Transmission of Monetary Policy with Heterogeneity in Household Portfolios

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Online Appendix

1   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:

$$k^* : \frac{\partial u(c_a^*)}{\partial c} q = \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial k} + (1 - \nu) \frac{\partial V_n(b_a^*, k^*; \mathbf{z}')}{\partial k} \right] \tag{1}$$

$$b_a^* : \frac{\partial u(c_a^*)}{\partial c} = \beta E \left[\nu \frac{\partial V_a(b_a^*, k^*; \mathbf{z}')}{\partial b} + (1 - \nu) \frac{\partial V_n(b_a^*, k^*; \mathbf{z}')}{\partial b} \right] \tag{2}$$

$$b_n^* : \frac{\partial u(c_n^*)}{\partial c} = \beta E \left[\nu \frac{\partial V_a(b_n^*, k; \mathbf{z}')}{\partial b} + (1 - \nu) \frac{\partial V_n(b_n^*, k; \mathbf{z}')}{\partial b} \right] \tag{3}$$

$$n_a^* : \frac{\partial u(n_a^*)}{\partial n} = \frac{\partial u(c_a^*)}{\partial c} \tau w h \tag{4}$$

$$n_n^* : \frac{\partial u(n_n^*)}{\partial n} = \frac{\partial u(c_n^*)}{\partial c} \tau w h \tag{5}$$

Note the subtle difference between (2) and (3) 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:

$$\frac{\partial V_a(b, k; \mathbf{z})}{\partial k} = \frac{\partial u[c_a^*(b, k; \mathbf{z})]}{\partial c} (q(\mathbf{z}) + r(\mathbf{z})) \tag{6}$$

$$\frac{\partial V_a(b, k; \mathbf{z})}{\partial b} = \frac{\partial u[c_a^*(b, k; \mathbf{z})]}{\partial c} \frac{R^b(\mathbf{z})}{\pi(\mathbf{z})} \tag{7}$$

$$\frac{\partial V_n(b, k; \mathbf{z})}{\partial b} = \frac{\partial u[c_n^*(b, k; \mathbf{z})]}{\partial c} \frac{R^b(\mathbf{z})}{\pi(\mathbf{z})} \tag{8}$$

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

$$
\begin{aligned}
\frac{\partial V_n(b, k; \mathbf{z})}{\partial k} =\ & r(\mathbf{z}) \frac{\partial u[c_n^*(b, k; \mathbf{z})]}{\partial c} \\
& + \beta E\left[\nu \frac{\partial V_a[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}']}{\partial k} + (1 - \nu) \frac{\partial V_n[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}']}{\partial k} \right] \\
=\ & r(\mathbf{z}) \frac{\partial u[c_n^*(b, k; \mathbf{z})]}{\partial c} + \beta \nu E \frac{\partial u\{c_a^*[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}], k; \mathbf{z}'\}}{\partial c} (q(\mathbf{z}') + r(\mathbf{z}')) \\
& + \beta(1 - \nu) E \frac{\partial V_n\{[b_n^*(b, k; \mathbf{z}), k; \mathbf{z}], k; \mathbf{z}'\}}{\partial k}
\end{aligned}
\tag{9}
$$

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

$$
\frac{\partial u[c_a^*(b, k; \mathbf{z})]}{\partial c} q(\mathbf{z}) = \beta E\left[\nu \frac{\partial u[c_a^*(b_a^*, k^*; \mathbf{z}')]}{\partial c} [q(\mathbf{z}') + r(\mathbf{z}')] + (1 - \nu) \frac{\partial V^n(b_a^*, k^*; \mathbf{z}')}{\partial k} \right]
\tag{10}
$$

$$
\frac{\partial u[c_a^*(b, k; \mathbf{z})]}{\partial c} = \beta E \frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')} \left[\nu \frac{\partial u[c_a^*(b_a^*, k^*; \mathbf{z}')]}{\partial c} + (1 - \nu) \frac{\partial u[c_n^*(b_a^*, k^*; \mathbf{z}')]}{\partial c} \right]
\tag{11}
$$

$$
\frac{\partial u[c_n^*(b, k, ; \mathbf{z})]}{\partial c} = \beta E \frac{R^b(\mathbf{z}')}{\pi(\mathbf{z}')} \left[\nu \frac{\partial u[c_a^*(b_n^*, k; \mathbf{z}')]}{\partial c} + (1 - \nu) \frac{\partial u[c_n^*(b_n^*, k; \mathbf{z}')]}{\partial c} \right]
\tag{12}
$$

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.

2   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

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

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

Table 1: 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).

smaller; see Table 1.

3   Distributional Consequences: Gini Indexes

Figure 1: Response of inequality to a monetary shock

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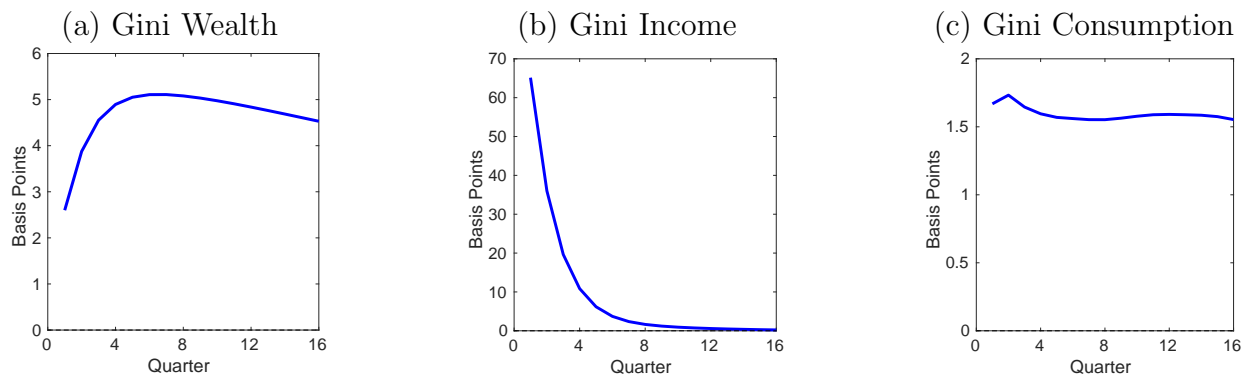
Notes: Impulse responses of Gini indexes of wealth, income, and consumption to a 36 basis points (annualized) monetary policy shock, ϵ^R. The y-axis shows basis point changes (an increase of "100" implies an increase in the Gini index from, say, 0.78 to 0.79).

Figure 1 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.

4   Description of Aggregate and Cross-Sectional Data

4.1   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); see Board of Governors of the Federal Reserve System (1952-2016). 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.

4.2   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 the response of household portfolios to monetary shocks and for the calibration of the model; see Board of Governors of the Federal Reserve System (1983-2007c). 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, Ferreira and Surico (2020). 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

Figure 2: Average portfolio liquidity by liquid/net wealth quintiles
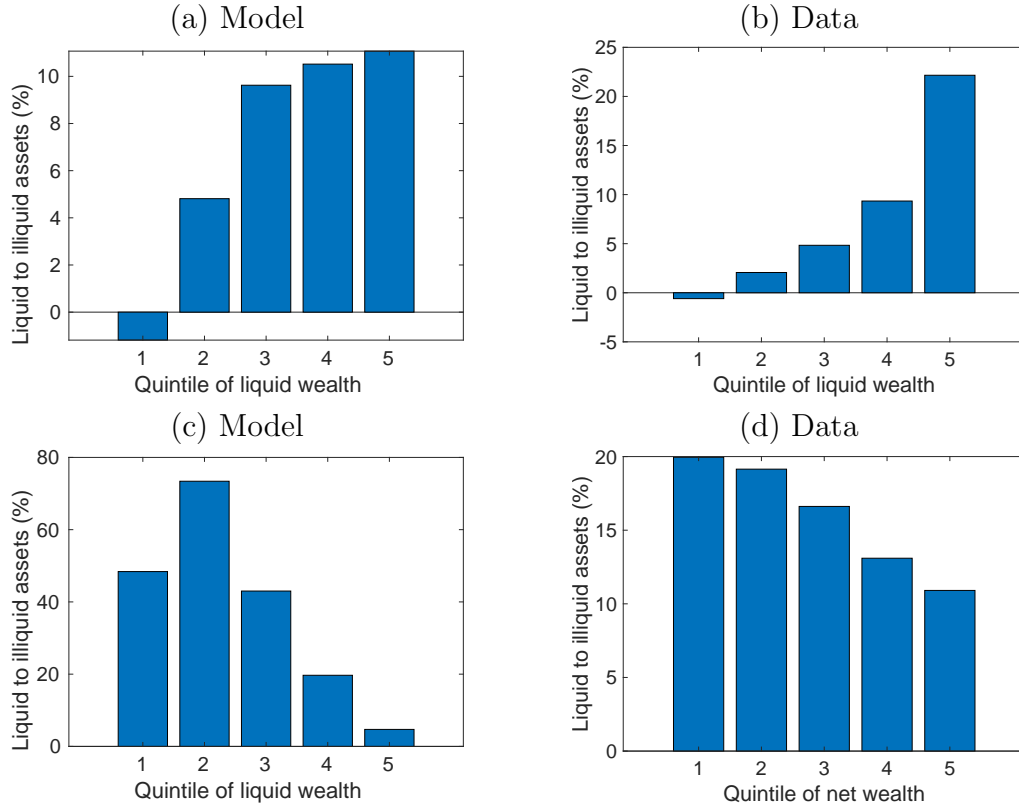
Notes: Panels (a) and (b): Estimated net liquid asset holdings relative to estimated net illiquid assets by quintile of the liquid wealth distribution. Panels (c) and (d): Estimated positive liquid asset holdings relative to estimated net illiquid assets by quintile of the net wealth distribution. Average over the estimates from the SCFs 1983-2007 (for households composed of at least two adults whose head is between 25 and 60 years of age). Estimation by a local linear estimator with a Gaussian kernel and a bandwidth of 0.1.

