Transmission of Monetary Policy with Heterogeneity in Household Portfolios*

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Abstract

This paper documents the importance of heterogeneity in household portfolios for the transmission of monetary policy in cross-sectional data and in a New Keynesian business cycle model with incomplete markets and portfolio choice under liquidity constraints. Heterogeneity in the responses to monetary shocks of both household consumption and portfolios makes aggregate consumption more and investment less responsive to the interest rate. The aggregate effects of monetary policy depend on the fraction of liquidity constrained households and the interaction between heterogeneity in portfolios and the redistributive consequences of monetary policy.

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A household's portfolio generally consists of non-tradable and tradable assets. The most important non-tradable asset is human capital. It is the primary source of income for most households and at the same time subject to substantial idiosyncratic shocks. The presence of such shocks gives rise to both precautionary savings and cross-sectional differences in holdings of tradable assets when markets are incomplete. Importantly, tradable assets vary in their degree of liquidity. In fact, a large fraction of households in the United States holds low levels of liquid assets relative to their income, although most households exhibit considerable positive net worth.[1] This has implications for the transmission of monetary policy, because the relative importance of substitution and income effects depends on household portfolios.

This paper assesses quantitatively the implications of heterogeneity in household portfolios for the transmission of monetary policy by using cross-sectional data on portfolios and consumption and by building a structural model that replicates the empirical findings. To this end, I build a New Keynesian dynamic stochastic general equilibrium (DSGE) 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, 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 heterogeneity in household portfolios makes aggregate consumption more and investment less responsive to monetary policy. While investment falls by 45% less in response to a monetary tightening, consumption falls by 20% more such that a monetary shock moves output to a similar extent in the representative and heterogeneous agent version of the model.[3] Behind this change in aggregate effects lies large

[1] Kaplan et al. (2014) document this fact for the U.S. and other countries.

[2] 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).

[3] This is in line with the theoretical results in Werning (2015).

heterogeneity in household consumption and portfolio responses to monetary shocks. Consumption reacts more strongly because a sizable fraction of households has high marginal propensities to consume. The reason for the smaller reaction of investment is heterogeneity in portfolio responses that follows from the non-trivial redistributive consequences of monetary policy.

A monetary tightening increases inequality and redistributes from households at the bottom, who are indebted, to households at the top of the wealth distribution.[4] The latter primarily hold real assets and thereby stabilize investment after a contractionary monetary policy shock. Households in the bottom 50% of the liquid wealth distribution reduce their savings after an increase in the interest rate. They use their liquid wealth to smooth consumption, which falls by 100% more than consumption of households with median wealth. Households in the top 5% of the wealth distribution increase their consumption because the income effect dominates the substitution effect.

These differential responses in consumption and portfolios are borne out by data. I provide novel evidence by regressing monetary policy shocks on repeated cross-sectional information on household portfolios from the Survey of Consumer Finances (SCF) and on consumption from the Consumption Expenditure Survey (CEX), in which I order households according to their liquid wealth. I find that consumption and portfolio liquidity of liquidity-poor households falls in line with the model, whereas both increase for liquidity-rich households in response to a monetary tightening.

An economy with incomplete markets is able to match the empirical household responses because the transmission of monetary policy works mostly through indirect equilibrium changes in income. Current income is a binding constraint for households at or close to the borrowing constraint. This and precautionary motives make savings and, thus, consumption less sensitive to the interest rate, while it reinforces the effect of income on consumption. All in all, the direct response to changes in the interest rate explains only 25% of the total change in consumption, while indirect effects account for the remaining 75%.

[4] Using cross-sectional data for the U.S., Coibion et al. (2012) find higher inequality after contractionary monetary shocks.

The importance of indirect effects contrasts sharply with the standard New Keynesian model that builds on a representative household. In the latter, the direct effects of the interest rate explain close to all of the consumption and savings response. The indirect effects are quantitatively unimportant, because they exclusively work through changes in life-time income, which monetary shocks hardly affect, and redistribution is non-existent.

With these results, my paper contributes to the recently evolving literature that incorporates market incompleteness and idiosyncratic uncertainty into New Keynesian models.[5] As such it builds on the New Keynesian literature with its focus on nominal rigidities. This literature has proven successful in replicating the impulse responses to monetary policy shocks as identified from aggregate time-series data (cf. Christiano et al., 2005). What my paper and other recent contributions add to this literature is the attempt to endogenize heterogeneity in wealth.[6] In this class of models, the response of consumption and portfolios depends on the distribution of wealth, which evolves in response to aggregate shocks.

Relative to this literature, my paper is the first to empirically document heterogeneity in the portfolio response to monetary shocks and analyze its implications for monetary policy in a business cycle model with portfolio liquidity. My work is most closely related to Kaplan et al. (2016), which originated in parallel. They also decompose the effects of monetary policy into direct and indirect effects but differ in focus as they look at the consumption response to a one-time unexpected monetary shock. My model, in contrast, is calibrated to match business cycle statistics and, thus, goes beyond their analysis by studying the effect of portfolio heterogeneity on consumption, investment, and output in unison.

The remainder of the paper is organized as follows. Section 1 presents the empirical evidence. Section 2 introduces the model, and Section 3 discusses the solution method. Section 4 explains the calibration of the model. Section 5 presents the quantitative results. Section 6 concludes.

[5]See Guerrieri and Lorenzoni (2011), Oh and Reis (2012), Gornemann et al. (2012), Ravn and Sterk (2013), Den Haan et al. (2014), Auclert (2015), Bayer et al. (2015), Werning (2015), McKay and Reis (2016), McKay et al. (2016), and Kaplan et al. (2016).

[6]Exogenous heterogeneity is well-established in New Keynesian models. See, for example, Iacoviello (2005) and Galí et al. (2007).

1 Empirical Evidence

Monetary policy shocks provide an important validation exercise for macroeconomic models (cf. Ramey, 2016). In this section, I extend this exercise beyond aggregate time series to cross-sectional data on household portfolios and consumption to provide evidence for heterogeneity in the response to monetary shocks across households with different portfolio positions.[7]

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 a measure of the liquidity premium. I then use cross-sectional information on household portfolios from the Survey of Consumer Finances (SCF) and on consumption from the Consumption Expenditure Survey (CEX). I find that the increase in average liquidity is driven by wealthy households, whereas poorer households see a substantial fall in consumption and portfolio liquidity in line with the model.

1.1 Aggregate Response to Monetary Shocks

Figure 1 shows the response of aggregate variables to a surprise increase in the federal funds rate. I estimate the response by local projections with monetary shocks identified by the narrative approach (cf. Romer and Romer, 2004):[8]

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

where $\bar{\epsilon}_t^D$ are monetary shocks with a normalized standard deviation of 1, $\mathbf{X}_t = [Y_t, C_t, I_t, G_t, R_t^B, \epsilon_t^D, \epsilon_{t-1}^D]$ are aggregate controls and lagged monetary shocks, and Υ_{t+j} is the endogeneous variable of interest at horizon j. I use quarterly data from 1983 to 2007.[9] See Appendix D for more details.

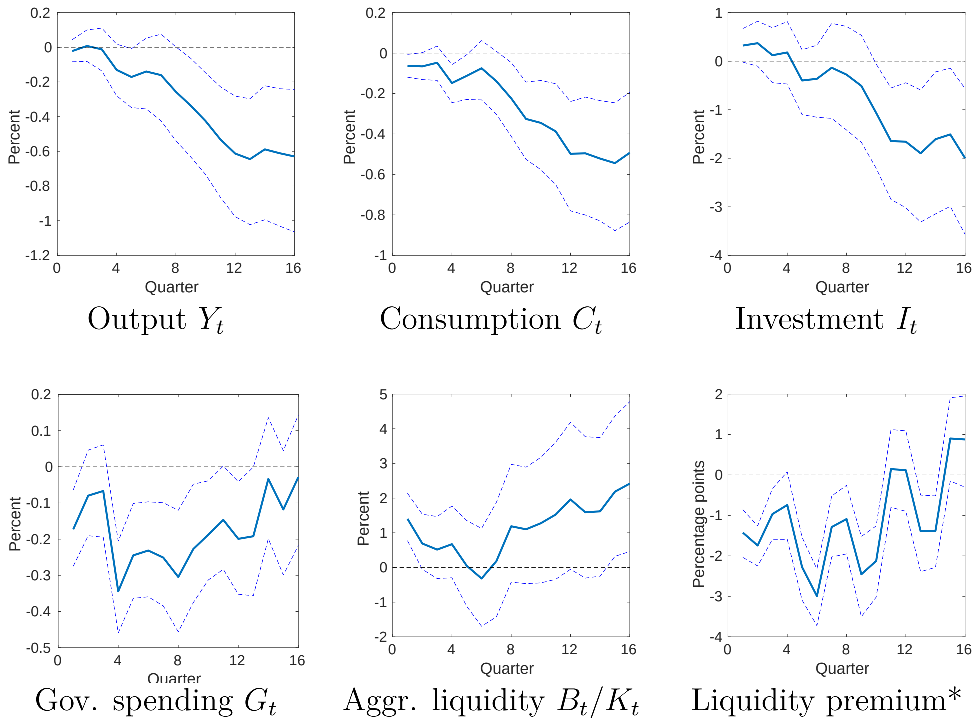
I consider a 1 standard deviation monetary shock (36 basis points annu-

[7]Coibion et al. (2012), Wong (2015), and Cloyne et al. (2016) also look at the cross-sectional response to monetary shocks. The first study analyzes the response of consumption and income inequality, the second documents the importance of age and the last the importance of housing tenure for the consumption response to monetary shocks.

