The Liquidity Channel of Fiscal Policy*

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Abstract

We provide evidence that expansionary fiscal policy lowers the return difference between more and less liquid assets—the liquidity premium. We rationalize this finding in an estimated heterogeneous-agent New-Keynesian (HANK) model with incomplete markets and portfolio choice, in which public debt affects private liquidity. In this environment, the short-run fiscal multiplier is amplified by the countercyclical liquidity premium. This liquidity channel stabilizes investment and crowds in consumption. We then quantify the long-run effects of higher public debt, and find a sizable decline of the liquidity premium, increasing the fiscal burden of debt, but little crowding out of capital.

Keywords: Fiscal Policy, Liquidity Premium, Business Cycles, Bayesian Estimation, Incomplete Markets, HANK

JEL-Codes: C11, D31, E32, E63

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1 Introduction

The Great Recession and its aftermath have reinvigorated the role of fiscal policy in stabilizing the business cycle. As a response, numerous studies have estimated fiscal multipliers conditional on the cycle, on monetary policy, on the composition of fiscal spending, etc.[1] Most of these studies understand fiscal transmission in terms of traditional Keynesian channels of demand stimulus. This paper, by contrast, highlights the importance of public debt as private liquidity – see, e.g., Woodford (1990) – for the transmission of fiscal policy. This nexus is arguably of even more importance in today's COVID-19 crisis, with public debt already high and about to substantially increase in 2020. We show that fiscal policy has a sizable impact on return differences between asset classes with different liquidity and quantify the importance of this liquidity channel using a monetary business cycle model with heterogeneous agents and incomplete markets (known as HANK models).

For this purpose, we first estimate the effect of fiscal spending shocks using local projections and look at the effect not only on the usual aggregates but also on measures of the return premium of illiquid assets. Irrespective of whether we use a Blanchard and Perotti (2002) identification of shocks or use an instrumented version following Ramey (2016), we find that an increase in public debt via higher government spending decreases the excess return of less liquid assets over public debt . The effect is sizable and ranges from a decrease of 2 basis points (annualized) in the spread relative to AAA-corporate bonds and a decrease of 50 basis points for estimated returns on real estate for a 1% increase in public debt. We are, to our knowledge, the first to provide evidence for this liquidity effect of fiscal shocks.[2]

Next, we build a heterogeneous-agent New-Keynesian model with portfolio choice between liquid and illiquid assets and estimate it using Bayesian methods. This model is well-suited to study fiscal policy because it features all shocks and frictions of the seminal Smets and Wouters (2007) model. The model highlights the role of self-insurance and assets of different liquidity such that fiscal policy operates through more than the traditional Keynesian channels because it affects the return differences between liquid and illiquid assets, i.e., the liquidity premium. When the government runs a larger deficit, it provides the economy with a greater supply of liquid savings devices. Households hold these additional assets only when the return difference between them and illiquid assets falls. Hence, equilibrium real interest rates on liquid and illiquid assets are a function of the amount of public debt in circulation. The model replicates the empirical findings and hence provides a laboratory to study the importance of this liquidity channel of fiscal policy.

[1]See Ramey (2019) for an overview.

[2]Krishnamurthy and Vissing-Jorgensen (2012) document the unconditional evolution of asset returns relative to US public debt. Most closely related and complementary to our paper is Bredemeier et al. (2018), who report that a fiscal expansion increases the return spread between treasury bonds and even more liquid assets like cash deposits.

Looking at short-run changes in government spending, we find that fiscal multipliers are 40% larger in the economy with an endogenous liquidity premium relative to the same economy with a constant liquidity premium. There are two forces behind this result. First, as liquid and illiquid assets are imperfect substitutes, an increase in government debt does not one-for-one substitute physical assets as savings devices, and as a result, there is less crowding out. Put differently, the aggregate effects of fiscal policy depend less on monetary policy because of the incomplete pass-through of the policy rate to investment. Second, the increase in liquidity improves the self-insurance of households overall and at a given level of capital, boosting consumption. As a result, better insured households can afford more easily to deal with the illiquidity of capital and require a lower premium for illiquid investments. These channels are absent in the counterfactual economy without the distinction between liquid and illiquid assets.

We then use the model to study more persistent changes in fiscal policy, for which reduced-form evidence is very limited. In particular, we ask how increases in public debt affect interest rates in the long run and, in addition, what effects such a policy would have on the capital stock and inequality. Specifically, we consider a de facto permanent increase in the debt target (debt to GDP ratio) by 10%. We model the adjustment period stretched over 10 years. We find that this fiscal policy increases the nominal rate (permanently) by 101 basis points (annualized) and inflation by 42 basis points. Hence, our estimated model implies a semi-elasticity of the real rate on public debt with respect to public debt of 5.9%.[3]

Even though the interest rate markedly increases, the crowding out of capital is mild at best because both assets are imperfect substitutes from the household's point of view. At the very long horizon, the fiscal expansion actually crowds in capital because households seek to structure their portfolios in a balanced way between liquid and illiquid assets. The increase in the real rate on bonds hardly affects the real return on capital but mostly reduces the return spread between liquid and illiquid assets (the liquidity premium). As a consequence, the effect on wages is mild as well.

At the same time, the implied change in the liquidity premium has an important fiscal consequence: The government has to pay higher interest on its outstanding debt. This effect dominates the immediate increase in interest outlays due to the increased principal. We derive a simple approximation of the interest burden of public debt that depends only on the semi-elasticity of the real rate to public debt. In our baseline treatment, we assume that the government reduces expenditures in the long run to cover the higher interest rate payments after the initial expansion phase. This long-run cut in expenses is substantial and amounts

[3]Summers and Rachel (2019) find a sizable elasticity as well and summarize the literature with a semi-elasticity of 4.

to roughly 2% of government spending before the fiscal expansion.

What is more, the response of interest rates to public debt implies a Laffer curve for debt: Lowering public debt beyond a certain threshold increases the fiscal burden of public debt. Using our approximation for the US, we find that the public debt level minimizing the fiscal burden of debt is about 67% of GDP for the period after the Great Recession. Any target level below that provides less liquidity to the private sector and less revenues to the government. This internal minimum reflects the fact that as debt decreases the $(r-g)$ differential on public debt eventually becomes negative. As debt vanishes, there are no revenues from rolling it over.

The fiscal expansion has very rich distributional consequences. While income inequality increases slightly, wealth and consumption inequality fall. The rise in income inequality comes from slightly higher real interest rates, which increase the incomes of wealthy households. The same rise in the interest rate for liquid assets stimulates the accumulation of wealth for the relatively poor, who – both empirically and in our model – start off by accumulating liquid wealth; the liquidity value of an asset is more important for them than its rate of return.[4] As a result, wealth inequality, measured by the Gini coefficient, falls by 2%, and the Gini coefficient of consumption falls by 1% because households can now smooth income shocks better.

With these results, we contribute to three literatures. First, our approach is closely related to the recent literature on HANK models that quantitatively studies the importance of heterogeneity for business cycles and policy.[5] To our knowledge, our paper is the first to use a two-asset HANK model to investigate the liquidity channel of fiscal policy. Auclert et al. (2018) and Hagedorn et al. (2019) also study fiscal multipliers but do so in models without portfolio choice. We show that the liquidity channel of public debt amplifies the multiplier obtained in models with perfectly liquid physical capital.

Second, the two-asset structure is important as it significantly changes the extent to which public debt crowds out physical private capital. With perfectly liquid physical capital, such as in Aiyagari and McGrattan (1998), there is much stronger crowding out of private capital through public debt. This key point has been already emphasized by Woodford (1990). Much of this literature has focused on the optimal level of public debt.[6] Our analysis is positive and adds to this literature by quantifying the importance of liquidity in an estimated model

[4]See Kaplan and Violante (2014) or Bayer et al. (2019).

[5]See, for example, Ahn et al. (2018); Bayer et al. (2019); Broer et al. (2019); Challe and Ragot (2015); Den Haan et al. (2017); Gornemann et al. (2012); Guerrieri and Lorenzoni (2017); McKay et al. (2016); McKay and Reis (2016); Ravn and Sterk (2017); Sterk and Tenreyro (2018); Wong (2019); Auclert et al. (2020)

[6]See, for example, Floden (2001), Gottardi et al. (2015), Angeletos et al. (2016), Cui (2016), Bhandari et al. (2017), Röhrs and Winter (2017), Acikgöz et al. (2018), Azzimonti and Yared (2019).

that features a multitude of nominal and real frictions, which are key for business cycle dynamics. We share this focus on dynamics with Heathcote (2005) and Challe and Ragot (2011). The former looks at tax shocks in a calibrated Aiyagari (1994) model and the latter at government spending shocks in a tractable model with incomplete markets.

Finally, we provide new empirical evidence on the effect of public debt on interest rates. Krishnamurthy and Vissing-Jorgensen (2012) or more recently Summers and Rachel (2019) document the unconditional evolution of asset returns relative to US and worldwide public debt. Earlier studies have also focused on how financial markets respond to fiscal policy measures. Ardagna (2009), for instance, reports that interest rates tend to decline in response to large fiscal consolidations. Laubach (2009) finds that future debt and deficits tend to raise US interest rates.

The remainder of this paper is organized as follows: Section 2 provides evidence for the liquidity channel using identified fiscal policy shocks and a flexible local projection technique to identify their dynamic effects. Section 3 describes our model economy, its sources of fluctuations, and its frictions. Section 4 discusses the parameters that we calibrate to match steady-state targets and the parameter estimates we obtain by Bayesian maximum likelihood. Section 5 discusses the short-run dynamics of the estimated model and how they fit with our reduced-form estimates from Section 2. Section 6 then asks what the model implies for the fiscal burden of long-run changes in government debt levels. Section 7 concludes. An appendix follows.

2 Time-Series Evidence

We start off by documenting that a fiscal expansion affects aggregate quantities *and* returns to assets of different liquidity. In the baseline, in order to use the longest sample possible, 1947 to 2018 at a quarterly frequency, our identifying assumption, dating back to Blanchard and Perotti (2002), is that government spending is predetermined within the quarter. As discussed by Blanchard and Perotti (2002), the rationale for this assumption is that government spending can be adjusted only subject to decision lags. Also, there is no automatic response, since government consumption does not include transfers or other cyclical items.

We establish the effects of government spending on the basis of fiscal shocks, ε_t^g, and proceed in two steps. In the first step, we estimate the following model to compute spending surprises:

$$\log g_t = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + A(L) X_{t-1} + \nu_t, \tag{1}$$

where X_{t-1} denotes a vector that includes the logs of (real) spending, output, government debt, and stock prices.[7] $A(L)$ is a lag polynomial, and ν_t is a reduced-form disturbance. We allow for four lags, since the model is estimated on quarterly data, and we also include linear and quadratic time trends. Under our identifying assumption explained above, the structural shock ε_t^g equals the estimated reduced-form disturbance $\hat{\nu}_t$.[8]

In the second step, we estimate local projections à la Jordà (2005). Letting x_{t+h} denote the variable of interest in period $t+h$, we estimate how it responds to fiscal shocks in period t on the basis of the following specification:

$$x_{i,t+h} = \beta_0 + \beta_1 t + \psi_h \varepsilon_t^g + \Gamma(L) Z_{t-1} + u_{t+h} \ . \tag{2}$$

Here, the coefficient ψ_h provides a direct estimate of the impulse response at horizon h to the government spending shock in period t. Z_{t-1} is a vector of control variables that always includes four lags of government spending, output, and debt, plus lags of the respective dependent variable. The error term u_{t+h} is assumed to have zero mean and strictly positive variance. We compute Newey-West standard errors that are robust with respect to heteroskedasticity and serial correlation.

We first look at the responses of a number of standard macro variables in Figure 1. Solid black lines depict impulse response functions (IRFs) to the positive government spending shock that are scaled so that the maximum response of government debt is 1%. Government spending itself increases and follows a hump-shaped pattern, while government debt increases persistently. Output increases – at least in the short run – and investment falls, while consumption is fairly unresponsive. The real interest rate on long-term government bonds increases, albeit weakly so. Overall, as in Ramey (2016), fiscal spending shocks have only small effects on aggregate quantities when considering the whole post-war period.