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, Moll and Violante, 2018). From gross illiquid asset holdings, I subtract all debt except for credit card debt.

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 2 and Table 2 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:

$$w_{it}LI_{it} = \lambda^{LI}(prc,t)w_{it} + \beta^{LI}(prc,t)(\mathbf{prc}_{it} - prc)w_{it} + \zeta_{it}^{LI}, \tag{13}$$

$$w_{it}IL_{it} = \lambda^{IL}(prc,t)w_{it} + \beta^{IL}(prc,t)(\mathbf{prc}_{it} - prc)w_{it} + \zeta_{it}^{IL}, \tag{14}$$

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

Figure 3 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, Moll and Violante, 2018).

Table 2: Household portfolio composition:
Survey of Consumer Finances 1983-2007
Married households with head between 25 and 60 years of age

Moments	Model	Data
Fraction with $b < 0$	0.16	0.16
Fraction with $k > 0$	0.85	0.89
Fraction with $b \leq 0$ and $k > 0$	0.10	0.13
Gini liquid wealth	0.64	0.83
Gini illiquid wealth	0.83	0.79
Gini total wealth	0.78	0.77

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.

Figure 3: Deviation of portfolio liquidity from mean in SCF and FoF
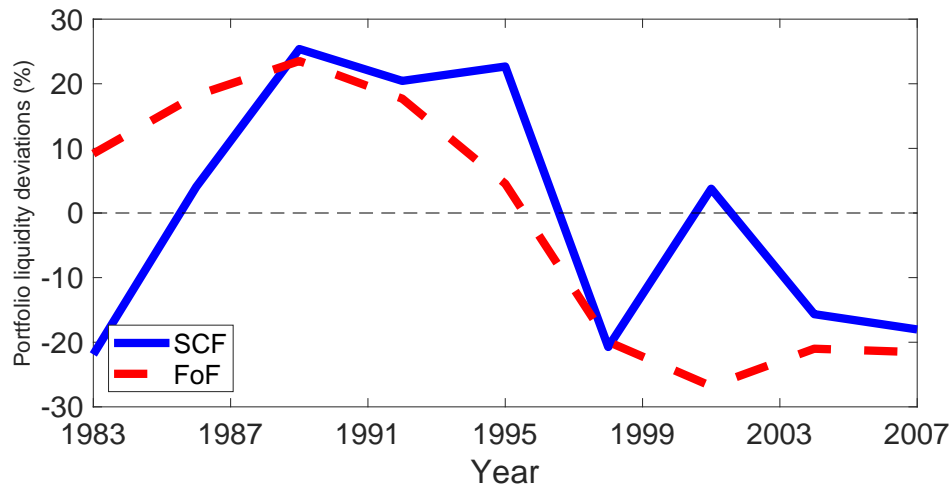
4.3 Other Aggregate Data

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); see U.S. Bureau of Economic Analysis, (1983-2007b) and U.S. Bureau of Economic Analysis, (1983-2007a). GDP is calculated as the sum of real consumption, real investment, and real government purchases (GCEC1); see U.S. Bureau of Economic Analysis (1983-2007).

Data on the federal funds rate, Board of Governors of the Federal Reserve System (1983-2007b), 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), LLC (1987-2007), divided by the all-items CPI (CPIAUCSL), U.S. Bureau of Labor Statistics, (1983-2007a). 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):

$$LP_t = \frac{R_{h,t}}{H_t} + \frac{H_{t+1}}{H_t} - (1 + R_t^B)^{\frac{1}{4}}. \tag{15}$$

Rents are imputed on the basis of the CPI for rents on primary residences paid by all urban consumers (CUSR0000SEHA), U.S. Bureau of Labor Statistics, (1983-2007b) fixing the rent-price-ratio in 1983Q1 to 4%. The capital premium is the return on capital as measured by Gomme, Ravikumar and Rupert (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), Associates (1983-2007), 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), Federal Reserve Bank of St. Louis (1983-2007), minus 10-Year Treasury Constant Maturity Rate (GS10), Board of Governors of the Federal Reserve System (1983-2007a).

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

5.1 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 $\epsilon_{t-1}^R, \epsilon_{t-2}^R$:

$$\Upsilon_{t+j} = \beta_{j,0} + \beta_{j,1}t + \beta_{j,2}\bar{\epsilon}_t^R + \beta_{j,3}\mathbf{X}_{t-1} + \nu_{t+j}, \ j = 0...15 \tag{16}$$

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), obtained via Ramey (2016).

Figure 4 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 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).

Figure 4: Aggregate response to a monetary shock
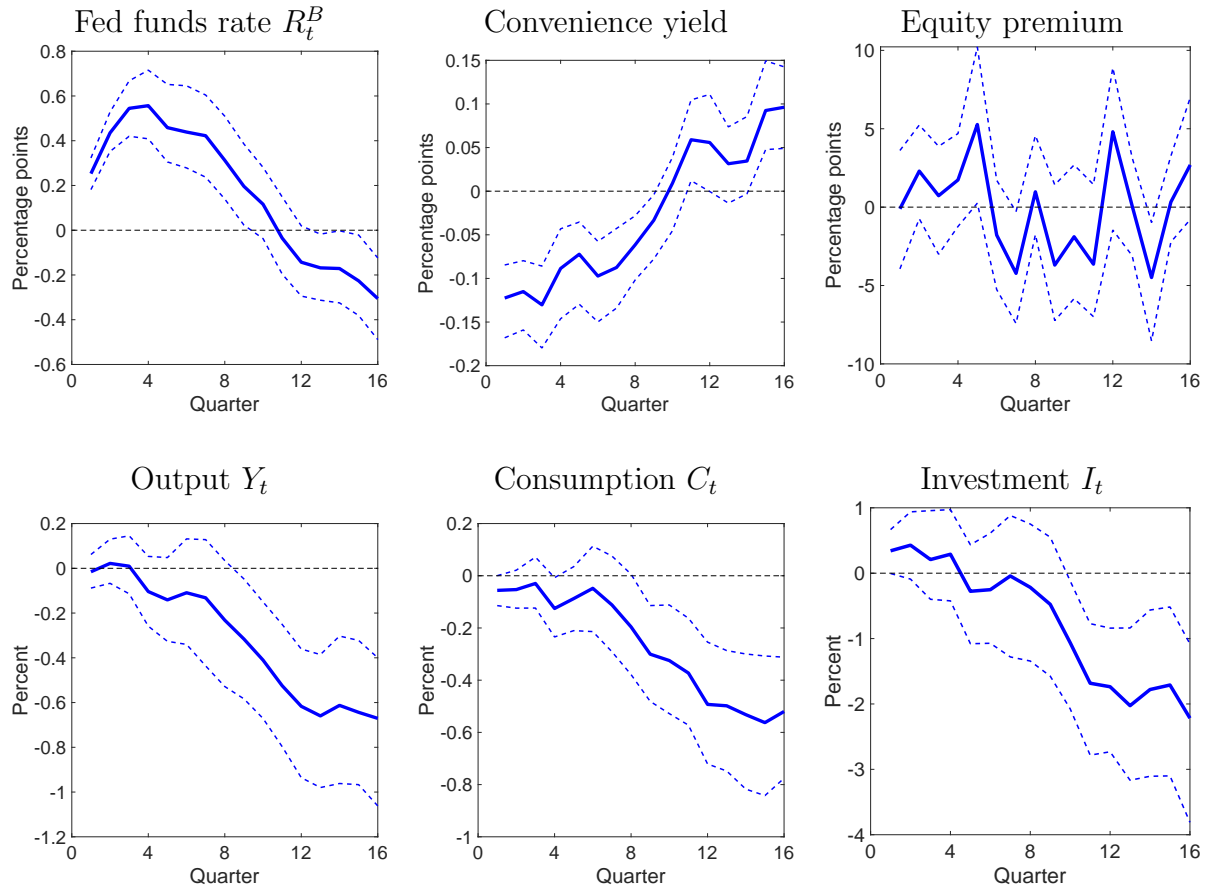
Estimated response of each time series at $t+j, j = 1\ldots16$ to a monetary policy shock, $\epsilon_t^R = 36$ basis points, where t corresponds to quarters from 1983Q1 to 2007Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, R_t^B, \epsilon_t^R, \epsilon_{t-1}^R]$. Bootstrapped 90% confidence bands are shown in the dashed lines (block bootstrap). 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.

