Transmission of Monetary Policy with Heterogeneity in Household Portfolios

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Abstract

This paper assesses the importance of heterogeneity in household portfolios for the transmission of monetary policy in a New Keynesian business cycle model with uninsurable income risk and assets with different liquidity. In this environment, monetary transmission works through investment, but redistribution lowers the elasticity of investment via two channels: 1) heterogeneity in marginal propensities to invest, 2) time variation in the liquidity premium. Monetary contractions redistribute to wealthy households who have high propensities to invest and a low marginal value of liquidity, thereby stabilizing investment. I provide empirical evidence for countercyclical liquidity premia and heterogeneity in household portfolio responses.

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At least since Tobin (1969) it is well understood that a satisfactory understanding of the monetary transmission mechanism has to go beyond consumption and include household portfolio balances. Changes in the interest rate affect both the intertemporal substitution of consumption and the portfolio composition between liquid nominal claims like government bonds and illiquid real assets like capital. Demand for these different assets translates differently into demand for goods. An increase in the interest rate translates into a shortfall of spending only in so far as higher savings do not increase investment one-for-one. Importantly, households differ enormously in their wealth and portfolio composition. The fraction of savings going into real assets increases in wealth.[1] Therefore, monetary transmission depends on both the distribution of the marginal propensities to consume (MPC) and, via households' portfolio choices, the marginal propensities to invest (MPI).

This paper assesses the importance of heterogeneity in household portfolios for the transmission mechanism of monetary policy in the context of a Heterogeneous Agent New Keynesian (HANK) model with asset-market incompleteness, idiosyncratic income risk, and sticky prices. The key feature of the model is to allow for portfolio choice between liquid and illiquid assets in a business-cycle framework. The illiquid asset is real capital. It can only be traded with a certain probability each period but pays a higher return than the liquid asset in equilibrium, which comprises nominal government and household debt and can be traded without frictions. These characteristics enable the model to endogenously generate the distribution of portfolio shares and marginal propensities to consume across households as documented for the United States.[2]

My main finding is that monetary transmission works through the response of investment, which is crucially shaped by redistribution. While consumption is less responsive to the policy rate (cf. Kaplan et al., 2018), the elasticity of investment is still sizable. Quantitatively, the direct effect of the policy rate explains only one third of the total change in consumption, while equilibrium changes in income account for the remaining two

[1]Stocks and businesses account for most of the wealth at the very top of the wealth distribution, while households below median wealth hold a disproportionate share of their wealth in very liquid form like cash and deposits; see Kuhn and Ríos-Rull (2013).

[2]For evidence on the distribution of MPCs, see the empirical literature on the consumption response to transfers, e.g., Johnson et al. (2006), Parker et al. (2013), or Misra and Surico (2014).

thirds. The policy rate, however, still explains 86% of the investment response. Yet, the distributional consequences of monetary policy mute the investment response with heterogeneity in household portfolios.[3] This matters for the aggregate effects of monetary policy. Quantitatively, investment falls by one third less in response to a monetary tightening in comparison to the same economy with a representative portfolio. The output response is smaller as well but less so, because consumption falls more due to the importance of current income.[4]

Redistribution affects monetary transmission via two channels: First, the endogenous premium of the illiquid asset over and above the return on the liquid asset falls in response to a monetary tightening. Hence, there is incomplete pass-through of the policy rate to the return on illiquid capital, which stabilizes investment. The decrease of the liquidity premium is a consequence of the redistribution induced by the monetary tightening. A monetary tightening increases income and wealth inequality (in both liquid and illiquid assets).[5] The liquidity premium falls in equilibrium until wealthy households, who have a low marginal value of liquidity, are willing to hold a larger fraction of outstanding liquid assets.

Second, heterogeneity in MPCs and MPIs interacts with the distributional consequences of monetary policy. Households at the top of the wealth distribution benefit from the revaluation of nominal balances, i.e., the Fisher channel, and because a disproportionate share of their income stems from profits, which increase while labor income falls. Wealthy households primarily hold capital and, thus, have a high marginal propensity to invest but low marginal propensity to consume. Higher inequality thereby stabilizes investment after a contractionary monetary policy shock but amplifies the drop in consumption. When wealth inequality is higher as in the U.S. post-2008, the redistribution channel of monetary policy becomes more important in the transmission and, hence, further decreases the investment response but increases the response of consumption.

Redistribution via the Fisher channel from unexpected inflation is quantitatively important. Its effect depends on the covariance between redis-

[3] I use the terms portfolio heterogeneity and two-asset model interchangeably.

[4] I abstract from financial frictions on the firm side to isolate the effect of frictions in household portfolios. The line of work following Bernanke et al. (1999) or the recent work by Ottonello and Winberry (2018) shows that the former might amplify the investment response.

[5] This is in line with U.S. data. See Coibion et al. (2017), who find higher inequality after contractionary monetary shocks.

tribution and the marginal propensities to consume and invest. When the economy is demand-driven, the Fisher channel amplifies the aggregate effects of monetary shocks through heterogeneity in propensities to consume by 9%. When prices are flexible, in contrast, the Fisher channel leads to a boom in investment through redistributing to high MPI households.

This paper makes two empirical contributions as well. First, I provide novel evidence for heterogeneity in portfolio responses to monetary shocks. I regress repeated cross-sectional data on household portfolios from the Survey of Consumer Finances (SCF) on monetary policy shocks.[6] Sorting households according to percentiles of net wealth, I find that, when rates increase, households below median wealth reduce their portfolio liquidity, while households above median wealth increase portfolio liquidity.

The liquidity friction is key for the model to generate the differential sign and magnitude of the estimated portfolio responses. As I increase the liquidity of capital, fewer households lower their liquid savings in response to a monetary tightening. When capital becomes perfectly liquid, all households increase their portfolio liquidity, which is counterfactual, since more than 50% of households lower portfolio liquidity in the data. The ability of the two-asset model to match the differential portfolio response provides new evidence for the importance of modeling illiquid assets beyond "wealthy-hand-to-mouth" households, which matter for the distribution of marginal propensities to consume (cf. Kaplan and Violante, 2014).

The second empirical contribution documents that measures of the liquidity premium decrease in response to a monetary tightening. I define two measures of the liquidity premium: 1) Gomme et al. (2011)'s return on capital, 2) the return on housing, over and above the risk free rate. For each measure, I run local projections on monetary shocks identified by the narrative approach (cf. Romer and Romer, 1989), and find that both premia fall in response to a monetary tightening in line with the predictions of the model.

My findings on the monetary transmission mechanism are complementary to the related work by Kaplan et al. (2018) (KMV). They also decompose the effects of monetary policy into direct and equilibrium effects but focus on heterogeneity in MPCs. The key difference between both models

[6]Wong (2015) and Cloyne et al. (2019) also look at the cross-sectional response to monetary shocks. The first study analyzes the importance of age and the second the importance of housing tenure for the consumption response to monetary shocks using the Consumption Expenditure Survey.

is the portfolio problem: KMV do not have a Fisher effect on bonds and assume that part of dividends and profits are paid into the illiquid account. In my model, in contrast, aggregate investment follows q-theory.[7] [8]

This paper also contributes to the assessment of the Fisher (1933) channel of unexpected inflation as a transmission mechanism of monetary policy. Auclert (2019) studies this channel for the consumption response to monetary shocks and derives a sufficient statistic that depends on the covariance between MPCs and inflation-induced redistribution. In my two-asset model, the Fisher channel works through marginal propensities to consume *and* invest, which are negatively correlated and hence potentially cancel each other in terms of the effect on output. However, I abstract from long-term debt and assets, which would increase inflation-induced redistribution.

My paper belongs to the recently evolving literature that incorporates market incompleteness and idiosyncratic uncertainty into New Keynesian models.[9] As such, it builds on the New Keynesian literature with its focus on nominal rigidities (cf. Christiano et al., 2005). What my paper and other recent contributions add to this literature is the attempt to endogenize heterogeneity in wealth.[10] Relative to this literature, my paper provides new evidence for the importance of modeling assets with different degrees of liquidity and is the first to discuss the importance of heterogeneity in propensities to invest for monetary policy.

The remainder of the paper is organized as follows. Section I introduces the model. Section II discusses the solution method and explains the calibration of the model. Section III presents the quantitative results. Section IV presents the empirical evidence. Section V concludes.

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[7]On a technical level, the advantage of random participation in the capital market is its transparency and the ease of implementation, while still being consistent with micro and macro evidence on portfolio allocations and liquidity premia.

[8]I allocate profits to the top 1% of the income distribution, a group of households that are well-insured and approximately follow the permanent income hypothesis. This has two advantages: 1) It fits the data on the distribution of income, 2) It does not imply counterfactual procyclical earnings risk for 99% of the population.

[9]See Guerrieri and Lorenzoni (2017), Oh and Reis (2012), Gornemann et al. (2012), Ravn and Sterk (2017), Den Haan et al. (2015), Auclert (2019), Bayer et al. (2019), Werning (2015), McKay and Reis (2016), McKay et al. (2016), and Kaplan et al. (2018).

[10]Exogenous heterogeneity is well-established in New Keynesian models. See, for example, Galí et al. (2007) and Bilbiie (2008).

I Model

The model economy consists of households, firms, and a government. Households consume, supply labor, obtain profit income, accumulate physical capital, and trade in the bond market. Firms combine capital and labor services to produce goods. The government issues bonds, raises taxes, and purchases goods, while the monetary authority sets the nominal interest rate on bonds. Let me describe each agent in turn.[11]

I.A Households

There is a continuum of ex-ante identical households of measure one indexed by $i \in [0, 1]$. Households are infinitely lived, have time-separable preferences with time-discount factor β, and their utility flow depends positively on consumption c_{it} and negatively on labor n_{it}, where $n_{it} \in [0, 1]$ are hours worked as a fraction of the time endowment, normalized to 1. The function u is strictly increasing and strictly concave in consumption, and strictly decreasing and strictly convex in hours worked:

$$V = E_0 \max_{\{c_{it}, n_{it}\}} \sum_{t=0}^{\infty} \beta^t u\left(c_{it}, n_{it}\right). \tag{1}$$

Households can be workers ($h_{it} > 0$) or entrepreneurs ($h_{it} = 0$). Transition between both types is exogenous and stochastic, but the fraction of households that are entrepreneurs at any given time $t = 0, 1, 2, ...$ is constant.[12]

Workers supply labor. Their labor income $w_t h_{it} n_{it}$ is composed of the wage rate, w_t, hours worked, n_{it}, and idiosyncratic labor productivity, h_{it}, which evolves according to the following first-order autoregressive process and a fixed probability of transition between the worker and the

[11] This model setup extends previous joint work Bayer et al. (2019), which assumes GHH preferences to simplify computation, and follows the exposition where there is overlay.

[12] Fixed types of workers and entrepreneurs (or capitalists) without stochastic transitions can be found in Walsh (2014) or Broer et al. (2016), while Romei (2014) uses stochastic transitions.

entrepreneur state:

$$h_{it} = \begin{cases} \exp\left(\rho_h \log h_{it-1} + \epsilon^h_{it}\right) & \text{with probability } 1-\zeta \text{ if } h_{it-1} \neq 0, \\ 1 & \text{with probability } \iota \text{ if } h_{it-1} = 0, \\ 0 & \text{else,} \end{cases} \tag{2}$$

with $\epsilon^h_{it} \sim N(0, \sigma_h)$. Entrepreneurs have zero productivity in the labor market, but instead receive an equal share of the economy's total profits Π_t.[13] They pay the same tax rate as workers, τ.

Asset markets are incomplete. Households may only self-insure in nominal bonds, $\tilde{b}_{it}$, and in capital, k_{it}. Holdings of capital have to be nonnegative, but households may issue nominal bonds up to an exogenously specified limit $\underline{b} \in (-\infty, 0]$. Moreover, trading capital is subject to a friction.

This trading friction only allows a randomly selected fraction of households, ν, to participate in the market for capital each period. All other households obtain dividends, but may only adjust their holdings of nominal bonds. For those households participating in the capital market, the budget constraint reads:

$$\begin{aligned} c_{it} + b_{it+1} + q_t k_{it+1} &= \frac{R^b_t}{\pi_t} b_{it} + (q_t + r_t) k_{it} + (1-\tau)\left[w_t h_{it} n_{it} + \mathbb{I}_{h_{it}=0} \Pi_t\right], \\ & k_{it+1} \geq 0, b_{it+1} \geq \underline{b}, \end{aligned} \tag{3}$$

where b_{it} is the real value of nominal bond holdings, k_{it} are capital holdings, q_t is the price of capital, r_t is the rental rate or "dividend," R^b_t is the gross nominal return on bonds, and $\pi_t = \frac{P_t}{P_{t-1}}$ is the inflation rate. I denote real bond holdings of household i at the end of period t by $b_{it+1} := \frac{\tilde{b}_{it+1}}{P_t}$. There is a wasted intermediation cost, $\overline{R}$, when households resort to unsecured borrowing. Therefore, R^b has two parts:

$$R^b_t(b_{it}, R^B_t) = \begin{cases} R^B_t & \text{if } b_{it} \geq 0 \\ R^B_t + \overline{R} & \text{if } b_{it} < 0. \end{cases} \tag{4}$$

[13] Attaching the rents in the economy to an exogenously determined group of households instead of distributing them with the factor incomes for capital or labor has the advantage that the factor prices and thus factor supply decisions remain the same as in the standard New Keynesian framework. Hence, aggregate investment follows q-theory.

This assumption creates a mass of households with zero unsecured credit but with the possibility to borrow, though at a penalty rate.

For those households that cannot trade in the market for capital the budget constraint simplifies to:

$$
\begin{aligned}
c_{it} + b_{it+1} &= \frac{R_t^b}{\pi_t} b_{it} + r_t k_{it} + (1-\tau)\left[w_t h_{it} n_{it} + \mathbb{I}_{h_{it}=0}\Pi_t\right], \\
b_{it+1} &\geq \underline{b}. \qquad (5)
\end{aligned}
$$

Note that I assume that the depreciation of capital is replaced through maintenance such that the dividend, r_t, is the net return on capital.

A household's optimal consumption-savings decision is a non-linear function of that household's asset portfolio $\{b_{it}, k_{it}\}$ and productivity $\{h_{it}\}$. Accordingly, the price level P_t and aggregate real bonds $B_{t+1} = \frac{\tilde{B}_{t+1}}{P_t}$ are functions of the joint distribution Θ_t over idiosyncratic states (b_t, k_t, h_t). This makes the distribution Θ_t a state variable of the households' planning problem. The distribution Θ_t fluctuates in response to aggregate monetary or total factor productivity shocks. Let Ω stand in for aggregate shocks.

With this setup, two Bellman equations characterize the dynamic planning problem of a household: V_a in the case where the household can adjust its capital holdings and V_n otherwise:

$$
\begin{aligned}
V_a(b,k,h;\Theta,\Omega) &= \max_{k',b'_a,n'_a} u[c(b,b'_a,k,k',h,n'_a)] + \beta[\nu E V^a(b'_a,k',h',\Theta',\Omega') \\
&\quad + (1-\nu) E V^n(b'_a,k',h',\Theta',\Omega')] \\
V_n(b,k,h;\Theta,\Omega) &= \max_{b'_n,n'_n} u[c(b,b'_n,k,k,h,n'_n)] + \beta[\nu E V^a(b'_n,k,h',\Theta',\Omega') \\
&\quad + (1-\nu) E V^n(b'_n,k,h',\Theta',\Omega')] \qquad (6)
\end{aligned}
$$

In line with this notation, I define the optimal consumption policies for the adjustment and non-adjustment cases as c_a^* and c_n^*, the labor supply policies as n_a^* and n_n^*, the nominal bond holding policies as b_a^* and b_n^*, and the capital investment policy as k^*. See Appendix A for the first-order conditions.

I.B Intermediate Good Producer

Intermediate goods are produced with a constant returns to scale production function:

$$Y_t = Z_t N_t^{\alpha} K_t^{(1-\alpha)},$$

where Z_t is total factor productivity (TFP). It follows a first-order autoregressive process:

$$\log Z_t = \rho_Z \log Z_{t-1} + \epsilon_t^Z, \quad \epsilon_t^Z \sim N(0, \sigma_Z). \tag{7}$$

Let MC_t be the relative price at which the intermediate good is sold to resellers. The intermediate-good producer maximizes profits,

$$MC_t Z_t N_t^{\alpha} K_t^{(1-\alpha)} - w_t N_t - (r_t + \delta) K_t,$$

and faces perfectly competitive markets such that the real wage and the user costs of capital are given by the marginal products of labor and capital:

$$w_t = \alpha MC_t Z_t \left(K_t / N_t\right)^{1-\alpha}, \tag{8}$$

$$r_t + \delta = (1-\alpha) MC_t Z_t \left(N_t / K_t\right)^{\alpha}. \tag{9}$$

I.C Resellers

Resellers differentiate the intermediate good and set prices. I assume price adjustment costs à la Rotemberg (1982). I assume that price setting is delegated to a mass-zero group of households (managers) that are risk neutral and compensated by a share in profits. They do not participate in any asset market. Under this assumption, price setting is carried out with a time-constant discount factor.[14] Managers maximize the present value of real profits given the demand for good j,

$$y_{jt} = \left(p_{jt} / P_t\right)^{-\eta} Y_t, \tag{10}$$

[14]The assumption of risk-neutral managers only simplifies the notation. Since I solve the model by first order perturbation in aggregate shocks, certainty equivalence holds and fluctuations in stochastic discount factors are irrelevant.

and quadratic costs of price adjustment, i.e., they maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t Y_t \left\{ \left(\frac{p_{jt}}{P_t} - MC_t \right) \left(\frac{p_{jt}}{P_t} \right)^{-\eta} - \frac{\eta}{2\kappa} \left(\log \frac{p_{jt}}{p_{jt-1}} \right)^2 \right\}. \tag{11}$$

From the corresponding first-order condition for price setting, it is straightforward to derive the Phillips curve:

$$\log(\pi_t) = \beta E_t \left[\log(\pi_{t+1}) \tfrac{Y_{t+1}}{Y_t} \right] + \kappa \left(MC_t - \tfrac{\eta-1}{\eta} \right), \tag{12}$$

where π_t is the gross inflation rate, $\pi_t := \frac{P_t}{P_{t-1}}$, and MC_t are the real marginal costs. The price adjustment then creates real costs $\frac{\eta}{2\kappa} Y_t \log(\pi_t)^2$.

Since managers are a measure-zero group in the economy, all profits – net of price adjustment costs – go to the entrepreneur-households. In addition, these households also obtain profit income from adjusting the aggregate capital stock. They can transform I_t consumption goods into ΔK_{t+1} capital goods (and back) according to the transformation function:

$$I_t = \tfrac{\phi}{2} \left(\Delta K_{t+1} / K_t \right)^2 K_t + \Delta K_{t+1}.$$

Since they are facing perfect competition in this market, entrepreneurs will adjust the stock of capital until the following first-order condition holds:

$$q_t = 1 + \phi \Delta K_{t+1} / K_t. \tag{13}$$

I.D Final Good Producer

Perfectly competitive final good producers use differentiated goods as input taking input and sell price as given. Final goods are used for consumption and investment. The problem of the representative final good producer is as follows:

$$\max_{Y_t, y_{jt} \in [0,1]} P_t Y_t - \int_0^1 p_{jt} y_{jt} dj \tag{14}$$

$$s.t.: Y_t = \left(\int_0^1 y_{jt}^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta}{\eta-1}},$$

where y_{jt} is the quantity of differentiated good j demanded as input. From the zero-profit condition, the price of the final good is given by $P_t =$

$\left(\int_0^1 p_{jt}^{1-\eta} dj\right)^{\frac{1}{1-\eta}}$.