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

[9]I focus on the time after the Volcker disinflation and before the Great Recession for two 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.

Figure 1: Aggregate response to a monetary shock



Estimated response of each time series at $t+j, j = 1 \ldots 16$ to a monetary policy shock, $\epsilon_t^D = 36$ basis points, where t corresponds to quarters from 1983 Q1 to 2007 Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, G_t, R_t^B, \epsilon_t^D, \epsilon_{t-1}^D]$. Bootstrapped 90% confidence bounds in dashed (block bootstrap).

alized) 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 falls slightly less then output with a similar dynamic. Investment falls too, but its reaction is roughly three times as strong as the output reaction.

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 middle panel of Figure 1. 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.[10] While average liquidity goes

[10] Kaplan et al. (2016) adopt a very similar asset taxonomy. The reason to treat equities as illiquid is that most equities are held in form of pension funds. Equity shares

up by around 2%, the liquidity premium falls by 2 percentage points. I proxy the liquidity premium by 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 rate.[11]

Figure 1 also reports the response of government spending, which falls in response to a surprise increase in the federal funds rate. When markets are incomplete, it is important to jointly specify monetary and fiscal policy because Ricardian equivalence does not hold.[12]

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

1.2 Household Response to Monetary Shocks

In the following, I estimate the response of households with different portfolio positions to monetary policy shocks. In particular, I order households by their liquid wealth and document heterogeneity in the response of consumption and portfolio liquidity across the liquid wealth distribution.

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 liquid wealth for each SCF survey year t from 1983 to 2007. The definition of net liquid wealth corresponds to the Flow of Funds data, i.e., net liquid assets are classified as 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 to be illiquid. Appendix C.2 discusses the asset classification and how the liquidity ratios are constructed in more detail.

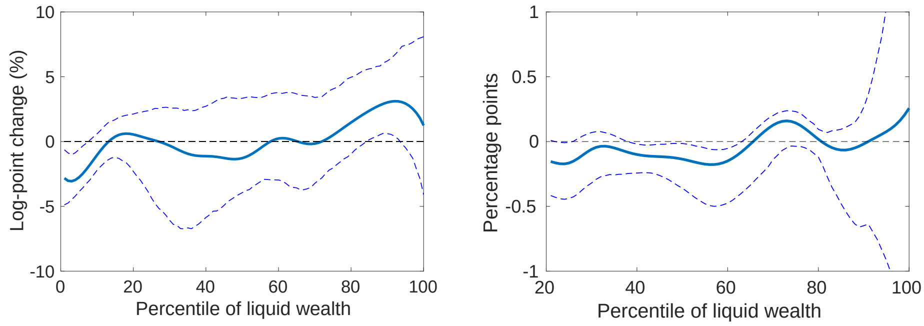
Similarly, I estimate non-durable consumption $\lambda^C(prc,t)$ by each percentile of liquid wealth from the Consumption Expenditure Survey for each quarter from 1983 to 2007. The CEX does not have detailed information on household portfolios, but asks participants about the amount of savings

held directly only play a role above the 85th wealth percentile. Publicly traded equities which 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.

[11]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%.

[12]See Sterk and Tenreyro (2015) for an example of the interaction between monetary and fiscal policy when Ricardian equivalence does not hold.

Figure 2: Household response to a federal funds rate shock



Consumption c_{it} Portfolio liquidity $\frac{b_{it}}{k_{it}}$

Estimated difference of non-durable consumption (in logs) and liquid-to-illiquid ratio of household portfolios across the liquid wealth distribution in response to a 1 standard deviation contemporaneous monetary policy shock (36 basis points annualized). Data is estimated from the CEX and SCF survey years 1983-2007, only household with at least two adults and the household head being between 30 and 55 years of age are included. Bootstrapped 66% confidence bands in dashed-lines, based on a non-parametric bootstrap.

they hold in deposits. I take this as a proxy for liquid assets. See Appendix C.3.

I regress these consumption and portfolio measures for each percentile of liquid wealth on normalized monetary shocks, $\gamma_2(prc)$, including an intercept, $\gamma_0(prc)$, a linear time trend, $\gamma_1(prc)$, and further controls $\mathbf{X}_t$:

$$\lambda^{C/LI/IL}(prc,t) = \gamma_0(prc) + \gamma_1(prc)t + \gamma_2(prc)\bar{\epsilon}_t^D + \gamma_3(prc)\mathbf{X}_t + \zeta,$$

i.e., I use a local projection technique. Appendix D spells out the details. For consumption I use quarterly data and for portfolios annual data. Figure 2 reports the coefficients, $\gamma_2(prc)$, of the contemporaneous portfolio and consumption response to monetary shocks by liquid wealth percentiles. I use a block bootstrap to estimate confidence bands.

Figure 2 reveals large heterogeneity in the response of consumption and portfolio liquidity to a surprise increase in the federal funds rate. In the left panel, consumption by liquidity-poor households falls by 3%, whereas liquidity-rich households increase their consumption. The positive gradient of the consumption response in liquid wealth points towards the importance of income effects. Households in the bottom part of the distribution are indebted. For them the substitution and income effect work in the same direction, amplifying the decline in consumption, whereas households in the top 20% receive sizable income gains from a higher interest rate. Replicating this differential consumption response therefore requires a model that matches the distribution of wealth.

The response of portfolio liquidity, in the right panel of Figure 2, exhibits a similar gradient. The liquidity ratio of portfolios held by the bottom 60% falls by around 0.2 percentage points. Only those households in the top of the liquid wealth distribution respond to a higher return on liquid assets by increasing the liquidity of their portfolios. This differential portfolio response becomes more pronounced after 2 years; see Figure 7. The increase in average liquidity as seen in the Flow of Funds data in Figure 1 is thus driven by the response of liquidity-rich households. The fall in the liquidity premium (also Figure 1) is in line with rich households holding a larger fraction of liquid assets after a contractionary monetary shock. Rich households are well insured. The liquidity value of additional liquid savings is lower for them than for liquidity-poor households.

The differential portfolio response demonstrates that it is important to model individual portfolio decisions. The following section introduces a model with incomplete markets that is able to replicate the heterogeneity in the empirical consumption and portfolio response.

2 Model

The model economy consists of households, firms, and a government/ monetary authority. Households consume, supply labor, obtain profit income, accumulate physical capital, and trade in the bonds 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. Let me describe each agent in turn.[13]

[13] This model setup extends previous joint work (c.f. Bayer et al., 2015).

2.1 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 derive felicity from consumption c_{it} and leisure. Households can be entrepreneurs ($s_{it} = 0$) or workers ($s_{it} = 1$). 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.

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:

$$\log h_{it} = \rho_h \log h_{it-1} + \epsilon_{it}, \quad \epsilon_{it} \sim N(0, \sigma_h). \tag{2}$$

Entrepreneurs have zero productivity on the labor market, but instead receive an equal share of the economy's total profits Π_t.[14] They pay the same tax rate as workers, $1 - \tau$.

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 non-negative, 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:

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

[14] Attaching the rents in the economy to an exogenously determined group of households instead of distributing it 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 any standard New-Keynesian framework.

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-1} 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 $b_{it+1} := \frac{\tilde{b}_{it+1}}{P_t}$. As in Kaplan et al. (2016) there is a wasted intermediation cost, $\overline{R}$, when households resort to unsecured borrowing. Therefore, R^b has two parts:

$$R^b_{t-1}(b_{it}, R^B_{t-1}) = \begin{cases} R^B_{t-1} & \text{if } b_{it} \geq 0 \\ R^B_{t-1} + \overline{R} & \text{if } b_{it} < 0. \end{cases} \tag{4}$$

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:

$$\begin{aligned} c_{it} + b_{it+1} &= \frac{R^b_{t-1}}{\pi_t} b_{it} + r_t k_{it} + \tau \left[s_{it} w_t h_{it} N_t + (1 - s_{it}) \Pi_t \right], \\ b_{it+1} &\geq -\underline{b}. \end{aligned} \tag{5}$$

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.

Households have GHH preferences (cf. Greenwood et al., 1988) and maximize the discounted sum of felicity:

$$V = E_0 \max_{\{c_{it}, n_{it}\}} \sum_{t=0}^{\infty} \beta^t u\left(x_{it}\right), \tag{6}$$

where $x_{it} = c_{it} - h_{it} G(n_{it})$ is household i's composite demand for the physical consumption good c_{it} and leisure.

The disutility of work, $h_{it} G(n_{it})$, determines a workers' labor supply given the aggregate wage rate through the first-order condition:

$$h_{it} G'(n_{it}) = \tau w_t h_{it}. \tag{7}$$

Under the above assumption, a workers' labor decision does not respond to idiosyncratic productivity h_{it}, but only to the net aggregate wage τw_t.