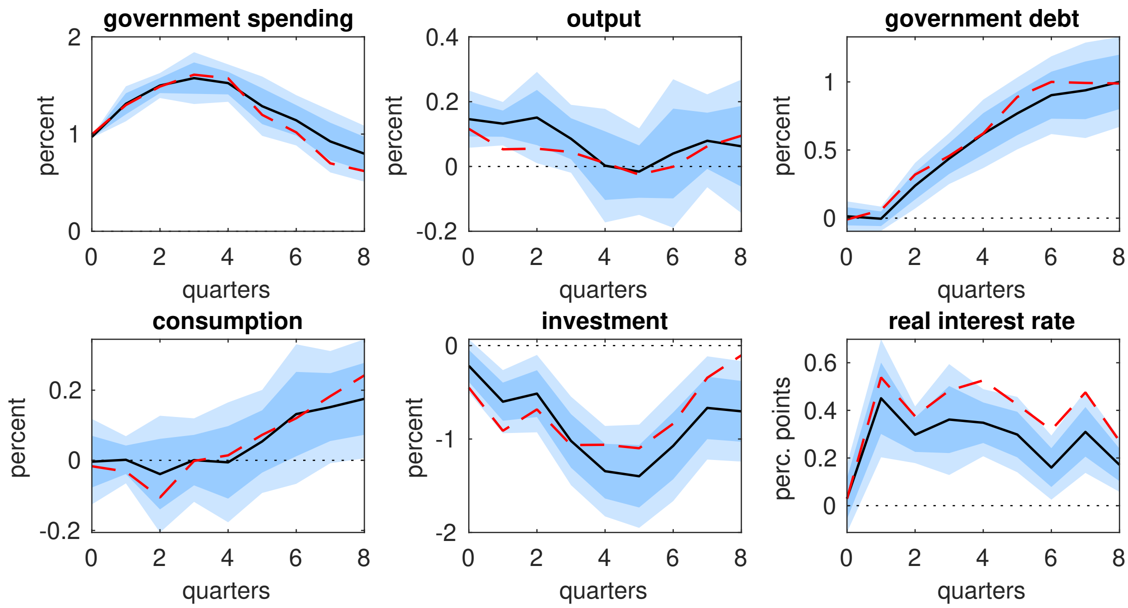
The novel contribution is to estimate the response of a variety of proxies for the liquidity premium. The liquidity premia in the top row of Figure 2 are based on Gomme et al. (2011), who compute the rates of return on various forms of capital. To compute the premium, we subtract a long-term government bond rate. As an alternative housing return measure, we use the return on housing from Knoll et al. (2017) to compute the premium (lower left panel). We also consider the convenience yield (lower middle panel), i.e., the difference between the AAA corporate bond yield and the long-term rate on government bonds (Krishnamurthy and Vissing-Jorgensen, 2012). Finally, we include Robert Shiller's equity premium.

Figure 2 shows that, while the magnitudes differ somewhat, all variants of the liquidity

[7] See Appendix A for data sources and detailed construction descriptions.

[8] The estimated shocks ε_t^g in this specification are generated regressors in the second stage. However, as shown in Pagan (1984), the standard errors on the generated regressors are asymptotically valid under the null hypothesis that the coefficient is zero; see also Coibion and Gorodnichenko (2015), footnote 18, on this point.

Figure 1: Empirical Responses to Fiscal Spending Shocks



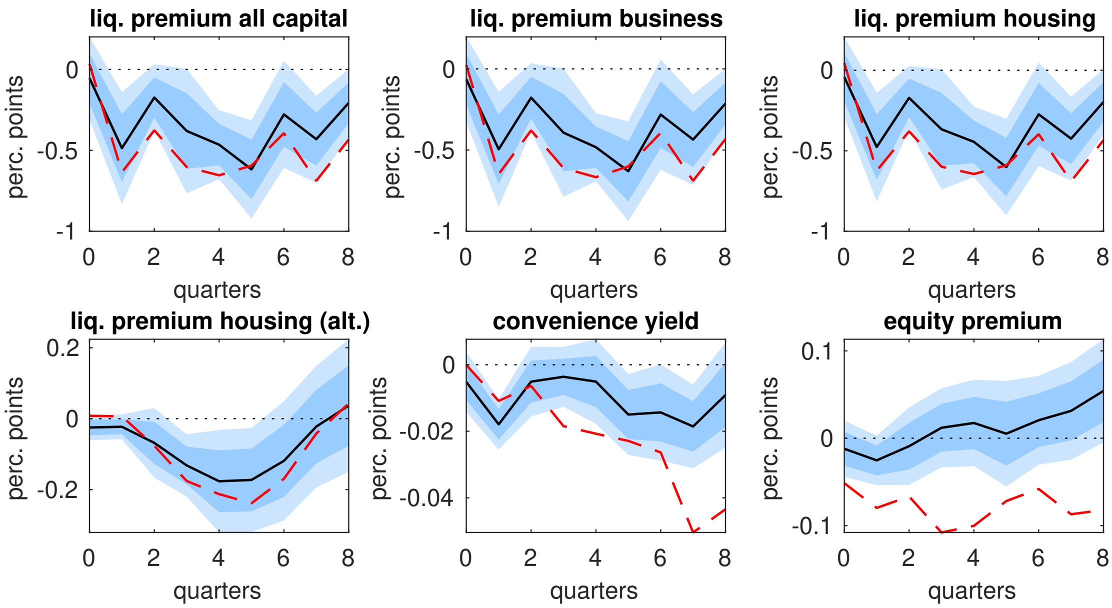
Notes: Impulse responses to a government spending shock. Solid black line: IRFs based on Blanchard and Perotti (2002)-style recursive identification; dashed red lines: IRFs based on IV approach (see text for details). IRFs scaled so that the maximum debt response is 1%. Light (dark) blue areas are 90% (68%) confidence bounds based on Newey-West standard errors.

premium significantly fall in response to the fiscal expansion. The convenience yield falls by 2 basis points and the remaining proxies fall by around 20-50 basis points. The former is the most conservative measure of the liquidity premium because it looks at the spread between very similar financial assets, government and corporate bonds, that are highly marketable. Only the equity premium stays flat, which is important, because all return-on-capital measures, of course, include other premia besides the one on liquidity.

Given the debate on the potential forecastability of Blanchard-Perotti shocks (see, e.g., Ramey, 2011, 2016), and even though we include the forward-looking stock-price variable in our first stage (Sims, 2012), we also consider an alternative estimation in which we instrument the estimated fiscal shocks from the first stage. As instruments, we use both the military news series from Ramey (2011) and the government spending forecast errors from Auerbach and Gorodnichenko (2012).[9]Results are included as red dashed lines in Figures 1 and 2. The IRFs look very similar, with the fall in the liquidity premium measures being even slightly larger in this specification.

[9]The Auerbach and Gorodnichenko (2012) forecast errors are only available starting in 1966. Until then, we augment the series with model-based forecasts. The first-stage F-statistic of 144.28 is well above the Staiger and Stock (1997)-rule-of-thumb value for instrument relevance of 10.

Figure 2: Empirical Responses to Fiscal Spending Shocks: Liquidity Premia



Notes: Impulse responses to a government spending shock. See notes to Figure 1 and the main text for the definitions of premia.

Overall, this novel evidence shows that fiscal policy has sizable effects on the liquidity premium. Fiscal expansions drive down the excess returns on assets that are less liquid than government bonds.[10] We will later show that our estimated model can replicate the sign and size of the empirical responses, and we will then use this model to investigate the importance of the liquidity channel of fiscal policy.

3 Model

We model an economy composed of a firm sector, a household sector, and a government sector.[11] The firm sector comprises (a) perfectly competitive intermediate goods producers who rent out labor services and capital; (b) final goods producers who face monopolistic competition, producing differentiated final goods out of homogeneous intermediate inputs; (c) producers of capital goods who turn consumption goods into capital subject to adjustment costs; (d) labor packers who produce labor services combining differentiated labor from (e) unions that differentiate raw labor rented out from households. Price setting for the final goods as well as wage setting by unions is subject to a pricing friction à la Calvo (1983).

[10] In line with Bredemeier et al. (2018), we also find that the excess return of bonds over more liquid assets goes up. Results are available upon request.

[11] The model builds on Bayer et al. (2020) and the exposition follows that paper where there is overlap.

Households earn income from supplying (raw) labor and capital and from owning the firm sector, absorbing all its rents that stem from the market power of unions and final goods producers, and decreasing returns to scale in capital goods production.

The government sector runs both a fiscal authority and a monetary authority. The fiscal authority levies taxes on labor income and distributed profits, issues government bonds, and adjusts expenditures to stabilize debt in the long run and aggregate demand in the short run. The monetary authority sets the nominal interest rate on government bonds according to a Taylor rule.

3.1 Households

The household sector is subdivided into two types of agents: workers and entrepreneurs. The transition between both types is stochastic. Both rent out physical capital, but only workers supply labor. The efficiency of a worker's labor evolves randomly, exposing worker-households to labor-income risk. Entrepreneurs do not work, but earn all pure rents in our economy, except for the rents of unions which are equally distributed across workers. All households self-insure against the income risks they face by saving in a liquid nominal asset (bonds) and a less liquid asset (capital). Trading illiquid assets is subject to random participation in the capital market.

To be specific, there is a continuum of ex-ante identical households of measure one, indexed by i. Households are infinitely lived, have time-separable preferences with time-discount factor β, and derive felicity from consumption c_{it} and leisure. They obtain income from supplying labor, n_{it}, from renting out capital, k_{it}, and from earning interest on bonds, b_{it}, and potentially from profits or union transfers. Households pay taxes on labor and profit income.

3.1.1 Productivity, labor supply and labor income

A household's gross labor income $w_t n_{it} h_{it}$ is composed of the aggregate wage rate on raw labor, w_t, the household's hours worked, n_{it}, and its idiosyncratic labor productivity, h_{it}. We assume that productivity evolves according to a log-AR(1) process and a fixed probability of transition between the worker and the entrepreneur state:

$$\tilde{h}_{it} = \begin{cases} \exp\left(\rho_h \log \tilde{h}_{it-1} + \epsilon^h_{it}\right) & \text{with probability } 1-\zeta \text{ if } h_{it-1} \neq 0, \\ 1 & \text{with probability } \iota \text{ if } h_{it-1} = 0, \\ 0 & \text{else,} \end{cases} \tag{3}$$

with individual productivity $h_{it} = \frac{\tilde{h}_{it}}{\int \tilde{h}_{it} di}$ such that $\tilde{h}_{it}$ is scaled by its cross-sectional average, $\int \tilde{h}_{it} di$. The shocks ϵ^h_{it} to productivity are normally distributed with constant variance.

With probability ζ households become entrepreneurs ($h = 0$). With probability ι an entrepreneur returns to the labor force with median productivity. An entrepreneur obtains a fixed share of the pure rents (aside from union rents), Π^F_t, in the economy (from monopolistic competition in the goods sector and the creation of capital). We assume that the claim to the pure rent cannot be traded as an asset. Union rents, Π^U_t are distributed lump-sum across workers, leading to labor-income compression.

This modeling strategy serves two purposes. First and foremost, it generally solves the problem of the allocation of pure rents without distorting factor returns and without introducing another tradable asset.[12] Second, we use the entrepreneur state in particular – a transitory state in which incomes are very high – to match the income and wealth distribution following the idea by Castaneda et al. (1998). The entrepreneur state does not change the asset returns or investment opportunities available to households.

With respect to leisure and consumption, households have Greenwood et al. (1988) (GHH) preferences and maximize the discounted sum of felicity:[13]

$$\mathbb{E}_0 \max_{\{c_{it}, n_{it}\}} \sum_{t=0}^{\infty} \beta^t u \left[c_{it} - G(h_{it}, n_{it})\right]. \tag{4}$$

The maximization is subject to the budget constraints described further below. The felicity function u exhibits a constant relative risk aversion (CRRA) with risk aversion parameter $\xi > 0$,

$$u(x_{it}) = \frac{1}{1-\xi} x_{it}^{1-\xi},$$

where $x_{it} = c_{it} - G(h_{it}, n_{it})$ is household i's composite demand for goods consumption c_{it} and leisure and G measures the disutility from work. Goods consumption bundles varieties

[12] There are basically three possibilities for dealing with the pure rents. One attributes them to capital and labor, but this affects their factor prices; one introduces a third asset that pays out rents as dividends and is priced competitively; or one distributes the rents in the economy to an exogenously determined group of households. The latter has the advantage that factor supply decisions remain the same as in any standard New-Keynesian framework and still avoids the numerical complexity of dealing with three assets.

[13] The assumption of GHH preferences is mainly motivated by the fact that many estimated DSGE models of business cycles find small aggregate wealth effects in the labor supply; see, e.g., Born and Pfeifer (2014). It also simplifies the numerical analysis somewhat. Unfortunately, it is not feasible to estimate the flexible form of preference of Jaimovich and Rebelo (2009), which also encompasses King et al. (1988) preferences. This would require solving the stationary equilibrium in every likelihood evaluation, which is substantially more time consuming than solving for the dynamics around this equilibrium.

j of differentiated goods according to a Dixit-Stiglitz aggregator:

$$c_{it} = \left(\int c_{ijt}^{\frac{\eta_t - 1}{\eta_t}} dj \right)^{\frac{\eta_t}{\eta_t - 1}}.$$

Each of these differentiated goods is offered at price p_{jt}, so that for the aggregate price level, $P_t = \left(\int p_{jt}^{1-\eta_t} dj \right)^{\frac{1}{1-\eta_t}}$, the demand for each of the varieties is given by

$$c_{ijt} = \left(\frac{p_{jt}}{P_t} \right)^{-\eta_t} c_{it}.$$

The disutility of work, $G(h_{it}, n_{it})$, determines a household's labor supply given the aggregate wage rate, w_t, and a labor income tax, τ, through the first-order condition:

$$\frac{\partial G(h_{it}, n_{it})}{\partial n_{it}} = (1 - \tau) w_t h_{it}. \tag{5}$$

Assuming that G has a constant elasticity w.r.t. n, $\frac{\partial G(h_{it}, n_{it})}{\partial n_{it}} = (1 + \gamma) \frac{G(h_{it}, n_{it})}{n_{it}}$ with $\gamma > 0$, we can simplify the expression for the composite consumption good x_{it} making use of the first-order condition (5):

$$x_{it} = c_{it} - G(h_{it}, n_{it}) = c_{it} - \frac{(1 - \tau) w_t h_{it} n_{it}}{1 + \gamma}. \tag{6}$$

When the Frisch elasticity of labor supply is constant, the disutility of labor is always a constant fraction of labor income. Therefore, in both the household's budget constraint and its felicity function, only after-tax income enters and neither hours worked nor productivity appears separately.