I.E Central Bank and Government

Monetary policy sets the gross nominal interest rate, R_t^B, according to a Taylor (1993)-type rule that reacts to deviations of inflation from target and exhibits interest rate smoothing:

$$\frac{R_{t+1}^B}{\bar{R}^B} = \left(\frac{R_t^B}{\bar{R}^B}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\theta_\pi} \epsilon_t^R, \tag{15}$$

where $\log \epsilon_t^R \sim N(0, \sigma_R)$ are monetary policy shocks. All else equal, the central bank raises the nominal rate above its steady-state value R^B whenever inflation exceeds its target value.[15] The parameter ρ_R captures "intrinsic policy inertia."

The fiscal authority decides on government spending, G_t, raises tax revenues, T_t, and issues nominal bonds. Let B_{t+1} denote their time t real value. The government budget constraint reads: $B_{t+1} = \frac{R_t^B}{\pi_t} B_{it} + G_t - T_t$, where real tax revenues are given by $T_t = \tau[\nu \int w_t h_{it} n_{it}^a d\Theta_t + (1 - \nu) \int w_t h_{it} n_{it}^n d\Theta_t + \Pi_t]$. I assume that the government issues bonds according to the rule (c.f. Woodford, 1995):

$$\frac{B_{t+1}}{\bar{B}} = \left(\frac{B_t R_t^B / \pi_t}{\bar{B}\bar{R}^B / \bar{\pi}}\right)^{\rho_B}. \tag{16}$$

The coefficient ρ_B captures whether and how fast the government seeks to repay its outstanding obligations $B_t R_t^B / \pi_t$. For $\rho_B < 1$ the government actively stabilizes real government debt via adjusting government spending, and for $\rho_B = 1$ the government rolls over all outstanding debt including interest.[16]

I.F Market Clearing Conditions

The labor market clears at the competitive wage given in (8); so does the market for capital services if (9) holds. The nominal bond market clears

[15] Note the economy is non-Ricardian because households value government debt for its consumption-smoothing services. Hence, the standard Taylor principle, $\theta_\pi > 1$, does not apply here; see Hagedorn (2018).

[16] Adjustment via government spending is the baseline formulation because changing taxes would directly redistribute across households. This also applies to lump-sum taxes in this environment. See Appendix F.G for robustness to different fiscal rules.

whenever the following equation holds:

$$B_{t+1} = \int \left[\nu b_a^*(b,k,h) + (1-\nu) b_n^*(b,k,h)\right] \Theta_t(b,k,h) db dk dh. \tag{17}$$

Last, the market for capital has to clear:

$$\begin{aligned} q_t &= 1 + \phi \frac{K_{t+1} - K_t}{K_t}, \\ K_{t+1} &= \int \left[\nu k_a^*(b,k,h) + (1-\nu) k_n(b,k,h)\right] \Theta_t(b,k,h) db dk dh, \end{aligned} \tag{18}$$

where the first equation stems from competition in the production of capital goods, and the second equation defines the aggregate supply of funds from households. The goods market then clears due to Walras' law, whenever labor, bond, and capital markets clear.

I.G Recursive Equilibrium

A *recursive equilibrium* is a set of policy functions $\{c_a^*, c_n^*, n_a^*, n_n^*, b_a^*, b_n^*, k_a^*\}$, value functions $\{V_a, V_n\}$, pricing functions $\{r, R^B, w, \pi, q\}$, aggregate bonds, capital, and labor supply functions $\{B, K, N\}$, distributions Θ_t over individual asset holdings and productivity, and a perceived law of motion Γ, such that

1. Given V_a, V_n, Γ, prices, and distributions, the policy functions solve the households' planning problem, and given prices, distributions, and the policy functions, the value functions $\{V_a, V_n\}$ are a solution to the Bellman equations (6).

2. The labor, the final-goods, the bond, the capital, and the intermediate-goods markets clear, i.e., (8), (12), (17), and (18) hold.

3. The actual law of motion and the perceived law of motion Γ coincide, i.e., $\Theta' = \Gamma(\Theta, \Omega')$.

II Numerical Implementation and Calibration

II.A Numerical Implementation

The dynamic program (6) and hence the recursive equilibrium are not computable, because it involves the infinite dimensional object Θ_t. I discretize the distribution Θ_t and represent it by its histogram, a finite dimensional object.

I solve for the households' policy functions by applying an endogenous grid point method as originally developed in Carroll (2006) and extended by Hintermaier and Koeniger (2010), iterating over the first-order conditions. I approximate the idiosyncratic productivity process by a discrete Markov chain with 4 states, using the method proposed by Tauchen (1986). I solve the household policies for 75 points on a log-grid for bonds and for capital.

I solve for aggregate dynamics by first-order perturbation around the stationary equilibrium without aggregate shocks as in Reiter (2009). To reduce the dimensionality of the problem I follow Bayer and Luetticke (2018) and approximate the three-dimensional distribution Θ_t by a distribution that has a fixed copula and time-varying marginals and the value function and its derivatives by a sparse polynomial around their stationary equilibrium solutions. Appendix B provides more details on the algorithm and its numerical accuracy.

II.B Calibration

I calibrate the model to the U.S. economy over the time period 1983Q1 to 2007Q4, since I focus on conventional monetary policy. One period in the model is a quarter. Table 1 shows the targeted moments of the wealth distribution, and Table 2 summarizes the calibration. In detail, I choose the parameter values as follows, with all parameters reported for the quarterly frequency of the model.

II.B.1 Households

I assume that the felicity function is of constant-relative-risk-aversion form: $u(c,n) = \frac{c^{1-\xi}}{1-\xi} - \psi \frac{n^{1+1/\gamma}}{1+1/\gamma}$, where $\xi = 4$, as in Kaplan and Violante (2014). The Frisch elasticity of labor supply, $\gamma = 1$, is in line with estimates by

Table 1: Targeted moments of the wealth distribution

Targets	Model	Data	Source	Parameter
Mean illiquid assets (K/Y)	2.86	2.86	NIPA	Discount factor
Mean liquidity (B/K)	0.09	0.09	SCF	Participation frequency
Gini total wealth	0.78	0.78	SCF	Fraction of entrepreneurs
Fraction borrowers	0.16	0.16	SCF	Borrowing penalty

Chetty et al. (2011), and ψ is chosen such that 5% of households work two jobs, i.e., h=1 for 5% of households.[17] The time-discount factor, $\beta = 0.983$, and the capital market participation frequency, $\nu = 12.5\%$, are jointly calibrated to match the ratio of capital to output and liquid assets to capital.[18] I equate capital to all capital goods relative to nominal GDP. The annual capital-to-output ratio is therefore 286%. This implies an annual real return on capital of about 4.5%. I equate liquid assets to the outstanding government debt held by private domestic agents, which implies an annual liquid-to-illiquid ratio of 9%.

I set the borrowing limit in bonds, $\underline{b}$, to half of the average quarterly income and choose the penalty rate for unsecured borrowing, $\bar{R}$, such that 16% of households have negative net nominal positions as in the Survey of Consumer Finances 1983-2007.[19]

I calibrate the transitions in and out of the entrepreneur state to capture the distribution of wealth in the U.S. economy. For simplicity, I assume that the probability of becoming an entrepreneur is the same for workers independent of their labor productivity and that, once they become workers again, they start with median productivity. I calibrate the probability of leaving the entrepreneurial state to 1/16 per quarter following the numbers that Guvenen et al. (2014) report on the probability of dropping out of the top 1% income group in the U.S. (see their Table 2, roughly 25% p.a.). In order to match a wealth Gini index of 0.78, this implies that roughly 1%

[17] See Table 36 "Multiple jobholders by selected characteristics" from the U.S. Current Population Survey.

[18] The participation frequency of 12.5% per quarter is higher than in the optimal participation framework of Kaplan and Violante (2014). They find a participation frequency of 4.5% for working households given a fixed-adjustment cost of \$500.

[19] Appendix D.B provides a more detailed discussion of the cross-sectional data.

of households are entrepreneurs.[20]

I set the quarterly standard deviation of persistent shocks to idiosyncratic labor productivity to 0.06 and the quarterly autocorrelation to 0.98 – both standard values in the literature (c.f. Storesletten et al., 2004).

II.B.2 Production Sectors

The labor and capital share including profits (2/3 and 1/3) align with long-run U.S. averages. The persistence of the TFP shock is set to $\rho_Z = 0.95$. The standard deviation of the TFP shock, $\sigma_Z = 0.01$, is calibrated to make the model match the standard deviation of H-P-filtered U.S. output.

To calibrate the parameters of the resellers' problem, I use standard values for markup and price stickiness that are widely employed in the New Keynesian literature (c.f. Christiano et al., 1999). The Phillips curve parameter κ implies an average price duration of 4 quarters, assuming flexible capital at the firm level. The steady-state marginal costs, $\frac{\eta-1}{\eta} = 0.95$, imply a markup of 5%. I calibrate the adjustment cost of capital, $\phi = 10$, to match a relative investment volatility of 4.5 in response to TFP shocks – a standard value for U.S. data.

II.B.3 Central Bank and Government

I set the inflation rate to zero and the real return on bonds to 2% in line with the average federal funds rate in the U.S. in real terms from 1983 to 2007. Clarida et al. (2000) provide an estimate for the parameter governing interest rate smoothing, $\rho_R = 0.8$, while the central bank's reaction to deviations of inflation from target is standard, $\theta_\pi = 1.5$. The standard deviation of the monetary policy shock, σ_D, is 36 basis points annualized, which corresponds to the average quarterly shock as identified by the narrative approach (c.f. Wieland and Yang, 2016).

The government levies a proportional tax on labor income and profits to finance government spending and interest expense on debt. A tax rate of $\tau = 0.3$ closes the budget constraint given the interest expense and a government-spending-to-GDP ratio of 20% in the steady state. Government spending, in turn, follows a fiscal rule similar to Woodford (1995) or Bi et al. (2013). Specifically, I set $\rho_B = 0.86$, as estimated in Bayer et al.

[20] This mimics the U.S. income distribution. According to the Congressional Budget Office, the top 1% of the income distribution receives about 30% of their income from financial income, a much larger share than any other segment of the population.

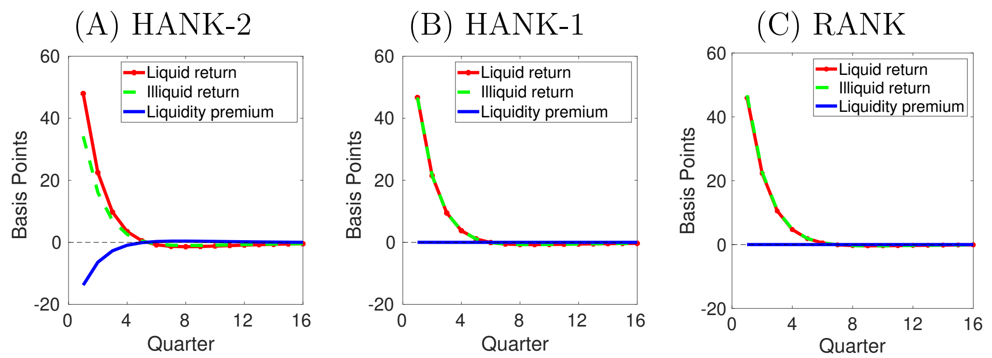
(2019), so that most of the adjustment goes through government debt and future government spending adjusts to bring debt back to its steady-state value. Appendix F.G provides robustness checks.

Table 2: Calibrated parameters

Parameter	Value	Description	Target
Households			
β	0.983	Discount factor	see Table 1
ν	12.5%	Participation frequency	see Table 1
ξ	4	Relative risk aversion	Kaplan and Violante (2014)
γ	1	Frisch elasticity	Chetty et al. (2011)
ψ	1	Disutility of labor	h=1 for 5% of HHs
$\overline{R}$	16%	Borrowing penalty	see Table 1
ρ_h	0.98	Persistence of productivity	Standard value
σ_h	0.06	STD of innovations	Standard value
Intermediate Goods			
α	70%	Share of labor	Income share labor of 66%
δ	1.35%	Depreciation rate	NIPA: Fixed assets
ρ_Z	0.95	Persistence of TFP shock	Standard value
σ_Z	0.01	STD of TFP shock	Volatility of output
Final Goods			
κ	0.09	Price stickiness	4 quarters
η	20	Elasticity of substitution	5% markup
Capital Goods			
ϕ	10	Capital adjustment costs	STD(I)/STD(Y)=4.5
Fiscal Policy			
τ	0.3	Tax rate	$G/Y = 20\%$
ρ_B	0.86	Autocorrelation of debt	Bayer et al. (2019)
Monetary Policy			
Π	1	Inflation	0% p.a.
R^B	1.005	Nominal interest rate	2% p.a.
θ_π	1.5	Reaction to inflation	Standard value
ρ_R	0.8	Interest rate smoothing	Clarida et al. (2000)
σ_R	9e-4	STD of monetary shock	Wieland and Yang (2016)

Notes: All values are reported for the quarterly frequency of the model.

Figure 1: Impulse responses to a monetary shock - Returns



Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). HANK-2 refers to the baseline model with household heterogeneity and two assets. HANK-1 refers to baseline model with only one asset (represent. portfolio). RANK refers to the representative household model. Dotted red line: Expected real return on liquid assets. Dashed green line: Expected real return on (illiquid) capital. Solid blue line: Liquidity premium $E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$. All returns are annualized.

III Monetary Transmission: Results

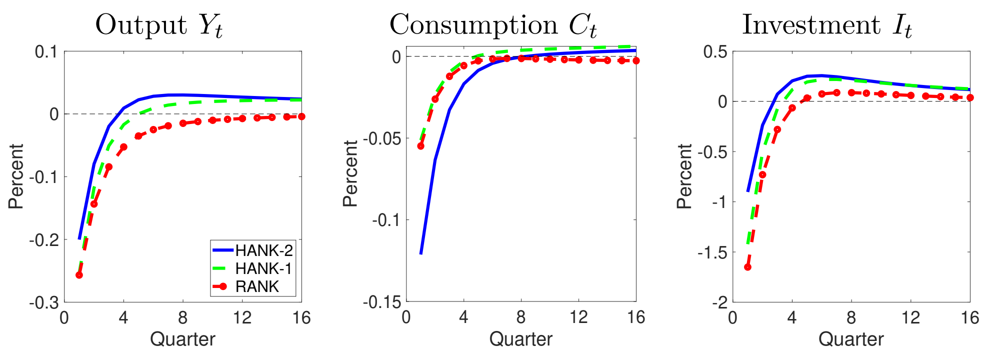
I first compare the aggregate effects of a monetary shock in the economy with heterogeneity in household portfolios to the same economy with 1) household heterogeneity but a representative portfolio and 2) a representative household.[21] I then further analyze and quantify the monetary transmission channels in the model with heterogeneity in household portfolios.

III.A Equilibrium Effects of a Monetary Policy Shock

I consider the effect of a monetary surprise that, all else equal, would increase the nominal interest rate on liquid assets by 1 standard deviation, i.e., 36 basis points (annualized), in period 1. Figure 1 compares the response of real returns in the economies with and without portfolio heterogeneity. In all three panels, the expected real return to liquid assets increases by 48 basis points (annualized). However, there is incomplete pass-through to the return on illiquid assets in the economy with portfolio heterogeneity. When both assets are liquid, the household portfolio posi-

[21] I keep the parameters of the models unchanged to isolate the effect of heterogeneity in household portfolios on the transmission of monetary policy.

Figure 2: Impulse responses to a monetary shock - Aggregate quantities



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). See Figure 1 for legend.

tion between the two assets is indeterminate in the steady state as long as the expected returns on both assets are equal

$$E_t\left[\frac{q_{t+1}+r_{t+1}}{q_t}\right] = E_t\left[\frac{R^B_{t+1}}{\pi_{t+1}}\right], \tag{19}$$

and in equilibrium they must be equal for households to be willing to hold a positive amount of both assets.[22] As a result, the return on capital moves one-to-one with the policy rate in Panel (B) and (C). In the model with portfolio heterogeneity, by contrast, the liquidity premium decreases in response to the monetary tightening by 16 basis points (annualized); see Panel (A). The liquidity premium falls because the monetary shock redistributes to wealthy households with a low marginal value of liquidity; see the next Section III.B.

The incomplete-pass through to illiquid returns matters for the aggregate effects of monetary policy; see Figure 2. Aggregate investment falls by one third less in the model with portfolio heterogeneity relative to the complete-markets model as well as the incomplete-markets model with representative portfolio. The output response is smaller as well but less so because consumption falls more in response to the monetary tightening. Consumption responds more because a sizable fraction of households are wealthy-hand-to-mouth and have high marginal propensities to consume;

[22]Since the solution method linearizes the problem in the presence of aggregate shocks, the portfolio problem remains indeterminate. Therefore, I assume that all households hold the same bond-to-capital ratio, which is in the aggregate determined by (19) and by the supply of government bonds.

see Kaplan et al. (2014). Hence, the composition of the output response markedly changes in the model with heterogeneity in household portfolios relative to models with a representative portfolio.[23]

The next section quantifies the transmission channels and elaborates on the role of portfolio heterogeneity and redistribution for the transmission.

III.B Transmission Channels of Monetary Policy

This section decomposes the monetary transmission in the model with heterogeneous household portfolios by writing aggregate consumption and investment as functions of a sequence of household policy functions induced by equilibrium prices $\{\Omega_t\}_{t\geq 0}$, with $\Omega_t = \{R_t^b/\pi_t, q_t + r_t, w_t, \Pi_t\}$:

$$C_t(\{\Omega_t\}_{t\geq 0}) = \int [\nu c_t^a(b,k,h;\{\Omega_t\}_{t\geq 0}) + (1-\nu)c_t^n(b,k,h;\{\Omega_t\}_{t\geq 0})]d\Theta_t,$$
$$K_t(\{\Omega_t\}_{t\geq 0}) = \int [\nu k_t^a(b,k,h;\{\Omega_t\}_{t\geq 0}) + (1-\nu)k^n(b,k,h)]d\Theta_t,$$

where $\Theta_t(db, dk, dh; \{\Omega_t\}_{t\geq 0})$ is the joint distribution of liquid and illiquid assets and idiosyncratic income. Totally differentiating both functions decomposes the total response to monetary shocks into the parts explained by each of the prices; see Auclert (2019) and Kaplan et al. (2018).