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 5. 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 5: Aggregate response to a monetary shock (high-frequency identification)
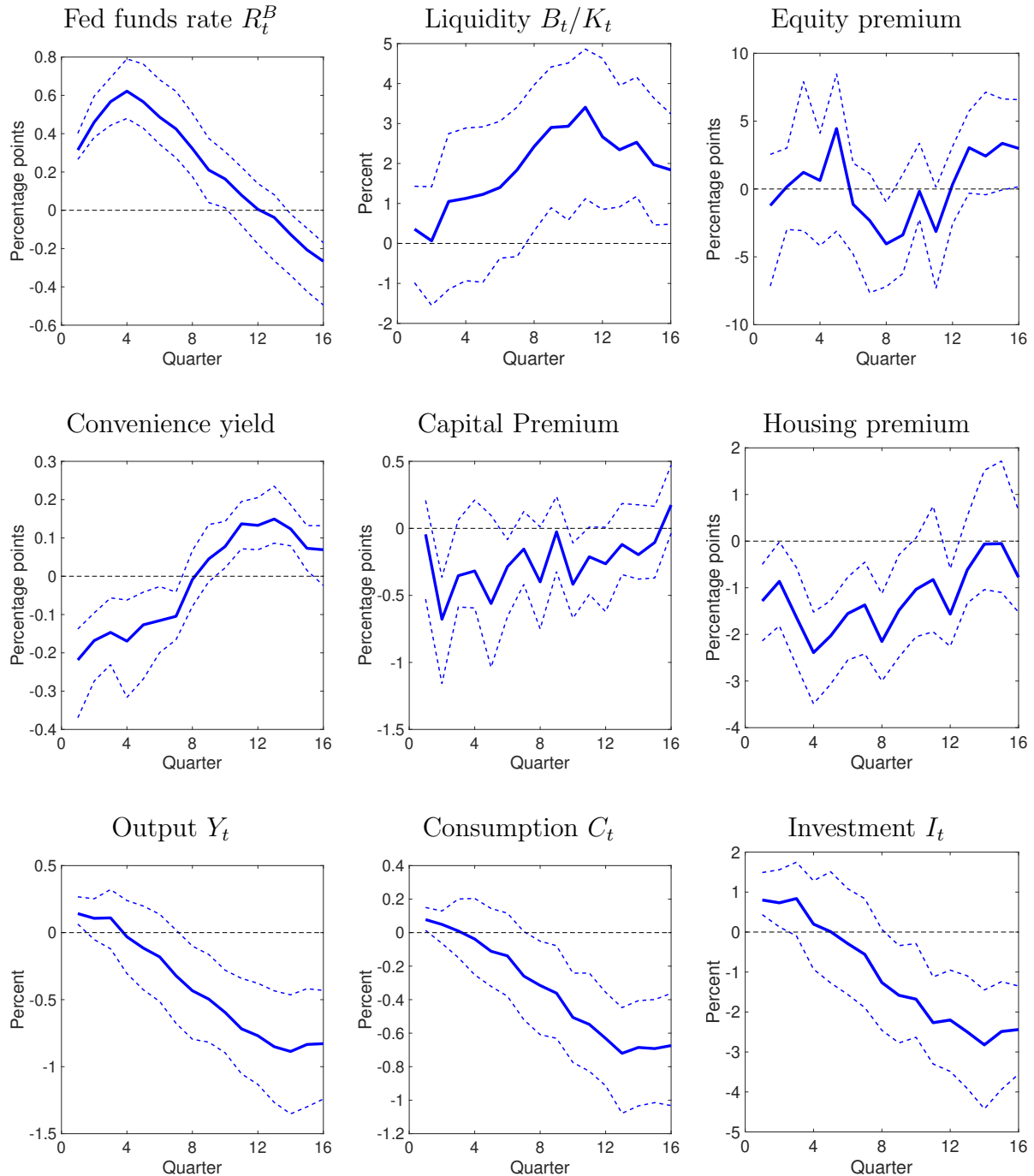
Estimated response of each time series at $t+j, j = 1\ldots16$ to monetary policy shocks identified by Gertler and Karadi (2015), where t corresponds to quarters from 1990Q1 to 2012Q4. The regressions control for the lagged state of the economy $\mathbf{X}_{t-1}$, where $\mathbf{X}_t = [Y_t, C_t, I_t, R_t^B, \epsilon_t^R, \epsilon_{t-1}^R]$. 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, Ravikumar and Rupert (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 6: Portfolio response, $\Delta(\frac{b_{it}}{q_t k_{it}})$, to a monetary shock in equilibrium
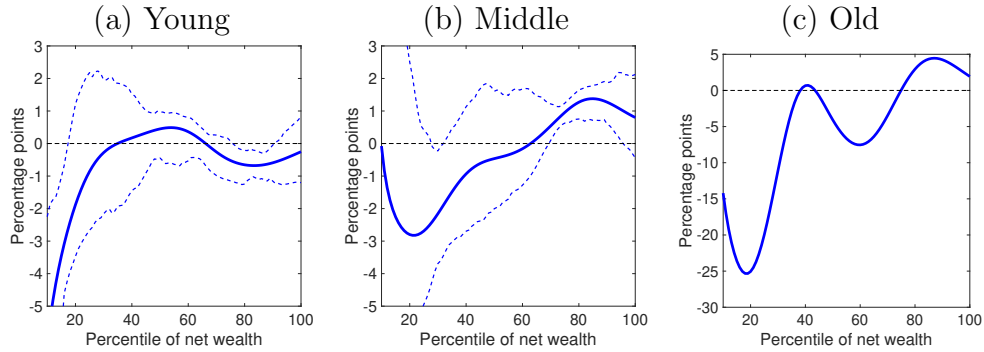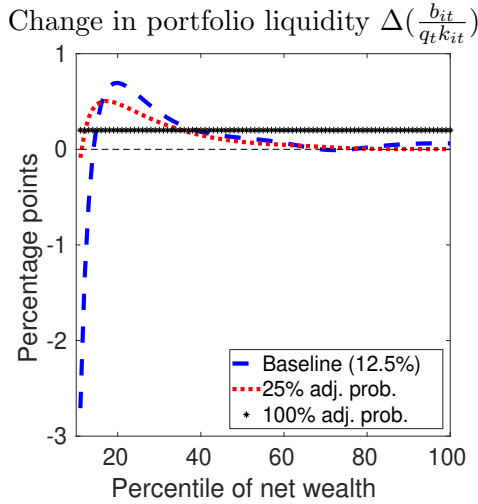

Change in portfolio liquidity for each synthetic cohort (young, born after 1949; middle, born between 1935 and 1949; old, born before 1935) after a 1 standard deviation monetary shock, $\epsilon^R = 36$ basis points (annualized), after 3 years. Portfolio response by wealth percentile are estimated using 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.

5.2   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 4.2, 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 6 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 7: 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.

6 Model Extensions

6.1 Model with liquid capital

The model with liquid capital implies a counterfactual increase in the portfolio liquidity of all households. Figure 7 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.

6.2 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 8 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.