This implies that we can assume $G(h_{it}, n_{it}) = h_{it} \frac{n_{it}^{1+\gamma}}{1+\gamma}$ without further loss of generality as long as we treat the empirical distribution of income as a calibration target. This functional form simplifies the household problem as h_{it} drops out from the first-order condition and all households supply the same number of hours $n_{it} = N(w_t)$. Total effective labor input, $\int n_{it} h_{it} di$, is hence also equal to $N(w_t)$ because $\int h_{it} di = 1$. This means that we can read off productivity risk directly from the estimated income risk and treat both interchangeably. Correspondingly, we will – as a shorthand notation – call the risk households face regarding their productivity "income risk" and the shocks to h "income shocks," accordingly.

3.1.2 Consumption, Savings, and Portfolio Choice

Given this labor income, households optimize intertemporally subject to their budget constraint:

$$c_{it} + b_{it+1} + q_t k_{it+1} = b_{it}\frac{R(b_{it}, R^b_t, A_t)}{\pi_t} + (q_t + r_t)k_{it} + (1-\tau)(h_{it} w_t N_t + \mathbb{I}_{h_{it}\neq 0}\Pi^U_t + \mathbb{I}_{h_{it}=0}\Pi^F_t),$$
$$k_{it+1} \geq 0, \quad b_{it+1} \geq \underline{B}\ ,$$

where Π^U_t is union profits, Π^F_t is firm profits, b_{it} is real bond holdings, k_{it} is the amount of illiquid assets, q_t is the price of these assets, r_t is their dividend, $\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}}$ is realized inflation, and R is the nominal interest rate on bonds, which depends on the portfolio position of the household and the central bank's interest rate R^b_t, which is set one period before. All households that do not participate in the capital market ($k_{it+1} = k_{it}$) still obtain dividends and can adjust their bond holdings. Depreciated capital has to be replaced for maintenance, such that the dividend, r_t, is the net return on capital. Holdings of bonds have to be above an exogenous debt limit $\underline{B}$, and holdings of capital have to be non-negative.

Households make their savings choices and their portfolio choice between liquid bonds and illiquid capital in light of a capital market friction that renders capital illiquid because participation in the capital market is random and i.i.d. in the sense that only a fraction, λ, of households is selected to be able to adjust their capital holdings in a given period.

What is more, we assume that there is a wasted intermediation cost that drives a wedge between the government bond yield R^b_t and the interest paid by/to households R_t. This wedge, A_t, is given by a time-varying term plus a constant, $\overline{R}$, when households resort to unsecured borrowing. This means, we specify:

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

The extra wedge for unsecured borrowing creates a mass of households with zero unsecured credit but with the possibility to borrow, though at a penalty rate. If A_t goes down, households will implicitly demand fewer government bonds and find it more attractive to save in (illiquid) real capital, akin to the "risk-premium shock" in Smets and Wouters (2007). This shock follows an AR(1) process in logs and fluctuates in response to shocks, ϵ^A_t

Since a household's saving decision will be some non-linear function of that household's wealth and productivity, inflation and all other prices will be functions of the joint distribution, Θ_t, of (b, k, h) in t. This makes Θ a state variable of the household's planning problem and this distribution evolves as a result of the economy's reaction to aggregate shocks. For simplicity, we summarize all effects of aggregate state variables, including the distribution of wealth and income, by writing the dynamic planning problem with time-dependent continuation values.

This leaves us with three functions that characterize the household's problem: value function V^a for the case where the household adjusts its capital holdings, the function V^n for the case in which it does not adjust, and the expected envelope value, $\mathcal{V}$, over both:

$$
\begin{aligned}
V_t^a(b,k,h) &= \max_{k',b'_a} u[x(b,b'_a,k,k',h)] + \beta \mathcal{V}_t(b'_a,k',h) \\
V_t^n(b,k,h) &= \max_{b'_n} u[x(b,b'_n,k,k,h)] + \beta \mathcal{V}_t(b'_n,k,h) \\
\mathcal{V}_t(b',k',h) &= \mathbb{E}_t\left[\lambda V_{t+1}^a(b',k',h')|h\right] + \mathbb{E}_t\left[(1-\lambda)V_{t+1}^n(b',k,h')|h\right]
\end{aligned}
\tag{7}
$$

Expectations about the continuation value are taken with respect to all stochastic processes conditional on the current states. Maximization is subject to the corresponding budget constraint.

3.2 Firm Sector

The firm sector consists of four sub-sectors: (a) a labor sector composed of "unions" that differentiate raw labor and labor packers who buy differentiated labor and then sell labor services to intermediate goods producers, (b) intermediate goods producers who hire labor services and rent out capital to produce goods, (c) final goods producers who differentiate intermediate goods and then sell them to goods bundlers, who finally sell them as consumption goods to households, and to (d) capital goods producers, who turn bundled final goods into capital goods.

When profit maximization decisions in the firm sector require intertemporal decisions (i.e. in price and wage setting and in producing capital goods), we assume for tractability that they are delegated to a mass-zero group of households (managers) that are risk neutral and compensated by a share in profits.[14] They do not participate in any asset market and have the same discount factor as all other households. Since managers are a mass-zero group in the economy, their consumption does not show up in any resource constraint and all but the unions' profits go to the entrepreneur households (whose $h = 0$). Union profits go lump sum to worker households.

[14] Since we solve the model by a first-order perturbation in aggregate shocks, the assumption of risk-neutrality only serves as a simplification in terms of writing down the model. With a first-order perturbation we have certainty equivalence and fluctuations in stochastic discount factors become irrelevant.

3.2.1 Labor Packers and Unions

Worker households sell their labor services to a mass-one continuum of unions indexed by j, each of which offers a different variety of labor to labor packers who then provide labor services to intermediate goods producers. Labor packers produce final labor services according to the production function

$$N_t = \left(\int \hat{n}_{jt}^{\frac{\zeta_t - 1}{\zeta_t}} dj \right)^{\frac{\zeta_t}{\zeta_t - 1}}, \tag{8}$$

out of labor varieties $\hat{n}_{jt}$. Cost minimization by labor packers implies that each variety of labor, each union j, faces a downward-sloping demand curve

$$\hat{n}_{jt} = \left(\frac{W_{jt}}{W_t^F} \right)^{-\zeta_t} N_t,$$

where W_{jt} is the *nominal* wage set by union j and W_t^F is the nominal wage at which labor packers sell labor services to final goods producers.

Since unions have market power, they pay the households a wage lower than the price at which they sell labor to labor packers. Given the nominal wage W_t at which they buy labor from households and given the *nominal* wage index W_t^F, unions seek to maximize their discounted stream of profits. However, they face a Calvo-type (1983) adjustment friction with indexation with the probability λ_w to keep wages constant. They therefore maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_w^t \frac{W_t^F}{P_t} N_t \left\{ \left(\frac{W_{jt} \bar{\pi}_W^t}{W_t^F} - \frac{W_t}{W_t^F} \right) \left(\frac{W_{jt} \bar{\pi}_W^t}{W_t^F} \right)^{-\zeta_t} \right\}, \tag{9}$$

by setting W_{jt} in period t and keeping it constant except for indexation to $\bar{\pi}_W$, the steady-state wage inflation rate.

Since all unions are symmetric, we focus on a symmetric equilibrium and obtain the linearized wage Phillips curve from the corresponding first-order condition as follows, leaving out all terms irrelevant at a first-order approximation around the stationary equilibrium:

$$\log \left(\frac{\pi_t^W}{\bar{\pi}_W} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{t+1}^W}{\bar{\pi}_W} \right) + \kappa_w \left(\frac{w_t}{w_t^F} - \frac{1}{\mu_t^W} \right), \tag{10}$$

with $\pi_t^W := \frac{W_t^F}{W_{t-1}^F} = \frac{w_t^F}{w_{t-1}^F} \pi_t^Y$ being wage inflation, w_t and w_t^F being the respective *real* wages for households and firms, and $\frac{1}{\mu_t^W} = \frac{\zeta_t - 1}{\zeta_t}$ being the target mark-down of wages the unions pay to households, W_t, relative to the wages charged to firms, W_t^F and $\kappa_w = \frac{(1-\lambda_w)(1-\lambda_w \beta)}{\lambda_w}$. This target fluctuates in response to markup shocks, $\epsilon_t^{\mu W}$, and follows a log

AR(1) process.[15]

3.2.2 Final Goods Producers

Similar to unions, final goods producers differentiate a homogeneous intermediate good and set prices. They face a downward-sloping demand curve

$$y_{jt} = (p_{jt}/P_t)^{-\eta_t} Y_t$$

for each good j and buy the intermediate good at the nominal price MC_t. As we do for unions, we assume price adjustment frictions à la Calvo (1983) with indexation.

Under this assumption, the firms' managers maximize the present value of real profits given this price adjustment friction, i.e., they maximize:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_Y^t (1-\tau) Y_t \left\{ \left(\frac{p_{jt}\bar{\pi}_Y^t}{P_t} - \frac{MC_t}{P_t} \right) \left(\frac{p_{jt}\bar{\pi}^t}{P_t} \right)^{-\eta_t} \right\}, \tag{11}$$

with a time constant discount factor.

The corresponding first-order condition for price setting implies a Phillips curve

$$\log\left(\frac{\pi_t}{\bar{\pi}}\right) = \beta \mathbb{E}_t \log\left(\frac{\pi_{t+1}}{\bar{\pi}}\right) + \kappa_Y \left(mc_t - \frac{1}{\mu_t^Y} \right), \tag{12}$$

where we again dropped all terms irrelevant for a first-order approximation and have $\kappa_Y = \frac{(1-\lambda_Y)(1-\lambda_Y\beta)}{\lambda_Y}$. Here, π_t is the gross inflation rate of final goods, $\pi_t := \frac{P_t}{P_{t-1}}$, $mc_t := \frac{MC_t}{P_t}$ is the real marginal costs, $\bar{\pi}$ is steady-state inflation and $\mu_t^Y = \frac{\eta_t}{\eta_t - 1}$ is the target markup. As for the unions, this target fluctuates in response to markup shocks, $\epsilon^{\mu Y}$, and follows a log AR(1) process.

3.2.3 Intermediate Goods Producers

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

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

[15] Including the first-order irrelevant terms, the Phillips curve reads

$$\log\left(\frac{\pi_t^W}{\bar{\pi}^W}\right) = \beta \mathbb{E}_t \left[\log\left(\frac{\pi_{t+1}^W}{\bar{\pi}^W}\right) \frac{\zeta_{t+1}}{\zeta_t} \frac{W_{t+1}^F P_t}{W_t^F P_{t+1}} \frac{N_{t+1}}{N_t} \right] + \kappa_w \left(\frac{w_t}{w_t^F} - \frac{1}{\mu_t^W} \right) .$$

where Z_t is total factor productivity and follows an autoregressive process in logs, and $u_t K_t$ is the effective capital stock taking into account utilization u_t, i.e., the intensity with which the existing capital stock is used. Using capital with an intensity higher than normal results in increased depreciation of capital according to $\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \delta_2/2\,(u_t - 1)^2$, which, assuming $\delta_1, \delta_2 > 0$, is an increasing and convex function of utilization. Without loss of generality, capital utilization in the steady state is normalized to 1, so that δ_0 denotes the steady-state depreciation rate of capital goods.

Let mc_t be the relative price at which the intermediate good is sold to final goods producers. The intermediate goods producer maximizes profits,

$$mc_t Z_t Y_t - w_t^F N_t - [r_t + q_t \delta(u_t)]\, K_t,$$

where r_t^F and q_t are the rental rate of firms and the (producer) price of capital goods respectively. The intermediate goods producer operates in perfectly competitive markets, such that the real wage and the user costs of capital are given by the marginal products of labor and effective capital:

$$w_t^F = \alpha mc_t Z_t \left(\frac{u_t K_t}{N_t}\right)^{1-\alpha}, \tag{13}$$

$$r_t + q_t \delta(u_t) = u_t (1-\alpha) mc_t Z_t \left(\frac{N_t}{u_t K_t}\right)^{\alpha}. \tag{14}$$

We assume that utilization is decided by the owners of the capital goods, taking the aggregate supply of capital services as given. The optimality condition for utilization is given by

$$q_t \left[\delta_1 + \delta_2 (u_t - 1)\right] = (1-\alpha) mc_t Z_t \left(\frac{N_t}{u_t K_t}\right)^{\alpha}, \tag{15}$$

i.e., capital owners increase utilization until the marginal maintenance costs equal the marginal product of capital services.

3.2.4 Capital Goods Producers

Capital goods producers take the relative price of capital goods, q_t, as given in deciding about their output, i.e., they maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t I_t \left\{ \Psi_t q_t \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] - 1 \right\}, \tag{16}$$

where Ψ_t governs the marginal efficiency of investment à la Justiniano et al. (2010, 2011), which follows an AR(1) process in logs and is subject to shocks ϵ_t^{Ψ}.[16]

Optimality of the capital goods production requires (again dropping all terms irrelevant up to first order)

$$\Psi_t q_t \left[1 - \phi \log \frac{I_t}{I_{t-1}}\right] = 1 - \beta \mathbb{E}_t \left[\Psi_{t+1} q_{t+1} \phi \log \left(\frac{I_{t+1}}{I_t}\right)\right], \tag{17}$$

and each capital goods producer will adjust its production until (17) is fulfilled.

