), 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. 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). All variables except output are expressed as annual rates. The results shown in the upper part of the table come from a simulation of the model for 100,000 periods, detrended by a Hodrick-Prescott filter with smoothing weight 1600. The shock size was chosen such that the standard deviation of output in the benchmark case (short-term bonds, benchmark policy) is 1.21 percent, the number for US GDP in the period 1984-2017.

The upper part of table Table 3 confirms standard results. With demand shocks, there seems to be very little trade-off. A more aggressive policy, both in the form of a higher coefficient on inflation in the Taylor rule ($\gamma_\pi = 4.5$ versus $\gamma_\pi = 1.5$), and in the form of

	BM		$\gamma_\pi = 4.5$		$\rho_R = 0$		$\gamma_H = 0.1$		$\pi = 0$	
Model simulations detrended with HP 1600										
Short-run nominal assets										
Y	1.21	(1.00)	0.42	(1.00)	0.39	(1.00)	1.37	(1.00)	0.10	(1.00)
Π	1.35	(0.95)	0.37	(0.90)	1.43	(0.99)	1.63	(0.96)	0.00	(-)
R	1.50	(0.56)	1.02	(0.42)	2.37	(0.99)	1.69	(0.63)	1.05	(-0.99)
$Rreal$	1.59	(-0.74)	0.98	(-0.48)	1.72	(0.14)	1.79	(-0.73)	1.05	(-0.61)
Δp^B	0.51	(-1.00)	0.23	(-1.00)	0.68	(-0.77)	0.59	(-1.00)	0.21	(0.47)
Δp^H	0.61	(-0.23)	0.80	(-0.26)	0.78	(-0.91)	0.56	(-0.23)	0.92	(0.88)
Long-run nominal assets										
Y	1.17	(1.00)	0.40	(1.00)	0.33	(1.00)	1.33	(1.00)	0.12	(1.00)
Π	1.37	(0.94)	0.37	(0.88)	1.47	(0.99)	1.68	(0.94)	0.00	(-)
Short-run real assets										
Y	1.21	(1.00)	0.42	(1.00)	0.40	(1.00)	1.37	(1.00)	0.10	(1.00)
Π	1.34	(0.95)	0.37	(0.91)	1.43	(0.99)	1.61	(0.96)	0.00	(-)
Long-run real assets										
Y	1.17	(1.00)	0.40	(1.00)	0.38	(1.00)	1.33	(1.00)	0.12	(1.00)
Π	1.32	(0.95)	0.37	(0.89)	1.44	(0.99)	1.58	(0.96)	0.00	(-)
Only capitalists, short-run nominal assets										
Y	1.21	(1.00)	0.45	(1.00)	0.46	(1.00)	1.08	(1.00)	0.00	(-)
Π	1.28	(0.97)	0.36	(0.95)	1.44	(0.98)	1.13	(0.97)	0.00	(-)
Undetrended model simulations										
Short-run nominal assets										
Y	2.06	(1.00)	1.31	(1.00)	1.62	(1.00)	2.46	(1.00)	1.72	(1.00)
Π	2.34	(0.78)	0.67	(0.08)	2.99	(0.68)	2.71	(0.68)	0.00	(-)
Long-run nominal assets										
Y	2.04	(1.00)	0.76	(1.00)	1.68	(1.00)	2.38	(1.00)	1.09	(1.00)
Π	2.46	(0.64)	0.64	(0.45)	3.21	(0.43)	3.04	(0.57)	0.00	(-)
Short-run real assets										
Y	2.06	(1.00)	1.34	(1.00)	1.63	(1.00)	2.47	(1.00)	1.72	(1.00)
Π	2.33	(0.77)	0.67	(0.07)	2.99	(0.67)	2.68	(0.69)	0.00	(-)
Long-run real assets										
Y	2.09	(1.00)	0.87	(1.00)	1.70	(1.00)	2.49	(1.00)	1.09	(1.00)
Π	2.30	(0.70)	0.64	(0.36)	3.00	(0.59)	2.72	(0.57)	0.00	(-)

Table 3: Standard deviations for model driven by demand shocks

no interest rate smoothing ($\rho_R = 0$), reduces the volatility of both output and inflation. In fact, stricter monetary policy reduces the variance of output and inflation under all asset structures. Only housing prices become more volatile, due to the variations in interest rates. Including housing prices in the policy function stabilizes the housing market, but at the cost of destabilizing both output and general inflation. The last column reports results for strict inflation targeting. Completely eliminating inflation reduces the standard deviation of output by a factor of about ten, so that the "divine coincidence" continues to hold approximately.