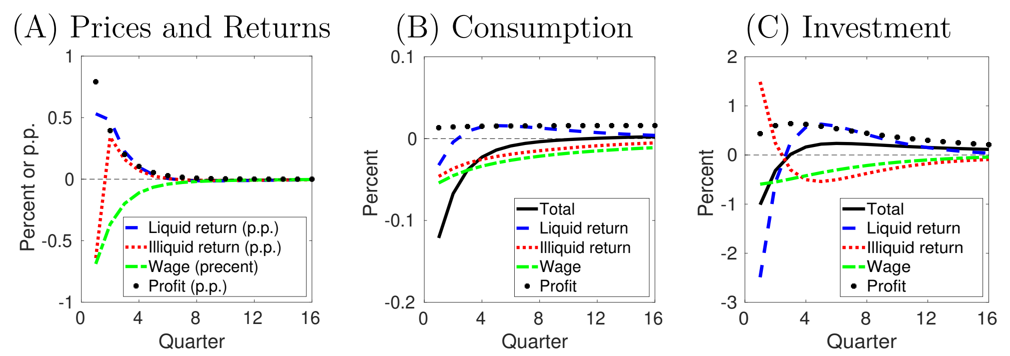
Figure 3 Panel (B) shows that the decline in wages explains around 40% of the initial fall in consumption; see Panel (A) for the sequence of prices and returns. Low wages have a persistently negative effect on consumption for the following 16 quarters. Lower illiquid returns effect consumption similarly. The change in the liquid return induced by the monetary shock explains only 30% of the initial decline in consumption, and this effect is very short-lived.[24]

With complete markets, these indirect price effects matter for consumption only in so far as they change lifetime income, because the consumption path is determined by a sequence of Euler equations and a single lifetime budget constraint. With incomplete markets, however, current income becomes an important determinant of consumption and portfolio decisions because of borrowing constraints.

[23]The finding of a lower elasticity of investment to monetary shocks is robust to the assumptions on fiscal policy, allocation of profits, and aggregate capital adjustment costs; see Appendix F.

[24]In a similar experiment, Kaplan et al. (2018) find that the liquid return explains 20% of the consumption response.

Figure 3: Transmission Channels - Aggregates



Panel (A): Impulse responses of prices and returns to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). For readability, I plot profit expressed as p.p. of steady-state markups. Liquid and illiquid returns are annualized. Panel (B) and (B): Decomposition of aggregate consumption and investment into the effect of each price sequence by using household policy functions.

The liquid return, however, still affects investment because wealthy households, who are unconstrained, hold most of the capital stock. The increase in the liquid return by itself would have decreased investment by 2.5%; see Panel (C). As investment falls, the expected return to illiquid capital increases, which dampens the fall in investment. This arbitrage channel is the only force at work in the two models with a representative portfolio. With individual portfolio choice other prices matter for investment as well. Low wages contribute to the fall in investment, while high profits partly offset this. Overall, the direct effect of the liquid return via arbitrage explains 86% of the aggregate investment response. Importantly, these price changes do not affect households with different portfolios to the same extent.

Table 3 summarizes the gains and losses on each source of income. They are reported relative to the average consumption of each wealth bracket. Labor income for households below median wealth falls by more than 1% of consumption, while households in the top quintile of the wealth distribution enjoy higher returns on their human capital on average because an disproportionate share are entrepreneurs. They receive profit income that increases while labor income falls.[25] The top quintile incurs the highest

[25]The results are qualitatively robust to allocating profits lump-sum; see Appendix F.E.

Table 3: Exposure to monetary shocks by wealth holdings

	Income gains/losses			Capital gains/losses
By wealth quintiles	Interest $\Delta(R^B_{t-1}/\pi_t)$	Dividends Δr_t	Labor/Profit $\Delta(W_t N_t + \Pi_t)$	on real assets Δq_t
1.	-0.01	-0.01	-1.09	-0.01
2.	0.15	-0.03	-1.20	-0.18
3.	0.24	-0.10	-1.15	-0.54
4.	0.28	-0.19	-1.04	-1.09
5.	0.38	-1.14	2.35	-6.49

Notes: Gains and losses in percent of within group consumption in period 0 to a one-standard deviation monetary policy shock, $\epsilon^D = 36$ basis points (annualized). Results are expressed in terms of steady-state consumption and averaged by using frequency weights from the steady-state wealth distribution.

losses on the real asset position. However, most of it is caused by lower asset prices that are not completely realized.

Overall, a tightening of monetary conditions increases inequality because it redistributes from borrowers to savers and from households that earn wage income to those that earn profit income. Both channels transfer from the bottom to the top of the wealth distribution and hence increase inequality.[26]

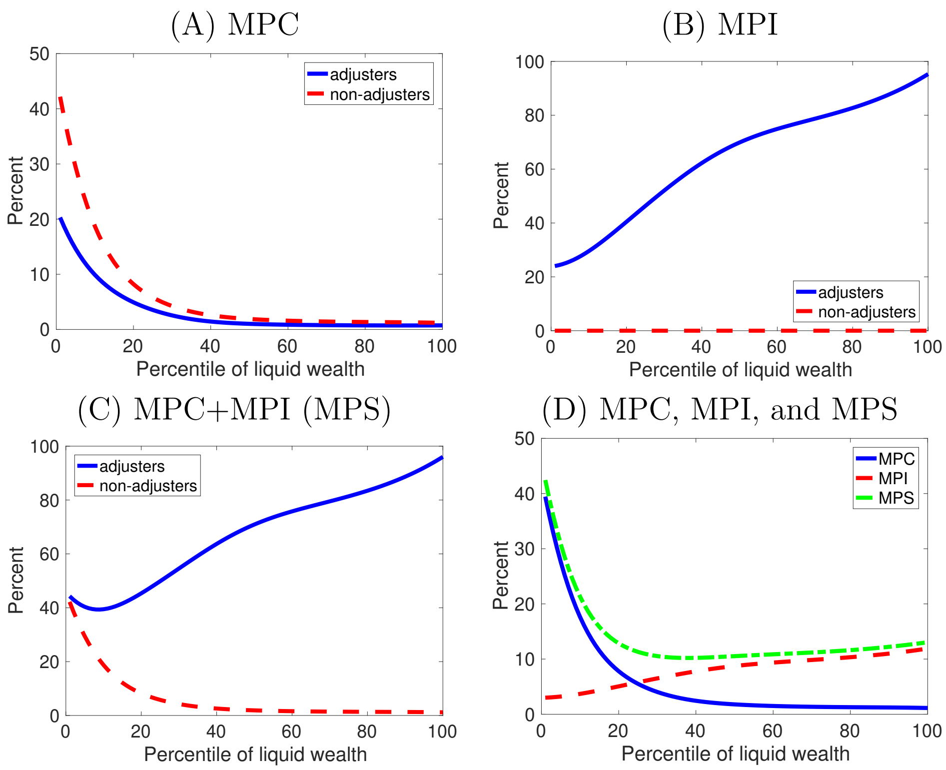
Redistribution affects monetary transmission because households differ in their marginal propensities to consume and invest. These measure how a household spends one additional dollar in liquid wealth in terms of consumption, investment, and bonds:

$$MPC_i^a = \frac{\partial c^a(b,k,h)}{\partial b}, \quad MPC_i^n = \frac{\partial c^n(b,k,h)}{\partial b}, \quad MPI_i^a = \frac{\partial k^a(b,k,h)}{\partial b},$$

where a stands for households that can adjust their portfolios and n for non-adjusters. Figure 4 plots these marginal propensities for each percentile of the liquid wealth distribution. Households close to the borrowing constraint have the highest marginal propensity to consume, around 40%, but the fraction of an additional dollar that goes into investment is less then 5%. Households above median wealth, in contrast, invest twice as much of any additional dollar. As wealthy households have a higher marginal propensity

[26]See Appendix C for the response of the Ginis of consumption, income, and wealth. These findings mirror recent empirical evidence by Coibion et al. (2017).

Figure 4: Marginal propensities to consume and invest

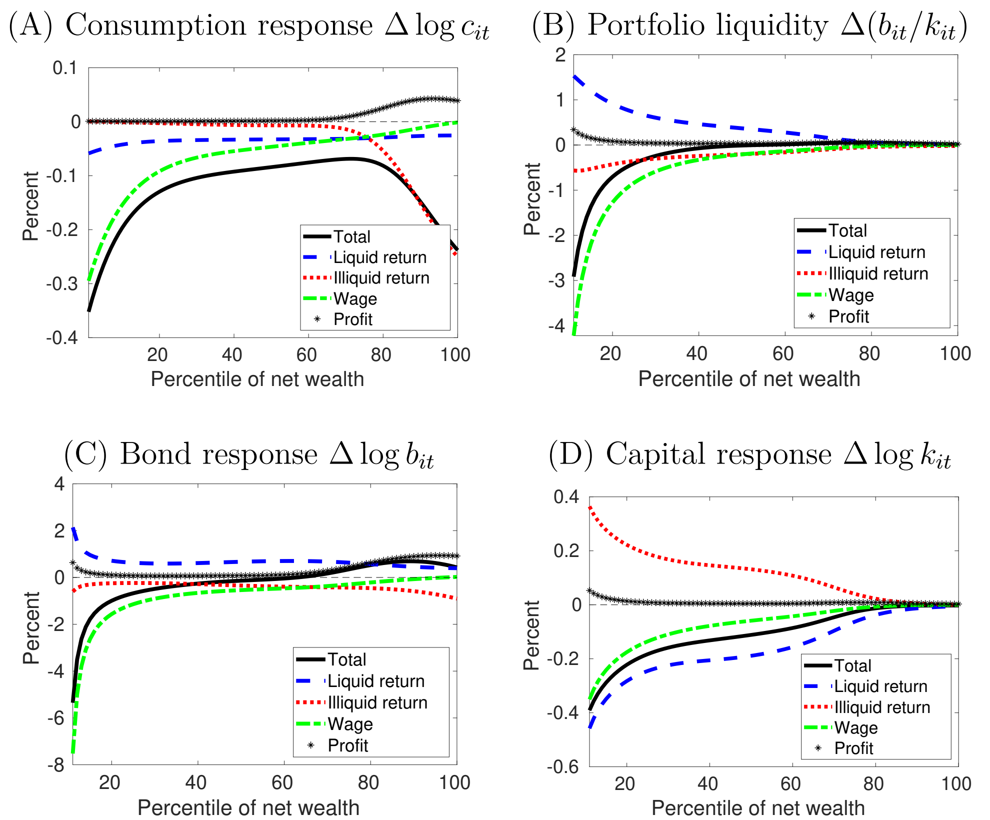


Marginal propensities to spend an additional dollar on (A) consumption, (B) investment, and (C) consumption plus investment for households that can and cannot adjust their illiquid asset position. Panel (D) shows all three propensities (MPC, MPI, MPS) for all households combined. Policies by liquid wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1.

to invest, they stabilize investment demand as they get richer through redistribution.

Figure 5 decomposes the change in consumption and portfolio choices across the wealth distribution. The fall in wages has the strongest impact on households with low wealth. For these households, who primarily rely on wage income and have high MPCs, the fall in wages explains 80% of the consumption response. Households below median net wealth even reduce their liquid wealth and portfolio liquidity – despite the fact that liquid returns are high – to smooth consumption. Wealthy households, by contrast, increase their holdings of liquid wealth and portfolio liquidity. As they now hold a larger fraction of aggregate liquid wealth, the liquidity premium falls because they have a lower marginal value of liquidity than wealth-poor

Figure 5: Transmission Channels - Heterogeneity



Response of individual consumption and asset demand policies to a 1 standard deviation monetary shock, $\epsilon^R = 36$ basis points (annualized). Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Asset demand policies start at the 11th percentile because poorer households hold negative liquid wealth.

households. The heterogeneity in household portfolio responses matches the empirical estimates of the portfolio response to monetary shocks; see next Section IV.

Redistribution via the Fisher channel is quantitatively important. Surprise deflation redistributes from borrowers to savers; see the column labeled 'Interest' in Table 3. On average, borrowers have higher marginal propensities to consume but lower marginal propensities to invest than savers. Hence, the Fisher channel amplifies the aggregate effects of monetary policy through aggregate demand. I quantify the Fisher channel by solving a version of the model with real debt, in which inflation-induced redistribution is absent, and find that aggregate output falls by roughly

9% more in the baseline model with nominal debt.[27] The immediate response of inflation in the model amplifies the effect of quarterly nominal debt. A sluggish response of inflation would weaken the Fisher channel, while adding long-term debt would strengthen it.[28] When prices are flexible, heterogeneity in propensities to consume does not matter because any shortfall in spending is offset by firms lowering prices. Only heterogeneity in the marginal propensity to invest matters in this case because it affects the future capital stock. For this reason, a monetary tightening leads to an investment boom with flexible prices as inflation redistributes from borrowers with low to savers with high marginal propensities to invest.

The importance of redistribution for monetary transmission increases in times of high wealth inequality. When I calibrate the model to the U.S. post-2008 by setting the return on liquid assets to zero, wealth inequality increases because the liquidity premium increases from 2.5 to 4.5 percentage points in the new steady state. Wealth-poor households, who predominantly save in the liquid asset, are less well-insured, while wealth-rich households, who predominantly save in the illiquid asset, get roughly the same return as before. Higher inequality amplifies the importance of the redistribution channel and, hence, further increase the consumption response while decreasing the response of investment.[29]

IV Empirical Evidence

Monetary policy shocks provide an important validation exercise for macroeconomic models (cf. Ramey, 2016). In this section, I use aggregate time-series data on liquidity premia and cross-sectional data on household portfolios to provide evidence for heterogeneity in the response to monetary shocks across households with different wealth.

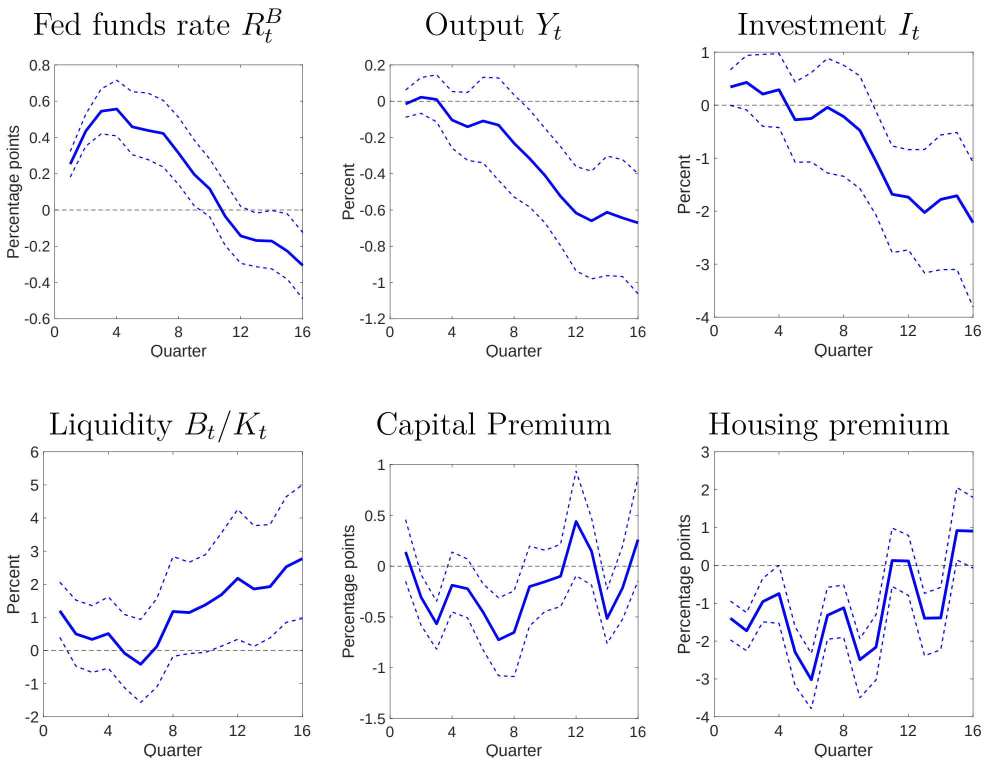
To that end, I first estimate the effect of monetary policy shocks on aggregate economic activity, average household portfolios from the Flow of Funds, and measures of liquidity premia. I then use cross-sectional information on household portfolios from the Survey of Consumer Finances (SCF). I find that wealthy households drive the increase in average liquidity,

[27] See Appendix F.C for impulse responses.

[28] Auclert (2019) discusses the importance of debt maturity for the Fisher channel.

[29] In the new steady state, I set the return on liquid assets to zero, $\bar{R}^B = 1.0$. This increases the Gini coefficient of wealth by 2.6%. See Appendix F.B for impulse responses.

Figure 6: Aggregate response to a monetary shock



Estimated response of each time series at $t+j, j = 1\ldots16$ to a monetary policy shock, $\epsilon_t^R = 36$ basis points, where t corresponds to quarters from 1983Q1 to 2007Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, R_t^B, \epsilon_t^R, \epsilon_{t-1}^R]$. Bootstrapped 90% confidence bands are shown in the dashed lines (block bootstrap). Capital premium: Gomme et al. (2011)'s return on capital minus the federal funds rate. Housing premium: Realized return on housing (rent-price ratio in t plus realized growth rate of house prices in $t+1$) minus the federal funds rate.

whereas poorer households see a substantial fall in portfolio liquidity in line with the model.

IV.A Aggregate Response to Monetary Shocks

Figure 6 shows the response of aggregate variables to a surprise increase in the federal funds rate. I estimate the responses by local projections with monetary shocks identified by the narrative approach (cf. Romer and

Romer, 2004):[30]

$$\Upsilon_{t+j} = \beta_{j,0} + \beta_{j,1}t + \beta_{j,2}\bar{\epsilon}_t^R + \beta_{j,3}\mathbf{X}_{t-1} + \nu_{t+j},\ j = 0...15, \tag{20}$$

where $\bar{\epsilon}_t^R$ are monetary shocks with a normalized standard deviation of 1, $\mathbf{X}_t = [Y_t, C_t, I_t, R_t^B, \epsilon_t^R, \epsilon_{t-1}^R]$ are aggregate controls and lagged monetary shocks, and Υ_{t+j} is the endogenous variable of interest at horizon j. I use quarterly data from 1983 to 2007.[31] See Appendix E.A for more details.

I consider a 1 standard deviation monetary shock (36 basis points annualized) that pushes up the federal funds rate for 3 years. In response, output falls by roughly 0.6% after 3 years and recovers only slowly. Consumption (reported in Appendix E.A) falls slightly less than output with a similar dynamic. Investment falls too, but its reaction is roughly three times as strong as the output reaction. This is qualitatively in line with the model with the difference that the model does not feature hump-shaped responses, which require different aggregate frictions; see e.g. Christiano et al. (2005).

The decline in investment finds its reflection in household balance sheets. The ratio of liquid-to-illiquid assets goes up after a monetary tightening; see upper middle panel of Figure 6. I calculate this ratio from the Flow of Funds (Table Z1-B.101) by defining liquid assets as all deposits, cash, debt securities (including government bonds), and loans held directly, while I treat all other real and financial assets as illiquid.[32]

While average liquidity goes up by around 2%, proxies for the liquidity premium fall. I proxy the liquidity premium by two measures. First, the return on capital as measured by Gomme et al. (2011) relative to the federal funds rate. Second, the realized return on housing (rent-price ratio in t plus realized growth rate of house prices in $t+1$) relative to the federal funds

[30] I use the updated shock series by Wieland and Yang (2016).

[31] I focus on the time after the Volcker disinflation and before the Great Recession for three reasons. First, the SCF is only available from 1983 onwards and monetary shocks only up to 2007. Second, this period is less likely to feature structural breaks. Third, I want to exclude the Great Recession because financial frictions are constant in the model.