Thus I can drop the household-specific index i, and set $n_{it} = N_t$.[15]

The Frisch elasticity of aggregate labor supply is constant with γ being the inverse elasticity:

$$G(N_t) = \frac{1}{1+\gamma} N_t^{1+\gamma}, \quad \gamma > 0.$$

Exploiting the first-order condition on labor supply, the disutility of working can be expressed in terms of the net wage rate:

$$h_{it} G(N_t) = h_{it} \frac{N_t^{1+\gamma}}{1+\gamma} = \frac{h_{it} G'(N_t) N_t}{1+\gamma} = \frac{\tau w_t h_{it} N_t}{1+\gamma}.$$

In this way the demand for x_{it} can be rewritten as:

$$x_{it} = c_{it} - h_{it} G(N_t) = c_{it} - \frac{\tau w_t h_{it} N_t}{1+\gamma}.$$

The budget constraint and the household problem can therefore be expressed in terms of composite good x_{it}.

A household's optimal consumption-savings decision is a non-linear function of that household's asset portfolio $\{b_{it}, k_{it}\}$ and employment type $\{h_{it}, s_{it}\}$. 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 $(b_t, k_t, h_t s_t)$. This makes the distribution Θ_t a state variable of the households' planning problem. The distribution Θ_t fluctuates in response to aggregate monetary and 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 case the household can adjust its capital

[15] Weighting the disutility of work by productivity h_{it} is simply a calibration trick. There is no endogenous reaction of hours worked to income risk and, thus, the cross-sectional dispersion of income directly follows from the assumed idiosyncratic productivity process. Besides this, any weighting of the disutility G is irrelevant, when the Frisch elasticity is constant, as long as the distribution of *log incomes* is treated as a date, because the disutility of labor is always a constant fraction of labor income.

holdings and V_n otherwise:

$$\begin{aligned}
V_a(b,k,hs;\Theta,\Omega) = & \max_{k',b'_a} u[c(b,b'_a,k,k',hs)] + \beta[\nu EV^a(b'_a,k',h's',\Theta',\Omega') \\
& + (1-\nu)EV^n(b'_a,k',h's',\Theta',\Omega')] \\
V_n(b,k,hs;\Theta,\Omega) = & \max_{b'_n} u[c(b,b'_n,k,k,hs)] + \beta[\nu EV^a(b'_n,k,h's',\Theta',\Omega') \\
& + (1-\nu)EV^n(b'_n,k,h's',\Theta',\Omega')]
\end{aligned} \tag{8}$$

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 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.

2.2 Intermediate Good Producer

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

$$Y_t = Z_t \tilde{N}_t^{\alpha} K_t^{(1-\alpha)},$$

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

$$\log Z_t = \rho_Z \log Z_{t-1} + \epsilon_t^Z, \quad \epsilon_t^Z \sim N(0, \sigma_Z). \tag{9}$$

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

$$MC_t Y_t = MC_t Z_t \tilde{N}_t^{\alpha} K_t^{(1-\alpha)} - w_t \tilde{N}_t - (r_t + \delta) K_t,$$

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:

$$w_t = \alpha MC_t Z_t \left(K_t/\tilde{N}_t\right)^{1-\alpha}, \tag{10}$$

$$r_t + \delta = (1-\alpha) MC_t Z_t \left(\tilde{N}_t/K_t\right)^{\alpha}. \tag{11}$$

2.3 Resellers

Resellers differentiate the intermediate good and set prices. I assume price adjustment costs á la Rotemberg (1982). For tractability, 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. Managers maximize the present value of real profits given the demand for good j,

$$y_{jt} = (p_{jt}/P_t)^{-\eta} Y_t, \tag{12}$$

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

$$E_0 \sum_{t=0}^{\infty} \beta^t Y_t \left\{ \left(\frac{p_{jt}}{P_t} - MC_t \right) \left(\frac{p_{jt}}{P_t} \right)^{-\eta} - \frac{\eta}{2\kappa} \left(\log \frac{p_{jt}}{p_{jt-1}} \right)^2 \right\}. \tag{13}$$

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

$$\log(\pi_t) = \beta E_t \left[\log(\pi_{t+1}) \tfrac{Y_{t+1}}{Y_t} \right] + \kappa \left(MC_t - \tfrac{\eta-1}{\eta} \right), \tag{14}$$

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:

$$q_t = 1 + \phi \Delta K_{t+1}/K_t. \tag{15}$$

2.4 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:

$$\max_{Y_t, y_{jt} \in [0,1]} P_t Y_t - \int_0^1 p_{jt} y_{jt} dj \tag{16}$$

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

where y_{jt} is the demanded quantity of differentiated good j as input. From the zero-profit condition, the price of the final good is given by $P_t = \left(\int_0^1 p_{jt}^{1-\eta} dj \right)^{\frac{1}{1-\eta}}$.

2.5 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 inflation deviations from target and exhibits interest rate smoothing:

$$\frac{R_{t+1}^B}{\bar{R}^B} = \left(\frac{R_t^B}{\bar{R}^B} \right)^{\rho_{R^B}} \left(\frac{\pi_t}{\bar{\pi}} \right)^{(1-\rho_{R^B})\theta_\pi} \epsilon_t^D, \tag{17}$$

where $\log \epsilon_t^D \sim N(0, \sigma_D)$ 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.[16] The parameter ρ_{R^B} captures "intrinsic policy inertia".

The fiscal authority decides on government purchases, 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:

$$B_{t+1} = \frac{R_{t-1}^B}{\pi_t} B_{it} + G_t - T_t, \tag{18}$$

[16] Note that determinacy of the price level in this model does not depend on the Taylor principle $\theta_\pi > 1$. The economy is non-Ricardian because households value real government debt for its consumption-smoothing services. Hence, for any given path of the nominal interest rate, there is only one path of the inflation rate that clears the bond market. See Leith and von Thadden (2008).

where real tax revenues are given by $T_t = (1-\tau)[N_t W_t H_t + \Pi_t]$. I assume that government purchases stabilize the debt level:

$$\frac{G_t}{\bar{G}} = \left(\frac{B_t}{\bar{B}}\right)^{-\theta_G}, \tag{19}$$

where θ_G governs the reaction of government purchases to debt deviations from steady state.[17]

2.6 Market Clearing Conditions

The labor market clears at the competitive wage given in (10); so does the market for capital services if (11) holds. The nominal bonds market clears whenever the following equation holds:

$$B_{t+1} = \int \left[\nu b_a^*(b,k,hs;q,\pi) + (1-\nu) b_n^*(b,k,hs;q,\pi)\right] \Theta_t(b,k,hs)dbdkdhs. \tag{20}$$

Last, the market for capital has to clear:

$$\begin{aligned} q_t &= 1+\phi\frac{K_{t+1}-K_t}{K_t} = 1+\nu\phi\frac{K_{t+1}^*-K_t}{K_t}, \qquad (21)\\ K_{t+1}^* &:= \int k^*(b,k,hs;q_t,\pi_t)\Theta_t(b,k,hs)dbdkdhs,\\ K_{t+1} &= K_t + \nu(K_{t+1}^*-K_t), \end{aligned}$$

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

2.7 Recursive Equilibrium

A *recursive equilibrium* is a set of policy functions $\{c_a^*, c_n^*, b_a^*, b_n^*, k^*\}$, value functions $\{V_a, V_n\}$, pricing functions $\{r, R^B, w, \pi, q\}$, aggregate bonds, cap-

[17] Adjustment via government purchases is the baseline formulation because changing taxes would directly redistribute across households. This also applies to lump-sum taxes in this environment. Government purchases, in contrast, do not have any direct distributional consequences.

ital, and labor supply functions $\{B, K, N\}$, distributions Θ_t over individual asset holdings, types, 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 (8).

2. The labor, the final-goods, the bonds, the capital, and the intermediate-good markets clear, i.e. (10), (14), (20), and (21) hold.

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

3 Numerical Implementation

The dynamic program (8) and hence the recursive equilibrium is 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.

3.1 Solving the Household's Planning Problem

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 80 points on the grid for bonds and for capital.

3.2 Aggregate Fluctuations

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 et al. (2015) 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.

4 Calibration

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

4.1 Households

I assume that the felicity function is of constant-relative-risk-aversion form: $u(x) = \frac{1}{1-\xi}x^{1-\xi}$, where $\xi = 4$, as in Kaplan and Violante (2014). The inverse Frisch elasticity of labor supply is 0.75 in line with estimates by Chetty et al. (2011). The time-discount factor, $\beta = 0.98$, and the capital market participation frequency, $\nu = 0.065$, are jointly calibrated to match the ratio of capital and government bonds to output.[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 government bonds to the outstanding government debt held by private domestic agents, which implies an annual bonds-to-output ratio of 24%.

I set the borrowing limit in bonds, $\underline{b}$, to 1 time 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.

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

[18]The participation frequency of 6.5% 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.

Table 1: Calibrated parameters

Parameter	Value	Description	Target
Households			
β	0.98	Discount factor	$K/Y = 286\%$ (annual)
ν	6.5%	Participation frequency	$B/Y = 24\%$ (annual)
ξ	4	Coefficient of rel. risk av.	Kaplan and Violante (2014)
γ	0.75	Inv. Frisch elasticity	Chetty et al. (2011)
Intermediate Goods			
α	70%	Share of labor	Income share labor of 66%
δ	1.35%	Depreciation rate	NIPA: Fixed assets
ρ_Z	0.9	Persistence of TFP shock	Standard value
σ_Z	0.007	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	11.5	Capital adjustment costs	STD(I)/STD(Y)=4.6
Fiscal Policy			
$1-\tau$	0.3	Tax rate	$G/Y = 20\%$
θ_G	1	G reaction function	Empirical response
Monetary Policy			
Π	1	Inflation	0% p.a.
R^B	1.0062	Nominal interest rate	2.5% p.a.
θ_π	1.5	Reaction to inflation	Standard value
ρ_{R^B}	0.8	Interest rate smoothing	Clarida et al. (2000)
σ_D	36e-3	STD of monetary shock	Wieland and Yang (2016)
Income Process			
ρ_h	0.987	Persistence of productivity	Standard value
$\bar{\sigma}$	0.06	STD of innovations	Standard value

that the probability of becoming an entrepreneur is the same for workers independent of their labor productivity and that, once they become a worker 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. (25% p.a.). In order to match a wealth Gini index of 0.78 this implies that roughly 1% of households are entrepreneurs.[19]

I set the quarterly standard deviation of persistent shocks to idiosyncratic labor productivity to 0.06 and the quarterly autocorrelation to 0.987 – both standard values in the literature (c.f. Storesletten et al., 2004).

