The Liquidity Channel of Fiscal Policy*

Christian Bayer, Benjamin Born, and Ralph Luetticke

First version: June 2020
This version: April 2021

Abstract

We provide evidence that expansionary fiscal policy lowers return differences between public debt and less liquid assets—the liquidity premium. We rationalize this finding in an estimated heterogeneous-agent New-Keynesian model with incomplete markets and portfolio choice, in which public debt affects private liquidity. This liquidity channel stabilizes fixed-capital investment. We then quantify the long-run effects of higher public debt and find little crowding out of capital, but a sizable decline of the liquidity premium, which increases the fiscal burden of debt. We show that the revenue-maximizing level of public debt is positive and has increased to 60 percent of GDP post-2010.

Keywords: Business Cycles, Fiscal Policy, HANK, Incomplete Markets, Liquidity Premium, Public debt
JEL-Codes: C11, D31, E21, E32, E63

*Bayer: University of Bonn, CEPR, CESifo, and IZA, christian.bayer@uni-bonn.de, Born: Frankfurt School of Finance & Management, CEPR, CESifo, and ifo Institute, b.born@fs.de, Luetticke: University College London, CEPR, and CFM, r.luetticke@ucl.ac.uk. We would like to thank Wei Cui, Morten Ravn, and participants at various conferences and seminars for helpful comments and suggestions. Luis Calderon provided excellent research assistance. Christian Bayer gratefully acknowledges support through the ERC-CoG project Liquid-House-Cycle funded by the European Union's Horizon 2020 Program under grant agreement No. 724204.

1 Introduction

In response to the 2020 recession, governments have issued substantial public debt to finance large-scale transfers and government spending. With public debt climbing to levels unprecedented in peacetime, it has become a pressing issue to understand the effects of public debt on the economy and particularly on government bond yields—both in the short run and in the long run. In this, an essential aspect of public debt is its role as private liquidity (Woodford, 1990), because this role implies that the demand for public debt is not perfectly elastic in its supply. In the present paper, we quantify this liquidity role. First, we show empirically that fiscal policy has a sizable impact on the return differences between public debt and less liquid assets. Second, we rationalize and analyze this finding using a monetary business cycle model with heterogeneous agents and incomplete markets (a "HANK model") in which public debt provides private liquidity, and asset classes vary in their degree of liquidity.

Concretely, we first estimate the effects of an increase in public debt, induced by a spending shock, using local projections (Jordà, 2005). Importantly, we go beyond the effects on aggregates and look at the return premia of various assets. We use quarterly data from the US as well as annual international data. 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. For a 1 percent increase in US public debt, it ranges from a 2 basis points (annualized) lower yield premium of AAA-corporate bonds to a 35 basis points lower premium on real estate—always relative to a long-term government-bond yield. We are, to our knowledge, the first to provide evidence for this differential effect of fiscal shocks on asset returns.[1] International data corroborates the US evidence. What is more, it allows us to exploit cross-country heterogeneity. Countries that rely more heavily on deficits to finance spending also see a larger decline of the liquidity premium to a government spending shock.

Next, we adapt the heterogeneous-agent New-Keynesian model of Bayer et al. (2020) 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 as well as self-insurance, the private creation of liquid assets through unsecured credit, and portfolio choice between assets of different liquidity. Therefore, fiscal policy operates through more than the traditional Keynesian channels because it additionally affects the liquidity premium. When the government runs a larger deficit, it provides the economy with a greater supply of liquid savings devices on top of the pre-existing public debt and private debt. Households hold these additional assets only when the return difference between them and illiquid assets

[1] Krishnamurthy and Vissing-Jorgensen (2012) document the unconditional evolution of asset returns relative to US public debt. Complementary to our paper, Bredemeier et al. (2021) report that a fiscal expansion increases the return spread between treasury bonds and even more liquid assets like cash deposits.

falls. Hence, equilibrium real interest rates on liquid and illiquid assets are a function of public debt in circulation. The model replicates the findings from the local projections and, hence, provides a laboratory to study the importance of this liquidity channel of fiscal policy.

Looking at short-run changes in government spending, we find that in the model, the liquidity premium falls after an expansionary fiscal policy shock. The magnitude (-14 basis points after a 1 percent increase in public debt) is in line with our empirical evidence from the local projections. We also find that the decrease in the liquidity premium is stronger the less tax-financed the spending shock is—in line with the international evidence. In the short run, this movement in the liquidity premium increases the economy's response to the fiscal stimulus. Fiscal multipliers are on impact 40 percent larger in the economy with an endogenous liquidity premium relative to the same economy with a constant one. There are two forces behind this result. First, the increase in liquidity improves the self-insurance of households overall, boosting consumption. Second, as liquid and illiquid assets are imperfect substitutes, an increase in public debt does not one-for-one substitute physical assets as savings devices. As a result, there is less crowding out of investment, making the response to stimulus stronger. This has persistent effects on the capital stock, and the cumulative fiscal multipliers of both models diverge as the time horizon increases.