[32] Kaplan et al. (2018) adopt a very similar asset taxonomy. The reason to treat equities as illiquid is that most equities are held in the form of pension funds. Equity shares held directly only play a role above the 85th wealth percentile. Publicly traded equities that a single household can sell without price impact play a significant role in household portfolios only for a relatively small fraction of households and a small fraction of the aggregate capital stock.

rate.[33] Both measures of the liquidity premium decrease in response to the monetary tightening. Quantitatively, the range of the decline is between 10 to 100 basis points (annualized), which includes the 16 basis points decline of the liquidity premium predicted by the model.

I use these two proxies for the liquidity premium as they most closely correspond to the definition of illiquidity in the model. Houses take time to sell and are the most important asset for the median U.S. household. Aggregate capital includes the housing stock as well as privately owned companies, which together make up around 2/3 of capital in the U.S. In this respect, I differ from the previous literature, which has focused on risk premia as measured by the equity premium or bond premium. This literature typically finds that risk premia are counter-cyclical and attributes this to financial frictions; see Gertler and Karadi (2015) for the bond premium and Bernanke and Kuttner (2005) for equity premium.[34] My paper, in contrast, keeps financial frictions constant and highlights the effects of a time-varying distribution of households who differ in their marginal value of liquidity.

The next section shows that behind the increase in average liquidity lies large heterogeneity in household responses.

IV.B Household Response to Monetary Shocks

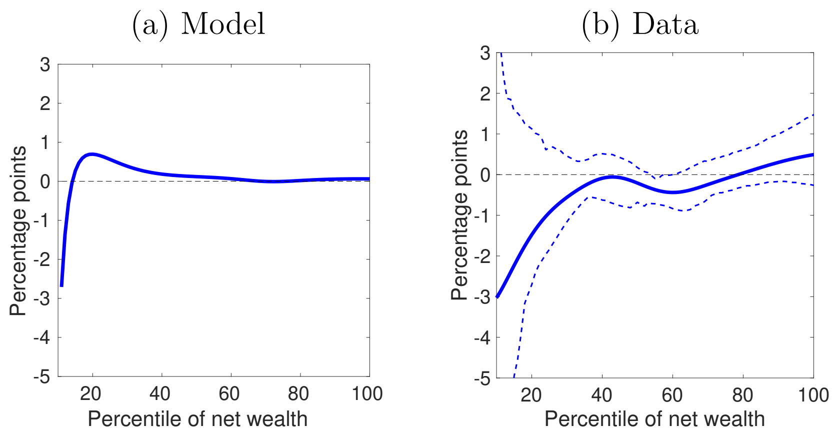
In the following, I estimate the response of household portfolios to monetary policy shocks. I order households by their net wealth and document heterogeneity in the response of portfolio liquidity across the wealth distribution in line with the model.

I use the Survey of Consumer Finances, which is the only U.S. survey that has rich information on household's balance sheets since the 1980s. Given the nature of the SCF (triannual repeated cross-sections), the identification assumption is that, for a given level of wealth, households at time t (when the shock occurs) are comparable to households at time t+3 along dimensions other than wealth. I follow the approach by Cloyne et al. (2019) to control for changing demographics as portfolios have a strong life-cycle

[33] The house price is the Case-Shiller S&P national house price index. Rents are imputed on the basis of the CPI for rents of primary residences, fixing the rent-price ratio in 1983Q1 to 4%.

[34] Appendix E.A shows the response of the equity premium and bond premium for my regressions. I also provide robustness checks using monetary shocks identified by the high frequency approach and find my results to be robust.

Figure 7: Portfolio response, $\Delta(\frac{b_{it}}{q_t k_{it}})$, to a monetary shock in equilibrium



Change in portfolio liquidity after a 1 standard deviation monetary shock (at yearly frequency), $\epsilon^R = 96$ basis points (annualized), after 3 years. Portfolio response by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Data correspond to the local projection with SCF data as in Section IV. Bootstrapped 66% confidence bands are shown in the dashed lines, based on a non-parametric bootstrap. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

component. In particular, I control non-parametrically for age, and work with residual portfolio positions. I also construct synthetic cohorts by using three birth cohorts (young, born after 1949; middle, born between 1935 and 1949; old, born before 1935).[35]

Using the Survey of Consumer Finances, I estimate the liquidity ratio $\frac{\lambda^{LI}(prc,t)}{\lambda^{IL}(prc,t)}$ by each percentile, prc, of net wealth for each SCF survey year t from 1983 to 2007 after controlling for demographics. The definition of net liquid wealth corresponds to the Flow of Funds data, i.e., net liquid assets include all savings and checking accounts, call and money market accounts, certificates of deposit, all types of bonds, and private loans net of credit card debt. All other assets are considered illiquid. Appendix D.B discusses the asset classification and the construction of the liquidity ratios in more detail.

I regress these residual portfolio measures for each percentile of wealth on annual monetary shocks, $\gamma_2(prc)$, including an intercept, $\gamma_0(prc)$, and a

[35]The cohort-specific regressions are reported in Appendix E.B.

linear time trend, $\gamma_1(prc)$:

$$\lambda^{LI/IL}(prc, t+j) = \gamma_0(prc) + \gamma_1(prc)t + \gamma_2(prc)\bar{\epsilon}_t^R + \zeta,$$

i.e., I use a local projection technique. Appendix E.B spells out the details. Figure 7 reports the coefficients, $\gamma_2(prc)$, of the portfolio response to a one standard deviation monetary shock after 3 years.[36] I use a block bootstrap to estimate confidence bands.

Figure 7 Panel (b) reveals large heterogeneity in the response of portfolio liquidity to a surprise increase in the federal funds rate. The liquidity ratio of portfolios held by households with below median wealth falls by up to 3 percentage points. Only those households in the top of the wealth distribution respond to a higher return on liquid assets by increasing the liquidity of their portfolios. Therefore, wealthy households drive the increase in average liquidity as seen in the Flow of Funds data in Figure 6.

This is in line with the predictions by the model; see Figure 7 Panel (a). The portfolio adjustment friction is key for the model to generate the sign difference in the portfolio response across households. As capital becomes more liquid, fewer households lower their portfolio liquidity.[37]

V Conclusion

In a monetary model with assets of different liquidity that matches U.S. household portfolios, monetary transmission works through the response of investment, which is crucially shaped by redistribution. Liquidity constraints lead to heterogeneity in marginal propensities to consume and invest, which interact with the distributional consequences of monetary shocks. Monetary contractions redistribute to wealthy households, who have high propensities to invest and a low marginal value of liquidity, which dampens the response of investment. At the same time, redistribution amplifies the consumption response of wealth-poor households.

Redistribution through the Fisher channel from unexpected inflation is quantitatively important. When the economy is demand-driven, the Fisher

[36] I sum up the monthly shocks to create yearly monetary shocks. The standard deviation of yearly shocks is 96 basis points (annualized).

[37] See Appendix F.A for counterfactuals.

channel amplifies the aggregate effects of monetary shocks through heterogeneity in propensities to spend. When prices are flexible, in contrast, the Fisher channel works through investment and leads to an expansion of investment after a monetary tightening.

These results challenge the conventional view of the monetary transmission mechanism that solely focuses on the intertemporal consumption choice. To further assess the importance of heterogeneity in household portfolios, the portfolio problem could be extended in a number of dimensions. So far, the Fisher channel only works through unsecured debt in the model. The introduction of collateralized debt should further increase its quantitative importance. Modeling long-term debt goes in the same direction. This also opens a new channel of redistribution through unhedged interest rate exposures; see Auclert (2019).

More generally, it is important to reassess optimal policy in a New Keynesian model with incomplete markets to analyze potential trade-offs between aggregate stabilization and inequality.

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A First Order Conditions

Denote the optimal policies for consumption, labor supply, bond holdings, and capital holdings as $c_i^*, n_i^*, b_i^*, k^*, i \in \{a, n\}$ respectively. Let $\mathbf{z}$ be a vector of potential aggregate states. The first-order conditions for an inner solution in the (non-)adjustment case read:

$$
\begin{aligned}
&(21) \qquad k^* : \frac{\partial u(c_a^*)}{\partial c} q &&= \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial k} + (1-\nu) \frac{\partial V_n(b_a^*, k^*; \mathbf{z}')}{\partial k} \right] \\
&(22) \qquad b_a^* : \frac{\partial u(c_a^*)}{\partial c} &&= \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial b} + (1-\nu) \frac{\partial V_n(b_a^*, k^*; \mathbf{z}')}{\partial b} \right] \\
&(23) \qquad b_n^* : \frac{\partial u(c_n^*)}{\partial c} &&= \beta E \left[\nu \frac{\partial V_a(b_n^*, k; \mathbf{z}')}{\partial b} + (1-\nu) \frac{\partial V_n(b_n^*, k; \mathbf{z}')}{\partial b} \right] \\
&(24) \qquad n_a^* : \frac{\partial u(n_a^*)}{\partial n} &&= \frac{\partial u(c_a^*)}{\partial c} \tau w h \\
&(25) \qquad n_n^* : \frac{\partial u(n_n^*)}{\partial n} &&= \frac{\partial u(c_n^*)}{\partial c} \tau w h
\end{aligned}
$$

Note the subtle difference between (22) and (23) that is the different capital stocks k^* vs. k in the right-hand side expressions.

Differentiating the value functions with respect to k and b, I obtain the following:

(26)
$$\frac{\partial V_a(b,k;\mathbf{z})}{\partial k} = \frac{\partial u[c_a^*(b,k;\mathbf{z})]}{\partial c}(q(\mathbf{z})+r(\mathbf{z}))$$
(27)
$$\frac{\partial V_a(b,k;\mathbf{z})}{\partial b} = \frac{\partial u[c_a^*(b,k;\mathbf{z})]}{\partial c}\frac{R^b(\mathbf{z})}{\pi(\mathbf{z})}$$
(28)
$$\frac{\partial V_n(b,k;\mathbf{z})}{\partial b} = \frac{\partial u[c_n^*(b,k;\mathbf{z})]}{\partial c}\frac{R^b(\mathbf{z})}{\pi(\mathbf{z})}$$
(29)
$$\begin{aligned}\frac{\partial V_n(b,k;\mathbf{z})}{\partial k} &= r(\mathbf{z})\frac{\partial u[c_n^*(b,k;\mathbf{z})]}{\partial c} \\ &+ \beta E\left[\nu\frac{\partial V_a[b_n^*(b,k;\mathbf{z}),k;\mathbf{z}']}{\partial k} + (1-\nu)\frac{\partial V_n[b_n^*(b,k;\mathbf{z}),k;\mathbf{z}']}{\partial k}\right] \\ &= r(\mathbf{z})\frac{\partial u[c_n^*(b,k;\mathbf{z})]}{\partial c} + \beta\nu E\frac{\partial u\{c_a^*[b_n^*(b,k;\mathbf{z}),k;\mathbf{z}],k;\mathbf{z}'\}}{\partial c}(q(\mathbf{z}')+r(\mathbf{z}')) \\ &+ \beta(1-\nu)E\frac{\partial V_n\{[b_n^*(b,k;\mathbf{z}),k;\mathbf{z}],k;\mathbf{z}'\}}{\partial k}\end{aligned}$$

The marginal value of capital in the case of non-adjustment is defined recursively.

Substituting the second set of equations into the first set of equations, I obtain the following Euler equations (in slightly shortened notation):

(30)
$$\frac{\partial u[c_a^*(b,k;\mathbf{z})]}{\partial c}q(\mathbf{z}) = \beta E\left[\nu\frac{\partial u[c_a^*(b_a^*,k^*;\mathbf{z}')]}{\partial c}[q(\mathbf{z}')+r(\mathbf{z}')] + (1-\nu)\frac{\partial V^n(b_a^*,k^*;\mathbf{z}')}{\partial k}\right]$$
(31)
$$\frac{\partial u[c_a^*(b,k;\mathbf{z})]}{\partial c} = \beta E\frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')}\left[\nu\frac{\partial u[c_a^*(b_a^*,k^*;\mathbf{z}')]}{\partial c} + (1-\nu)\frac{\partial u[c_n^*(b_a^*,k^*;\mathbf{z}')]}{\partial c}\right]$$
(32)
$$\frac{\partial u[c_n^*(b,k,;\mathbf{z})]}{\partial c} = \beta E\frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')}\left[\nu\frac{\partial u[c_a^*(b_n^*,k;\mathbf{z}')]}{\partial c} + (1-\nu)\frac{\partial u[c_n^*(b_n^*,k;\mathbf{z}')]}{\partial c}\right]$$

In words, the optimal portfolio allocation compares the one-period return difference between the two assets for the case of adjustment and non-adjustment, taking into account the adjustment probability. In case of adjustment, the return difference is $E\frac{R^b(z')}{\pi(z')} - E\frac{r(z')+q(z')}{q(z)}$ weighted with the marginal utility under adjustment. In case of non-adjustment, the return difference becomes $E\frac{R^b(z')}{\pi(z')}\frac{\partial u[c_n^*(b_a^*,k';z')]}{\partial c} - \frac{\partial V^n(b_a^*,k';z')}{\partial k'}$, where the latter part is the marginal value of illiquid assets when not adjusting. The latter reflects both the utility derived from the dividend stream and the utility from occasionally selling the asset.

B Numerical Solution

My model has a three-dimensional idiosyncratic state space with two endogenous states. This renders solving the model by perturbing the histogram and the value functions on a full grid infeasible such that I cannot apply a perturbation method without state-space reduction as done in Reiter (2002).

Instead, I apply a method developed in joint-work with Christian Bayer. Bayer and Luetticke (2018) propose a variant of Reiter's (2009) method to solve heterogeneous agent models with aggregate risk. The key to reducing the dimensionality of the system is Sklar's Theorem. I write the distribution function in its copula form: $\Theta_t = \mathcal{C}_t(F_t^b, F_t^k, F_t^h)$ with the copula $\mathcal{C}_t$ and the marginal distributions for liquid and illiquid assets and productivity $F_t^{b,k,h}$. Assuming $\mathcal{C}_t = \mathcal{C}$ breaks the curse of dimensionality because one only needs to perturb the marginal distributions.

The idea behind this approach is that given the economic structure of the model, prices only depend on aggregate asset demand and supply, as in Krusell and Smith (1998), and not directly on higher moments of the *joint* distributions Θ_t, Θ_{t+1}. Fixing the copula to its steady state imposes no restriction on how the marginal distributions change, i.e., how many more or less liquid assets the portfolios of the x-th percentile have. It only restricts the change in the likelihood of a household being among the x-percent richest in liquid assets to be among the y-percent richest in illiquid assets.

For the policies, I use a sparse polynomial $P(b, k, h)$ with parameters $\Xi_t = \Xi(R_t^B, \Theta_t, \epsilon_t^R)$ to approximate the value functions at all grid points around their value in the stationary equilibrium without aggregate risk, $V^{SS}(b, k, h)$. For example, I write the value function as

$$V(b, k, h; R_t^B, \Theta_t, \epsilon_t^R)/V^{SS}(b, k, h) \approx P(b, k, h)\Xi_t.$$

Table 4: Den Haan (2010) statistic

	Absolute error (in %) for			
	Price of Capital q_t	Capital K_t	Inflation π_t	Real Bonds B_t
Mean	0.05	0.28	0.02	0.05
Max	0.19	0.81	0.07	0.17

Notes: Differences in percent between the simulation of the linearized solution of the model with monetary shocks and a simulation in which I solve for the actual intratemporal equilibrium prices in every period given the implied expected continuation values for $t = \{1, ..., 1000\}$; see Den Haan (2010).

Note the difference to a global approximation of the value function for finding the stationary equilibrium without aggregate risk. Here, I only use the sparse polynomial to capture *deviations* from the stationary equilibrium values, cf. Ahn et al. (2018) and different from Winberry (2018) and Reiter (2009). I define the polynomial basis functions such that the grid points of the full grid coincide with the Chebyshev nodes for this basis.

The economic model boils down to a dynamic system that can be represented by a set of non-linear difference equations, for which hold

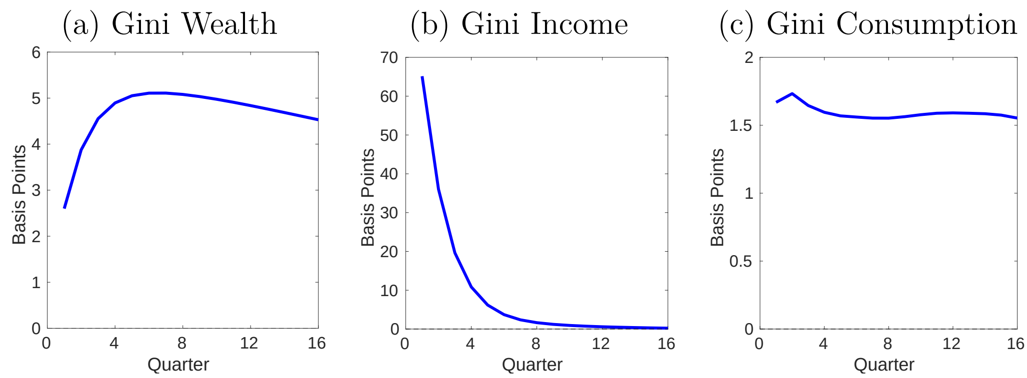
$$E_t F\left(X_t, X_{t+1}, Y_t, Y_{t+1}\right) = 0,$$

where the set of control variables is $Y_t = (\frac{\partial V_t^a}{\partial b}, \frac{\partial V_t^n}{\partial b}, \frac{\partial V_t}{\partial k}, \tilde{Y}_t)$, i.e., derivatives of the value function with respect to b and k as well as some aggregate controls $\tilde{Y}_t$ such as dividends, wages, etc. The set of state variables $X_t = (\Theta_t, R_t^B, \epsilon_t^R)$ is given by the histogram Θ_t of the distribution over (b, k, h) and the aggregate states R_t^B and ϵ_t^R.

Finally, I check the quality of the linearized solution (in aggregate shocks) by solving the household planning problem given the implied expected continuation values from the approximate solution but solving for the actual intratemporal equilibrium, as suggested by Den Haan (2010). I simulate the economy over T=1000 periods and calculate the differences between the linearized solution and the non-linear one. The maximum difference is 0.8% for the capital stock and 0.2% for bonds while the mean absolute errors are substantially smaller; see Table 4.

C Distributional Consequences: Gini Indexes

Figure 8: Response of inequality to a monetary shock



Notes: Impulse responses of Gini indexes of wealth, income, and consumption to a 36 basis points (annualized) monetary policy shock, ϵ^R. The y-axis shows basis point changes (an increase of "100" implies an increase in the Gini index from, say, 0.78 to 0.79).

Figure 8 displays the Gini indexes for total wealth, income, and consumption. Inequality in income and consumption instantaneously react to the contractionary monetary policy shock, whereas wealth inequality slowly builds up. The initial increase in the Gini index for income is almost 10 times larger than the increase in the Gini index for consumption. This implies substantial consumption smoothing. The dynamics of income inequality follow the response of inflation, which quickly returns to its steady state value and with it profits as well. The increase in consumption inequality, in contrast, is more persistent because of a prolonged time of higher wealth inequality.