4.2 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 $\rho_Z = 0.9$. The standard deviation of the TFP shock, $\sigma_Z = 0.007$, is calibrated to make the model match the standard deviation of H-P-filtered U.S. output.

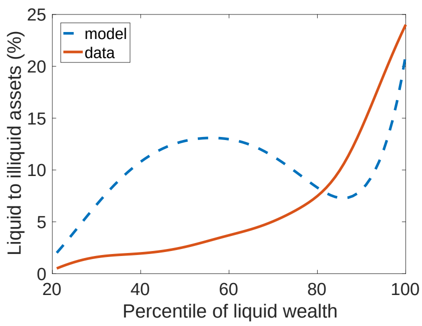
To calibrate the parameters of the resellers' problem, I use standard values for markup and price stickiness that are widely employed in the New Keynesian literature (c.f. Christiano et al., 1999). The Phillips curve parameter κ implies an average price duration of 4 quarters, assuming flexible capital at the firm level. The steady state marginal costs, $exp(-\mu) = 0.95$, imply a markup of 5%. I calibrate the adjustment cost of capital, $\phi = 11.5$, to match a relative investment volatility of 4.6 in response to TFP shocks as observed in U.S. data; see Table 2.

4.3 Central Bank and Government

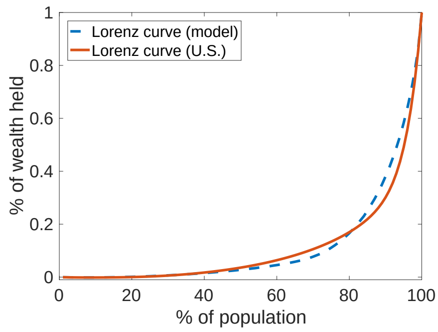
I set the inflation rate to zero and the real return on bonds to 2.5% in line with the average federal funds rate in the U.S in real terms from 1983 to 2007. Clarida et al. (2000) provide an estimate for the parameter governing interest rate smoothing, $\rho_{R^B} = 0.8$, while the central bank's reaction to

[19]This is in line with 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.

Figure 3: Household portfolios



(a) Portfolio liquidity



(b) Wealth inequality

Notes: U.S. data corresponds to average of the Survey of Consumer Finances 1983-2007. Only household with at least two adults and the household head being between 30 and 55 years of age are included.
(a): Liquid wealth relative to illiquid wealth. Households below the 20th percentile have been excluded because they hold negative net liquid positions. See Appendix C.2 for a detailed asset taxonomy.
(b): Wealth Lorenz curve in the model (dashed line) against Lorenz curve of wealth defined as financial plus non-financial assets minus debt for the U.S. (solid line).

inflation deviations 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 purchases and interest expense on debt. I adjust $1 - \tau = 0.3$ to close the budget constraint given the interest expense and a government-spending-to-GDP ratio of 20% in steady state. Government purchases, in turn, react to debt deviations from steady state such that the debt level remains bounded. Specifically, I set $\theta_G = 1$ to match the average government spending response to monetary shocks as displayed in Figure 1.

4.4 Model Fit

Figure 3 (a) shows that there are large differences in the liquidity of U.S. household portfolios, where the data corresponds to the average over the SCF waves from 1983 to 2007. Liquidity-rich households hold up to 20% of their wealth in liquid assets, but a large fraction of households holds little liquid wealth. The distribution of liquid assets in household portfolios generated by the model matches well the liquidity ratio of poor and rich households, but overestimates the liquidity of the median household.[20]

The model performs well in matching U.S. wealth inequality. Figure 3 (b) compares the Lorenz curve of wealth implied by the model to U.S. data. The U.S. Gini coefficient of 0.78 is matched by construction, but the model also generates realistic shares in total wealth across all percentiles of the wealth distribution.

Table 2: Business cycle statistics

	MODEL			DATA		
	STD	CORR	AC(1)	STD	CORR	AC(1)
GDP	0.97	1.00	0.88	0.97	1.00	0.72
Consumption	1.05	0.76	0.57	0.85	0.88	0.68
Investment	4.42	0.53	0.84	4.42	0.87	0.79

Notes: Model with TFP shocks only. Standard deviation, correlation with GDP, and autocorrelation after log-HP(1600)-filtering. Standard devation is multiplied by 100.

Table 2 reports the business cycle statistics implied by the model with TFP shocks only. The volatility of output and investment are calibrated to U.S. data, while the remaining statistics are not targeted.

5 Results

This section discusses how heterogeneity in household portfolios affects the transmission of monetary policy shocks to the aggregate economy. I first consider the theoretical channels through which monetary policy affects household decisions in this model, and then compare the aggregate effects

[20]This may be partly explained by the SCF under reporting liquid wealth relative to Flow of Funds data; see Appendix C.2.

in the economy with heterogeneity in household portfolios to the same economy with a representative household.[21] I elaborate on the heterogeneity in the consumption and portfolio response to highlight the importance of heterogeneity in household portfolios for aggregate outcomes.

5.1 Transmission Channels of Monetary Policy

Key for understanding the transmission of monetary policy in any DSGE model is the household consumption-savings decision. The decision problem of households in an incomplete-markets setting differs from that of a representative household in that borrowing constraints do apply and wealth holdings are heterogeneous. This gives rise to differences in optimal decisions as income effects differ and households take the existence of borrowing constraints into account or might actually be at the constraint. The effect of monetary policy on household decisions, in turn, can be split into direct and indirect effects along the lines of Table 3.

Consider a contractionary monetary policy shock. All else equal, an increase in the nominal interest rate also increases the real return on nominal assets and, thus, the intertemporal relative price of composite consumption of leisure and goods, X_t, today vs. tomorrow.[22] At the same time, higher interest payments on nominal assets imply an income effect that is positive or negative depending on a household's net liquid asset position. I refer to the effects of the interest rate change as the direct channel of monetary policy.

Figure 4 shows the individually optimal response across the liquid wealth distribution to an increase in the interest rate – keeping all other prices and quantities fixed. Consumption falls the most for indebted households at the bottom of the distribution. In their case, substitution and income effect go in the same direction. Rich households, by contrast, increase their consumption because the income effect dominates the substitution effect. All

[21] The representative household version of the model does not feature limited participation in the capital market because households are perfectly insured through state-contingent claims. I keep the parameters of the model unchanged to isolate the effect of heterogeneity in household portfolios on the transmission of monetary policy.

[22] Recall that the household problem can be expressed in terms of composite consumption X_t with GHH preferences: $x_{it} = c_{it} - \frac{\tau w_t h_{it} N_t}{1+\gamma}$. It is therefore the intertemporal allocation of composite consumption that matters for the household in this model.

Table 3: Monetary policy transmission mechanism in the model

Decision	Determined by	Relevant prices	Effect is
	sequence of Euler equations	$\{R^B_{t-1}/\pi_t\}$	direct
intertemporal consumption -savings $\{X_t\}_{t=0\ldots\infty}$	life-time budget	$\{w_t, r_t, \pi_t\}$	
	borrowing constraints	$\{w_t, r_t, \pi_t, q_t\}$	indirect
intratemporal labor-leisure $\{N_t\}\{C_t = \{X_t + G(N_t)\}$	marginal dis-utility of work	$\{w_t\}$	

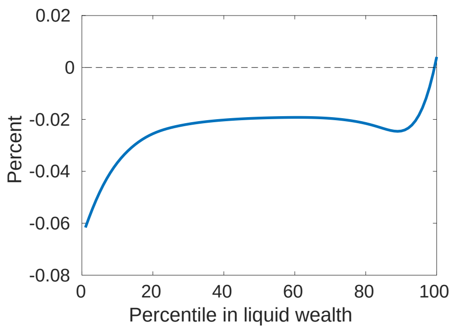
Notes: The table breaks the household problem down into inter- and intratemporal decisions. The gray shaded block represents the effects of monetary policy through general equlibrium changes in prices, i.e. the indirect effects. **Borrowing constraints** (in bold) **only** bind **in** the **incomplete markets** version of the model.

households increase the liquidity of their portfolios, and, if possible, sell illiquid capital to buy liquid bonds. This is at odds with the empirical portfolio response; see Figure 2. To understand the differential response in the data it is necessary to take into account equilibrium changes in prices.