6.3 Model with real debt

Figure 9 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 8: Aggregate response to a monetary shock with scarce liquidity
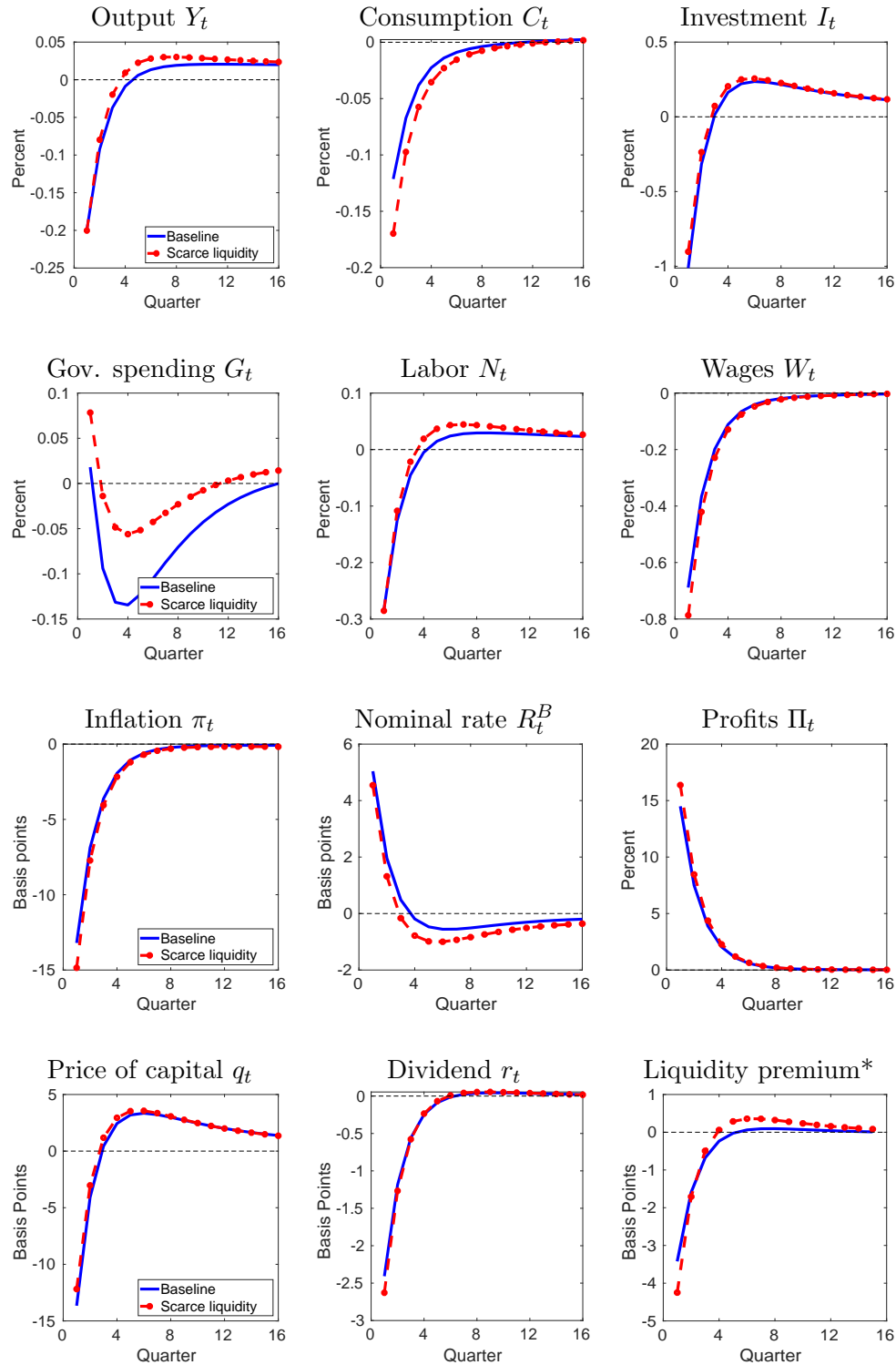
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R_{t+1}^B}{\pi_{t+1}}$

Figure 9: Aggregate response to a monetary shock with real debt
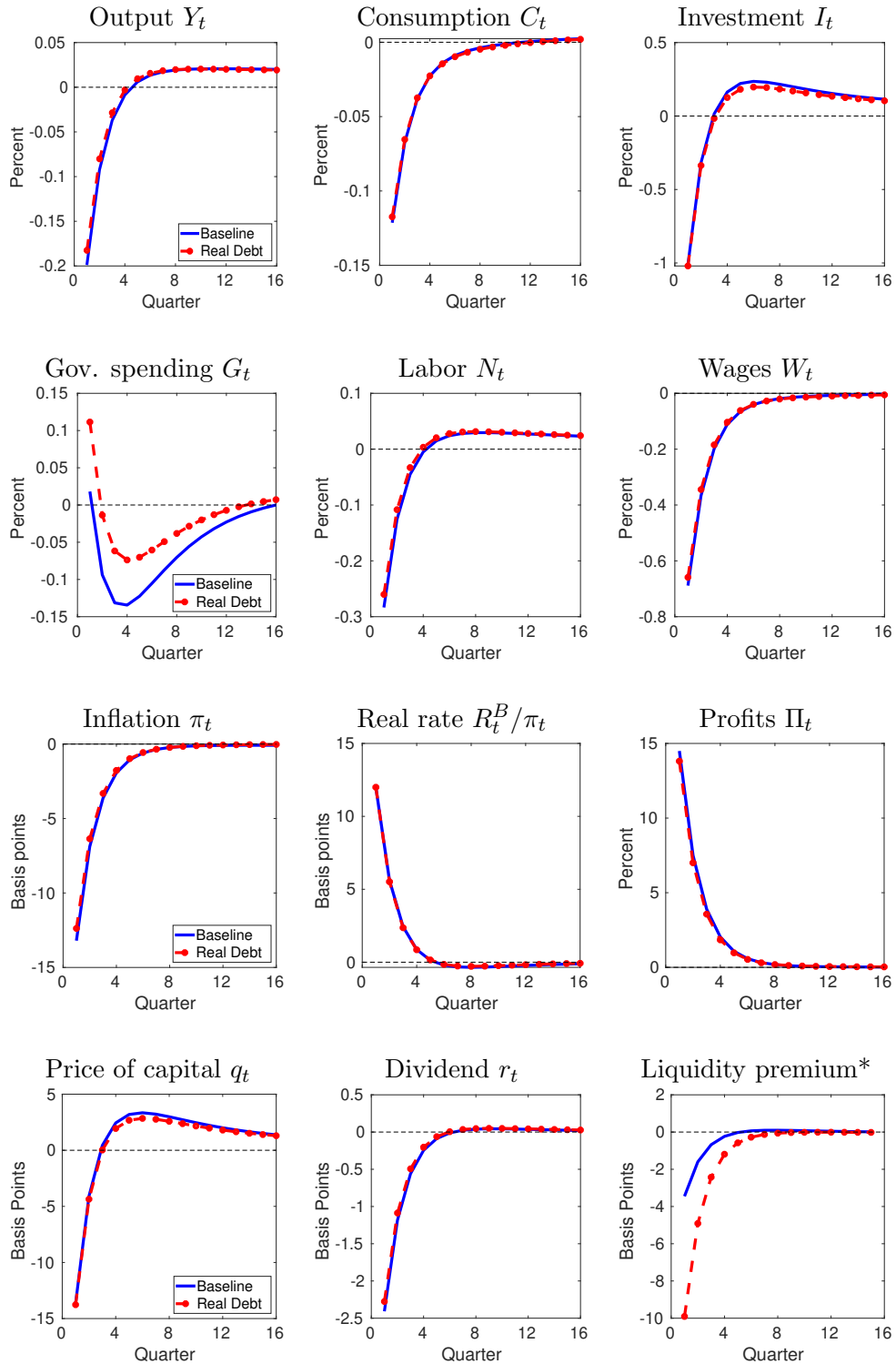
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1} + r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

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6.4 Robustness to aggregate capital adjustment costs

Figure 11 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 10.

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 10: Portfolio response without aggregate capital adjustment costs
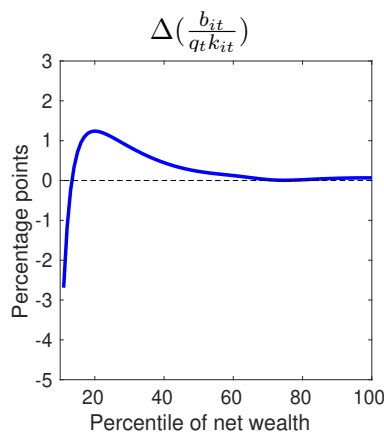
Notes: Change in portfolio liquidity after a monetary shock, $\epsilon^R = 96$ basis points (annualized), after 3 years. Policies by wealth percentile are estimated using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1. Plotted from the 11th percentile onwards because poorer households hold negative liquid wealth.