Looking across the four different asset regimes, the numbers are very similar, which one would expect after having seen the impulse responses. There are some small differences, in particular output is slightly more stable under long-run assets, both nominal and real. From this picture, it appears that all the heterogeneity in the economy has no important implications for monetary policy, at least if it is concerned with economic aggregates.

The lower part of Table 3 provides the same information for undetrended time series. Remember that our model is a stationary model, so the Hodrick-Prescott filter is not necessary to stationarize the data, but the detrending partially filters out the low-frequency movements. The total variance of the undetrended series is of course higher. What about the policy trade-offs? Aggressive monetary policy ($\gamma_\pi = 4.5$) is still the right way to counteract demand shocks. However, being "aggressive" in the sense of raising interest rates immediately (no interest rate smoothing, $\rho_R = 0$), is now much less effective. In particular, it raises the variability of inflation. Most surprisingly, the divine coincidence now fails to hold by a wide margin. If the central bank sets the interest rate so as to perfectly stabilize inflation, more than two thirds of output fluctuations remain. For the undetrended variables, there are substantial differences across asset regimes. Aggressive monetary policy reduces output fluctuations much more in the case of long-term bonds, and we are closer to perfect stabilization. Since households are less affected by short-term variations in interest rates, their use for inflation stabilization causes less redistribution.

5.3 Why perfect stabilization fails

In a representative agent model, the central bank could counter the effect of a negative shock to D_t in Equs. (19) and (23) by an offsetting increase in R_t^B. In our benchmark model, however, this policy leads to a redistribution towards the middle class, which holds positive nominal assets on average, and within this group from the young to the middle aged. The redistribution to the middle class means that, for a given level of labor input, wages have to increase because of a wealth effect on labor supply. This raises marginal cost and therefore inflation. To stabilize inflation, the central bank has to set the interest rate so that output and labor input decline to the point where the increase in wages is matched by an increase in labor