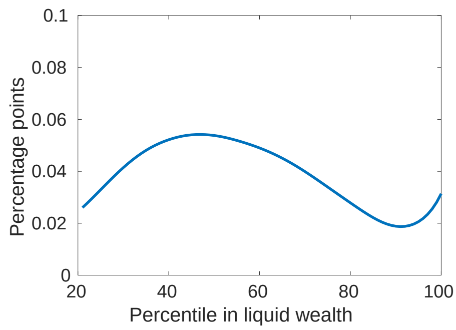
Since prices are sticky, the decrease in consumption is not completely offset by lower prices, and output falls. Lower output, in turn, decreases income and consumption, which again reduces income and so forth. I refer to the equilibrium changes in income and prices as the indirect effects of monetary policy.

In the complete markets economy, these indirect effects matter for composite consumption only in so far as they change life-time income, because the consumption path is determined by a sequence of Euler equations and a single life-time budget constraint. The consumption of final goods, C_t, and labor supply, N_t, then follows through the intratemporal consumption-leisure trade-off that solely depends on the wage rate. With incomplete

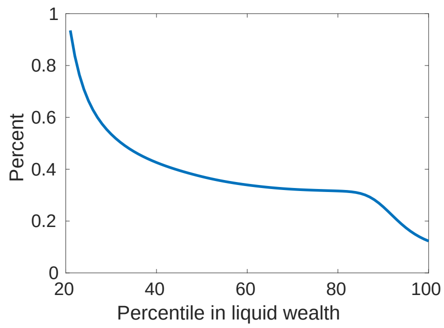
Figure 4: Partial equilibrium – Individual response to a monetary shock



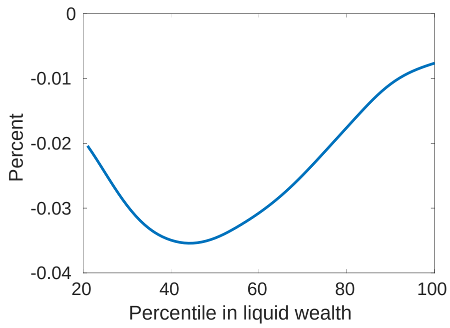
(a) Consumption response $\Delta \log c_{it}$



(b) Portfolio liquidity $\Delta(b_{it}/k_{it})$



(a) Bond response $\Delta \log b_{it}$



(b) Capital response $\Delta \log k_{it}$

Response of individual consumption and asset demand policies at constant prices and price expectations to a 1 standard deviation monetary shock, $\epsilon^D = 36$ basis points (annualized). Policies by liquid wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.05.

markets, however, current income becomes an important determinant of composite and final-goods consumption because of borrowing constraints.[23]

The next section first describes the aggregate effects of monetary shocks in the model with and without complete markets. Afterwards I discuss the heterogeneous household responses in equilibrium when both direct and

[23]The indirect effects of monetary policy work through the (life-time) budget constraint and the complementarity of consumption and hours worked inherent in GHH preferences in this model. This paper is about the effect of borrowing constraints on household decisions through the budget constraint channel. For this purpose, GHH preferences and the specific form of the disutility of labor adopted are helpful. They rule out wealth effects on labor supply and more generally make labor supply independent of all idiosyncratic states. As a result, labor supply only depends on the aggregate wage rate in both versions of the model.

indirect effects are at work.

5.2 Aggregate Effects of a Monetary Policy Shock

In the following, I consider the effect of a monetary surprise that, all else equal, would increase the nominal interest rate by 1 standard deviation, i.e., 36 basis points (annualized), in period 1. Figure 5 compares the responses of the economy with and without heterogeneity in household portfolios.

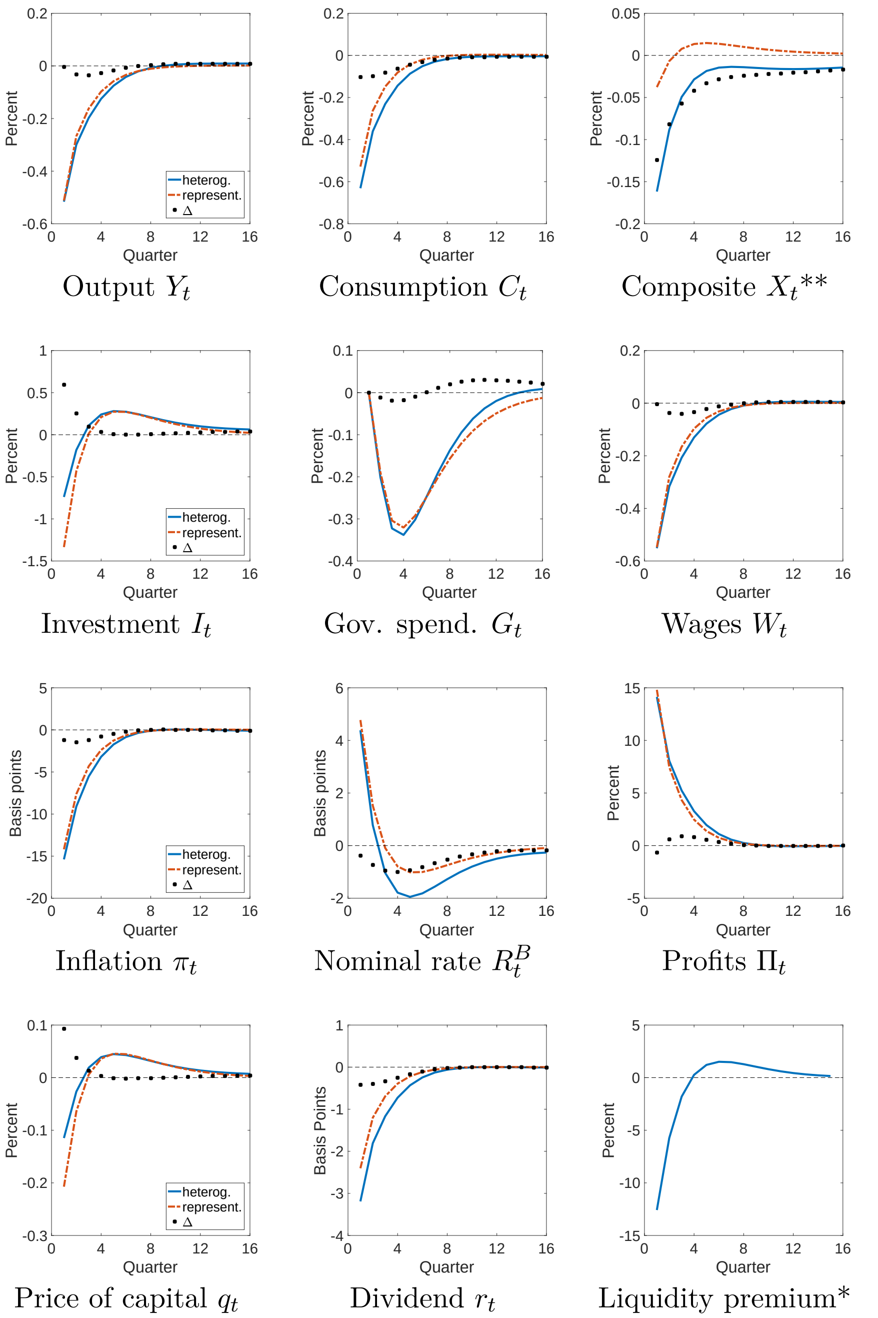
What stands out immediately is that the output response is very similar. The initial drop in output is about 0.5 percent in both versions of the model. The composition of the output drop, however, is quite different. The fall in consumption is steeper and more persistent in the economy with heterogeneous households, while the reverse is true for investment. Consumption falls by 20% more and the total consumption loss over 4 years is 0.5 percentage points higher with incomplete markets. Investment, however, falls by 45% less when markets are incomplete, which leaves the output response the same.

Looking at composite consumption X_t, which abstracts from the interaction between wage rate and final goods consumption inherent in GHH preferences (see Table 3), makes the difference between both economies even more evident.[24] Composite consumption falls in equilibrium four times more when current income, and not life-time income, is the relevant constraint. The indirect effects through the life-time budget constraint are of minor importance, and consumption is basically determined by the direct effect of the interest rate when markets are complete. Current income, however, responds strongly and so does composite consumption with market-incompleteness because of borrowing constraints. Quantitatively, the indirect effect explains 75% of the drop in composite consumption with market-incompleteness, while the direct effect through interest rate changes accounts for only 25%.[25]

[24] More leisure time decreases the marginal utility of consumption with GHH preferences such that, all else equal, consumption falls with labor supply N_t.

[25] This difference becomes substantially higher when the indirect effect through GHH preferences is included. Looking at consumption of final goods, indirect effects explain about 95% of the total response. The GHH effect, however, is also present in the complete-markets setting. It accounts for about 90% of the response in consumption of final goods there. This is driven by the adopted preference specification, of course, and vanishes with additively separable preferences in consumption and leisure. With such preferences, the response of composite consumption applies, which is determined by the direct effect with complete markets.

Figure 5: Aggregate response to a monetary shock



Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^D = 36$ basis points (annualized). Solid line: the model with heterogeneous households. Dashed line: same calibration with a representative household. Dots: Difference between both (solid minus dash). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = \frac{E_t q_{t+1} + r_t}{q_t} - \frac{R_t^B}{E_t \pi_{t+1}}$ $**X_t = \int (c_{it} - h_{it} \frac{n_{it}^{1+\gamma}}{1+\gamma}) di$

The indirect effects are key to understanding the difference in investment as well. The bottom panel of Figure 5 shows that the liquidity premium falls in response to the contractionary shock in line with the empirical results. The decline in the premium suggests that the marginal holder of liquid assets changes. Heterogeneity of portfolio responses is discussed next.