Figure 12 shows the impulse responses of an economy with liquid capital but with re-calibrated 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 11: Aggregate response to a monetary shock with liquid capital and zero aggregate capital adjustment costs
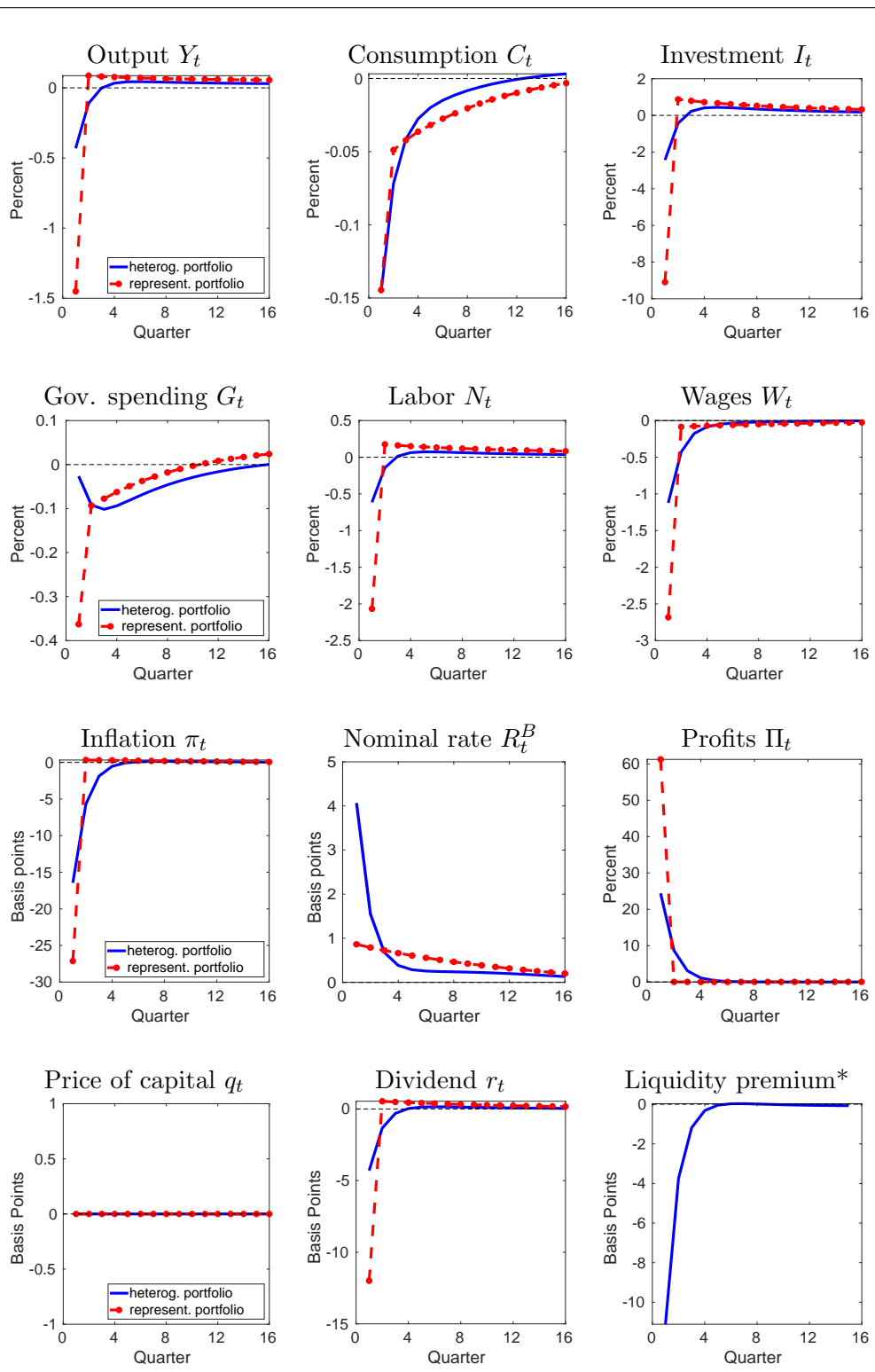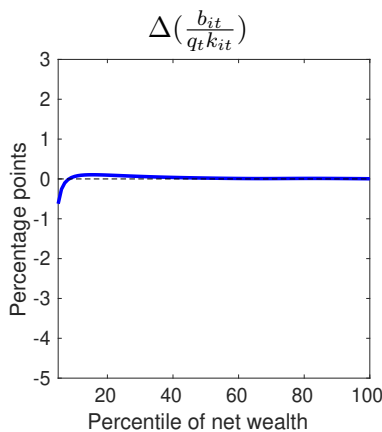

Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP_t = E_t \frac{q_{t+1} + r_{t+1}}{q_t} - E_t \frac{R_{t+1}^B}{\pi_{t+1}}$

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Figure 12: Aggregate response to a monetary shock with liquid capital and recalibrated aggregate capital adjustment costs
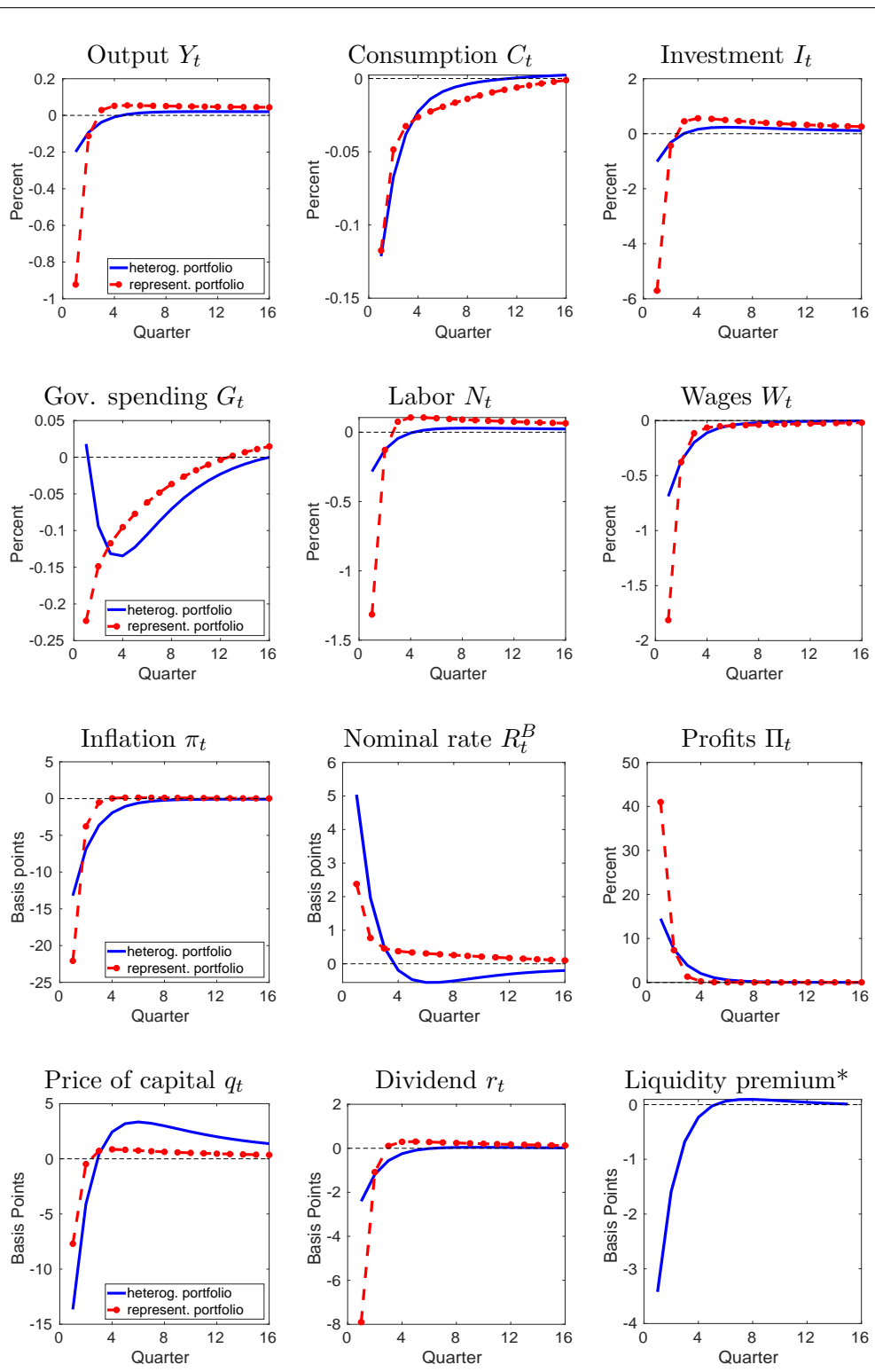
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. *$LP_t = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

6.5 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 14 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 13.