Since all capital goods producers are symmetric, we obtain as the law of motion for aggregate capital

$$K_t - (1 - \delta(u_t)) K_{t-1} = \Psi_t \left[1 - \frac{\phi}{2}\left(\log \frac{I_t}{I_{t-1}}\right)^2\right] I_t \ . \tag{18}$$

The functional form assumption implies that investment adjustment costs are minimized and equal to 0 in the steady state.

3.3 Government

The government operates a monetary and a fiscal authority. The monetary authority controls the nominal interest rate on liquid assets, while the fiscal authority issues government bonds to finance deficits, chooses the average tax rate in the economy, and adjusts expenditures to stabilize debt in the long run and output in the short run.

We assume that monetary policy sets the nominal interest rate following a Taylor-type (1993) rule with interest rate smoothing:

$$\frac{R^b_{t+1}}{\bar{R}^b} = \left(\frac{R^b_t}{\bar{R}^b}\right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_R)\theta_\pi} \left(\frac{Y_t}{Y^*_t}\right)^{(1-\rho_R)\theta_Y} \epsilon^R_t. \tag{19}$$

The coefficient $\bar{R}^b \geq 0$ determines the nominal interest rate in the steady state. The coefficients $\theta_\pi, \theta_Y \geq 0$ govern the extent to which the central bank attempts to stabilize inflation and the output gap, where the gap, $\frac{Y_t}{Y^*_t}$, is defined relative to what output would be at stationary equilibrium markups, Y^*_t. $\rho_R \geq 0$ captures interest rate smoothing.

We assume that the government runs a budget deficit and hence accumulates debt gov-

[16] This shock has to be distinguished from a shock to the relative price of investment, which has been shown in the literature (Justiniano et al., 2011; Schmitt-Grohé and Uribe, 2012) to not be an important driver of business cycles as soon as one includes the relative price of investment as an observable. We therefore focus on the MEI shock.

erned by a rule (c.f. Woodford, 1995):

$$\frac{B_{t+1}}{B_t} = \left(\frac{B_t}{\bar{B}_t}\right)^{-\gamma_B} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\gamma_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\gamma_Y} D_t \ , \qquad D_t = D_{t-1}^{\rho_G} \epsilon_t^G, \tag{20}$$

where D_t is a persistent shock to the government's structural deficit. Besides issuing bonds, the government uses tax revenues T_t, defined below, to finance government consumption, G_t, and interest on debt. The parameters γ_B, γ_Y, and γ_π measure, respectively, how the deficit reacts to outstanding debt, the output gap, and inflation. The debt target, $\bar{B}_t$, is potentially time-varying, which we will use for counterfactuals. For the estimation, the debt target is constant and equal to the steady-state level of debt.

Total taxes T_t are then $T_t = \tau \left(w_t n_{it} h_{it} + \mathbb{I}_{h_{it} \neq 0} \Pi_t^U + \mathbb{I}_{h_{it}=0} \Pi_t^F\right)$, with constant tax rate τ, and the government budget constraint determines government spending residually: $G_t = B_{t+1} + T_t - R_t^b / \pi_t B_t$.

There are thus two shocks to government rules: monetary policy shocks, ϵ_t^R, and persistent structural deficit shocks, i.e., government spending shocks, ϵ_t^G. We assume these shocks to be log normally distributed with mean zero.

3.4 Goods, Bonds, Capital, and Labor Market Clearing

The labor market clears at the competitive wage given in (13). The bond market clears whenever the following equation holds:

$$B_{t+1} = B^d(R_t^b, A_t, r_t, q_t, \Pi_t^F, \Pi_t^U, w_t, \pi_t, \Theta_t, V_{t+1}) := \mathbb{E}_t \left[\lambda b_{a,t}^* + (1-\lambda) b_{n,t}^*\right], \tag{21}$$

where $b_{a,t}^*, b_{n,t}^*$ are functions of the states (b, k, h), and depend on how households value asset holdings in the future, $V_{t+1}(b, k, h)$, and the current set of prices $(R_t^b, A_t, r_t, q_t, \Pi_t^F, \Pi_t^U, w_t, \pi_t)$. Future prices do not show up because we can express the value functions such that they summarize all relevant information on the expected future price paths. Expectations in the right-hand-side expression are taken w.r.t. the distribution $\Theta_t(b, k, h)$. Equilibrium requires the total *net* amount of bonds the household sector demands, B^d, to equal the supply of government bonds. In gross terms there are more liquid assets in circulation as some households borrow up to $\underline{B}$.

Last, the market for capital has to clear:

$$K_{t+1} \quad = \quad K^d(R_t^b, A_t, r_t, q_t, \Pi_t^F, \Pi_t^U, w_t, \pi_t, \Theta_t, V_{t+1}) := \mathbb{E}_t[\lambda k_t{}^* + (1-\lambda)k] \ , \tag{22}$$

where the first equation stems from competition in the production of capital goods, and the second equation defines the aggregate supply of funds from households – both those that trade capital, λk_t^*, and those that do not, $(1-\lambda)k$. Again k_t^* is a function of the current prices and continuation values. The goods market then clears due to Walras' law, whenever labor, bonds, and capital markets clear.

3.5 Equilibrium

A *sequential equilibrium with recursive planning* in our model is a sequence of policy functions $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$, a sequence of value functions $\{V_t^a, V_t^n\}$, a sequence of prices $\{w_t, w_t^F,\ \Pi_t^F, \Pi_t^U, q_t, r_t, R_t^b, \pi_t, \pi_t^W\}$, a sequence of stochastic states A_t, Ψ_t, Z_t and shocks $\epsilon_t^R, \epsilon_t^G, \epsilon_t^A, \epsilon_t^Z, \epsilon_t^\Psi, \epsilon_t^{\mu W}, \epsilon_t^{\mu Y}$, aggregate capital and labor supplies $\{K_t, N_t\}$, distributions Θ_t over individual asset holdings and productivity, and expectations Γ for the distribution of future prices, such that

1. Given the functional $\mathbb{E}_t V_{t+1}$ for the continuation value and period-t prices, policy functions $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$ solve the households' planning problem, and given the policy functions $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$ and prices, the value functions $\{V_t^a, V_t^n\}$ are a solution to the Bellman equation (7).

2. Distributions of wealth and income evolve according to households' policy functions.

3. The labor, the final goods, the bond, the capital, and the intermediate goods markets clear in every period, interest rates on bonds are set according to the central bank's Taylor rule, fiscal policies are set according to the fiscal rules, and stochastic processes evolve according to their law of motion.

4. Expectations are model consistent.

4 Calibration and Estimation

We follow a two-step procedure to estimate the model. First, we calibrate or fix all parameters that affect the steady state of the model. Second, we estimate by full-information methods all parameters that only matter for the dynamics of the model, i.e., the aggregate shocks and frictions. Table 1 summarizes the calibrated and externally chosen parameters and Table 3 lists the estimated parameters. One period in the model refers to a quarter of a year and we target the US from 1954 to 2018.

Table 1: External/calibrated parameters (quarterly frequency)

Parameter	Value	Description	Target
Households			
β	0.98	Discount factor	see Table 2
ξ	4	Relative risk aversion	Kaplan et al. (2018)
γ	2	Inverse of Frisch elasticity	Chetty et al. (2011)
λ	0.1	Portfolio adj. prob.	see Table 2
ρ_h	0.98	Persistence labor income	Storesletten et al. (2004)
σ_h	0.12	STD labor income	Storesletten et al. (2004)
ζ	1/5000	Trans.prob. from W. to E.	see Table 2
ι	1/16	Trans.prob. from E. to W.	Guvenen et al. (2014)
$\bar{R}$	1.65%	Borrowing penalty	see Table 2
Firms			
α	0.68	Share of labor	62% labor income
δ_0	1.75%	Depreciation rate	Standard value
$\bar{\eta}$	11	Elasticity of substitution	Price markup 10%
$\bar{\zeta}$	11	Elasticity of substitution	Wage markup 10%
Government			
τ	0.29	Tax rate level	$G/Y = 20\%$
$\bar{R}^b$	1.00	Nominal rate	0% p.a.
$\bar{\pi}$	1.00	Inflation	0% p.a.

4.1 Calibrated Parameters

We fix a number of parameters either following the literature or targeting steady-state ratios; see Table 1 (all at quarterly frequencies of the model). For the household side, we set the relative risk aversion to 4, which is common in the incomplete markets literature; see Kaplan et al. (2018). We set the Frisch elasticity to 0.5; see Chetty et al. (2011). We take estimates for idiosyncratic income risk from Storesletten et al. (2004), $\rho_h = 0.98$ and $\bar{\sigma}_h = 0.12$. Guvenen et al. (2014) provide the probability that a household will fall out of the top 1% of the income distribution in a given year, which we take as the transition probability from entrepreneur to worker, $\iota = 1/16$.

Table 2 summarizes the calibration of the remaining household parameters. We match 4 targets: 1) average illiquid assets (K/Y=2.88), 2) average liquidity (B/Y=0.56), 3) the fraction of borrowers, 16%, and 4) the average top 10% share of wealth, which is 67%. This yields a discount factor of 0.98, a portfolio adjustment probability of 10%, a borrowing penalty of 1.65% quarterly (given a borrowing limit of two times average income), and a transition probability from worker to entrepreneur of 1/5000.[17]

[17] Detailed data sources can be found in Appendix A.

Table 2: Calibrated parameters

Targets	Model	Data	Source	Parameter
Mean illiquid assets (K/Y)	2.88	2.88	NIPA	Discount factor
Mean liquidity (B/Y)	0.56	0.56	FRED	Port. adj. probability
Top10 wealth share	0.67	0.67	WID	Fraction of entrepreneurs
Fraction borrowers	0.16	0.16	SCF	Borrowing penalty

For the firm side, we set the labor share in production, α, to 68% to match a labor income share of 62%, which corresponds to the average BLS labor share measure over 1954-2015. The depreciation rate is 1.75% per quarter. An elasticity of substitution between differentiated goods of 11 yields a markup of 10%. The elasticity of substitution between labor varieties is also set to 11, yielding a wage markup of 10%. Both are standard values in the literature.

The tax rate, τ, is set to clear the government budget constraint that corresponds to a government share of $G/Y = 20\%$. The policy rate is set to 0.0%. This broadly captures the average federal funds rate in real terms minus output growth over 1954-2018. We set steady-state inflation to zero as we have assumed indexation to the steady-state inflation rate in the Phillips curves.

4.2 Estimation

We estimate by Bayesian full-information methods the remaining parameters that matter only for the dynamics of the model, i.e., the aggregate shocks and frictions and the policy rules.[18] We use quarterly US data from 1954Q3 to 2018Q3 and include the following seven observable time series: the growth rates of per capita GDP, private consumption, investment, and wages, all in real terms, the logarithm of the level of per capita hours worked, the log difference of the GDP deflator, and the (shadow) federal funds rate.

Columns 1–4 of Table 3 present the parameters we estimate and their assumed prior distributions. Where available, we use prior values that are standard in the literature and independent of the underlying data. Following Justiniano et al. (2011), we impose a gamma distribution with prior mean of 5.0 and standard deviation of 2.0 for δ_2/δ_1, the elasticity of marginal depreciation with respect to capacity utilization, and a gamma prior with mean

[18] See Appendix B and Bayer et al. (2020) for details on the estimation technique and Appendix A for details on data sources and construction.

Table 3: Prior and posterior distributions of estimated parameters

Parameter		Prior		Posterior			
	Distribution	Mean	Std. Dev.	Mean	Std. Dev.	5 %	95 %
			Frictions				
δ_s	Gamma	5.00	2.00	0.651	0.039	0.586	0.717
ϕ	Gamma	4.00	2.00	0.150	0.023	0.115	0.190
κ	Gamma	0.10	0.02	0.079	0.014	0.058	0.102
κ_w	Gamma	0.10	0.02	0.042	0.008	0.030	0.056
			Monetary policy rule				
ρ_R	Beta	0.50	0.20	0.840	0.015	0.815	0.864
σ_R	Inv.-Gamma	0.10	2.00	0.231	0.012	0.212	0.252
θ_π	Normal	1.70	0.30	2.382	0.134	2.167	2.607
θ_y	Normal	0.13	0.05	0.114	0.021	0.081	0.151
			Debt rule				
ρ_G	Beta	0.50	0.20	0.985	0.007	0.973	0.994
σ_G	Inv.-Gamma	0.10	2.00	0.303	0.019	0.273	0.337
γ_B	Gamma	0.10	0.08	0.219	0.024	0.180	0.260
γ_π	Normal	0.00	1.00	-0.919	0.068	-1.031	-0.806
γ_Y	Normal	0.00	1.00	-0.371	0.027	-0.418	-0.328
			Structural shocks				
ρ_A	Beta	0.50	0.20	0.755	0.038	0.689	0.815
σ_A	Inv.-Gamma	0.10	2.00	0.127	0.007	0.116	0.138
ρ_Z	Beta	0.50	0.20	0.995	0.002	0.991	0.998
σ_Z	Inv.-Gamma	0.10	2.00	0.578	0.027	0.536	0.623
ρ_Ψ	Beta	0.50	0.20	0.948	0.014	0.925	0.969
σ_Ψ	Inv.-Gamma	0.10	2.00	1.622	0.117	1.441	1.824
ρ_μ	Beta	0.50	0.20	0.921	0.019	0.888	0.948
σ_μ	Inv.-Gamma	0.10	2.00	1.385	0.178	1.158	1.682
$\rho_{\mu w}$	Beta	0.50	0.20	0.977	0.004	0.970	0.984
$\sigma_{\mu w}$	Inv.-Gamma	0.10	2.00	2.535	0.225	2.199	2.929

Notes: The standard deviations of the shocks and measurement errors have been transformed into percentages by multiplying by 100.