5.3 Heterogeneity in Household Responses

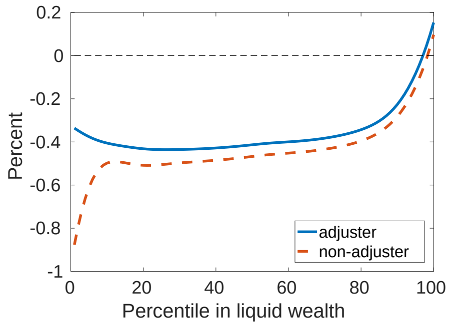
Figure 6 displays the equilibrium response of household consumption and portfolios to the monetary shock across the liquid wealth distribution in period 1.

Panel (b) of Figure 6 shows the change in portfolio liquidity for adjusters and all households. Adjusters increase the liquidity ratio of their portfolios by about 0.3 percentage points on average with the highest increase at the 40th percentile of the liquid wealth distribution. The solid line, however, reveals that portfolio liquidity falls for a large fraction of households when the response of adjusters and non-adjusters are combined. The liquidity ratio falls for the bottom 50% and markedly increases only for the richest households. This pattern closely resembles the empirical portfolio response to monetary shocks in Figure 2.

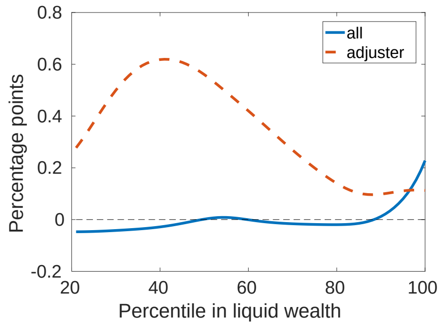
Panel (c) and (d) show the change in bond and capital holdings behind the change in portfolio liquidity. Capital holdings fall the most for households with below median liquidity, who increase portfolio liquidity the most as well. For households with above median liquidity, the fall in capital declines in liquid wealth and becomes positive for very liquidity-rich households. The fall in portfolio liquidity therefore is driven by households that cannot adjust their illiquid asset position. All non-adjusters, except for the top 10%, sell liquid assets and thereby lower the liquidity of their portfolios. Bond holdings fall the most, about -3%, for liquidity-poor households.

The differential change of portfolio liquidity cannot be explained by the direct effect of the interest rate alone. In partial equilibrium, when only the interest rate changes, all households increase portfolio liquidity; see Figure 4. In equilibrium, however, current income falls, and households with little liquid wealth relative to their income use liquid savings to smooth

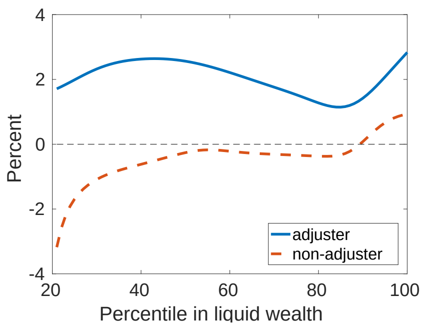
Figure 6: Consumption and portfolio response to a monetary shock



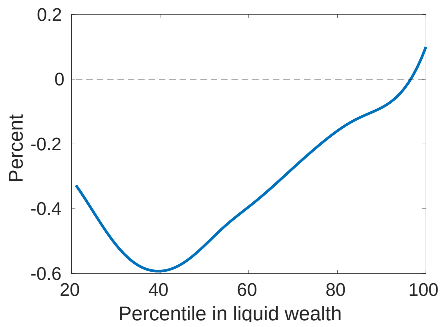
(a) Consumption response $\Delta \log c_{it}$



(b) Portfolio liquidity $\Delta(b_{it}/k_{it})$



(c) Bond response $\Delta \log b_{it}$



(d) Capital response $\Delta \log k_{it}$

Response of individual consumption and asset demand policies in equilibrium to a 1 standard deviation monetary shock, $\epsilon^D = 36$ basis points (annualized). Policies by liquid wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.05.

consumption. The indirect effects through the budget constraint are key to generate both households that increase and decrease the liquidity of their portfolios as in the data. When markets are complete, the representative household increases portfolio liquidity until expected returns are equalized using a representative stochastic discount factor. This leads to a stronger fall in investment in the latter relative to the former economy.

Non-trivial redistributive consequences that interact with heterogeneity in household portfolios dampen the investment response further. In contrast to the partial equilibrium response, households in the top 5% of the liquid wealth distribution actually increase their savings in capital when prices change. The reason is that a contractionary monetary shock in-

Table 4: Exposure to monetary shocks by liquid wealth holdings

	Income gains/losses			Capital gains/ losses
Liquid wealth quintiles	Interest $\Delta(R^B_{t-1}/\pi_t)$	Dividends Δr_t	Labor/Profit $\Delta(W_t N_t + \Pi_t)$	Δq_t
1.	-0.18	-0.42	-3.67	-1.53
2.	0.11	-0.22	-3.81	-0.80
3.	0.26	-0.24	-3.61	-0.88
4.	0.41	-0.41	-3.37	-1.46
5.	0.71	-1.10	0.73	-3.96

Notes: Gains and losses in percent of within group consumption in period 1 to a 1 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.

creases income inequality.

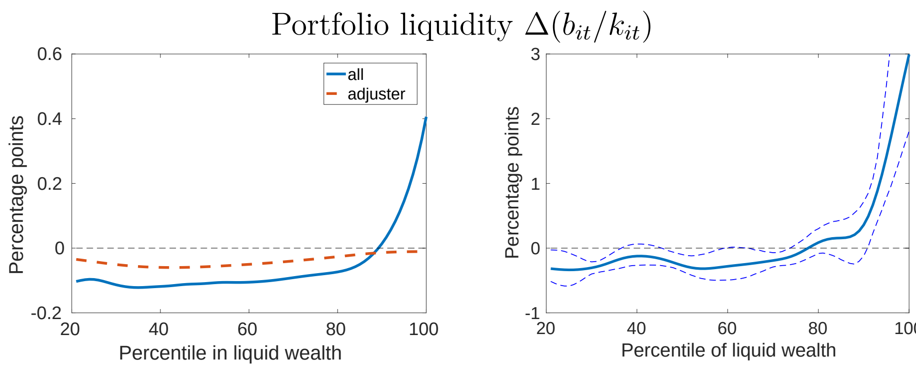
Table 4 summarizes the gains and losses on each source of income. They are reported relative to average consumption of each wealth bracket. Households in the top quintile of the liquid wealth distribution enjoy higher returns on their human capital on average because an over-proportionate share are entrepreneurs. They receive profit income that increases while labor income falls. The top quintile incurs the highest losses on the real asset position. However, most of it is caused by lower asset prices that are not completely realized. All in all, households in the top 5% of liquid wealth gain from a monetary tightening and, accordingly, increase their savings in bonds *and* capital.

The monetary shock leads to persistent changes in the distribution of wealth. The Gini indexes for wealth, income, and consumption increase for many quarters after a monetary tightening.[26] Figure 7 compares the differences in portfolio liquidity 2 years after the monetary tightening in the model and the data. The increase in the liquidity ratio at the top of the liquid wealth distribution is substantially stronger, and liquidity now falls for all households in the bottom 80%.

Table 4 also explains why consumption of households in the bottom

[26] See Appendix E.

Figure 7: Portfolio response to a monetary shock after 2 years



(a) Model (b) Data

Change in portfolio liquidity after 2 years to a 1 standard deviation monetary shock, $\epsilon^D = 36$ basis points (annualized). Policies by liquid wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.05. Data corresponds to the local projection with SCF data as in Section 1 at horizon 2 years. Bootstrapped 66% confidence bands in dashed-lines, based on a non-parametric bootstrap.

10% of the liquid wealth distribution falls so much more than the rest; see Figure 6. Households below the 16th percentile are indebted and suffer from higher interest payments on debt. Their low savings make them highly exposed to changes in income and explain why consumption at the very bottom falls 100% more than consumption at median liquidity.

6 Conclusion

This paper provides novel cross-sectional evidence that heterogeneity in household portfolios has important implications for the consumption and portfolio response to monetary shocks. I find that consumption and savings by liquidity-poor households fall in response to higher interest rates, while both increase for liquidity-rich households. To explain this differential response and its importance for the transmission of monetary policy, I build a New Keynesian business cycle model with incomplete markets and assets with different degrees of liquidity. I show that aggregate consumption becomes more and investment less responsive to monetary shocks.

The response of consumption is primarily driven by indirect equilibrium changes in income that strongly affect liquidity-constrained households. The redistributive consequences of monetary policy imply a muted investment response. The share of real assets in household portfolios increases in household wealth such that second-round changes in inequality affect the investment response.

The weakening of the interest rate channel and the importance of redistribution questions the existing results on optimal monetary policy rules and puts the interaction of monetary and fiscal policy at center stage. In future work, it is thus important to reassess optimal policy in a New Keynesian model with incomplete markets.