Importantly for the current debate, the model also allows us to study more persistent changes in public debt, for which the evidence from local projections does not allow us to make predictions. In particular, we ask how an increase in public debt affects interest rates in the long run and, in addition, what effects such a policy has on the capital stock and inequality. Specifically, we consider a quasi-permanent increase in the debt target (debt-to-GDP ratio) by 10 percent. We model the adjustment period stretched over 10 years and focus on the increase in debt being paid out as non-distortionary transfers. We find that this fiscal policy increases the nominal rate (permanently) by 62 basis points (annualized) and inflation by 37 basis points. Hence, our estimated model implies a semi-elasticity of the real bond rate with respect to public debt of 0.025.[2] In other words, interest rates typically overshoot in the short-run. The long-run elasticity of real bond rates to the size of public debt is an order of magnitude smaller than what the short-run response suggests. The return on the illiquid asset, by contrast, moves very little. This affects the relative incentives to save for the rich (who mostly save illiquid) and the poor (who mostly save liquid) asymmetrically. As a result, the increase in debt persistently lowers wealth inequality.

The fact that public debt and fixed capital are imperfect substitutes from the household's point of view is behind both, the pronounced interest-rate response and the limited capital crowding out. If all assets are equally liquid and hence perfect substitutes, as in the standard

[2]This is in line with the summary of estimates in the literature in Summers and Rachel (2019), Table 2.

incomplete markets setup (see, e.g., Aiyagari and McGrattan, 1998), there is more crowding out and a smaller movement in the interest rate. If on top, there are complete markets, such that we have a representative agent and Ricardian equivalence, a debt increase has neither an effect on interest rates nor aggregates if financed by changes in non-distortionary taxes.

As the crowding out of capital by public debt is smaller compared to the standard-incomplete-markets setup, the government can substantially increase the capital stock if it uses the receipts from issuing public debt to foster fixed-capital investment. We model this as a sovereign wealth fund. Such an extension of the government's balance sheet drives down the liquidity premium and increases output and capital in the long run. As wages increase and the return on capital falls, the economy becomes more equal. However, we estimate the necessary increase in bond yields on outstanding public debt to dominate what the government can earn as return on the additional capital. Hence, taxes need to increase slightly in the long run to finance the sovereign wealth fund.

This statement depends crucially on the initial amount of outstanding public debt because bond rates depend on the latter. This dependence implies a Laffer-curve relationship. The government can earn a form of "liquidity tax", the difference between the bond rate and the economy's growth rate, if bonds are scarce (c.f. Bassetto and Cui, 2018; Blanchard, 2019; Reis, 2021). Lowering public debt further decreases the "tax base" of this tax such that the revenues, the product of the two, fall again if public debt becomes very scarce. Expressed conversely, the fiscal burden of public debt has an internal minimum. Using our approximation for the US, we find that the public-debt level minimizing the fiscal burden of debt is around 60 percent of GDP for the last decade. Any target level below this number provides less liquidity to the private sector and fewer revenues to the government at the same time. Historically, however, this critical debt level has been with 20 percent of GDP much smaller. Our model predicts that today a debt-to-GDP ratio of 160 percent would achieve a zero interest-rate-growth differential.

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.[3] 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 capital.

[3]See, for example, Auclert et al. (2020); 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); Kaplan et al. (2018); Luetticke (2021); McKay et al. (2016); Sterk and Tenreyro (2018); Wong (2019).

Second, the two-asset structure is also crucial for the long run as it significantly changes the extent to which public debt crowds out fixed capital. With perfectly liquid capital, such as in Aiyagari and McGrattan (1998), there is much stronger crowding out of capital through public debt. This key point has already been emphasized by Woodford (1990). However, much of this literature has focused on the optimal level of public debt with perfectly liquid capital.[4] Our analysis is positive and adds to this literature by quantifying the importance of liquidity in the presence of illiquid capital in an estimated model that matches micro and macro moments of the data as well as the short-run response of the economy to a public debt injection. 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 differential asset returns. Several papers have documented that higher debt tends to raise government bond rates (see, e.g., Brook, 2003; Engen and Hubbard, 2004; Kinoshita, 2006; Laubach, 2009). Our approach goes beyond what this literature has done, by showing that bond rates and returns on less liquid assets are affected differently. We share this focus with Krishnamurthy and Vissing-Jorgensen (2012), who document the unconditional evolution of various asset returns relative to US debt. We complement this analysis by conditioning on identified fiscal shocks, by comparing to international data, and by adding returns to fixed capital and housing, as well as interpreting the findings through the lens of a DSGE model.

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 local-projection estimates from Section 2. Section 6 then asks what the model implies for the fiscal burden of changes in public debt levels in the long run. Section 7 concludes. An appendix follows.

---

[4] See, for example, Floden (2001), Gottardi et al. (2015), Bhandari et al. (2017), Röhrs and Winter (2017), Acikgöz et al. (2018), Azzimonti and Yared (2019). There are exceptions that assess the importance of liquidity frictions, for example, Angeletos et al. (2016); Cui (2016).