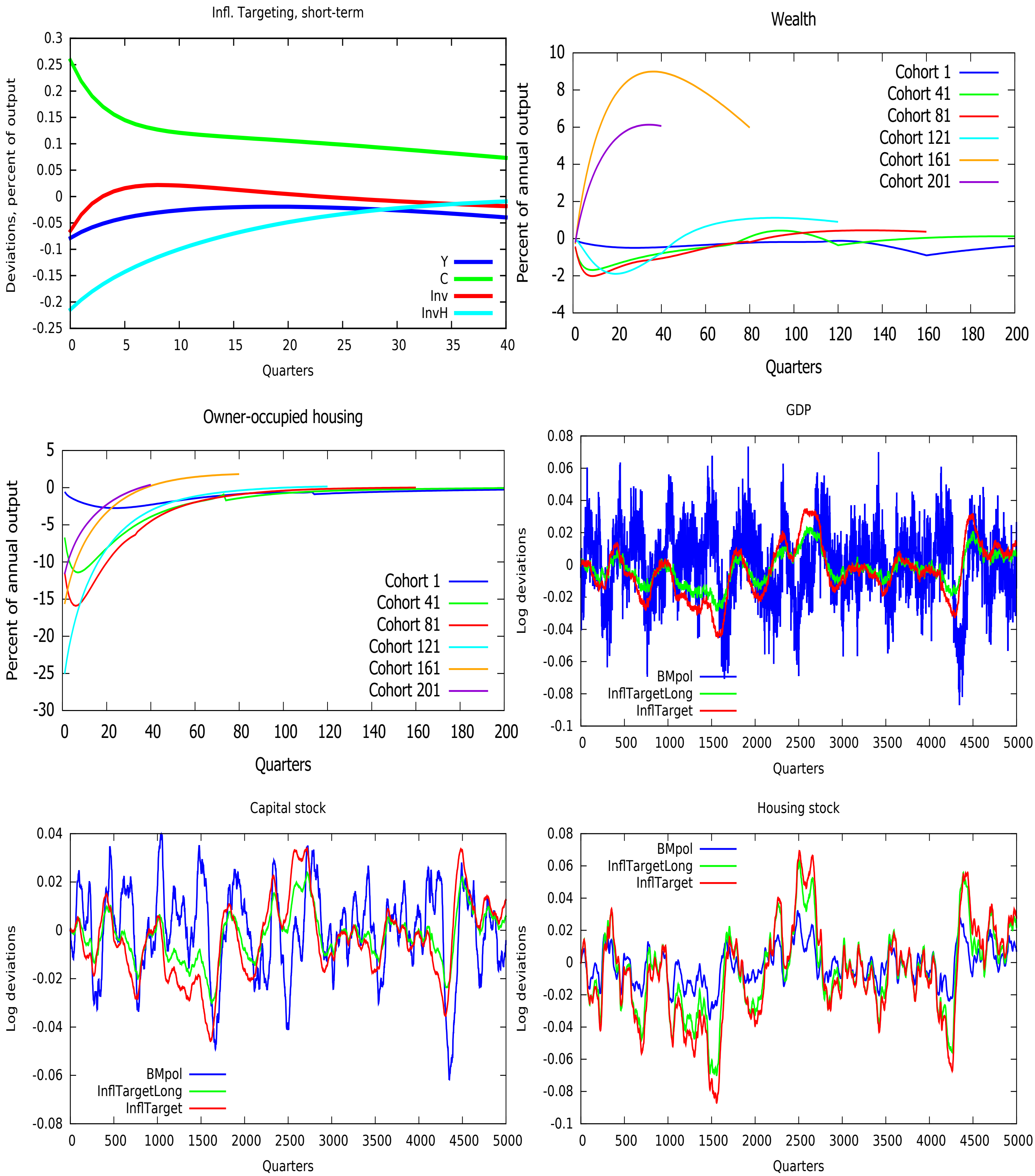

Figure 6: Model simulations under inflation targeting

productivity, which leaves the real marginal cost constant.[9] The size of this effect is illustrated in the upper left panel of Figure 6. It shows the response of the main economic aggregates to a one-standard-deviation expansionary demand shock under strict inflation targeting. As explained above, output falls on impact of the shock, but this fall is rather small, less than 0.1 percent. This is consistent with our finding that output stabilization is almost perfect at business cycle frequencies. The reduction in output is driven almost entirely by a reduction in housing investment. This comes from several mechanisms. First, the reduction in real wealth of young households who face the down payment constraint leads to a sharp reduction in their demand for housing. Furthermore, to generate a reduction in output, the interest rate has to increase by more than the wedge for several quarters (cf. below), which provides an incentive to shift assets away from housing into bonds.

If only a small decrease in output is necessary to maintain price stability after a demand shock, why does *undetrended* output fluctuate so much under inflation targetting (lower part of Table 3)? In general terms, the reason is that interest rate changes generate redistribution between household types and different cohorts. The aggregate effect of redistribution is small on impact, but very persistent, so that it builds up over time. The persistence of redistribution is illustrated in the upper right panel of Figure 6. It shows the impulse response of total wealth (bonds and owner occupied housing) of 6 different cohorts (of age 1, 41, 81 etc. at the time of the shock). Because of the increase in the real interest rate, the cohort at retirement age benefits most and maintains higher than steady state wealth until death, because of the bequest motive. Younger cohorts show smaller changes in total wealth. Because of the increase in interest rates, households change the composition of their wealth from housing to bonds, as can be seen from the middle left panel of Figure 6.