Figure 13: 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 14: Aggregate response to a monetary shock with lump-sum profits
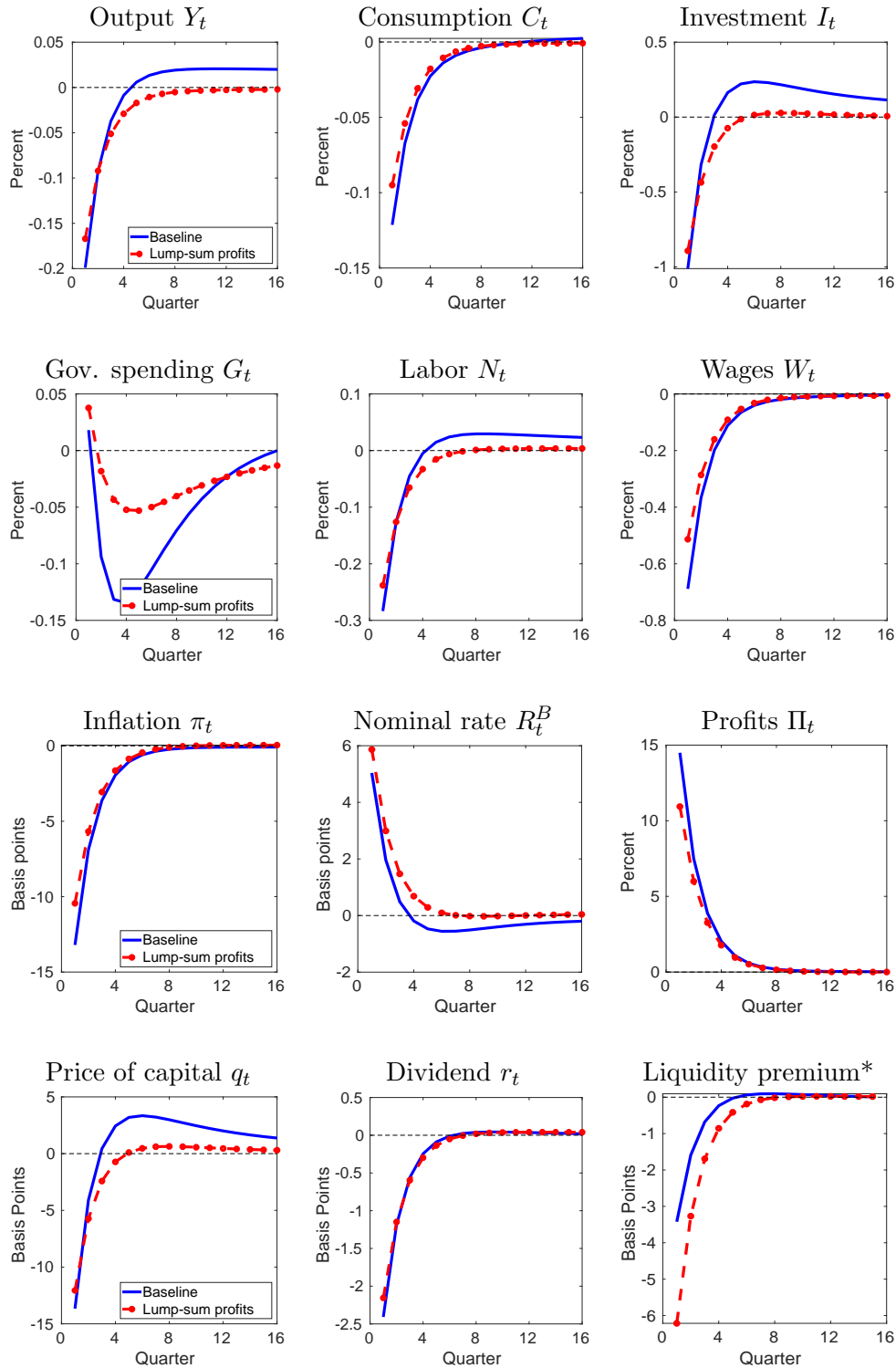
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

6.6 Model without sticky prices

Figure 15 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 16, 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 17.

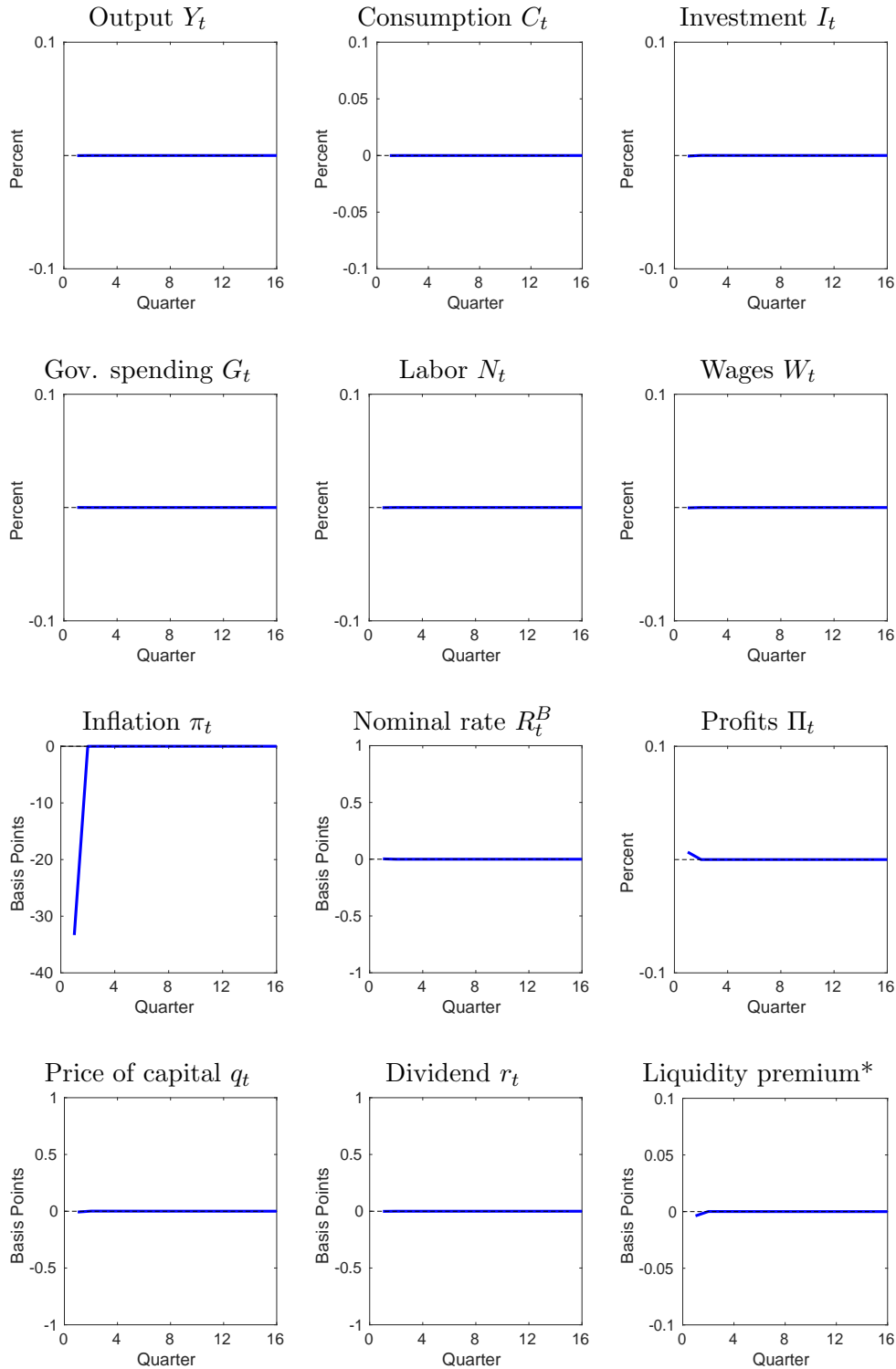# Figure 15: Aggregate response to a monetary shock without sticky prices
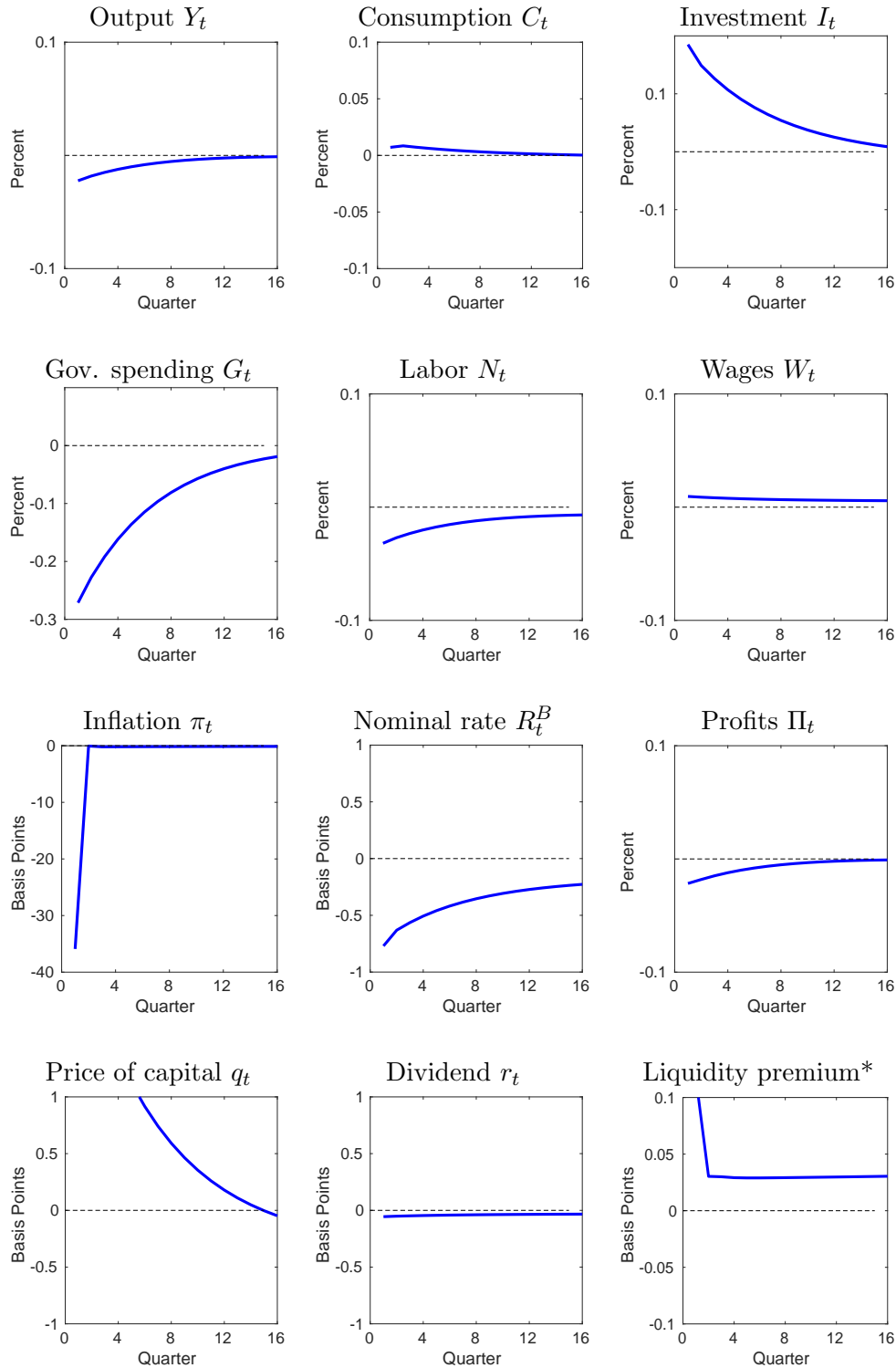
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