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A First Order Conditions

Denote the optimal policies for consumption, bond holdings, and capital holdings as $x_i^*, b_i^*, k^*, i \in \{a, n\}$ 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:

$$
\begin{aligned}
k^* : \frac{\partial u(x_a^*)}{\partial x} q &= \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial k} + (1-\nu) \frac{\partial V_n(b_a*, k*; \mathbf{z}')}{\partial k} \right] && (22) \\
b_a^* : \frac{\partial u(x_a^*)}{\partial x} &= \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial b} + (1-\nu) \frac{\partial V_n(b_a^*, k^*; \mathbf{z}')}{\partial b} \right] && (23) \\
b_n^* : \frac{\partial u(x_n^*)}{\partial x} &= \beta E \left[\nu \frac{\partial V_a(b_n^*, k; \mathbf{z}')}{\partial b} + (1-\nu) \frac{\partial V_n(b_n^*, k; \mathbf{z}')}{\partial b} \right] && (24)
\end{aligned}
$$

Note the subtle difference between (23) and (24), which lies in 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:

$$
\begin{aligned}
\frac{\partial V_a(b, k; \mathbf{z})}{\partial k} &= \frac{\partial u[x_a^*(b, k; \mathbf{z})]}{\partial x} (q(\mathbf{z}) + r(\mathbf{z})) && (25) \\
\frac{\partial V_a(b, k; \mathbf{z})}{\partial b} &= \frac{\partial u[x_a^*(b, k; \mathbf{z})]}{\partial x} \frac{R^b(\mathbf{z})}{\pi(\mathbf{z})} && (26) \\
\frac{\partial V_n(b, k; \mathbf{z})}{\partial b} &= \frac{\partial u[x_n^*(b, k; \mathbf{z})]}{\partial x} \frac{R^b(\mathbf{z})}{\pi(\mathbf{z})} && (27) \\
\frac{\partial V_n(b, k; \mathbf{z})}{\partial k} &= r(\mathbf{z}) \frac{\partial u[x_n^*(b, k; \mathbf{z})]}{\partial x} && (28) \\
&\quad + \beta E \left[\nu \frac{\partial V_a[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}']}{\partial k} + (1-\nu) \frac{\partial V_n[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}']}{\partial k} \right] \\
&= r(\mathbf{z}) \frac{\partial u[x_n^*(b, k; \mathbf{z})]}{\partial x} + \beta \nu E \frac{\partial u\{x_a^*[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}], k; \mathbf{z}'\}}{\partial x} (q(\mathbf{z}') + r(\mathbf{z}')) \\
&\quad + \beta(1-\nu) E \frac{\partial V_n\{[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}], k; \mathbf{z}'\}}{\partial k}
\end{aligned}
$$

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):

$$\frac{\partial u[x_a^*(b,k;\mathbf{z})]}{\partial x} q(\mathbf{z}) = \beta E\left[\nu \frac{\partial u[x_a^*(b_a^*,k^*;\mathbf{z}')]}{\partial x}[q(\mathbf{z}')+r(\mathbf{z}')] + (1-\nu)\frac{\partial V^n(b_a^*,k';\mathbf{z}')}{\partial k'}\right] \tag{29}$$

$$\frac{\partial u[x_a^*(b,k;\mathbf{z})]}{\partial x} = \beta E\frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')}\left[\nu \frac{\partial u[x_a^*(b_a^*,k^*;\mathbf{z}')]}{\partial x} + (1-\nu)\frac{\partial u[x_n^*(b_a^*,k';\mathbf{z}')]}{\partial x}\right] \tag{30}$$

$$\frac{\partial u[x_n^*(b,k,;\mathbf{z})]}{\partial x} = \beta E\frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')}\left[\nu \frac{\partial u[x_a^*(b_n',k;\mathbf{z}')]}{\partial x} + (1-\nu)\frac{\partial u[x_n^*(b_n^*,k;\mathbf{z}')]}{\partial x}\right] \tag{31}$$

In words, the optimal portfolio allocation compares the one-period return difference between the two assets for 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 $E\frac{R^b(z')}{\pi(z')}\frac{\partial u[x_n^*(b_a^*,k';z')]}{\partial x} - \frac{\partial V^n(b_a^*,k';z')}{\partial k'}$, 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.

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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 et al. (2015) propose a variant of Reiter's (2009) method to solve heterogeneous agent models with aggregate risk. Key to reduce the dimensionality of the system is using Sklar's Theorem and writing 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. I check whether the time-constant copula assumption creates substantial numerical errors and find none by comparing it to the Krusell and Smith (1998) solution.

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

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

Note the difference to a global approximation of the functions 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. (2017) and different from Winberry (2016) 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 as 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 $Y_t = (V_t, \frac{\partial V_t}{\partial b}, \frac{\partial V_t}{\partial k}, \tilde{Y}_t)$, i.e., value functions and their derivatives with respect to k, b as well as some aggre-

Table 5: Den Haan (2010) statistic

	Absolute error (in %) for			
	Price of Capital q_t	Capital K_t	Inflation π_t	Real Bonds B_t
Mean	0.03	0.38	0.05	0.30
Max	0.27	1.12	0.63	1.08

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 $t = \{1, ..., 5000\}$; see Den Haan (2010).

gate controls $\tilde{Y}_t$ such as dividends, wages, etc. The set of state variables $X_t = (\Theta_t, R_t^B, \Omega_t)$ is given by the histogram Θ_t of the distribution over (b, k, h) and the aggregate states R_t^B and Ω_t, where Ω stands for either monetary or technology shocks.

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=5000 periods and calculate the differences between the linearized solution and the non-linear one. The maximum difference is 1.12% for the capital stock and 1.08% for bonds while the mean absolute errors are substantially smaller; see Table 5.

C Description of Aggregate and Cross-Sectional Data

C.1 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 is composed of real estate at market value, life insurance reserves, pension entitlements, equipment and nonresidential intellectual property products of nonprofit organizations, proprietors' equity in non-corporate business, corporate equities, mutual fund shares subtracting home mortgages as well as commercial mortgages.

C.2 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 household portfolio responses to monetary shocks and for the calibration of the model. I restrict the sample to households with two married adults whose head is between 30 and 55 years of age to control for changing demographics and exclude education and retirement decisions that are not explicitly modeled. The asset taxonomy is the following.

Net liquid assets are classified as 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 to be 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 nonfinancial 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., 2016). From gross illiquid asset holdings, I subtract all debt except for credit card debt.

Table 6: Household portfolio composition:
Survey of Consumer Finances 1983-2007
Married households with head between 30 and 55 years of age

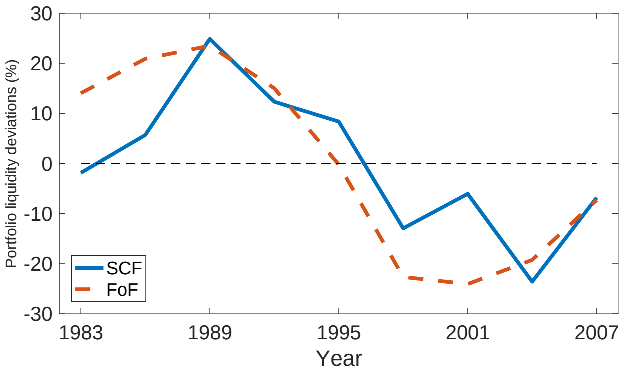
Moments	Model	Data
Fraction with $b < 0$	0.16	0.16
Fraction with $k > 0$	0.85	0.91
Fraction with $b \leq 0$ and $k > 0$	0.11	0.13
Gini liquid wealth	0.77	0.88
Gini illiquid wealth	0.80	0.78
Gini total wealth	0.78	0.78

Notes: Averages over the SCFs 1983-2007 using the respective cross-sectional sampling weights. Households whose liquid asset holdings fall below minus 1 time quarterly average 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.

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 1 time average quarterly household income – the debt limit I use in the model. Moreover, I exclude all households whose equity in illiquid assets is below the negative of 1 time average annual income. This excludes roughly 5% of U.S. households on average from the analysis. Table 6 displays 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 liquid wealth distribution by running a local linear regression that maps the percentile rank in liquid 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 the households by liquid wealth (LI_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

Figure 8: Deviation of portfolio liquidity from mean in SCF and FoF



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 $h = 0.05$ 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:

$$w_{it}LI_{it} = \lambda^{LI}(prc,t)w_{it} + \beta^{LI}(prc,t)(\mathbf{prc}_{it} - prc)w_{it} + \zeta_{it}^{LI}, \quad (32)$$

$$w_{it}IL_{it} = \lambda^{IL}(prc,t)w_{it} + \beta^{IL}(prc,t)(\mathbf{prc}_{it} - prc)w_{it} + \zeta_{it}^{IL}, \quad (33)$$

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

Figure 8 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. in Kaplan et al., 2016).

C.3 Data from the Consumption Expenditure Survey

I use 26 waves of the Consumption Expenditure Survey (CEX, 1983-2007) for the empirical analysis of household consumption responses to monetary shocks. Again, I restrict the sample to households with two married adults whose head is between 30 and 55 years of age to control for changing demographics and exclude education and retirement decisions that are not explicitly modeled.

As with the SCF, I would like to order households according to their liquid wealth. The CEX, however, does not provide a complete picture of household portfolios. For this reason, I order households according to their reported savings in checking accounts (variable name: ckbkactx). The portfolio data from the SCF shows that deposits are a good proxy for liquid wealth, especially at the bottom 50% of the distribution. I abstract from the limited panel dimension of the CEX, and, instead, treat the quarterly data as repeated cross-sections to focus on the heterogeneity of the consumption response across the liquid wealth distribution.