The difference between short-term and long-term stabilization is illustrated in the remainaing three panels of Figure 6, which show very long sample paths for GDP, the capital stock and the housing stock. Each panel compares simulations under the benchmark policy with short-term nominal interest rates (blue line), inflation targeting with short-term nominal interest rates (red line), and inflation targeting with long-term nominal interest rates (green line). The same realization of the shock series was used in the tree cases. The graph for GDP shows that inflation targeting eliminates most of the high-frequency fluctuations, but leaves a lot of low-frequency fluctuations. The low-frequency fluctuations are synchronized across GDP, capital and housing. Capital and housing never show much high-frequency fluctuations, and the longer swings are not much dampened by aggressive monetary policy, in the case of housing they are even amplified. The redistribution implied by the interest rate movements affects investment in both capital and housing. Those responses are not large, but very persistent, Since long-term bonds reduce the size of this redistribution, it also reduces the amplitude of these fluctuations.

[9]This effect would be larger with flexible wages, leading to even stronger deviations from the perfect stabilization. Details are available on request.

	BM		$\gamma_\pi = 4.5$		$\rho_R = 0$		$\gamma_H = 0.1$		$\pi = 0$	
	Poor	Middle	Poor	Middle	Poor	Middle	Poor	Middle	Poor	Middle
	Current utility, perc.of consumption									
shortnom	3.44	6.09	3.12	5.66	3.36	5.95	3.57	6.33	3.06	5.86
longnom	3.67	6.57	3.26	4.07	3.64	7.11	3.75	7.39	3.12	3.67
shortreal	3.43	6.29	3.12	5.76	3.35	6.31	3.56	6.53	3.06	5.86
longreal	3.60	5.00	3.23	3.94	3.51	4.64	3.73	5.34	3.12	3.67
	Lifetime welfare, perc.of lifetime consumption									
shortnom	1.29	1.35	1.10	1.25	1.26	1.46	1.38	1.42	1.14	1.36
longnom	1.49	1.21	1.14	0.71	1.53	1.35	1.55	1.32	1.08	0.73
shortreal	1.28	1.42	1.11	1.28	1.24	1.54	1.36	1.49	1.14	1.36
longreal	1.41	1.12	1.13	0.76	1.40	1.12	1.50	1.22	1.08	0.73

Table 4: Variability of utility and welfare, OLG households, model with demand shocks

This is in line with the results of , showing that house price fluctuations are not dampened by inflation targetting, unless the price of housing itself is targeted.

5.4 The variability of individual welfare

The reason why long-run fluctuations matter is that they affect household utility. To shed more light on this issue, Table 4 reports the variability of period utility and of lifetime welfare measures under different asset and policy regimes, separately for poor and for middle class households.[10] The first part of the table measures the variability of period utility, averaged over all cohorts. Being aggressive on inflation reduces this variability for both types of households, but the improvement is small under short-run nominal assets. Especially for the middle class, the reduction in volatility is much more pronounced under long-term nominal assets. In that case, households are protected against variations in the nominal rate, but benefit from the decrease of inflation variability.

The second part of the table measures the variability of lifetime welfare, wich depends not just on the variability of period utility, but on its correlation over time and cohorts. If cohorts are hit by a distributional shock, they cannot expect to be compensated in the future,

[10]We compute an approximation to welfare by evaluating the individual utility function at the linearized solution of the model for different monetary policies around the same deterministic steady state. Notice that this procedure is not adequate for optimal policy exercises, where different policies would lead to different stochastic steady states (see Benigno and Woodford (2006) for a discussion of optimal policy in linearized models). We therefore make only limited use of these welfare measures: they give the utility equivalent of the generated fluctuations in consumption, leisure etc., conditional on a given mean of all variables. We compute welfare as the realized value of the objective function in Equ. (15). We ignore the demand shocks D_t for this purpose, which we do not interpret as shocks to utility, but rather as a wedge between different assets, similar to Smets and Wouters (2007).

therefore distributional changes add up. For welfare, the asset structure matters. If bonds are short-term, the interest rate movements that are necessary to stabilize inflation generate random redistributions such that the welfare variability of middle class households is more or less unaffected (whether the variance of welfare goes up or down depends on the details of the calibration). Not so with long-term assets: households are largely shielded from interest rate movements, therefore inflation stabilization also stabilizes welfare variations. A further interesting result is that interest smoothing also smooths welfare. Abandoning it (the case $\rho_R = 0$) increases the variability of lifetime welfare of the middle class. This provides a new rationale for interest rate smoothing, different from the one in Woodford (2004).