Figure 16: Aggregate response to a monetary shock without sticky prices and GHH preferences
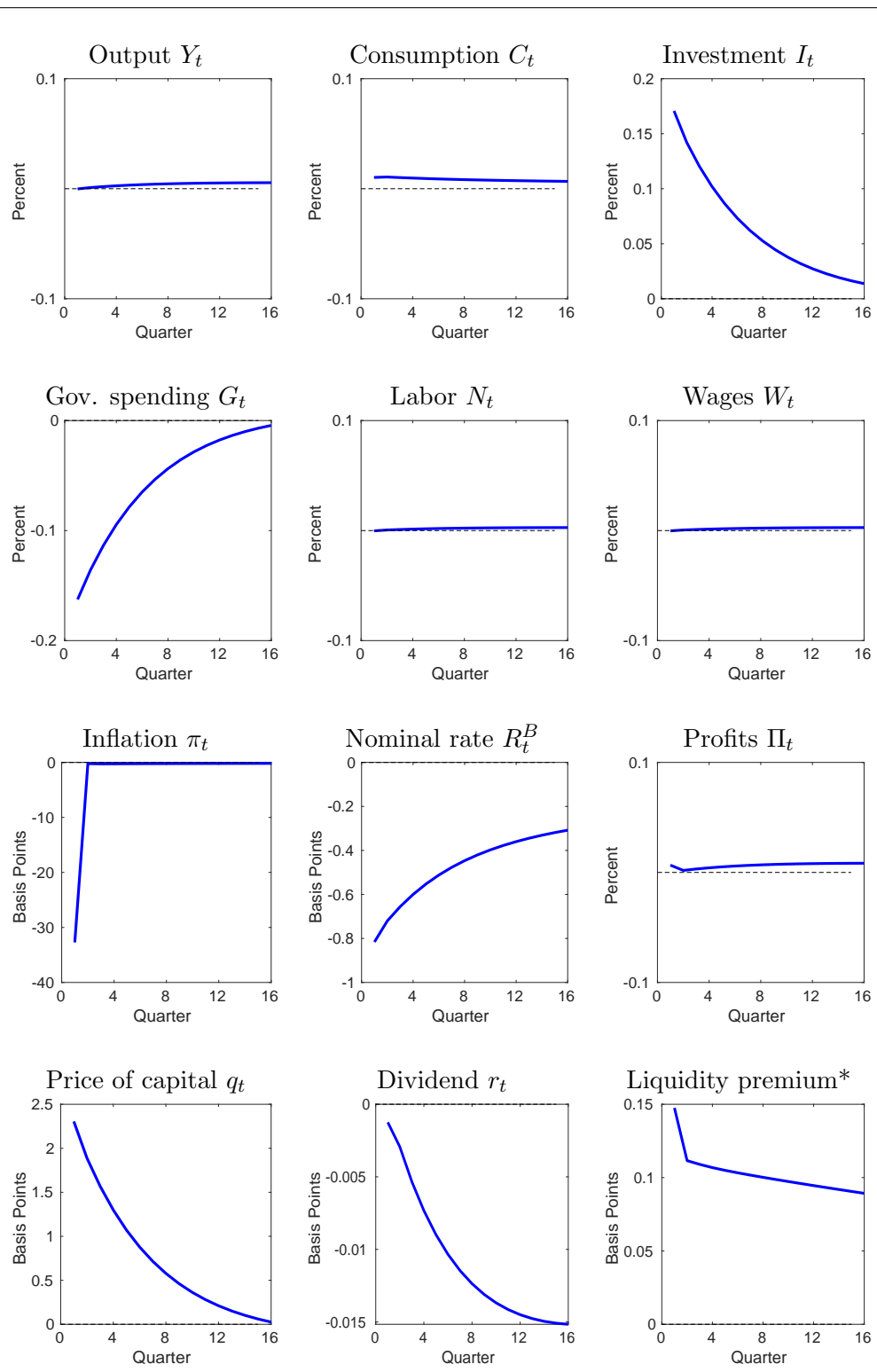
Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP_t = \frac{E_t q_{t+1} + r_t}{q_t} - \frac{R_t^B}{E_t \pi_{t+1}}$

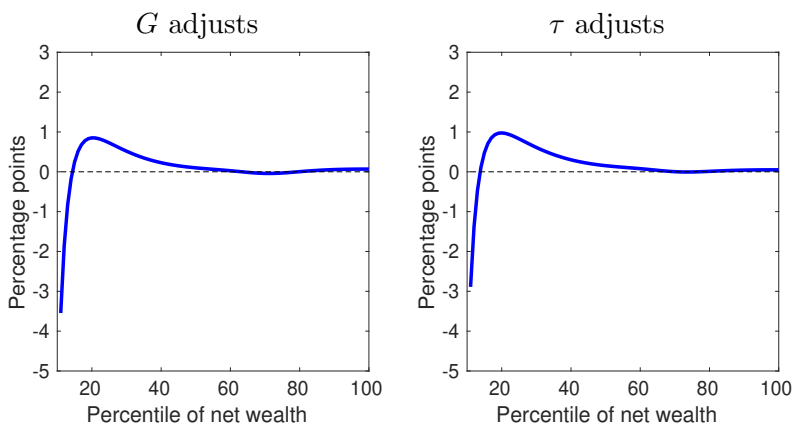Figure 17: Aggregate response to a monetary shock without sticky prices and real debt

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. $*LP = E_t \frac{q_{t+1} + r_{t+1}}{q_t} - E_t \frac{R^B_{t+1}}{\pi_{t+1}}$

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6.7 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.
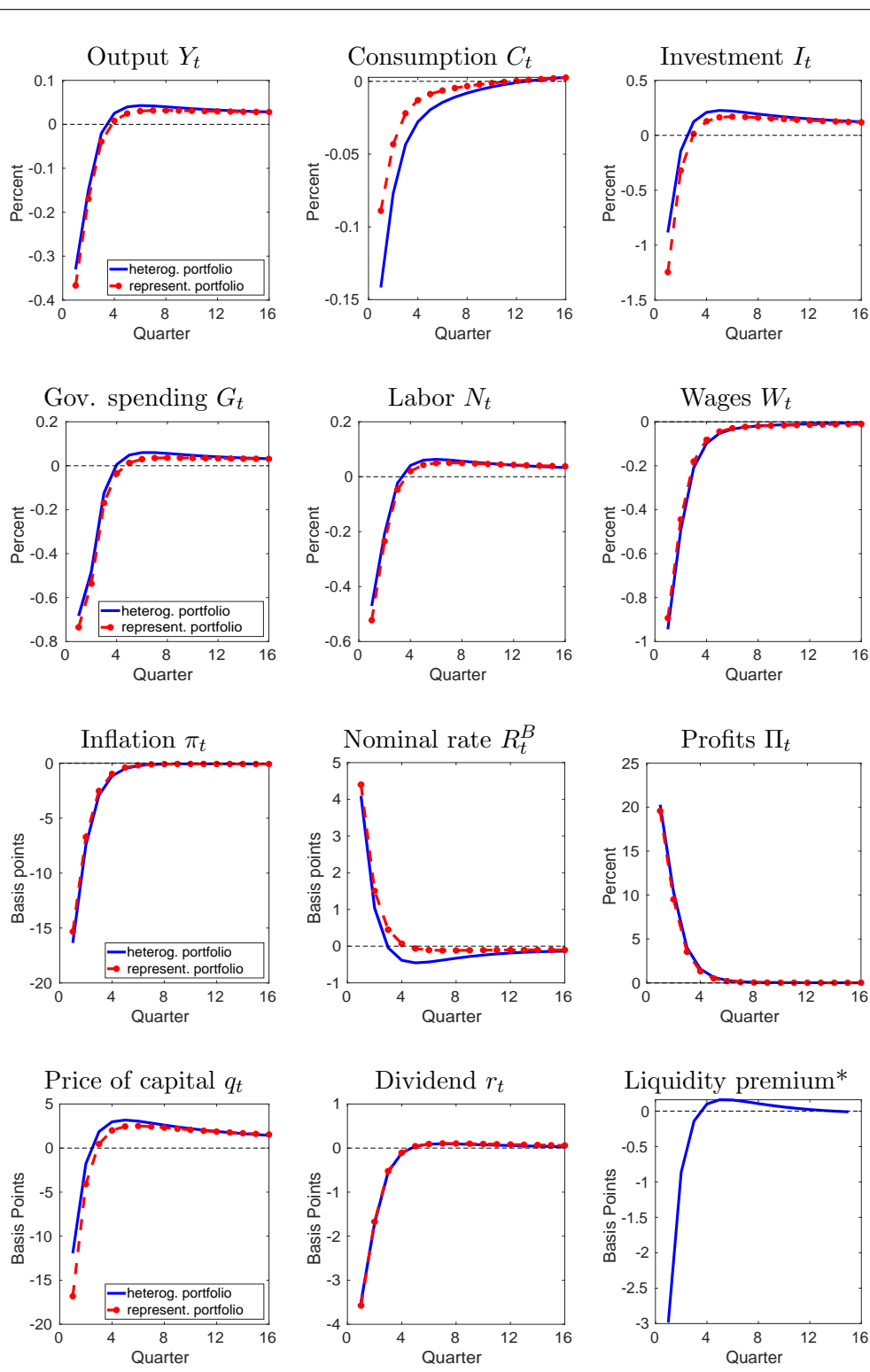
In the baseline model, I assume that most of the adjustment goes through government debt, and future government spending adjusts to bring debt back to steady state. In Figure 19, in contrast, I assume a balanced budget, $\rho_B = 0$, and an immediate reaction of government spending. The substantial fall 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 20. 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 18.