4.0 and standard deviation of 2.0 for the parameter controlling investment adjustment costs, ϕ. For the slopes of the price and wage Phillips curves, κ_Y and κ_w, we assume gamma priors with mean 0.1 and standard deviation 0.02, which corresponds to price and wage contracts having an average length of one year. Following Smets and Wouters (2007), the autoregressive parameters of the shock processes are assumed to follow a beta distribution with mean 0.5 and standard deviation 0.2. The standard deviations of the shocks follow inverse-gamma distributions with prior mean 0.1% and standard deviation 2%.

Regarding policy, for the inflation and output feedback parameters in the Taylor-rule, θ_π and θ_Y, we impose normal distributions with prior means of 1.7 and 0.13, respectively, while the interest rate smoothing parameter ρ_R has the same prior distribution as the persistence parameters of the shock processes. In the bond rule, the debt-feedback parameter γ_B is assumed to follow a gamma distribution with mean 0.10 and standard deviation 0.08, such that the prior for the autocorrelation of debt is centered around 0.9, implying a half-life of a deviation in debt of between one and eight years. The parameters governing feedback to inflation and output, γ_π and γ_Y, follow standard normal distributions.

Columns 5–8 of Table 3 report the posterior distributions of the estimated parameters. The estimation is conducted with 5 parallel RWMH chains started from an over-dispersed target distribution after an extensive mode search. After a burn-in of 20,000 draws in each chain, 200,000 draws from the posterior are used to compute the posterior statistics. The average acceptance rates across chains is 35%.[19]

The parameter estimates are broadly in line with the representative-agent literature (which corresponds to our priors that are taken from this literature). Real frictions are an exception. They are up to one order of magnitude smaller in our estimation. In particular, investment adjustment costs are substantially smaller. This reflects the portfolio adjustment costs at the household level that generate inertia in aggregate investment. Our estimates for nominal frictions are standard and close to the priors, with price stickiness about 4 quarters on average and wage stickiness somewhat higher at $5\frac{1}{2}$ quarters on average.

In terms of shocks, the estimated persistence and variance for the seven "standard" shocks are comparable to the results of Smets and Wouters (2007). The persistence ranges from 0.921 for price markups to 0.995 for TFP. The variance ranges from 0.13% for risk premium shocks to 2.53% for wage-markup shocks.

The estimated Taylor rule is in line with the literature. The coefficients on inflation and output deviations are 2.38 and 0.11, respectively, and there is substantial inertia of 0.84. The fiscal rule that governs deficits and hence government spending exhibits a countercyclical response to inflation and output deviations, −0.92 and −0.37, respectively. Debt is quickly stabilized with a feedback parameter of 0.219 which implies an autocorrelation of debt of 0.781, which translates to a half-life of debt deviations of around 3 quarters. The shock to the structural deficit itself is highly persistent with an autoregressive parameter of 0.985.

[19] Appendix C provides Gelman and Rubin (1992) convergence statistics. Traceplots of individual parameters are available on request.

5 Government Spending Shocks

In this section, we use the estimated model to quantify the importance of the liquidity channel in the transmission of fiscal policy. First, we look at the aggregate effects of short-lived government spending shocks. We show that the model replicates the time series evidence from Section 2, in particular the response of liquidity premia. Second, we quantify the importance of the liquidity channel for the fiscal multiplier.

5.1 Model Dynamics

Figure 3 (black solid lines) shows the impulse responses to a government spending shock in the estimated model. The estimated shock is very similar to the reduced-from shock identified with the Blanchard and Perotti (2002) approach in Section 2. Government spending persistently increases with a maximum increase around 1.7%.[20] Government spending later overshoots to stabilize public debt (not shown[21]), which increases by about 1% as in Section 2. Hence, the size and the persistence of the shock are very similar in the model and the data even though the sample period and the identification are different.

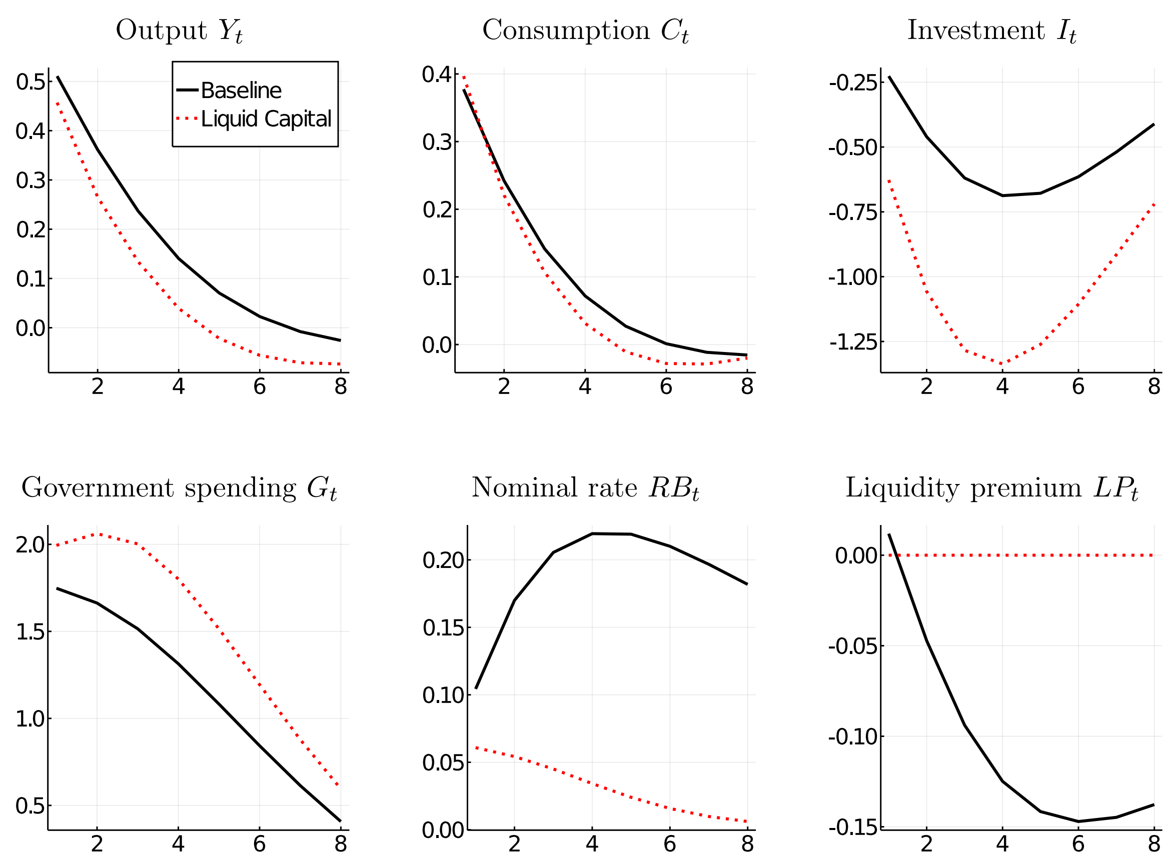
In response to higher government spending, output and consumption increase. The maximum output response is 0.5% in period 1, which implies a fiscal multiplier of 1.3 on impact. This leads to inflationary pressures and the policy rate increases by 22 basis points (annualized). Investment, by contrast, falls by 0.7% with the trough at 4 quarters. The dynamics of the investment response match the reduced-form evidence well and the size is within the confidence intervals. The response of output and consumption is somewhat stronger in the model.

In equilibrium, the liquidity premium falls by 15 basis points (annualized) after 6 quarters in the model. This model-implied response lines up well with the empirical estimates where we find a decline between 2 and 50 basis points; see Figure 2. Both in shape and in size they are very similar to the results we obtain when using the housing returns of Knoll et al. (2017) for the illiquid asset, which give an inverted hump-shaped response with a peak decline in the liquidity premium of about 18 basis points after 4 quarters.

[20] The model does not feature a hump-shape in government spending because the shock follows a simple AR(1) process.

[21] We show selected impulse responses that highlight the key mechanisms in this section. Impulse responses for more variables and longer horizons can be found in Appendix D.

Figure 3: Impulse Response Functions (estimated)

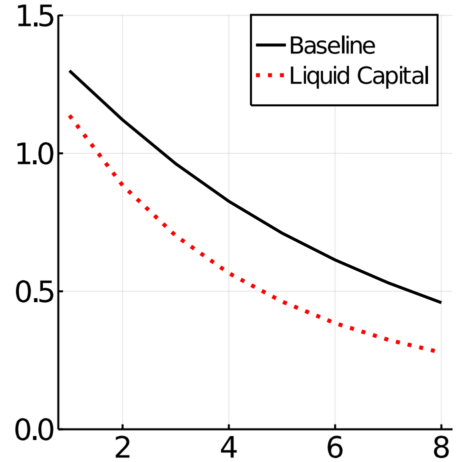


Notes: Black solid line: Impulse responses to the estimated government spending shock in the baseline model. Red dotted line: Impulse responses to government spending shock in the liquid-capital model under baseline parameters. Y-axis: Percent deviation from steady state for Y_t, C_t, I_t, G_t, and annualized percentage points for RB_t and LP_t. X-axis: Quarters.

5.2 The Role of Liquidity for the Fiscal Multiplier

How important is the liquidity injection that is generated by the fiscal shock for its effect? To answer this question and quantify the liquidity channel of fiscal policy, we run the same shock in an alternative specification of the HANK model under the assumption that all assets are liquid. Hence, the return to bonds and capital are equal (in expectation) and there is no endogenous liquidity premium. Except for the flat liquidity premium, the signs of the impulse responses remain the same as before; see the red dotted lines in Figure 3. However, the impact fiscal multiplier decreases by 12.5% (1.3 vs. 1.13) and the cumulative multiplier

Figure 4: Fiscal Multipliers



Notes: Cumulative multiplier is computed as $\sum_{j=1}^{k} y_i / \sum_{j=1}^{k} g_i$, where y_i is the deviation of output from baseline, g_i is government spending (both measured in percentage points of steady-state output), and k is quarters, measured along the horizontal axis.

after 2 years decreases by 40% (0.46 vs 0.28); see Figure 4.[22]

This lower multiplier comes from two sources. First, there is more crowding out of capital (roughly 50% more) along the lines studied in Aiyagari and McGrattan (1998). An increase in public debt decreases the need to accumulate physical capital for precautionary purposes. Second, the increase in consumption is less persistent. In the two-asset economy, households are on average worse insured (see Kaplan et al., 2018), such that Keynesian income effects are stronger. What is more, the extra liquidity is, relative to total assets, a much larger improvement of self-insurance.

6 Public Debt and Interest Rates

Given that our estimated model is capable of explaining the short-run dynamics of the liquidity premium, broadly matching our reduced-form empirical evidence on government spending shocks, we use it next to investigate more permanent changes in fiscal policy, for which empirical evidence is almost by definition very limited. In particular, we analyze the effects of very persistent increases in public debt on interest rates, the capital stock, and inequality. We also provide a simple approximation for the fiscal burden of public debt.

[22]The absolute size of the multiplier depends on the assumed GHH preferences. However, we quantify the additional effect coming from the liquidity channel.

Given the nature of this exercise, we deviate from the estimated fiscal rule but leave all other parameters as estimated in the model.

6.1 Increasing the Debt Target

As a baseline, we assume the government increases its debt target $\bar{B}_t$ by 10%. This increase is very persistent and implemented over 10 years.[23] Figure 5 shows the responses of public debt, government spending, output, capital, interest rates, and the liquidity premium to the change in the debt target.

Our main finding is that a persistent increase in public debt has a persistent and strong effect on the real interest rate of public debt. A 10% increase (i.e., an increase in the initially targeted bond-to-output ratio of roughly 5.6 percentage points) increases the real rate by 59 basis points annually in the long run.[24] Hence, we find a semi-elasticity of the real rate with respect to public debt of 5.9%. At the same time, the marginal product of capital hardly moves and capital initially falls only mildly. The elasticity of the real rate to public debt seems – prima facie – somewhat high. However, recall that for a transitory shock, responses of the real rate in both the model and the data are well aligned. Our results are also in line with Summers and Rachel (2019), who summarize the limited evidence in the literature with a semi-elasticity of 4.0.