These results force us to reconsider the rationale for inflation stabilization. The textbook argument why unexpected inflation is bad is that it causes random redistribution. However, the interest rate movements to stabilize inflation also cause redistribution. Under a realistic degree of household heterogeneity, it depends on the asset structure whether inflation stabilization benefits households to a substantial degree.

5.5 The importance of labor market frictions

The analysis above has highlighted a number of channels through which interest rate movements generate redistribution, which in turn affect the aggregate economy. These mechanisms depend crucially on the working of the labor market. We have assumed a frictionless labor market, with wage rigidity similar to many papers in the New Keynesian literature. With perfectly flexible wages, the wealth effects from redistribution generate large movements in the real wage, and therefore in real marginal costs and inflation. Real wage rigidity dampens the effect on inflation, and generally affect the redistribution between worker and capitalist households.

An important extension, left for future research, is the introduction of search frictions in the labor market, as in Gornemann, Kuester, and Nakajima (2016). Search frictions might substantially affect the welfare calculations. In a perfectly flexible labor market, a marginal increase in labor input does not increase welfare; the welfare effect comes from the change in wages. We have imposed a markup of wages over the marginal rate of substitution of ten percent, which generates some welfare gain from higher labor input. Moreover, the redistribution channel sheds new light on an ongoing discussion in the labor literature about the difference between wage rigidity for new hires versus and wage rigidity for continuing job matches (Haefke, Sonntag, and van Rens 2013; Pissarides 2009; Gertler and Trigari 2006). The latter has no allocative effects in standard models of frictional labor markets. Whether wages for new hires are more flexible is still disputed. To dampen the variability of marginal costs, it is necessary that wages at the margin (for new hires, overtime work etc.) are rigid. In our model, however, the wages of continuing matches also affect macroeconomic outcomes through the redistribution between workers and firm owners.

6 Conclusions

In this paper, we have investigated how household heterogeneity affects the ability of the central bank to stabilize the economy. For this purpose, we have developed a New Keynesian model with strong heterogeneity across households along several dimensions: skill level, access to bond markets, home ownership, and age. This generates diversity in the exposure of households to variations in the nominal interest rate and the inflation rate. The marginal effect of wealth on expenditures, both consumption and housing, differ widely across households.

In this environment, we find that household heterogeneity makes it harder for the central bank to stabilize the economy in the face of demand shocks. At the aggregate level, this becomes apparent if one considers not just conventionally detrended time series, but total fluctuations. Since the effect of redistribution is small but very persistent, monetary policy can generate welfare-relevant fluctuations at frequencies lower than business cycle frequencies. Then the goals of stabilizing macroeconomic aggregates and stabilizing individual welfare are not necessarily aligned. However, the two goals are more compatible if the assets traded have a fixed rather than an adjustable nominal interest rate. There has been a widespread decrease in the use of variable rate mortgages cross European countries over the last five to ten years (Bouyon 2017, Figure 2). From the view point of conventional monetary policy, this is highly welcome and allows the monetary authority to fight inflation more aggressively.

From the issues raised in this paper, we want to point out three areas for future research. The first one is the endogenous determination of the asset structure. For reasons of tractability, we have imposed the asset structure exogenously. In each version of the model, there was only one type of bond available. If asset choice were endogenized and the contracting parties chose the type of the asset that is optimal for them, what does this imply for the stabilization of the economy? Are there important externalities from asset choice? The second one is the role of labor market frictions. Distribution effects depend crucially on the behavior of wages, both wages of new hires and wages in ongoing employment relationships. Understanding the nature of wage rigidities is important not just for the analysis of the labor market, but also for monetary policy. Moreover, if we allow for search frictions and unemployment, would the long-run fluctuations in production lead to similar movements in unemployment? The third point is the design of optimal policy. If the short-run stabilization of output and employment does not necessarily reduce the fluctuations of household welfare in a world of incomplete markets, what is the right policy objective? Concerning the empirical validity of the model, does the household heterogeneity help to resolve the forward guidance puzzle (Del Negro, Giannoni, and Patterson 2012; McKay, Nakamura, and Steinsson 2016)?