Figure 18: 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 19: Aggregate response to a monetary shock with balanced budget by adjusting government spending

Output Y_t

Consumption C_t

Investment I_t

Gov. spending G_t

Labor N_t

Wages W_t

Inflation π_t

Nominal rate R_t^B

Profits Π_t

Price of capital q_t

Dividend r_t

Liquidity premium*

heterog. portfolio
represent. portfolio

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. *$LP_t = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R_{t+1}^B}{\pi_{t+1}}$

Figure 20: Aggregate response to a monetary shock with balanced budget by adjusting the tax rate
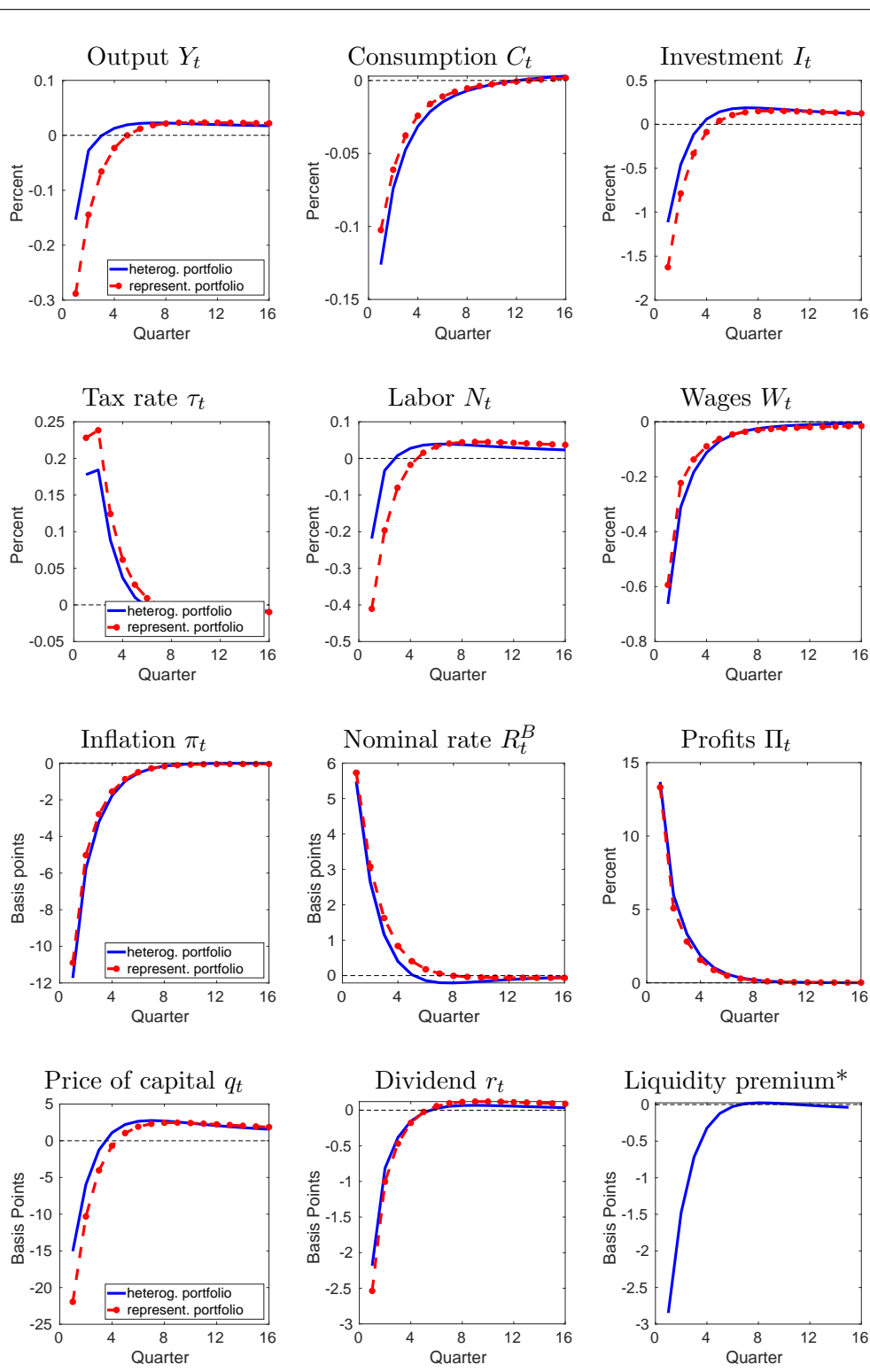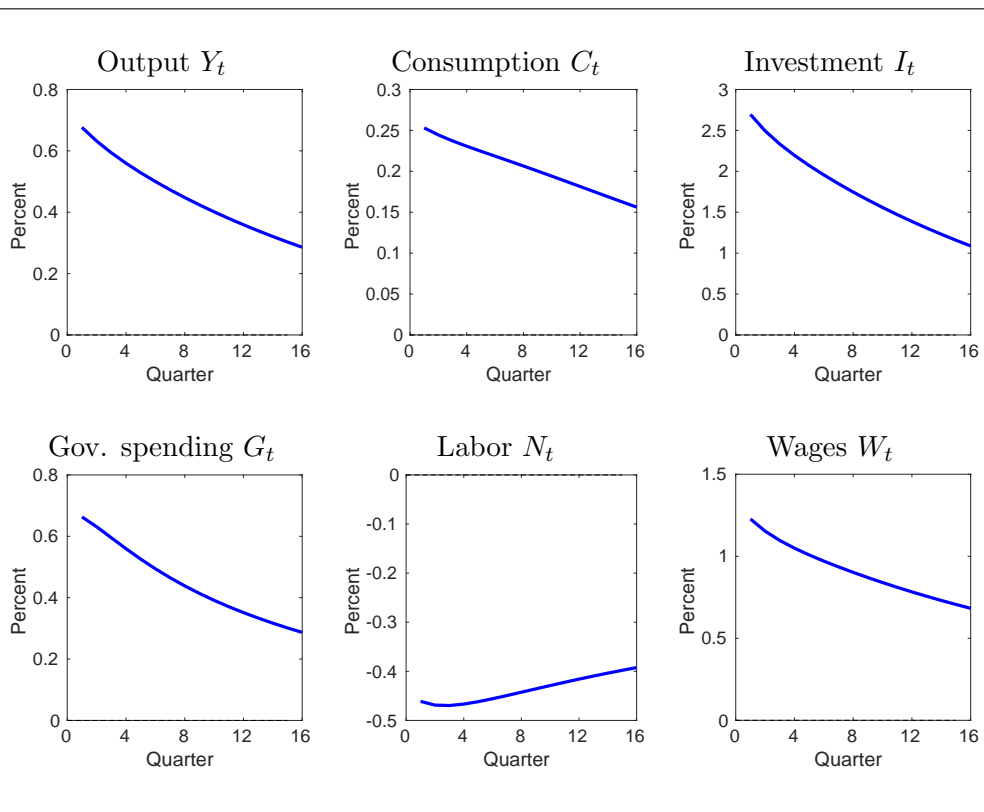

Notes: Impulse responses to a 1 standard deviation monetary policy shock, $\epsilon^R = 36$ basis points (annualized). All rates (dividends, interest, liquidity premium) are *not* annualized. $*LP = E_t \frac{q_{t+1}+r_{t+1}}{q_t} - E_t \frac{R_{t+1}^B}{\pi_{t+1}}$

6.8 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 21: Aggregate response to a TFP shock

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

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