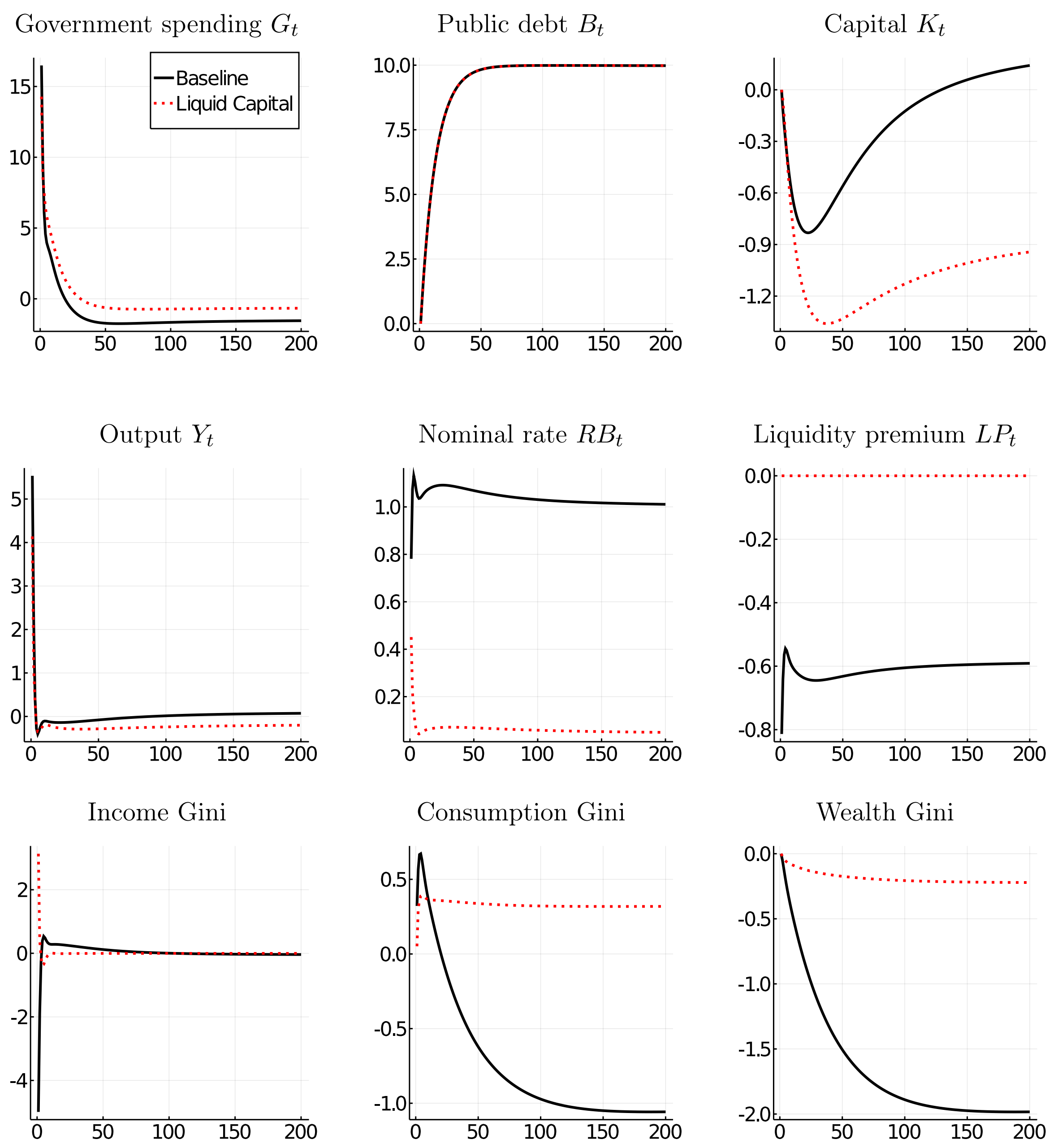
In fact, over a very long period of time, we see that capital eventually overshoots the steady state. The reason for this is that households want to balance their portfolios and, with an increase in liquidity, can now afford to also have more illiquid assets without jeopardizing their ability to smooth consumption, an argument that has already been made by Woodford (1990). This is very different than the liquid-capital specification where capital can be traded every period as are bonds. There, the increased supply of government bonds crowds out capital and quite strongly so: For an increase in government bonds by 5.6% of GDP, capital falls by roughly 3% of GDP. Key for this stark difference is the imperfect substitutability of liquid public debt by illiquid capital in the baseline model. The mirror image of this is the persistent and strong response of the interest rate on public debt, which requires the government to decrease expenditures permanently in the long run in order to service debt at constant tax rates.[25]

[23] We set $\gamma_B = 0.08$ such that it takes roughly 10 years to reach the new debt target and shut down countercyclical spending, i.e., we set $\gamma_Y = \gamma_\pi = 0$. The speed of this transition is not important for the long-run results.

[24] The nominal rate increases by 101 basis points and the inflation rate by 42 basis points permanently (annualized).

[25] Of course, one potential limit of our experiment is that we abstract from long-term reactions in private liquidity provision and foreign absorption of debt that might be absent in the short run but important in the long run. Having said this, private liquidity provision might go either way with higher public debt. For

Figure 5: Response to an Increase in the Debt Target (baseline)



Notes: Black solid line: Impulse responses to a 10% debt target shock in the baseline model. Red dotted line: Impulse responses to a 10% debt target shock in the liquid-capital model under baseline parameters. Y-axis: Percent deviation from steady state for B_t, G_t, Y_t, K_t, and annualized percentage points for RB_t and LP_t. X-axis: Quarters.

The increase in interest rates on liquid assets also has important implications for wealth and consumption inequality; see the bottom row of Figure 5. As the real rate on liquid assets goes up, poor households find it easier to accumulate assets. They are the ones that most strongly absorb the additional bonds in the long run (compared to their initial wealth). As a consequence of the larger accumulation of wealth, consumption is better insured for poor households, and consumption inequality falls in the long run. This is the case despite the fact that higher interest rate income increases income inequality during the transition – once markups are back at the steady state. The comparison to the liquid-capital model, in which capital and bonds are perfect substitutes, makes clear that the change in the liquidity premium is the key mechanism behind these results. It is worthwhile to note that this does not stand in contrast to the fact that liquid assets in our model are even more concentrated than wealth in general. Even though most liquid assets are held by the rich, liquid assets serve as a "port of entry" for wealth accumulation for the poor, and a lower liquidity premium through higher returns on liquid assets therefore helps to foster wealth equality.

6.2 Fiscal Implications

The substantial elasticity of the real interest rate to persistent public debt movements has important fiscal implications. The fiscal burden of public debt is $\mathcal{R}(B)B$, where $\mathcal{R} = r_t^b/\pi_t - \log(Y_{t+1}/Y_t)$ is the differential of the real rate on public debt and output growth. Since the interest-growth difference is an increasing function of government debt, the fiscal burden of debt increases by more than the marginal interest rate on debt upon a debt increase. The government also has to pay a higher interest rate on all debt that is currently outstanding. Expressed differently, the government is in a sense a monopolist in the provision of liquidity in the aggregate in our closed-economy model.[26]

Our log-linearized solution gives us a constant semi-elasticity of the interest-growth differential,

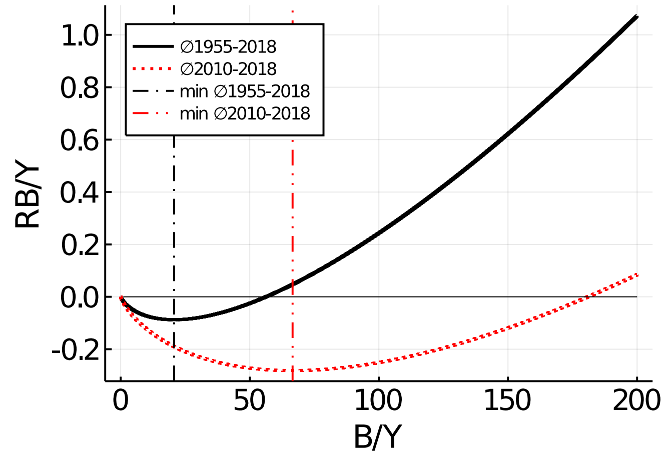
$$\mathcal{R}(B) \approx \mathcal{R}(\bar{B}) + \eta_B \ln\left(\frac{B}{\bar{B}}\right), \tag{23}$$

where $\bar{B}$ is the steady-state debt level. This formula implies that the marginal fiscal burden of additional debt starting from the steady state is $\frac{\partial(\mathcal{R}(B)B)}{\partial B} = \mathcal{R}(B) + \eta_B$. Our estimate of η_B is 5.9%, such that, despite the fact that the marginal real rate on government bonds is zero, there is an important fiscal burden from higher public debt. Again this is very different in the liquid capital version of the model, where physical capital and bonds are perfect substitutes and the interest rate responds very little. This means that if we raise

example, higher interest rates tighten the (natural) borrowing limit and the pledgeability of assets and hence lower private liquidity; see Antunes and Ercolani (2019).

[26] In the model there are also private IOUs but they represent only 10% of liquid assets because we target unsecured borrowing.

Figure 6: Interest Burden of Public Debt



Notes: Y-axis: Interest-burden-to-GDP ratio in percent (annual). X-axis: public-debt-to-GDP ratio in percent (annual). Black lines corresponds to the US data from 1955 to 2018. Red lines corresponds to US data in 2018.

debt above its steady-state value in our model, the government has to significantly reduce spending (or raise taxes) in the long run.

Vice versa, the fact that interest rates are a function of the debt level creates an interior minimum in the roll over fiscal burden of debt and this burden is actually a gain, if there is a positive level of debt at which the interest-growth differential is zero. In a sense, there is a Laffer curve of debt. At zero debt, even at negative interest-growth differences, the gain from rolling over debt is zero, as is the gain if the interest-growth differential is zero. In-between the two debt levels, the government constantly generates revenues from rolling over debt. Importantly, this also implies that lowering public debt beyond a certain positive threshold increases the fiscal burden of public debt. Figure 6 plots the interest rate burden of public debt, $\mathcal{R}(B)B$, against the level of public debt, B (both relative to annual output in the steady state). The black line corresponds to our baseline, which is calibrated to average US public debt and interest rates over the last 70 years. There are two intercepts with zero: $B/Y = 0$ and at $B/Y = 56\%$. The second point corresponds to our steady state, which has an interest burden of $\mathcal{R}(\bar{B}) = 0$. A higher debt-to-GDP ratio immediately increases the interest rate burden, while a lower ratio decreases the burden at first. However, while rates continue to fall with declining debt, at some point the interest-growth differential eventually becomes negative, and as debt vanishes, too, there are no revenues from rolling it over. We can find an internal solution B^* that minimizes the fiscal burden of debt, $\mathcal{R}(B)B$, with a simple approximate formula

$$\ln B^* = \ln B_t - 1 - \frac{\mathcal{R}_t}{\eta_B}. \tag{24}$$

For the US over the last seven decades, this revenue-maximizing debt level is at 21% of GDP; see the black vertical line in Figure 6. Any target level below that provides less liquidity to the private sector and less revenues to the government.

If we apply the formula to the post Great Recession period (2010-2018), the results look very different; see the red line in Figure 6. For this period, the US interest-growth differential is $\mathcal{R} = -3.5\%$ and the debt-to-GDP ratio is roughly 100%.[27] In this case, any debt-to-GDP ratio below 67% would lead to a greater fiscal burden and less liquidity provision. Similarly, one can use the approximation to calculate the debt level needed to obtain a zero interest-growth differential as $\ln B^0 = \ln B_t - \frac{R_t}{\eta_B}$. This implies that to achieve an interest rate equal to the growth rate, US public debt needs to be roughly 185% of GDP.

6.3 Debt-Financed Partial Socialization: A Sovereign Wealth Fund

In the current crisis, several governments are discussing partial socializations as a means to support the economy and avoid large-scale disinvestment. Some European commentators had already suggested this approach in different forms pre-crisis as a measure to provide market liquidity while building up a well-diversified sovereign wealth fund.[28] At first glance, this might seem advantageous as there is a liquidity premium the government can exploit when issuing debt in order to buy marketable capital goods. We calibrate a return difference of 1.5% p.a. between capital and public debt, which is the government's marginal gain from buying capital in a debt-financed way.[29] However, the marginal fiscal burden is (since the steady-state interest rate is zero) equal to our semi-elasticity of 5.9% and thus vastly larger than the liquidity premium. A wealth fund remains a fiscal burden as long as the return difference between government bonds and illiquid capital is smaller than this semi-elasticity η_B. In other words, the government buying marketable capital requires either lower government spending or higher taxes in the long run.