D Description of Aggregate and Cross-Sectional Data

D.A Data from the Flow of Funds

The financial accounts of the Flow of Funds (FoF), Table Z1, report the aggregate balance sheet of the U.S. household sector (including nonprofit organizations serving households). I use this data in my analysis to measure changes in the aggregate ratio of net liquid to net illiquid assets on a quarterly basis. The asset taxonomy is the following and closely corresponds to my definition of liquidity in the cross-sectional data.

Net liquid assets are defined as total currency and deposits, money market fund shares, various types of debt securities (Treasury, agency- and GSE-backed, municipal, corporate and foreign), loans (as assets), and total miscellaneous assets net of consumer credit, depository institution loans n.e.c., and other loans and advances.

Net illiquid wealth includes real estate at market value, life insurance reserves, pension entitlements, equipment and non-residential intellectual property products of non-profit organizations, proprietors' equity in non-corporate business, corporate equities, mutual fund shares subtracting home mortgages as well as commercial mortgages.

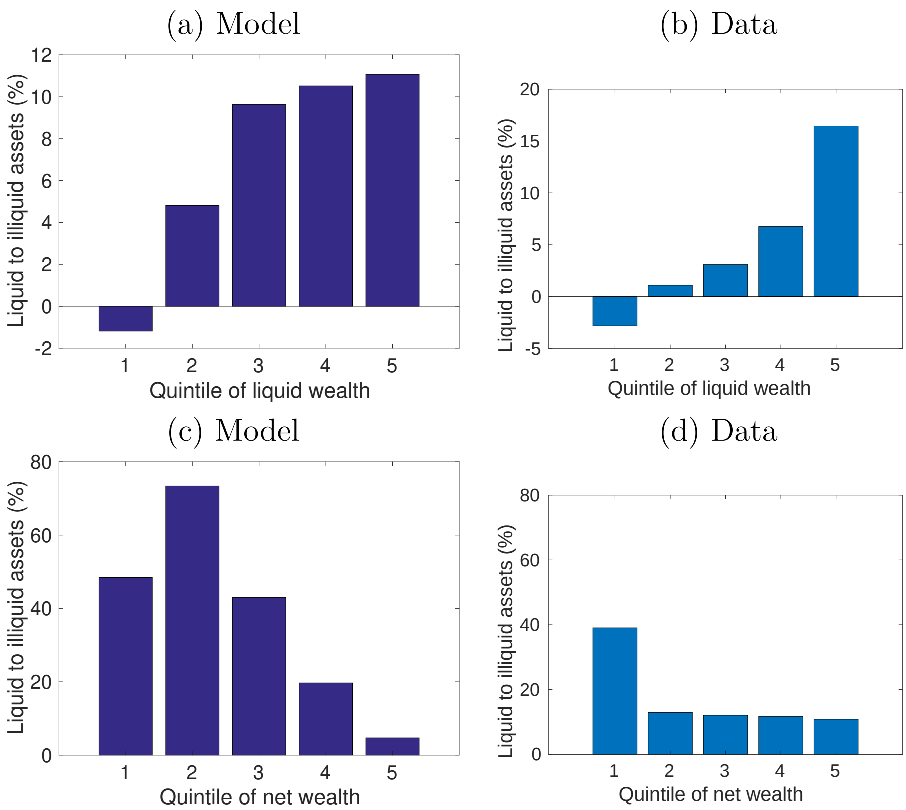
D.B Data from the Survey of Consumer Finances

I use nine waves of the Survey of Consumer Finances (SCF, 1983-2007) for the empirical analysis of the response of household portfolios to monetary shocks and for the calibration of the model. I restrict the sample to households with two married adults whose head is between 25 and 60 years of age to exclude education and retirement decisions that are not explicitly modeled. I control for changing demographics by regressing asset holdings on age-dummies and by constructing synthetic panels by birth year as done by Cloyne et al. (2019). The asset taxonomy is the following.

Net liquid assets include all households' savings and checking accounts, call and money market accounts (incl. money market funds), certificates of deposit, all types of bonds (such as savings bonds, U.S. government bonds, Treasury bills, mortgage-backed bonds, municipal bonds, corporate bonds, foreign and other tax-free bonds), and private loans net of credit card debt.

All other assets are considered illiquid. Most households hold their illiquid wealth in real estate and pension wealth from retirement accounts and life insurance policies. Furthermore, I treat business assets, other non-financial and managed assets and corporate equity in the form of directly held mutual funds and stocks as illiquid, because a large share of equities owned by private households is not publicly traded nor widely circulated (see Kaplan et al., 2018). From gross illiquid asset holdings, I subtract all debt except for credit card debt.

Figure 9: Average portfolio liquidity by liquid/net wealth quintiles



Notes: Panels (a) and (b): Estimated net liquid asset holdings relative to estimated net illiquid assets by quintile of the liquid wealth distribution. Panels (c) and (d): Estimated positive liquid asset holdings relative to estimated net illiquid assets by quintile of the net wealth distribution.
Average over the estimates from the SCFs 1983-2007 (for households composed of at least two adults whose head is between 30 and 55 years of age). Estimation by a local linear estimator with a Gaussian kernel and a bandwidth of 0.1.

I exclude cars and car debt from the analysis altogether. What is more, I exclude from the analysis households that hold massive amounts of credit card debt such that their net liquid assets are below minus half of the average quarterly household income – the debt limit I use in the model. Moreover, I exclude all households with negative equity in illiquid assets. This excludes roughly 5% of U.S. households on average from the analysis. Figure 9 and Table 5 display some key statistics of the distribution of liquid and illiquid assets in the population and the model.

I estimate the asset holdings at each percentile of the net wealth distribution by running a local linear regression that maps the percentile rank in net wealth into the net liquid and net illiquid asset holdings. In detail, let LI_{it} and IL_{it} be the value of liquid and illiquid assets of household i in the SCF of year t, respectively. Let ω_{it} be its sample weight. Then I first sort households by net wealth $(LI_t + IL_t)$ and calculate the percentile rank of a household i as $\mathbf{prc}_{it} = \sum_{j<i} \omega_{jt} / \sum_j \omega_{jt}$. I then run for each percentile, $prc = 0.01, 0.02, \ldots 1$, a local linear regression. For this regression, I calculate the weight of household i as $w_{it} = \sqrt{\phi(\frac{\mathbf{prc}_{it} - prc}{h})\omega_{it}}$, where ϕ is the probability density function of a standard normal, and $h = 0.1$ is the bandwidth. I then estimate the liquid and illiquid asset holdings at percentile prc at time t as the intercepts $\lambda^{LI,IL}(prc, t)$ obtained from the weighted regressions for year t:

$$w_{it} LI_{it} = \lambda^{LI}(prc,t) w_{it} + \beta^{LI}(prc,t)(\mathbf{prc}_{it} - prc) w_{it} + \zeta_{it}^{LI}, \tag{33}$$

$$w_{it} IL_{it} = \lambda^{IL}(prc,t) w_{it} + \beta^{IL}(prc,t)(\mathbf{prc}_{it} - prc) w_{it} + \zeta_{it}^{IL}, \tag{34}$$

where $\zeta^{LI/IL}$ are error terms.

Figure 10 compares the percentage deviations of average portfolio liquidity, $\sum_{prc} \lambda^{LI}(prc,t) / \sum_{prc} \lambda^{IL}(prc,t)$, from their long-run mean to those obtained from the FoF data for the years 1983 to 2007. Both data sources capture very similar changes in the liquidity ratio over time.

The average liquid to illiquid assets ratios, however, differ between the SCF and FoF. The SCF systematically underestimates gross financial assets and, hence, liquid asset holdings. The liquidity ratio in the FoF is roughly 20%, about twice as large as the one in the SCF. One reason is that households are more likely to underestimate their deposits and bonds due to a large number of potential asset items, whereas they tend to overestimate the value of their real estate and equity (compare also Table C.1.

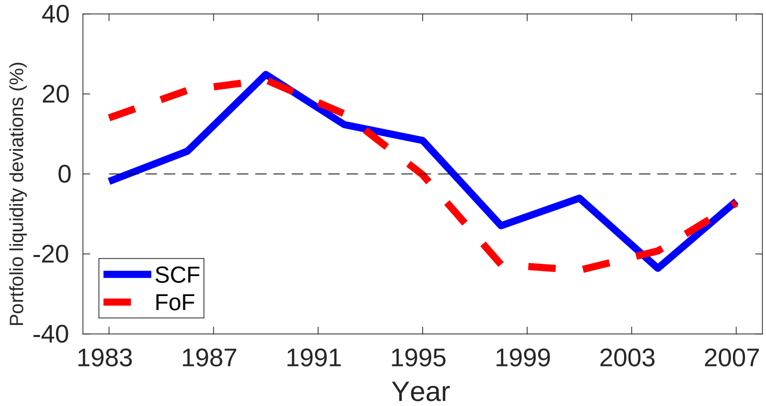
Table 5: Household portfolio composition:
Survey of Consumer Finances 1983-2007
Married households with head between 30 and 55 years of age

Moments	Model	Data
Fraction with $b < 0$	0.16	0.16
Fraction with $k > 0$	0.85	0.91
Fraction with $b \leq 0$ and $k > 0$	0.10	0.13
Gini liquid wealth	0.64	0.88
Gini illiquid wealth	0.83	0.78
Gini total wealth	0.78	0.78

Notes: Averages over the SCFs 1983-2007 using the respective cross-sectional sampling weights. Households whose liquid asset holdings fall below minus half of the average quarterly income are dropped from the sample. Ratios of liquid to illiquid wealth are estimated by first estimating local linear functions that map the percentile of the wealth distribution into average liquid and average illiquid asset holdings for each year, then averaging over years and finally calculating the ratios.

in Kaplan et al., 2018).

Figure 10: Deviation of portfolio liquidity from mean in SCF and FoF



D.C Other Aggregate Data

Section IV shows the impulse response functions of the log of real GDP, real personal consumption expenditures, and real gross private investment. These variables are taken from the national accounts data provided by the Federal Reserve Bank of St. Louis (Series: PCEC, GPDI). GDP is calculated as the sum of real consumption, real investment, and real government purchases (GCEC1).

Data on the federal funds rate and the liquidity premia come from the same source. I construct the housing premium from nominal house prices, the CPI for rents, and the federal funds rate. House prices come from the Case-Shiller S&P U.S. National Home Price Index (CSUSHPINSA) divided by the all-items CPI (CPIAUCSL). I measure the housing premium as the excess realized return on housing. This is composed of the rent-price-ratio, $R_{h,t}$, in t plus the quarterly growth rate of house prices in $t+1$, $\frac{H_{t+1}}{H_t}$, over the nominal rate, R_t^B, (converted to a quarterly rate):

$$LP_t = \frac{R_{h,t}}{H_t} + \frac{H_{t+1}}{H_t} - (1 + R_t^B)^{\frac{1}{4}}. \tag{35}$$

Rents are imputed on the basis of the CPI for rents on primary residences paid by all urban consumers (CUSR0000SEHA) fixing the rent-price-ratio in 1983Q1 to 4%. The capital premium is the return on capital as measured by Gomme et al. (2011), who use the National Income and Product Accounts, minus the federal funds rate. The equity premium is the growth rate of Wilshire 5000 Total Market Full Cap Index (WILL5000INDFC) minus the federal funds rate. Finally, the convenience yield, a measure of liquidity in financial markets, is equal to the Moody's Seasoned Aaa Corporate Bond Yield (AAA) minus 10-Year Treasury Constant Maturity Rate (GS10).

E Details on the Empirical Estimates of the Response to Monetary Shocks

E.A Local Projection Method for Aggregate Data

Figure 6 of Section IV shows impulse response functions based on local projections (see Jordà, 2005). This method does not require the specification and estimation of a vector autoregressive model for the true data generating process. Instead, in the spirit of multi-step direct forecasting, the impulse responses of the endogenous variables Υ at time $t+j$ to monetary shocks, ϵ_t^R, at time t are estimated using horizon-specific single regressions, in which the endogenous variable shifted ahead is regressed on the current normalized monetary shock $\bar{\epsilon}_t^R$ (with standard deviation 1), a constant, a time trend, and controls $\mathbf{X}_{t-1}$. These controls are specified as the lagged federal funds rate R_{t-1}^B and the log of GDP Y_{t-1}, consumption C_{t-1}, investment I_{t-1}, and of lagged monetary shocks $\epsilon_{t-1}^R, \epsilon_{t-2}^R$:

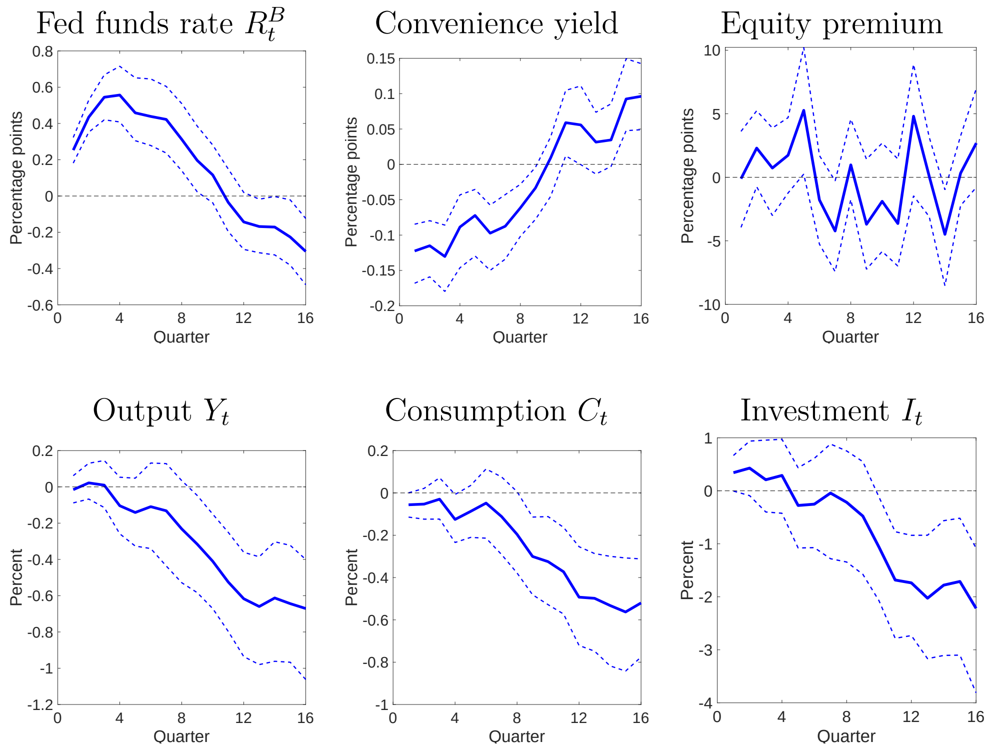
$$\Upsilon_{t+j} = \beta_{j,0} + \beta_{j,1}t + \beta_{j,2}\bar{\epsilon}_t^R + \beta_{j,3}\mathbf{X}_{t-1} + \nu_{t+j}, \;\; j = 0...15 \tag{36}$$

Hence, the impulse response function $\beta_{j,0}$ is just a sequence of projections of Υ_{t+j} in response to the shock $\bar{\epsilon}_t^R$, local to each forecast horizon $j = 0...15$. I focus on the post-Volcker disinflation era and use aggregate time series data from 1983Q1 to 2007Q4.

An important assumption made for employing the local projection method, which directly regresses the shocks on the endogenous variable of interest, is that the identified monetary shocks ϵ_t^R obtained from narrative approach are exogenous. To this end, I use monetary shocks identified by Wieland and Yang (2016) that improve on the original shock series by Romer and Romer (2004).

Figure 11 provides the impulse responses of the equity premium and the bond premium. The equity premium is not significantly different from zero. The bond premium as measured by the convenience yield (Moody's

Figure 11: Aggregate response to a monetary shock

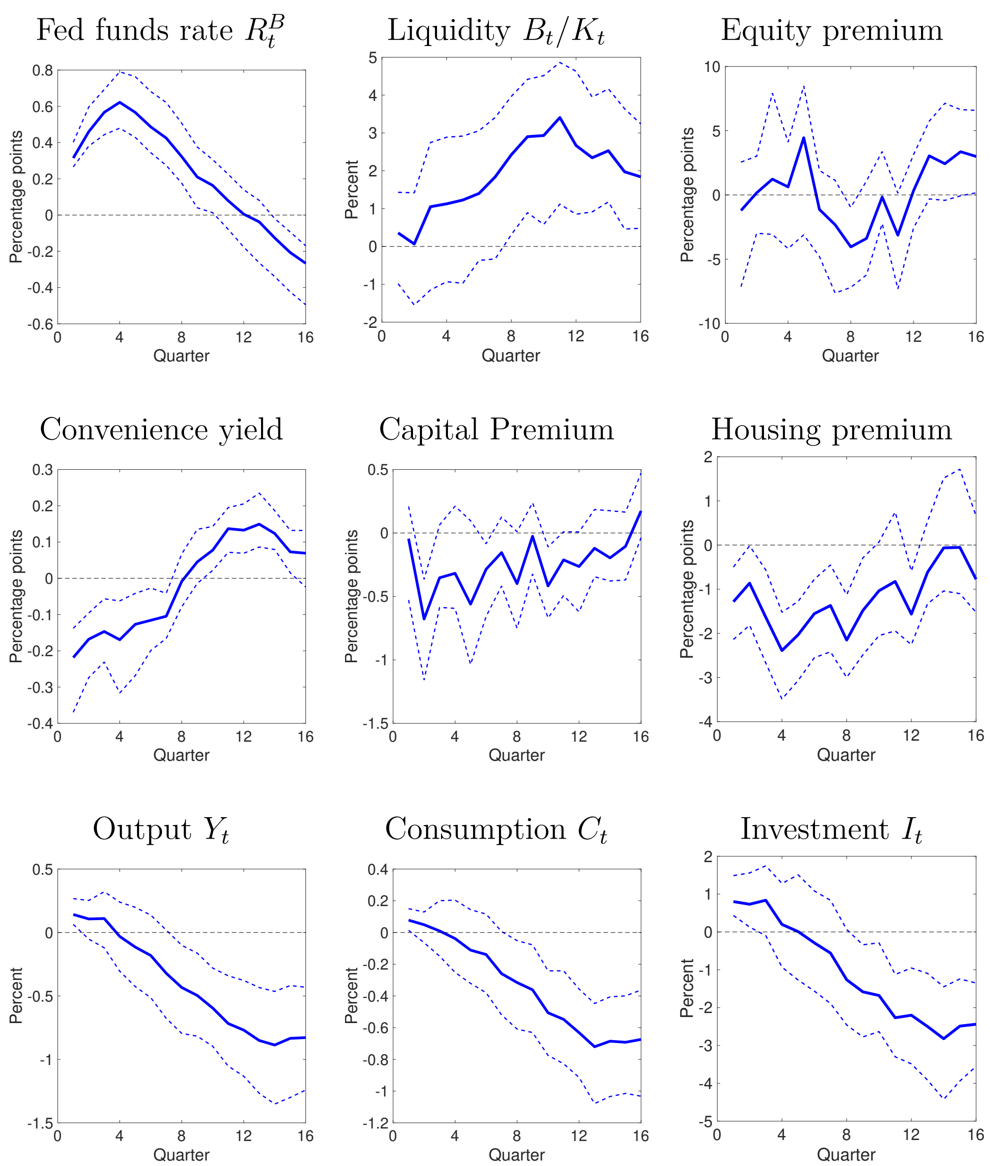


Estimated response of each time series at $t+j, j = 1 \dots 16$ to a monetary policy shock, $\epsilon^R_t = 36$ basis points, where t corresponds to quarters from 1983Q1 to 2007Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, R^B_t, \epsilon^R_t, \epsilon^R_{t-1}]$. Bootstrapped 90% confidence bands are shown in the dashed lines (block bootstrap). Equity premium: Growth rate of Wilshire 5000 Total Market Full Cap Index minus the federal funds rate. Convenience yield: Moody's Seasoned Aaa Corporate Bond Yield minus 10-Year Treasury Constant Maturity Rate.