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A Data from the Survey of Consumer Finances 2013

We present the data we used for calibrating our model in greater detail. These tables report the medians and means of important variables for five-year age bins. The categorization has been done by selecting the lowest 20 percent, the next 70 percent and the top 10 percent in terms of net worth in each age bin we consider. Notice that the data does not exhibit any panel dimension, so we cannot follow households over their life cycle.

Table 5: Median Networth

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	-3010	-20900	-22400	-16299	-6050	-5870	-2300	0	0	1410	16200	4700	2151	8680	5000
Middle	4810	6160	13330	26670	47300	76700	112400	158000	193750	230100	319800	253800	241700	236100	180700
Capitalists	44400	100050	232000	397300	919200	1381050	1414500	1917700	3349800	2929000	3906800	3384000	1635900	1516299	1840600

Table 6: Median Net Financial Assets

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	-12610	-25250	-35910	-43000	-16480	-30864	-18790	-2540	-3960	-520	-3900	0	-45	200	1150
Middle	110	-89	-1640	-6744	-7700	-5700	-6830	-910	6830	23980	44140	60640	35420	27500	28000
Capitalists	400	5220	-33920	-17400	80200	470000	400000	625500	1367500	1139000	2092005	1860000	831530	993000	1070000

Table 7: Median Value of Owner Occupied Housing

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	0	0	0	0	0	0	0	0	0	0	7500	0	0	0	0
Middle	0	0	0	3000	68000	108000	124000	140000	150000	150000	167000	165000	128000	150000	100000
Capitalists	44000	50000	201000	200000	485000	550000	675000	470000	580000	500000	750000	600000	500000	450000	221000

Table 8: Median Ownership Rate

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Middle	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Capitalists	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 9: Mean Networth

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	-9007	-31874	-44878	-28772	-18931	-22055	-17314	-10674	-7222	-25202	19676	5001	-4688	12187	8194
Middle	7027	9149	25556	52836	101999	148365	185919	263208	327759	346359	468285	429670	293594	290608	244753
Capitalists	44896	173835	562604	866459	1882061	3322961	3061251	4319746	5550647	5716305	7369097	7200125	4605141	3184188	4617706

Table 10: Mean Net Financial Assets

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	-11660	-37687	-67120	-92664	-61263	-90165	-65382	-40865	-39821	-67013	-43919	-18492	-31522	-12886	2722
Middle	1149	-7674	-26205	-51218	-53734	-40004	-15782	12887	66903	85774	152718	161172	76589	85030	93537
Capitalists	400	83971	100811	82380	356744	768185	880397	1528859	2351971	2607131	3779191	3693598	2120120	1682842	2733825

Table 11: Mean Housing

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	0	0	10893	44543	32784	55146	29995	21591	26790	29298	50668	16103	20539	20333	3111
Middle	1299	7531	34008	81306	113113	138733	149355	180119	179708	190177	219727	200590	163108	167089	130069
Capitalists	44496	58321	241399	293654	673941	746081	741126	676932	919926	789654	1085852	850153	613624	633374	416659

Table 12: Mean Ownership Rate

	<20	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	>84
Poor	0	0	0.07	0.3	0.25	0.38	0.28	0.2	0.24	0.21	0.52	0.34	0.26	0.41	0.12
Middle	0.03	0.09	0.33	0.5	0.6	0.69	0.73	0.83	0.84	0.86	0.96	0.94	0.94	0.92	0.91
Capitalists	1	0.7	0.9	0.81	0.97	0.92	0.96	0.92	0.99	0.97	0.94	0.99	0.99	0.95	0.98