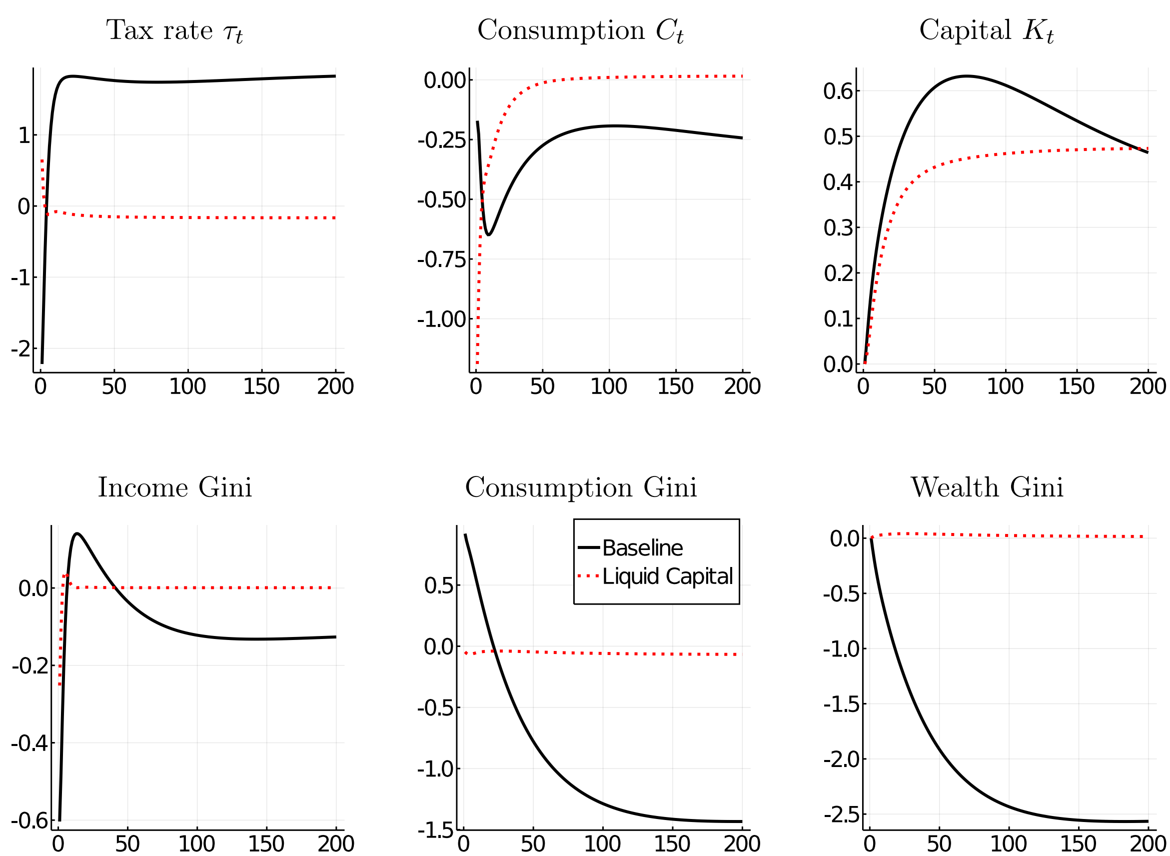
Higher taxes decrease labor supply and thus also the private incentives to accumulate capital. One may thus wonder whether a debt-financed build-up of government-owned marketable capital, if financed by taxes in the long run, increases or decreases the economy's

[27] We take the effective federal funds rate minus nominal GDP growth. In terms of the model, a risk premium shock, A_t, for example, might have lowered the interest rate.

[28] These proposals have been around since the euro-zone hit the ZLB; see for example Gros and Mayer (2012) or Fratzscher (2019).

[29] In this argument we set aside other political economy arguments for the government being less efficient or distortionary when holding capital.

Figure 7: Response to an Increase in the Debt Target to Finance a Sovereign Wealth Fund



Notes: Black solid line: Impulse responses to a 10% debt target shock in the baseline model. Red dotted line: Impulse responses to a 10% debt target shock in the liquid-capital model under baseline parameters. Y-axis: Percent deviation from steady state. X-axis: Quarters.

capital stock. Figure 7 provides an answer to this. Here we keep government expenditures constant and let taxes entirely stabilize public debt. Specifically, we assume that the government uses all revenues from issuing additional government debt to buy illiquid capital in the market. It then uses dividend income from this capital to partly finance its budget, and taxes adjust in every period to finance the remainder.

When capital and public debt are substitutes as in the liquid-capital model, taxes fall in the long run for the following reason: In both the liquid and illiquid capital model, private capital is not fully crowded out by public debt that is used to buy new capital goods. Therefore, the wealth fund increases the capital stock of the economy. In the liquid-capital model, this lowers the equilibrium real rate for capital and consequently also for bonds.

Importantly, this leads to a *lower* interest rate burden of the pre-existing public debt. Taxes can fall in the long run and consumption can increase.

When bonds and capital are imperfect substitutes, as in our baseline model with illiquid capital, this line of thinking is flawed. The liquidity premium falls and the debt-financed, government-owned capital stock does not provide sufficient revenues to compensate for the now higher interest rate on government bonds. Since this rate is more loosely connected to the rental rate of capital, the lower rental rate does not offer sufficient relief for the government's debt burden.

As a consequence, tax rates need to go up in the long run and labor supply falls. Still, it does not fall so much as to fully crowd out private capital through government-owned capital. However, the decrease in labor supply still leads to a reduction in goods production and thus consumption. The inequality dynamics from the partial socialization experiment are very strong and inequality falls more drastically than in our baseline. What is behind this is that liquid returns rise and poor households start accumulating these assets just as in the previous section. At the same time, the government-owned capital stock partly crowds out private capital and equilibrium returns fall. This induces rich households, which primarily save in illiquid wealth, to save less. On top of that, wages increase as the capital stock goes up. In fact, the lower illiquid return and higher wages are sufficient to lower the Gini coefficient of income even though we have seen increasing income inequality in our experiment without the wealth fund.

7 Conclusion

We highlight the importance of the liquidity channel of public debt in understanding the short- and long-run effects of fiscal policy. We provide novel evidence that fiscal spending shocks have a sizable impact on asset returns and lower liquidity premia. We replicate this evidence in a monetary business cycle model with heterogeneous agents and incomplete markets (known as HANK models) and use this framework to quantify the liquidity channel of fiscal policy. We find that short-run fiscal multipliers are larger and that additional government debt can successfully raise the real interest rate. Hence, the government can help to get the economy out of a low-inflation environment even if the government is committed to a passive fiscal policy in the long run that ensures government solvency.

What is more, and in line with the remarks by Woodford (1990) that government bonds do not necessarily crowd out private investment, we find very little impact on the private capital stock. If anything, we find that it increases in the long run. However, the increase in interest rates has a strong impact on the government's budget and as the interest burden of existing government debt increases. This means that an increase in government debt, even if it finances a sovereign wealth fund that makes a profit for every marginal debt-financed investment, is likely a fiscal burden that requires lower government consumption or higher taxes in the future. However, we show that, from a fiscal perspective, the optimal debt level is positive because there is a Laffer curve for public debt.

Of course, one needs to take into account that the model economy we look at is a closed economy and for many economies smaller than the US the estimated elasticities of the interest rate on bonds might be potentially too high. In addition, we ignore the possibility that the private sector, in its production of liquidity, reacts to long-term changes in the government's debt policy. We leave this for future work.

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A Data

A.1 Data for Local Projections

Unless otherwise noted, all series available at quarterly frequency from 1954Q3 to 2018Q4 from the St.Louis FED - FRED database (mnemonics in parentheses).

Output. Nominal GDP (GDP) divided by the GDP deflator (GDPDEF).

Investment. Gross private domestic investment (GPDI) divided by the GDP deflator (GDPDEF).

Consumption. Sum of personal consumption expenditures for nondurable goods (PCND), durable goods (PCDG) and services (PCESV) divided by the GDP deflator (GDPDEF).

Government spending. Government consumption expenditures and gross investment (GCE) divided by the GDP deflator (GDPDEF).

Government debt. Market value of gross federal debt (MVGFD027MNFRBDAL) divided by the GDP deflator (GDPDEF).

Long-term rate on government bonds. Yield on long-term U.S. government securities (LTGOVTBD) until June 2000 and 20-Year Treasury Constant Maturity Rate (GS20) afterwards (see Krishnamurthy and Vissing-Jorgensen, 2012).

Real interest rate. Long-term rate on government bonds minus log-difference of GDP Deflator (GDPDEF).

Stock price. S&P 500 index (SP500).

Return to capital. After-tax returns to housing capital, business capital, and all capital taken from Gomme et al. (2011).

Return to housing - alternative. Annual return to housing from Knoll et al. (2017), interpolated to quarterly frequency via cubic splines.

Liquidity premia. Difference between the respective return to capital and the long-term rate on government bonds.

Convenience yield. Spread between Moody's Aaa-rated corporate bond yield (AAA) and the long-term rate on government bonds.

Equity premium. Computed from Bob Shiller's CAPE measure as 1/CAPE minus the long-term rate on government bonds.

A.2 Data for Calibration

Mean illiquid assets. Fixed assets (NIPA table 1.1) over quarterly GDP (excluding net exports; see below), averaged over 1954-2018.

Mean liquidity. Gross federal debt held by the public as percent of GDP (FYPUGDA188S). Available from 1954-2018.

Fraction of borrowers. Taken from the Survey of Consumer Finances (1983-2013); see Bayer et al. (2019) for more details.

Average top 10% share of wealth. Source is the World Inequality Database (1954-2015).

A.3 Data for Model Estimation

The observation equation describes how the empirical times series are matched to the corresponding model variables:

$$OBS_t = \begin{bmatrix} \Delta \log (Y_t) \\ \Delta \log (C_t) \\ \Delta \log (I_t) \\ \Delta \log \left(w_t^F\right) \\ \Delta \log (T_t) \\ \log \left(\hat{N}_t\right) \\ \log \left(\hat{R}^b_{t+1}\right) \\ \log (\hat{\pi}_t) \end{bmatrix}$$

where Δ denotes the temporal difference operator and the hats above the variables denote relative deviations from the steady state.

Unless otherwise noted, all series available at quarterly frequency from 1954Q3 to 2018Q4 from the St.Louis FED - FRED database (mnemonics in parentheses).

Output. Sum of gross private domestic investment (GPDI), personal consumption expenditures for nondurable goods (PCND), durable goods (PCDG), and services (PCESV), and government consumption expenditures and gross investment (GCE) divided by the GDP deflator (GDPDEF) and the civilian noninstitutional population (CNP16OV).

Investment. Sum of gross private domestic investment (GPDI) and personal consumption expenditures for durable goods (PCDG) divided by the GDP deflator (GDPDEF) and the civilian noninstitutional population (CNP16OV).

Consumption. Sum of personal consumption expenditures for nondurable goods (PCND) and services (PCESV) divided by the GDP deflator (GDPDEF) and the civilian noninstitutional population (CNP16OV).

Federal tax receipts. Federal government current tax receipts (FEDT) divided by the GDP deflator (GDPDEF) and the civilian noninstitutional population (CNP16OV).

Real wage. Hourly compensation in the nonfarm business sector (COMPNFB) divided by the GDP deflator (GDPDEF).

Inflation. Computed as the log-difference of the GDP deflator (GDPDEF).

Nominal interest rate. Quarterly average of the effective federal funds rate (FEDFUNDS). From 2009Q1 till 2015Q4 we use the Wu and Xia (2016) shadow federal funds rate.

Hours worked. Nonfarm business hours worked (COMPNFB) divided by the civilian noninstitutional population (CNP16OV).

B Numerical Solution and Estimation Technique

We solve the model by perturbation methods. We choose a first-order Taylor expansion around the stationary equilibrium following the method of Bayer and Luetticke (2018). This method replaces the value functions with linear interpolants and the distribution functions with histograms to calculate a stationary equilibrium. Then it performs dimensionality reduction before linearization but after calculation of the stationary equilibrium. The dimensionality reduction is achieved by using discrete cosine transformations (DCT) for the value functions and perturbing only the largest coefficients of this transformation and by approximating the joint distributions through distributions with an approximated copula and full marginals. We approximate changes in the Copula relative to the steady state in the same way we approximate the value function with DCTs (plus additional constraints ensuring it remains a probability distribution). We solve the model originally on a grid of 80x80x22 points for liquid assets, illiquid assets, and income, respectively. The dimensionality-reduced number of states and controls in our system is roughly 900.

Approximating the sequential equilibrium in a linear state-space representation then boils down to the linearized solution of a non-linear difference equation

$$\mathbb{E}_t F(x_t, X_t, x_{t+1}, X_{t+1}, \sigma\Sigma\epsilon_{t+1}), \tag{25}$$

where x_t is "idiosyncratic" states and controls: the value and distribution functions, and X_t is aggregate states and controls: prices, quantities, productivities, etc. The error term ϵ_t represents fundamental shocks.

We use a Bayesian likelihood approach as described in An and Schorfheide (2007) and Fernández-Villaverde (2010) for parameter estimation. In particular, we use the Kalman filter to obtain the likelihood from the state-space representation of the model solution[30]

[30]The Kalman filter allows us to deal with missing values and mixed frequency data quite naturally. For

and employ a standard random walk Metropolis-Hastings algorithm to generate draws from the posterior likelihood. Smoothed estimates of the states at the posterior mean of the parameters are obtained via a Kalman smoother of the type described in Koopman and Durbin (2000) and Durbin and Koopman (2012).