Seasoned Aaa Corporate Bond Yield minus 10-Year Treasury Constant Maturity Rate) falls by 0.125 percentage points on impact. The previous literature typically finds that bond premia increase after a monetary tightening; see e.g. Gertler and Karadi (2015). There are three major differences: 1) Most papers use the so-called excess bond premium by Gilchrist and Zakrajšek (2012), which tries to condition on default risk, 2) I use quarterly data because data on the return to capital and housing are not available at higher frequency, 3) Ramey (2016) shows that Gertler and Karadi (2015)'s finding of an increase in the bond premium depends on their SVAR using a longer sample period (1979-2012) than their identified monetary shocks (1990-2012).

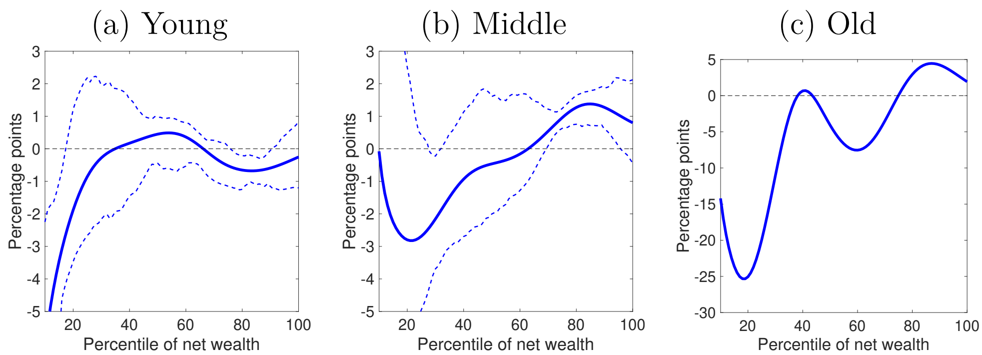
For robustness, I have repeated the local projections with the monetary shocks identified by Gertler and Karadi (2015) using the high frequency approach; see Figure 12. My finding of a decrease in liquidity premia in response to monetary contractions is unchanged. As I use local projections, I only use data from the sample period 1990-2012 for which they provide monetary shocks.

Figure 12: Aggregate response to a monetary shock (high-frequency identification)



Estimated response of each time series at $t + j, j = 1 \dots 16$ to monetary policy shocks identified by Gertler and Karadi (2015), where t corresponds to quarters from 1990Q1 to 2012Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, R_t^B, \epsilon_t^R, \epsilon_{t-1}^R]$. Bootstrapped 90% confidence bands are shown in the dashed lines (block bootstrap). Equity premium: Growth rate of Wilshire 5000 Total Market Full Cap Index minus the federal funds rate. Convenience yield: Moody's Seasoned Aaa Corporate Bond Yield minus 10-Year Treasury Constant Maturity Rate. Capital premium: Gomme et al. (2011)'s return on capital minus the federal funds rate. Housing premium: Realized return on housing (rent-price ratio in t plus realized growth rate of house prices in $t + 1$) minus the federal funds rate.

Figure 13: Portfolio response, $\Delta(\frac{b_{it}}{q_t k_{it}})$, to a monetary shock in equilibrium



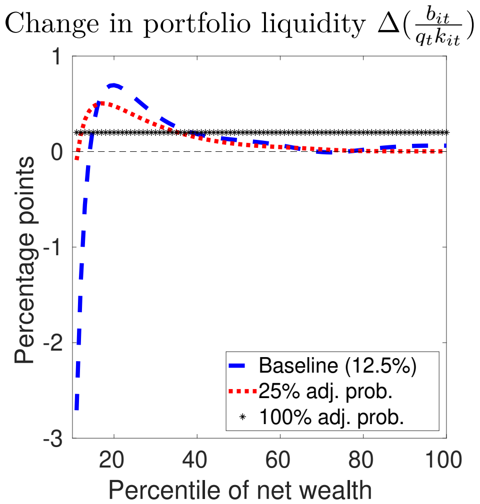
Change in portfolio liquidity for each synthetic cohort (young, born after 1949; middle, born between 1935 and 1949; old, born before 1935) after a 1 standard deviation monetary shock, $\epsilon^R = 36$ basis points (annualized), after 3 years. Portfolio response by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Data correspond to the local projection with SCF data as in Section IV. Bootstrapped 66% confidence bands are shown in the dashed lines, based on a non-parametric bootstrap. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

E.B Local Projection Method for Cross-Sectional Data

Similarly, in Figure 7 of Section IV, I use local projections to estimate the response of portfolio liquidity to monetary shocks across the wealth distribution. Toward this end, I treat the measures of residual portfolio liquidity by percentile of wealth, constructed in Section D.B, as endogenous variables and run single regressions for each percentile, i.e., $\lambda^{LI}(prc, t)$ and $\lambda^{IL}(prc, t)$, on normalized monetary shocks, $\bar{\epsilon}_t^R$. In each regression, I include as control a constant and time trend. The data from the SCF is annual such that I take the cumulative monetary shock in a given year.

Figure 13 reports the results for the local projections separately run for each birth cohort: young (born after 1949), middle (born between 1935 and 1949), old (born before 1935). Qualitatively, the results are unchanged: After a monetary tightening, portfolio liquidity strongly falls for wealth poor households, while it only increases for households in the top of the wealth distribution. The response of the old cohort is to be taken with a grain of salt as the sample size is small (no confidence intervals are reported for readability).

Figure 14: Portfolio response counterfactuals



Notes: Change in portfolio liquidity after a monetary shock, $\epsilon^R = 96$ basis points (annualized), after 3 years with a (1) 12.5% (baseline), (2) 25% and (3) 100% chance of trading capital in a given quarter. Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1.

F Model Extensions

F.A Model with liquid capital

The model with liquid capital implies a counterfactual increase in the portfolio liquidity of all households. Figure 14 shows counterfactuals for four versions of the model with different degree of illiquidity: (1) 12.5% (baseline), (2) 25% and (3) 100% chance of trading capital in a given quarter. As capital becomes more liquid, fewer households lower their portfolio liquidity and the magnitude of the portfolio response becomes substantially smaller. When capital and bonds are perfect substitutes, the individual portfolio problem is indeterminate. Aggregate liquidity, B_t/K_t, follows from the arbitrage condition between both assets and the government supply of bonds. Assuming that households hold the average portfolio, portfolio liquidity increases by 0.2 percentage point for all households in the first quarter after the monetary tightening.

F.B Model with scarce liquidity

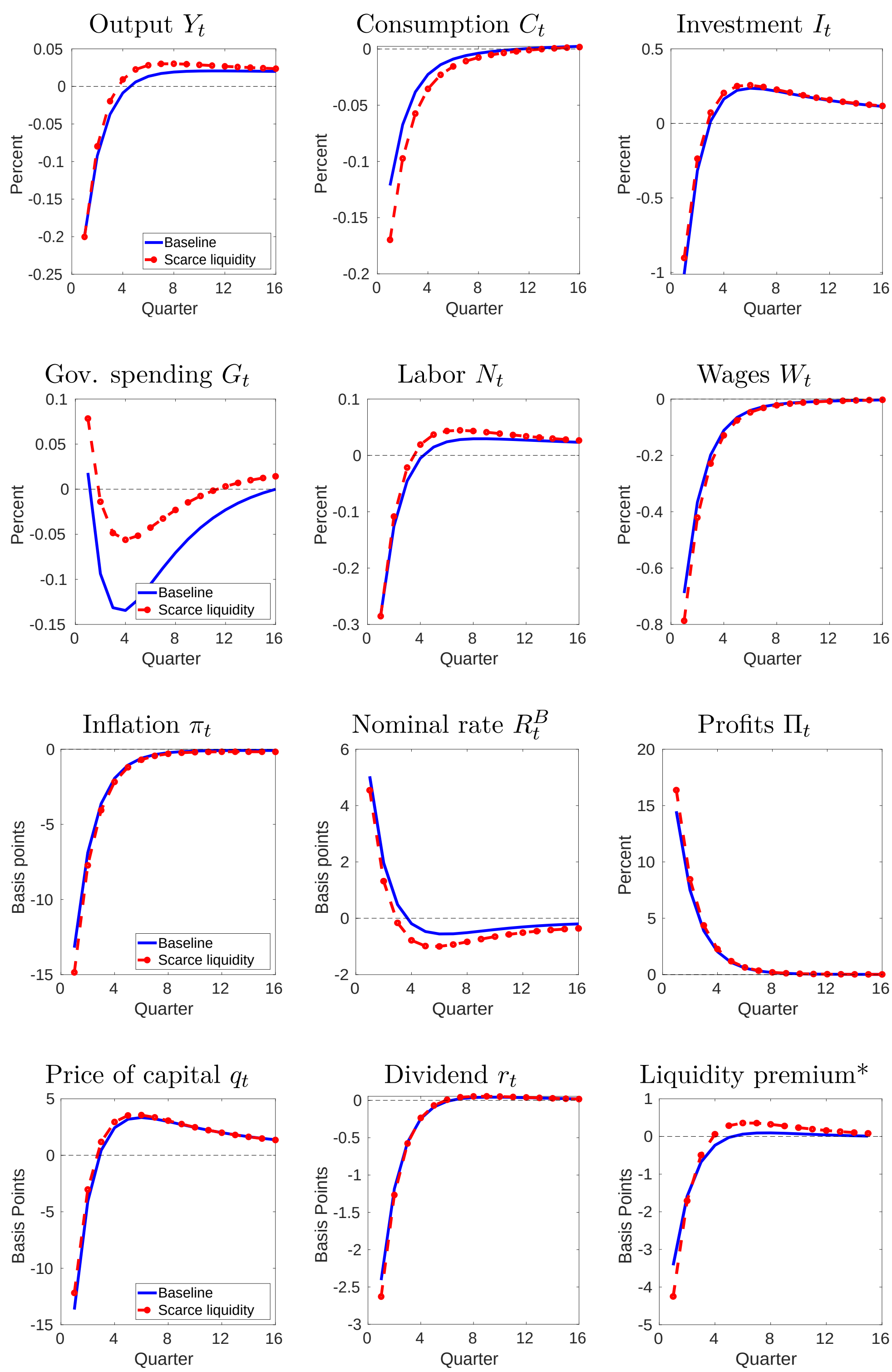
I set the return on liquid assets to zero, $\bar{R}^B = 1.0$, which corresponds to the U.S. post-2008. This yields a thirty percent lower liquid to illiquid ratio, $B/K = 0.06$, in the new steady state. The return on illiquid capital is almost unchanged such that the liquidity premium increases from 2.5 to 4.5 percentage points. As a consequence, wealth inequality markedly increases. The Gini coefficient for net wealth goes up from 0.78 to 0.80 in the new steady state. Higher inequality, in turn, increases the importance of redistribution in the transmission of monetary policy.

Figure 15 shows the impulse responses of the baseline model with scarce liquidity. The output response is almost identical, but the drop in consumption is 40% larger when liquidity is scarce. Investment falls by 11% less.

F.C Model with real debt

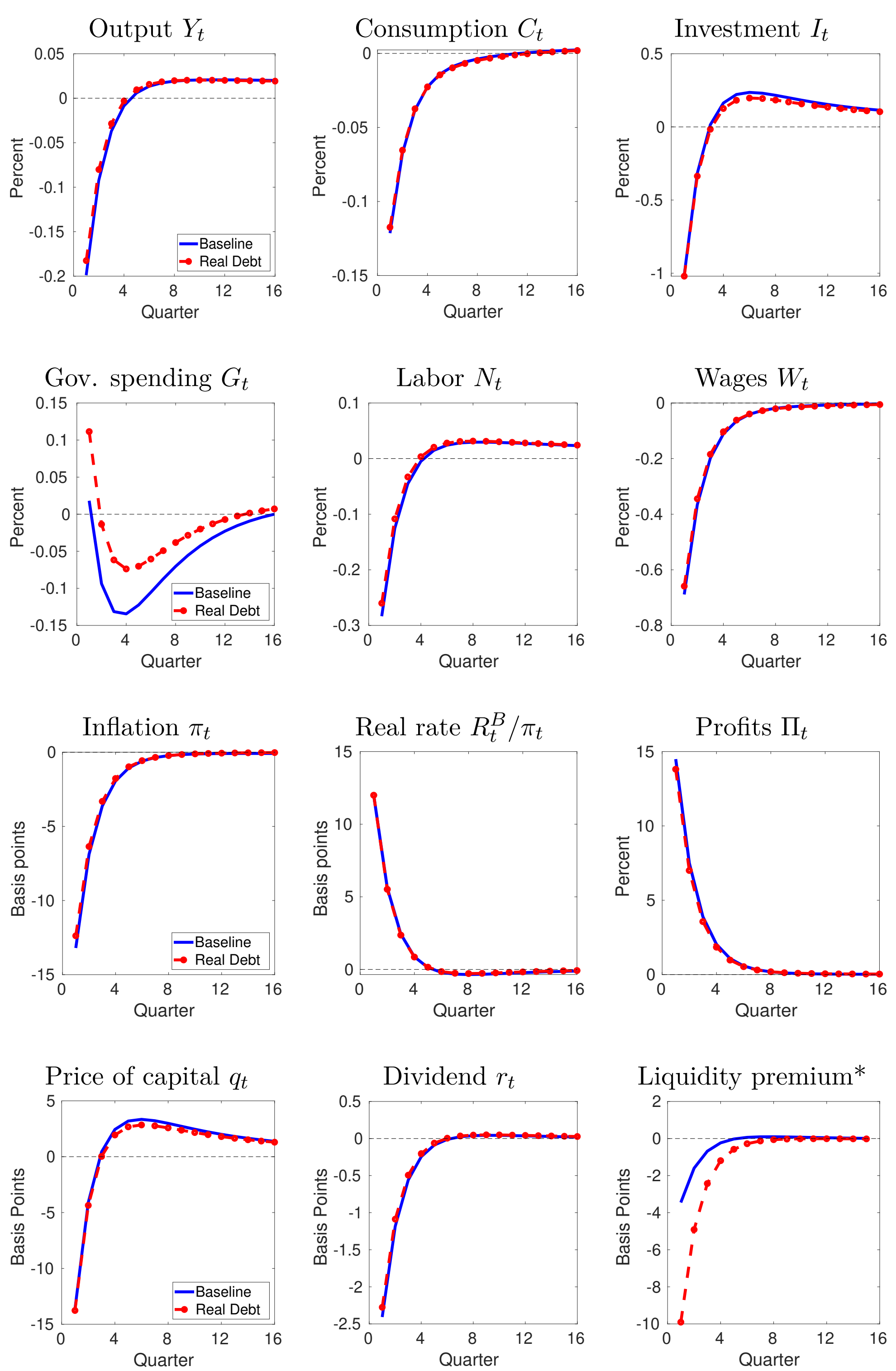
Figure 16 shows the impulse responses of the baseline model with real debt. This assumption shuts down the Fisher channel that works through redistribution via surprise inflation. To quantify the importance of the Fisher channel, I adjust the size and variance of the monetary shock to achieve the same path of the real rate in both economies. The Fisher channel explains 9% of the fall in output in the baseline when debt is nominal and fixed for one-period. The Fisher channel works through aggregate consumption by redistributing from borrowers with high MPCs to savers with low MPCs. At the same time, this stabilizes the investment response as savers have higher MPIs on average.

Figure 15: Aggregate response to a monetary shock with scarce liquidity



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $^*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

Figure 16: Aggregate response to a monetary shock with real debt



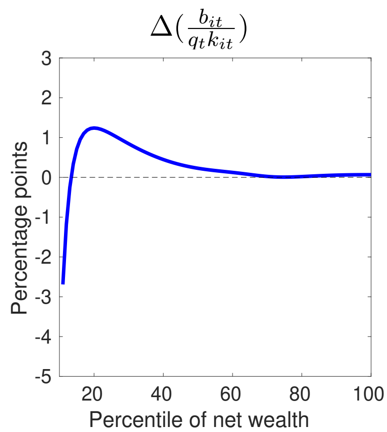
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

F.D Robustness to aggregate capital adjustment costs

Figure 18 plots the aggregate effects of a monetary tightening in the baseline model without aggregate capital adjustment costs, $\phi = 0$. The aggregate effects become more pronounced because investment falls more, while the price of capital is now constant. Overall, the results are very similar to the baseline. The fall in portfolio liquidity in the cross-section is also slightly stronger; see Figure 17.

When there is a representative portfolio, investment falls by 10% on impact without aggregate capital adjustment costs. Therefore, the difference to the model with portfolio heterogeneity becomes substantially larger when aggregate adjustment costs approach zero.