I estimate non-durable consumption at each percentile of the liquid wealth distribution by running a local linear regression that maps the percentile rank in liquid wealth into non-durable consumption. In detail, let C_{it} be the value of non-durable consumption of household i in the CEX of quarter t, respectively. Let ω_{it} be its sample weight. I first sort the households by liquid wealth (LI_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, $prc = 0.01, 0.02, \dots 1$, 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 $h = 0.05$ is the bandwidth. I then estimate consumption at percentile prc at time t as the intercepts $\lambda^C(prc, t)$ obtained from the weighted regressions for year t:

$$w_{it} C_{it} = \lambda^C(prc, t) w_{it} + \beta^C(prc, t)(\mathbf{prc}_{it} - prc) w_{it} + \zeta^C_{it} \qquad (34)$$

where ζ^C is an error term.

C.4 Other Aggregate Data

Section 1 shows the impulse response functions of the log of real GDP, real personal consumption expenditures, real gross private investment, and real government purchases. These variables are taken from the national accounts data provided by the Federal Reserve Bank of St. Louis (Series: PCEC, GPDI, GCEC1). GDP is calculated as a residual.

Data on house prices, federal funds rate and the liquidity premium come from the same source. House prices are captured by the Case-Shiller S&P U.S. National Home Price Index (CSUSHPINSA) divided by the all-items CPI (CPIAUCSL). I construct the liquidity premium from nominal house prices, the CPI for rents, and the federal funds rate. I measure the liquidity 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 Solow residual series comes from the latest version (date of retrieval 2016-12-21) of Fernald's raw TFP series (Fernald et al., 2012). I construct an index from the reported growth rates and use the log of this index.

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

D.1 Local Projection Method for Aggregate Data

Figure 1 of Section 1 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^D, 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 $\bar{\epsilon}_t^D$ (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}, of investment I_{t-1}, and of government expenditures G_{t-1} as well as lagged monetary shocks $\epsilon_{t-1}^D, \epsilon_{t-2}^D$:

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

Hence, the impulse response function $\beta_{j,0}$ is just a sequence of projections of Υ_{t+j} in response to the shock $\bar{\epsilon}_t^D$, 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^D 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).

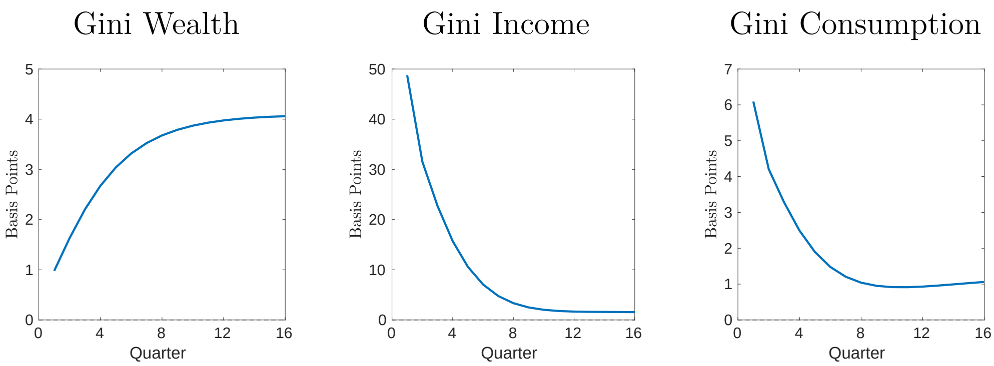
D.2 Local Projection Method for Cross-Sectional Data

Similarly, in Figure 2 of Section 1, I use local projections with horizon 1 to estimate the contemporaneous response of portfolio liquidity and consumption to monetary shocks across the liquid wealth distribution. Toward this end, I treat the measures of portfolio liquidity and consumption by percentile of liquid wealth, constructed in Section C.2 and C.3, as endogenous variables and run single regressions for each percentile, i.e., $\lambda^C(prc, t)$, $\lambda^{LI}(prc, t)$ and $\lambda^{IL}(prc, t)$, on normalized monetary shocks, $\bar{\epsilon}_t^D$. In each regression, I include as control a constant, a time trend, two lags of the monetary shock, and the contemporaneous federal funds rate. The data from the SCF is annual such that I take the cumulative monetary shock in a given year. The data from the CEX is quarterly and, hence, I include quarterly dummies to control for seasonal patterns.

E Distributional Consequences: Gini Indexes

Figure 9 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 points to 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, by contrast, is more persistent because of a prolonged time of higher wealth inequality.

Figure 9: Response of inequality to a monetary shock



Notes: Impulse responses of Gini indexes of wealth, income, and consumption to an 36 basis points (annualized) monetary policy shock, ϵ^D. 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).

F Individual Consumption Responses to Persistent and Transitory Income Shocks

In order for the model to provide a useful framework to study heterogeneity in consumption, it is important that the model replicates the empirical evidence on consumption responses to persistent and transitory income shocks (in partial equilibrium). For this purpose, I consider the average consumption elasticity to a persistent increase in income and an increase in liquid assets proportional to income (transitory income shock). These two elasticities are key to understanding the consumption smoothing behavior of an incomplete markets model; see Kaplan and Violante (2010) and Blundell et al. (2008).

Table 7 provides these statistics for the model. The model replicates the fact that transitory income shocks are well insured, while persistent income shocks are much less insured. Behind this average numbers lies large heterogeneity in elasticities. Liquidity-poor households have sizable elasticities with respect to transitory income shocks. This corresponds to the findings by Misra and Surico (2014) who show that liquid assets are a key predictor of the consumption response to one-off transfers.

Table 7: Consumption smoothing in model and data

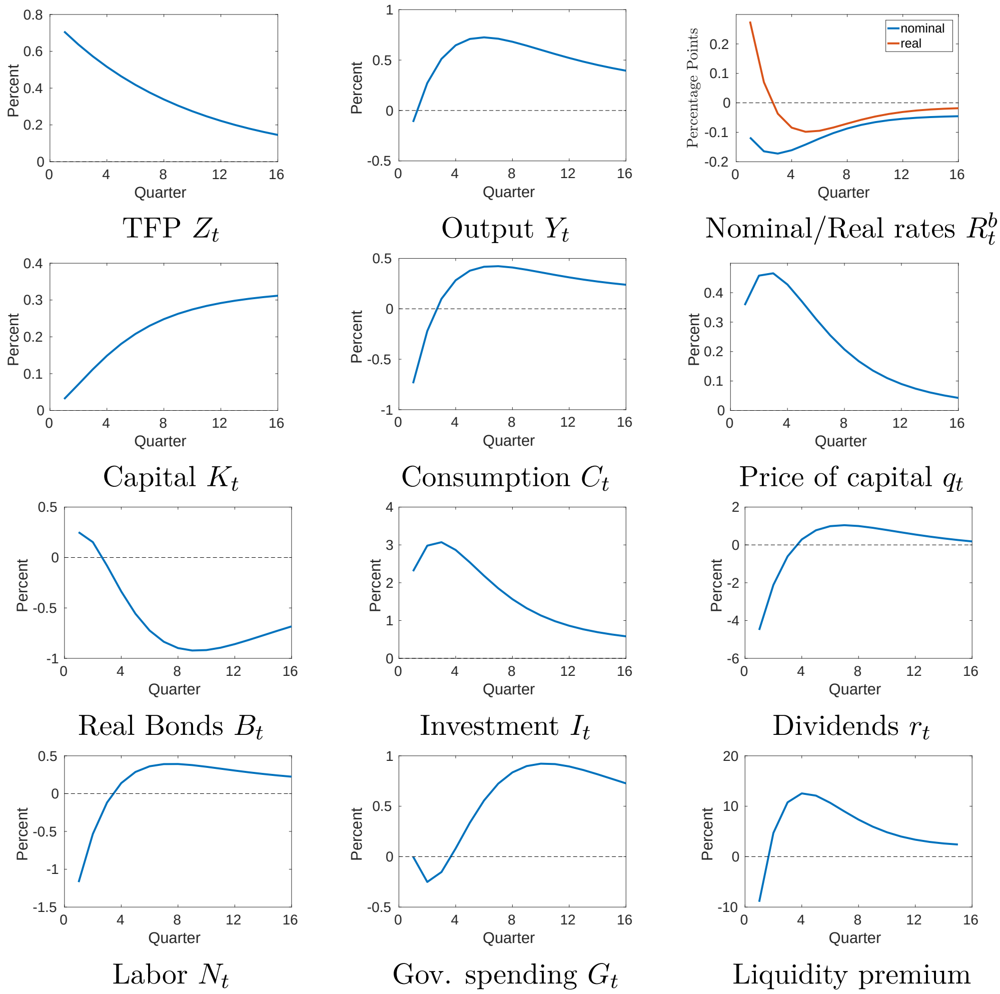
Elasticity of consumption to transitory and persistent income shocks		
	Data	Model
Transitory income change	0.05	0.05
Persistent income change	0.43	0.22

Data correspond to Kaplan and Violante (2010).

G Response of the Model to TFP Shocks

This section reports 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 0.9 and a standard deviation of 0.007.

Figure 10: Aggregate response to a TFP shock



Notes: Liquidity Premium: $\frac{E_t q_{t+1} + r_t}{q_t} - \frac{R_t^b}{E_t \pi_{t+1}}$.
Impulse responses to a one standard deviation increase in TFP. All rates (dividends, interest, liquidity premium) are *not* annualized.