C MCMC Diagnostics

Table 4: Gelman and Rubin (1992) convergence diagnostics

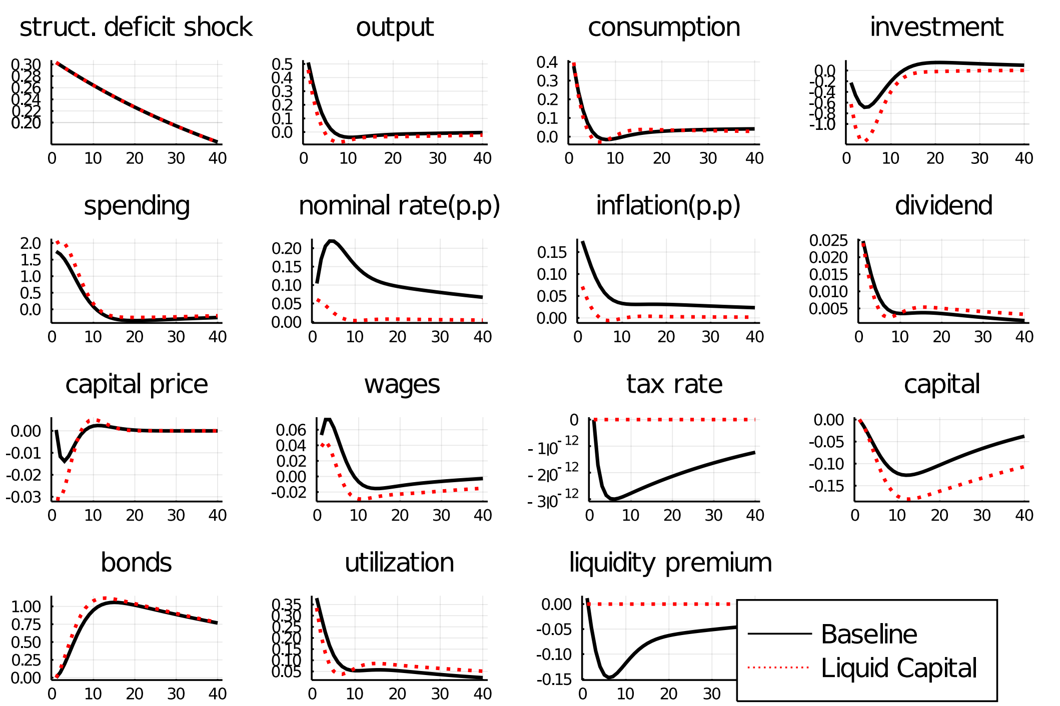
Parameter	PSRF	97.5%
δ_s	1.031	1.049
ϕ	1.001	1.002
κ	1.005	1.012
κ_w	1.001	1.001
ρ_A	1.003	1.007
σ_A	1.003	1.008
ρ_Z	1.001	1.002
σ_Z	1.000	1.001
ρ_Ψ	1.002	1.007
σ_Ψ	1.001	1.001
ρ_μ	1.002	1.004
σ_μ	1.021	1.032
$\rho_{\mu w}$	1.001	1.002
$\sigma_{\mu w}$	1.000	1.000
ρ_R	1.002	1.005
σ_R	1.000	1.001
θ_π	1.005	1.013
θ_y	1.001	1.002
γ_B	1.001	1.003
γ_π	1.003	1.008
γ_Y	1.002	1.004
ρ_G	1.002	1.004
σ_G	1.002	1.004

Note: Gelman and Rubin (1992) potential scale reduction factor and its 97.5% quantile based on 5 chains. A common rule-of-thumb declares convergence if $PSRF < 1.1$.

a one-frequency data set without missing values, one can speed up the estimation by employing so-called "Chandrasekhar recursions" for evaluating the likelihood. These recursions replace the costly updating of the state variance matrix by multiplications involving matrices of much lower dimension (see Herbst, 2014, for details). This is especially relevant for the two-asset HANK model as the speed of evaluating the likelihood is dominated by the updating of the state variance matrix, which involves the multiplication of matrices that are quadratic in the number of states.

D Further Impulse Responses

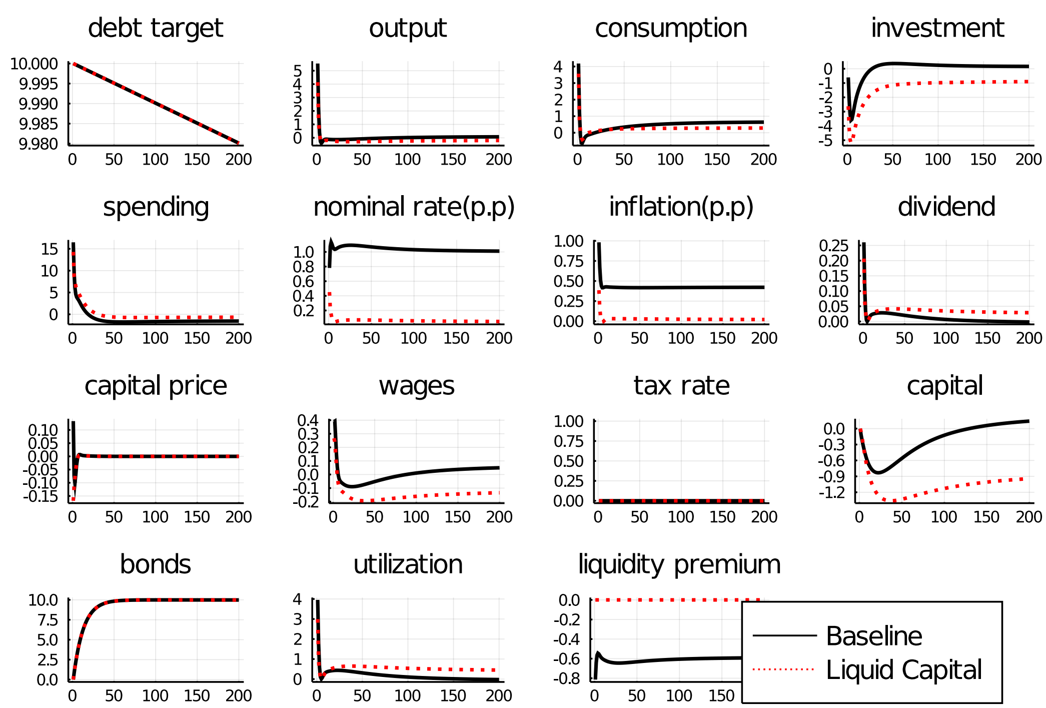
Figure 8: Impulse Response Functions (baseline)



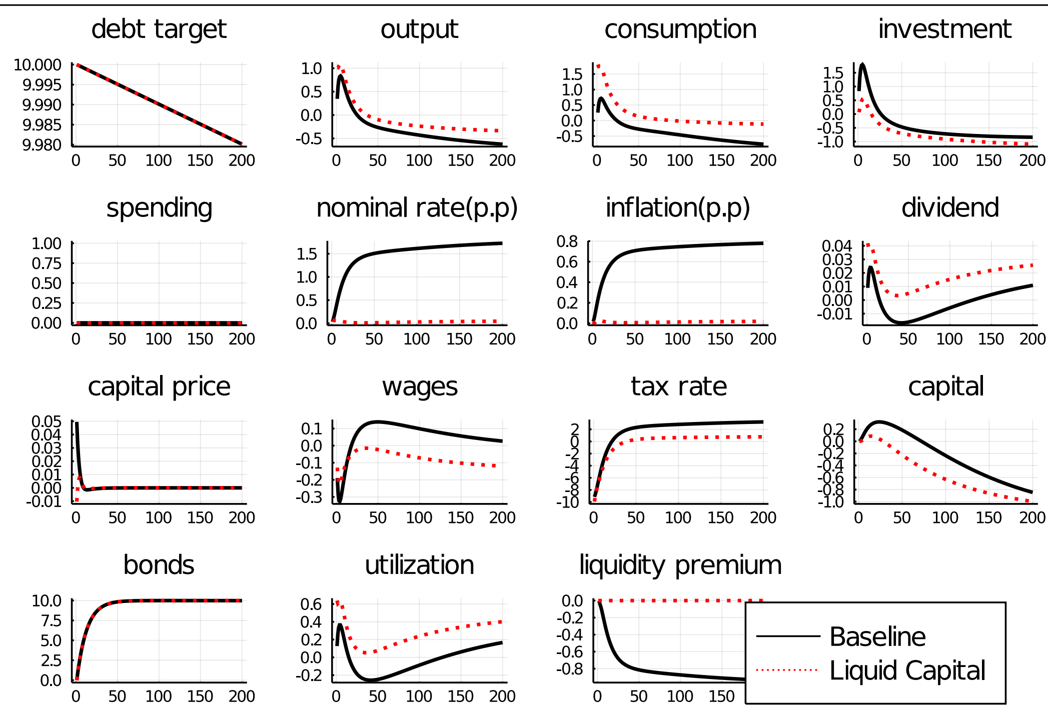
Government spending shock

Notes: Impulse responses to estimated government spending shock.

Figure 9: Counterfactuals Debt Target Shock: Tax vs Spending Adjustment



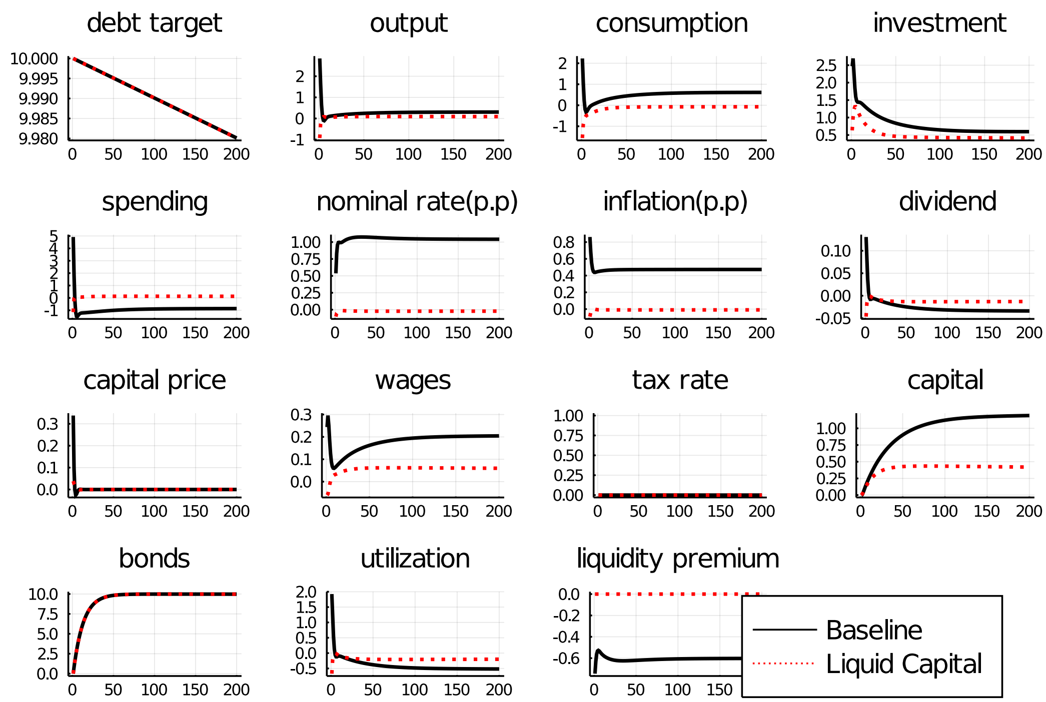
Government spending adjustment



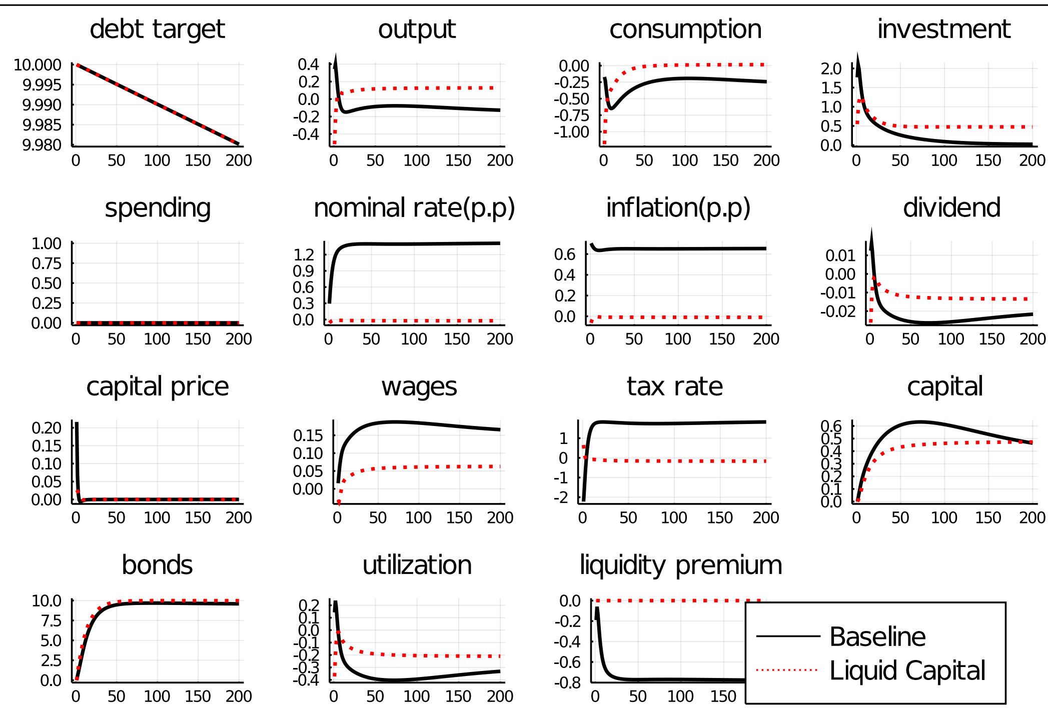
Tax adjustment

Notes: Impulse responses to 10% debt target shock.

Figure 10: Counterfactuals Debt Target Shock: Wealth Fund with Tax or Spending Adjustment



Government spending adjustment



Tax adjustment

Notes: Impulse responses to 10% debt target shock.