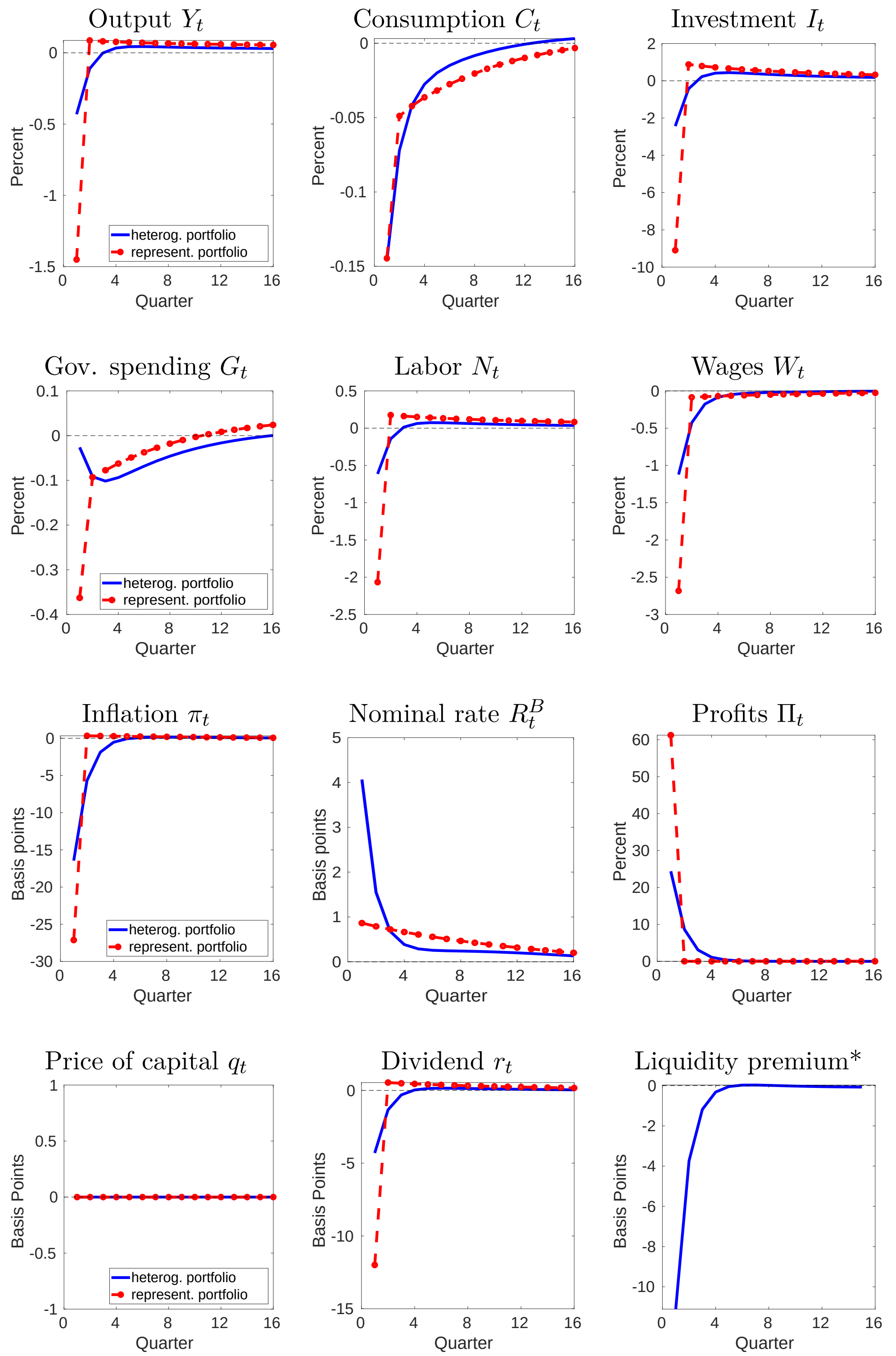
Figure 17: Portfolio response without aggregate capital adjustment costs



Notes: Change in portfolio liquidity after a monetary shock, $\epsilon^R = 96$ basis points (annualized), after 3 years. Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

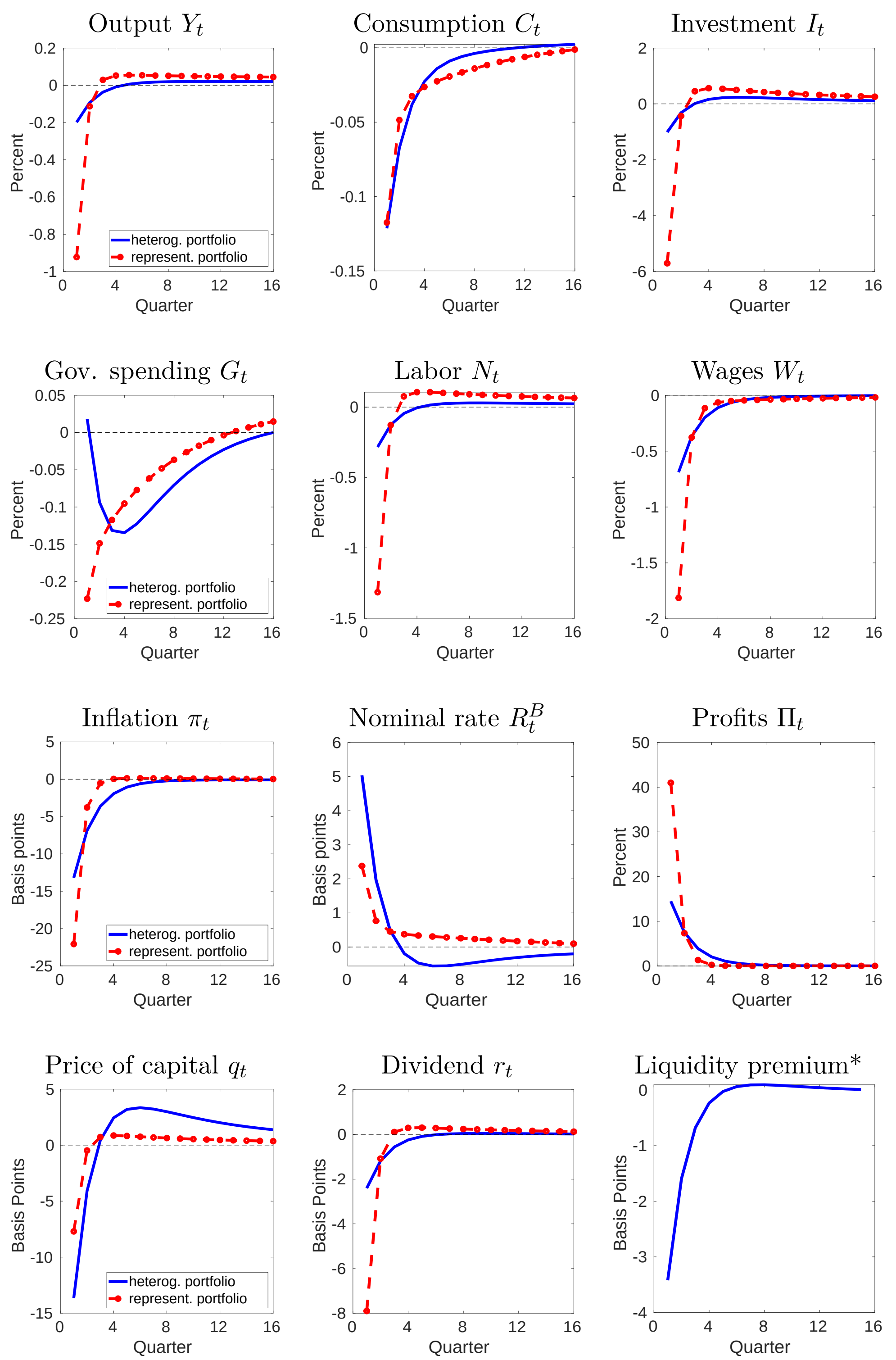
Figure 19 shows the impulse responses of an economy with liquid capital but with recalibrated adjustment costs parameter, $\phi = 1$, such that investment volatility is 4.5 times output volatility with TFP shocks (as in the baseline calibration). Investment falls 6 times more relative to the economy with heterogeneity in household portfolios. Aggregate capital adjustment costs mainly rescale the aggregate effects of monetary policy, but do not affect the composition of the output drop in terms of consumption and investment to the extent that heterogeneity in household portfolios does.

Figure 18: Aggregate response to a monetary shock with liquid capital and zero aggregate capital adjustment costs



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $^*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

Figure 19: Aggregate response to a monetary shock with liquid capital and recalibrated aggregate capital adjustment costs



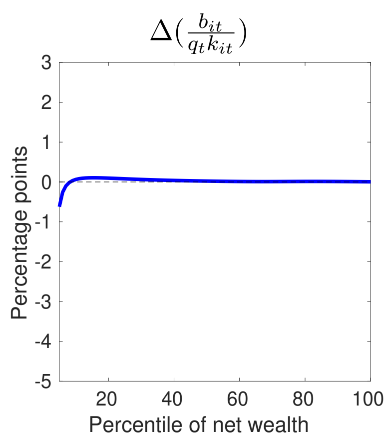
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

F.E Allocation of profits

In the baseline model the allocation of profits follows a simple and transparent rule that allocates profits to a random and small fraction of households. These households have zero productivity in the labor market but earn roughly 15 times more than the average worker. This mimics the U.S. distribution of income in terms of inequality and composition of income. According to the Congressional Budget Office, the top 1% of the income distribution receives about 30% of their income from financial income, a much larger share than any other segment of the population.

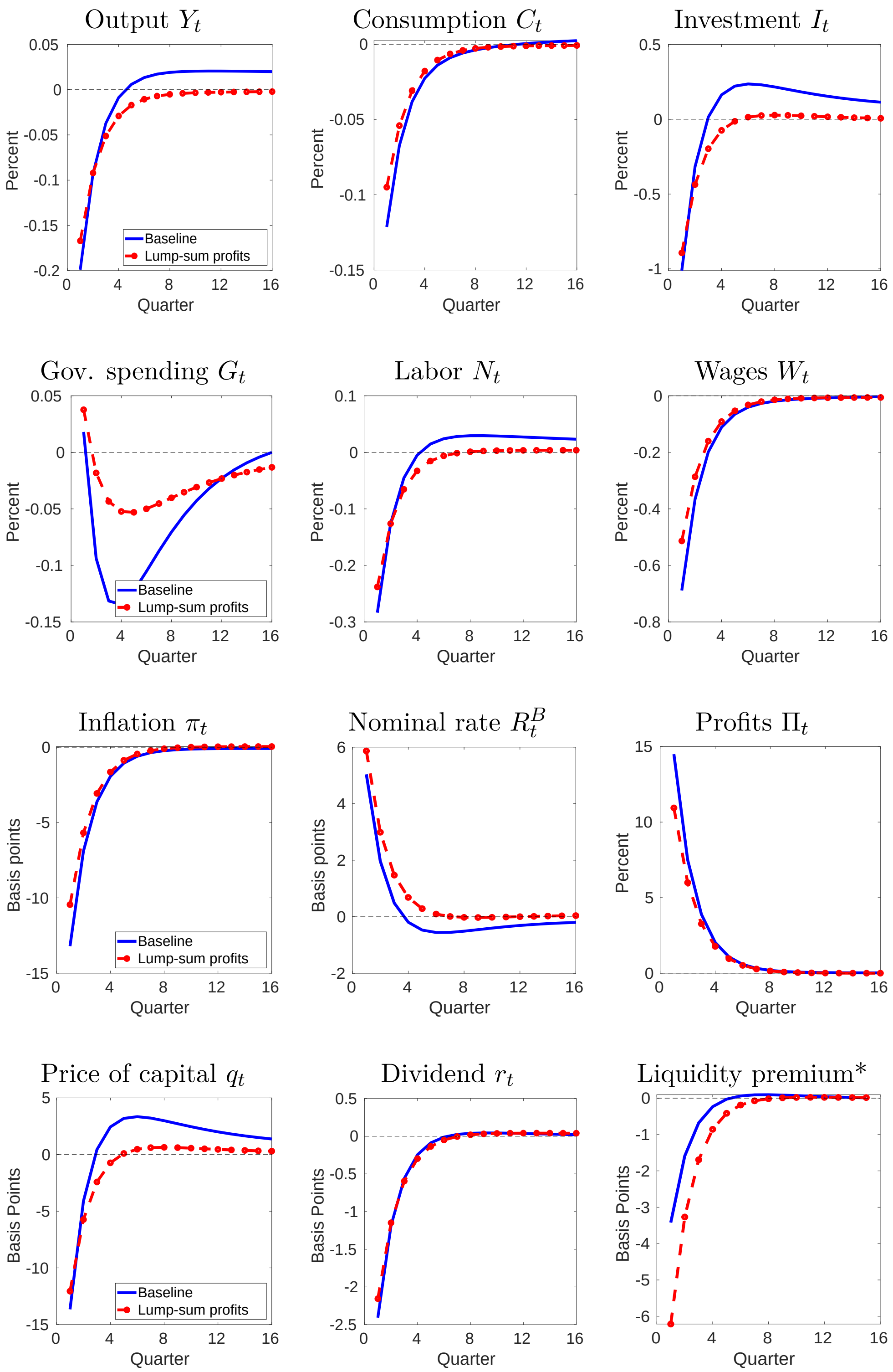
A lump-sum allocation of profits, in contrast, does not match these facts. It further makes earnings-risk procyclical in the model, which mitigates the aggregate effects of monetary policy shocks. Figure 21 plots the impulse responses for the model with lump-sum allocation of profits and without the 'entrepreneur' state (no parameters are recalibrated). The model still generates a sign difference in the portfolio response for wealthy and poor households, but the magnitude of the portfolio response is smaller; See Figure 20.

Figure 20: Portfolio response with lump-sum profits



Notes: Change in portfolio liquidity after a monetary shock, $\epsilon^R = 96$ basis points (annualized), after 3 years. Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

Figure 21: Aggregate response to a monetary shock with lump-sum profits



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

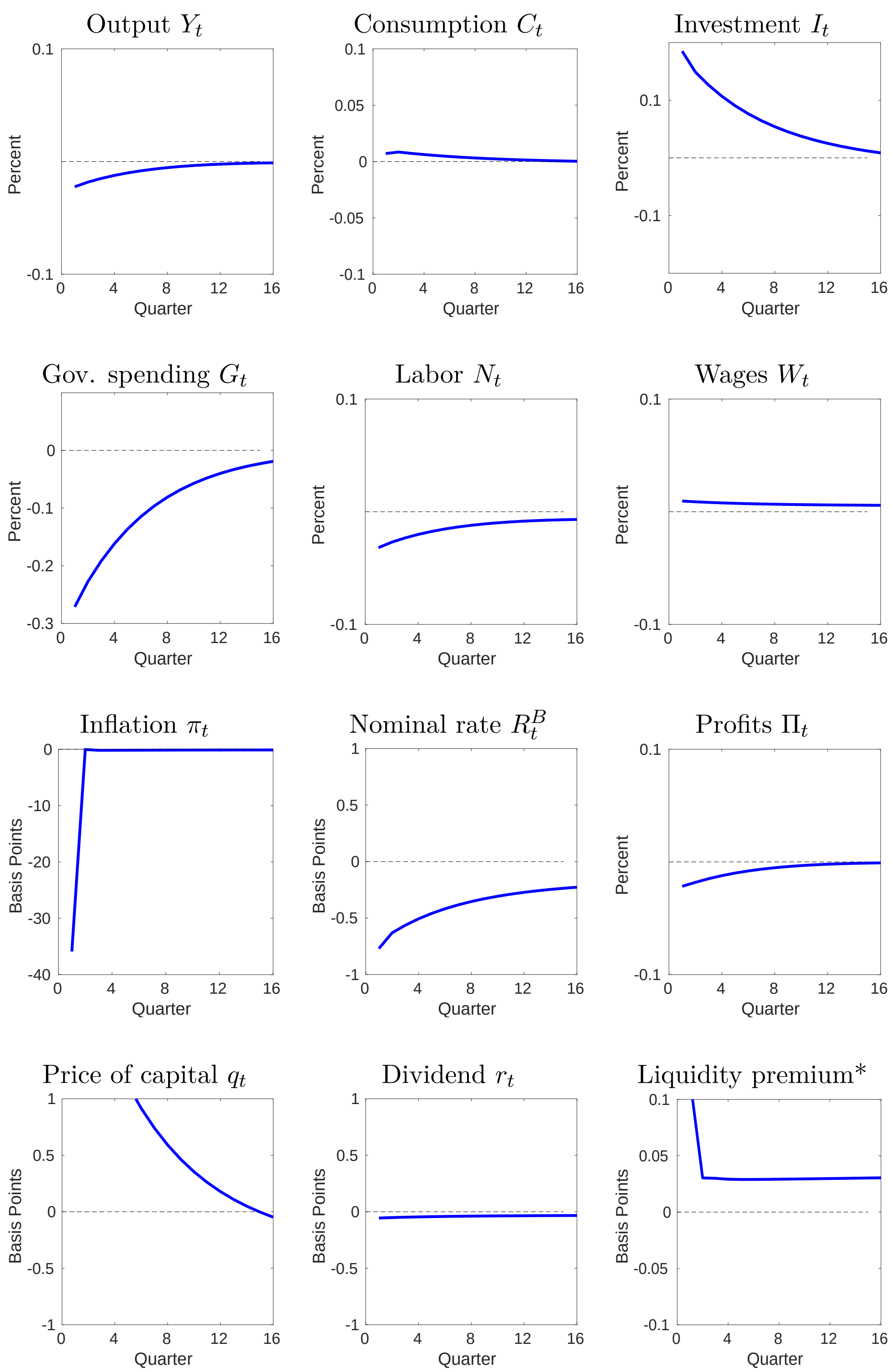
F.F Model without sticky prices

Figure 22 plots the aggregate effects of a monetary tightening in the baseline model without sticky prices, $\kappa = 0$. While inflation responds strongly in the first period, the monetary shock does not move the real interest rate that households face from period 1 onwards. Monetary policy still affects real variables through the interaction of the Fisher channel and heterogeneity in marginal propensities to invest. The ex-post redistribution through inflation from borrowers to savers leads to an investment boom because savers have higher marginal propensities to invest. Heterogeneity in marginal propensities to consume, on the other hand, does not affect output because falling prices restore any shortfall in demand. Overall, a monetary tightening leads to an expansion of investment through the Fisher channel when prices are flexible.

Whether output increases as well depends on the response of labor supply. Redistribution from borrowers to savers makes the former work more and latter work less. In total, this reduces labor supply because borrowers are more likely to be up against the labor supply constraint. Households cannot work more than two jobs, which corresponds to 16 hours of work. In the baseline calibration this applies to 5% of households, all of them are borrowers. In Figure 23, I shut down the wealth effect on labor supply by assuming GHH preferences. Under this assumption, output expands after a monetary tightening because the Fisher channel only works through investment.

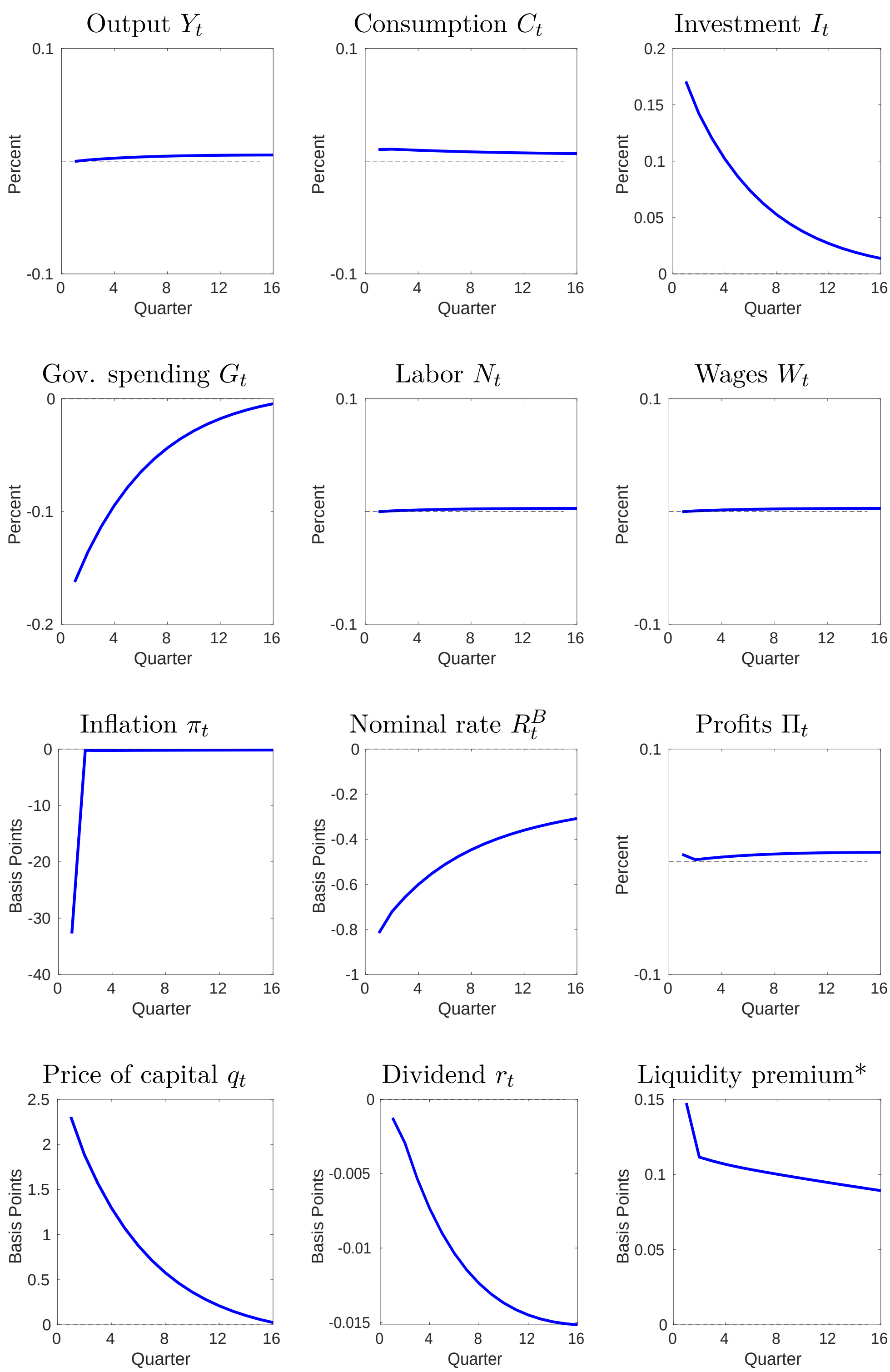
In a model with real debt, there is no redistribution through surprise inflation. In response to a monetary tightening, inflation falls until the Taylor rule undoes the increase in the nominal rate, and the real rate stays constant from period 1 onwards. The sizable movement of inflation, however, does not affect real variables because the Fisher channel is absent; see Figure 24.