B First order conditions middle class households

The utility function of the household is given by

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

Marginal utilities are

$$\begin{aligned}u_c =& \frac{1}{c_t} \\ u_l =& -\frac{\eta}{1 - l_t} \\ u_{h^R} =& \frac{\eta_H}{\left((h_t^R)^{(\sigma-1)/\sigma} + (\xi h_t^O + \kappa)^{(\sigma-1)/\sigma}\right)}(h_t^R)^{\frac{\sigma-1}{\sigma}-1} \\ u_{h^O} =& \frac{\eta_H}{\left((h_t^R)^{(\sigma-1)/\sigma} + (\xi h_t^O + \kappa)^{(\sigma-1)/\sigma}\right)}(\xi h_t^O + \kappa)^{\frac{\sigma-1}{\sigma}-1}\xi\end{aligned}$$

We set up the Lagrangian, using λ and $\tilde{\lambda}$ to denote the Lagrange multipliers. To simplify notation, we drop the age subscript s.

$$\begin{aligned}&\mathcal{L} = \max \mathbb{E}_0 \sum_{t=0}^{I-1} \beta^t u(c_t, l_t, h_t^R, h_t^O) - \\ &\lambda_t[p_t^B b_t + h_t^O p_t^H + c_t + r_t^H h_t^R - (1 - \tau) w_t \zeta_t l_t - \mathcal{I}_t^R \psi_t - \\ &((\mu + r^B) v_t^B + (1 - \mu) p_t^B) b_{t-1} - (1 - \delta_H) h_{t-1}^O p_t^H] \\ &+ \tilde{\lambda}_t[v_t^B b_t + \nu \mathbb{E} p_{t+1}^H h_t^O]\end{aligned}$$

Now taking the F.O.C.s yields (for brevity, omit the expectation operator $\mathbb{E}_t$)

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial c_t} &: u_{c_t} = \lambda_t \\ \frac{\partial \mathcal{L}}{\partial l_t} &: u_{l_t} + \lambda_t (1 - \tau) w_t \zeta_t = 0 \\ \frac{\partial \mathcal{L}}{\partial h_t^R} &: u_{h_t^R} - \lambda_t r_t^H = 0 \\ \frac{\partial \mathcal{L}}{\partial h_t^O} &: u_{h_t^O} - \lambda_t p_t^H + \tilde{\lambda}_t \nu \mathbb{E} p_{t+1}^H + \beta \lambda_{t+1} (1 - \delta_H) p_{t+1}^H = 0 \\ \frac{\partial \mathcal{L}}{\partial b_t} &: -\lambda_t p_t^B + \tilde{\lambda}_t v_t^B + \beta \lambda_{t+1}((\mu + r^B) v_{t+1}^B + (1 - \mu) p_{t+1}^B) = 0\end{aligned}$$

Expressing $\tilde{\lambda}_t$ gives

$$\tilde{\lambda}_t = \frac{\lambda_t p_t^B - \beta \lambda_{t+1}((\mu + r^B) v_{t+1}^B + (1 - \mu) p_{t+1}^B)}{v_t^B} \tag{35}$$

Plugging (35) into the FOC for owned housing and using $u_{c_t} = \lambda_t$ we get

$$u_{h_t^O} - u_{c_t} p_t^H + \frac{u_{c_t} p_t^B - \beta u_{c_{t+1}}((\mu + r^B) v_{t+1}^B + (1-\mu) p_{t+1}^B)}{v_t^B} \nu \mathbb{E} p_{t+1}^H + \beta u_{c_{t+1}} (1 - \delta_H) p_{t+1}^H = 0 \tag{36}$$

or

$$u_{h_t^O} - u_{c_t} [p_t^H - \frac{p_t^B}{v_t^B} \nu \mathbb{E} p_{t+1}^H] - \beta\beta u_{c_{t+1}} \left[\frac{((\mu + r^B) v_{t+1}^B + (1-\mu) p_{t+1}^B)}{v_t^B} \nu \mathbb{E} p_{t+1}^H - (1 - \delta_H) p_{t+1}^H \right] = 0$$