Figure 22: Aggregate response to a monetary shock without sticky prices



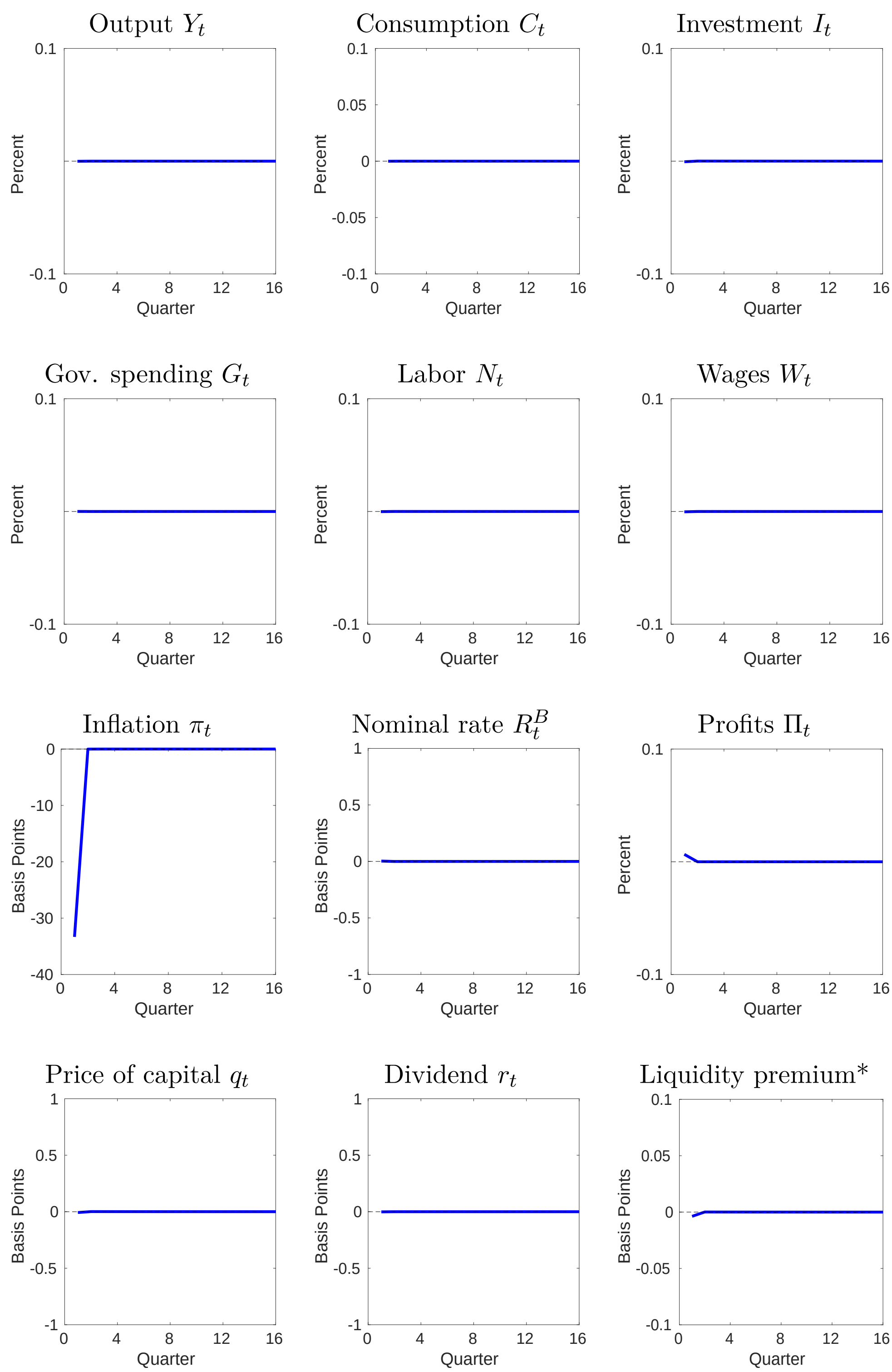
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

Figure 23: Aggregate response to a monetary shock without sticky prices and GHH preferences



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = \frac{E_t q_{t+1} + r_t}{q_t} - \frac{R_t^B}{E_t \pi_{t+1}}$

Figure 24: Aggregate response to a monetary shock without sticky prices and real debt



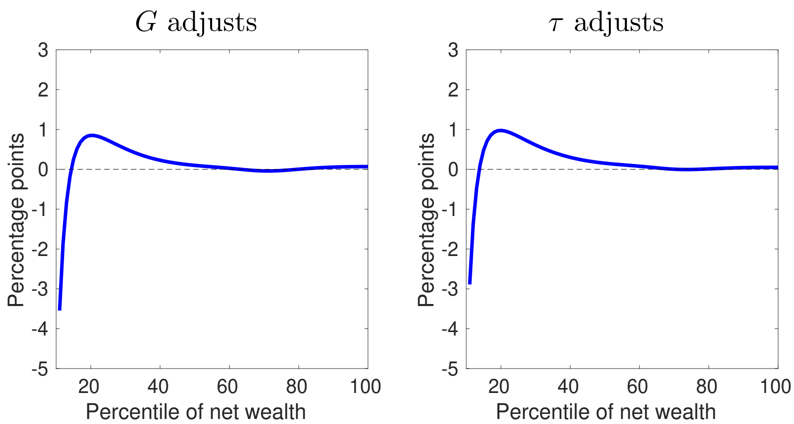
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

F.G Robustness to fiscal rules

When markets are incomplete, Ricardian equivalence does not hold, and fiscal policy matters for the monetary transmission. A change in real rates affect the government budget constraint. In turn, the government may either change spending or taxes and do it now or in the future. The choice of fiscal rules matters because they affect different households who may differ in marginal propensities to consume and invest.

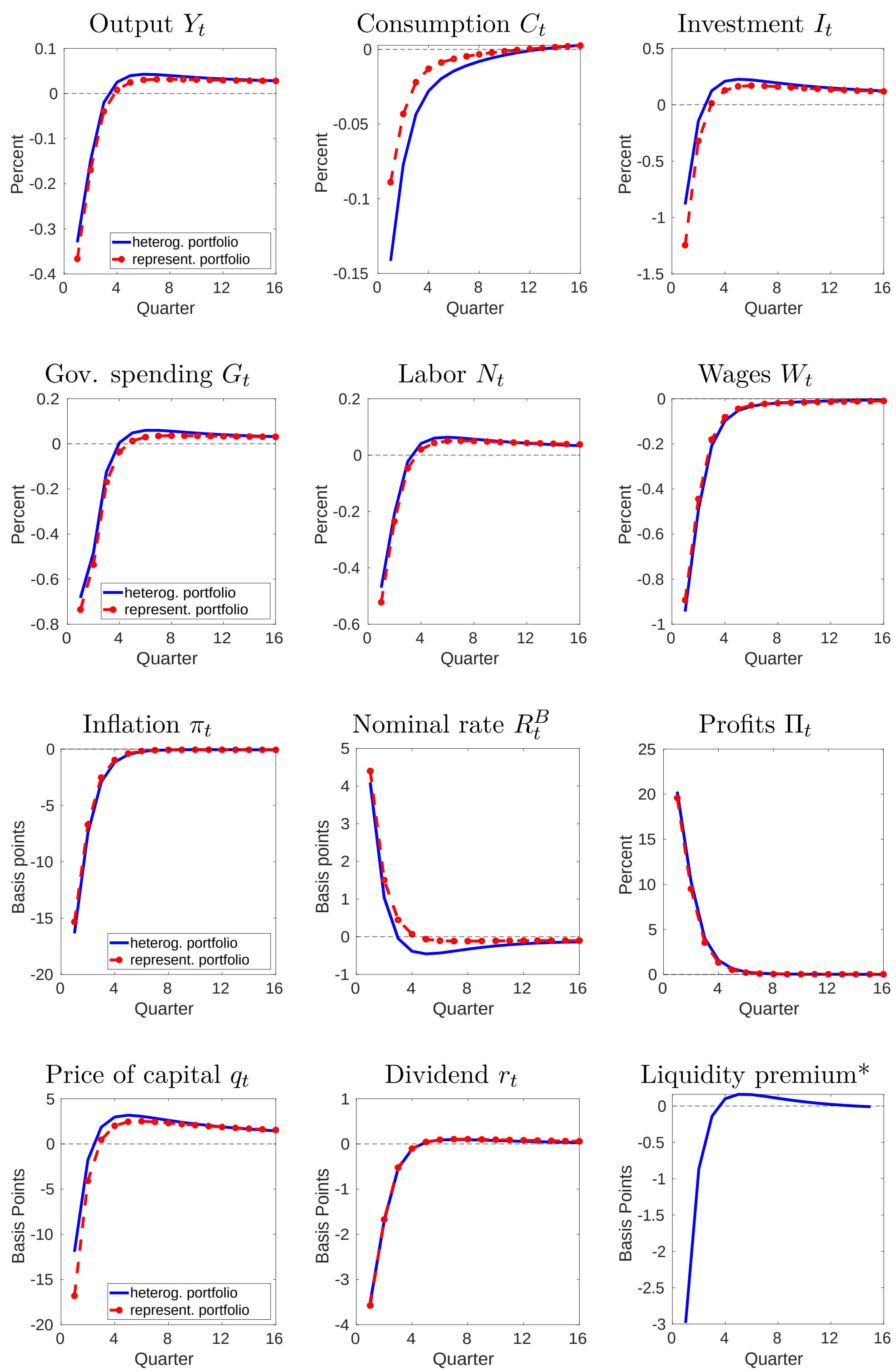
In the baseline model, I assume that most of the adjustment goes through government debt, and future government spending adjusts to bring debt back to steady state. In Figure 26, in contrast, I assume a balanced budget, $\rho_B = 0$, and an immediate reaction of government spending. The substantial fall in government spending amplifies the recessionary effect of a monetary tightening. Additionally, the fall in output is driven to an even larger extent by consumption. Alternatively, taxes may adjust to balance the budget as shown in Figure 27. In this case, consumption falls less and investment more relative to baseline. In comparison to a representative portfolio, investment falls in both cases by around 30 - 40% less with heterogeneity in household portfolios. In both cases, the sign difference in the portfolio responses remains and the magnitude of the fall in portfolio liquidity even increases; see Figure 25.

Figure 25: Portfolio response, $\Delta(\frac{b_{it}}{q_t k_{it}})$, with balanced budget



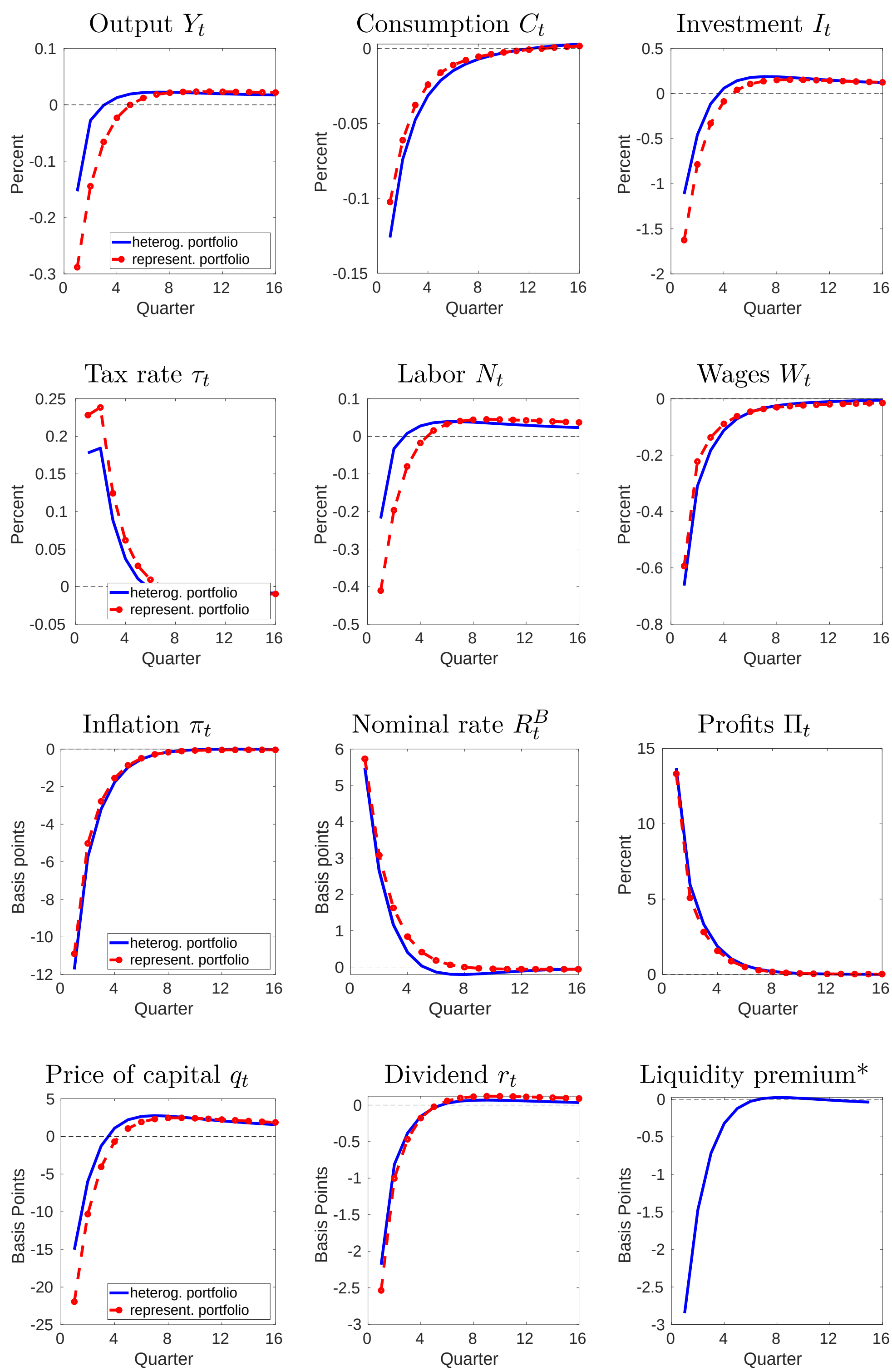
Notes: Change in portfolio liquidity after a monetary shock, $\epsilon^R = 96$ basis points (annualized), after 3 years. Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

Figure 26: Aggregate response to a monetary shock with balanced budget by adjusting government spending



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

Figure 27: Aggregate response to a monetary shock with balanced budget by adjusting the tax rate

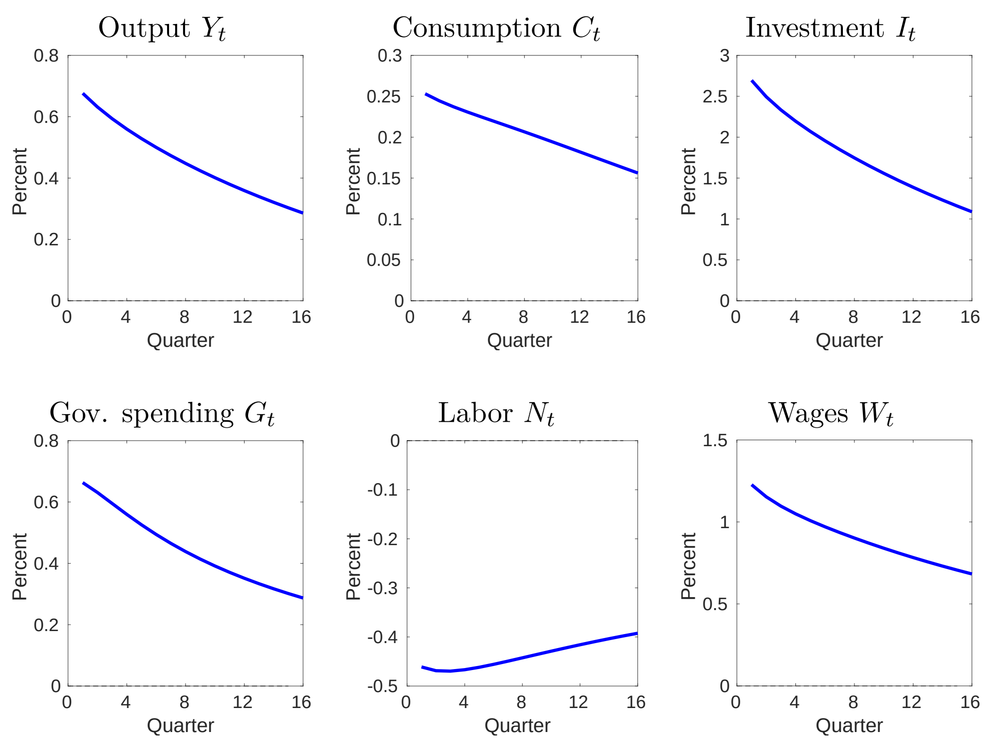


Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $^*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

F.H Response of the Model to TFP Shocks

This section reports the aggregate effects of a TFP shock for comparison. I generate the IRFs by solving the model without monetary shocks but with time-varying total factor productivity in production, such that $Y_t = Z_t F(K_t, L_t)$, where Z_t is total factor productivity and follows an AR(1) process in logs. I assume a persistence of 0.95 and a standard deviation of 0.01.

Figure 28: Aggregate response to a TFP shock



Notes: Impulse responses to a one standard deviation increase in TFP.