2 Evidence from Local Projections

We start by documenting that fiscal expansions affect aggregate quantities *and* the return differences between public debt and less liquid assets. Subsection 2.1 focuses on the US case, for which we have a variety of liquidity premia and identification approaches available. We then corroborate the US findings with international evidence in Subsection 2.2.

We are interested in understanding the effects of an expansion of public debt. A difficulty with this question is that most changes in public debt are endogenous responses to other shocks. For example, public debt might increase in a recession when tax revenues decline. We, therefore, look at exogenous changes in government spending or taxes—for which identification approaches are established in the literature—that increase public debt in their aftermath. As baseline, we focus on government spending shocks identified by the assumption, dating back to Blanchard and Perotti (2002), that government spending is predetermined within the quarter. This identification strategy allows us to run the same local projections for the US and other countries. We show robustness to narratively identified spending and tax shocks for the US.

We standardize government expenditure shocks so that the peak increase in public debt is 1 percent. Our focus is to look at the return differences between public debt and alternative assets. Of course, these returns include various premia, and a government spending shock potentially affects these returns through other channels than just through the supply of more debt. For this reason, we will later compare the effect on return premia to what we find in our estimated structural model, which we can use to isolate the effects of a public debt increase on the liquidity premium.

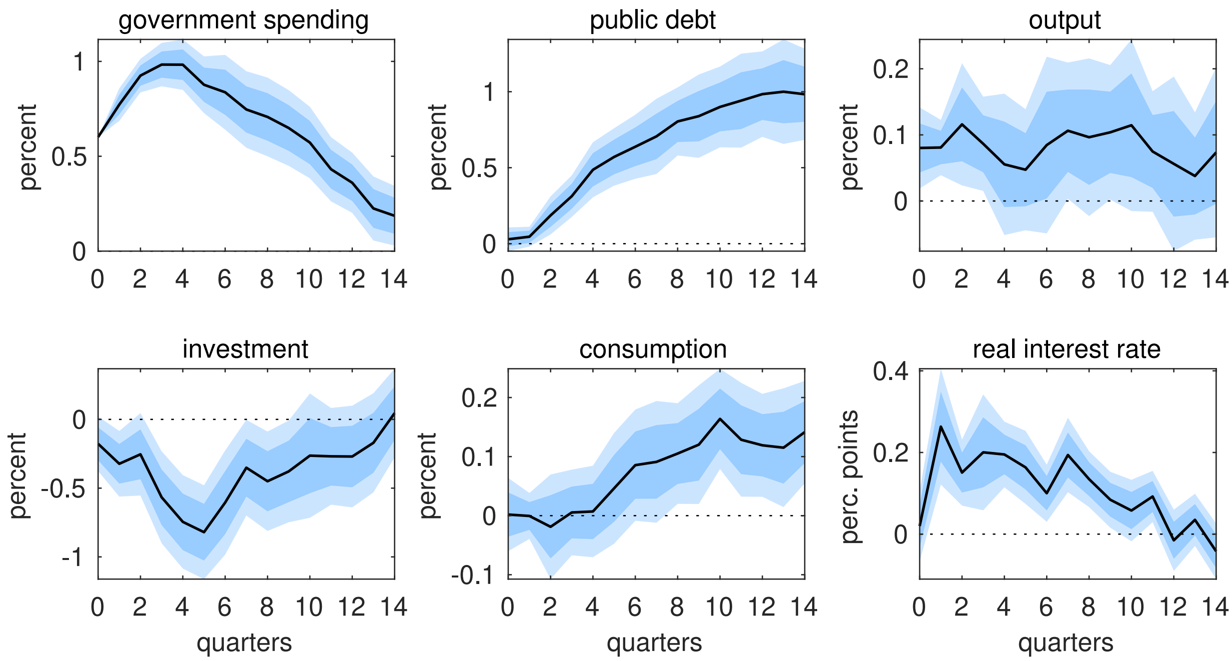
2.1 US Evidence

As discussed by Blanchard and Perotti (2002), the rationale for assuming that government spending is predetermined within the quarter is that it can only be adjusted subject to decision lags. Also, there is no automatic response since government spending does not include transfers or other cyclical items. We will show below that our results remain if we use military spending news à la Ramey (2011) to identify exogenous variation in government spending. In Appendix B.2, we study increases in debt induced by tax changes and find a similar negative link between debt and liquidity premia.

Our empirical estimates are based on local projections à la Jordà (2005) estimated on quarterly US time series from 1947Q1 to 2015Q4.[5] Letting x_{t+h} denote the variable of interest

[5] The constraining factor is the availability of some of the liquidity premia after 2015. See Appendix A for more details on the data.

Figure 1: Empirical Responses to Fiscal Spending Shocks: Aggregates



Notes: Impulse responses to a government spending shock. IRFs based on Blanchard and Perotti (2002)-style recursive identification; IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Newey and West (1987)-standard errors.

in period $t + h$, we estimate how it responds to fiscal shocks in period t on the basis of the following specification:

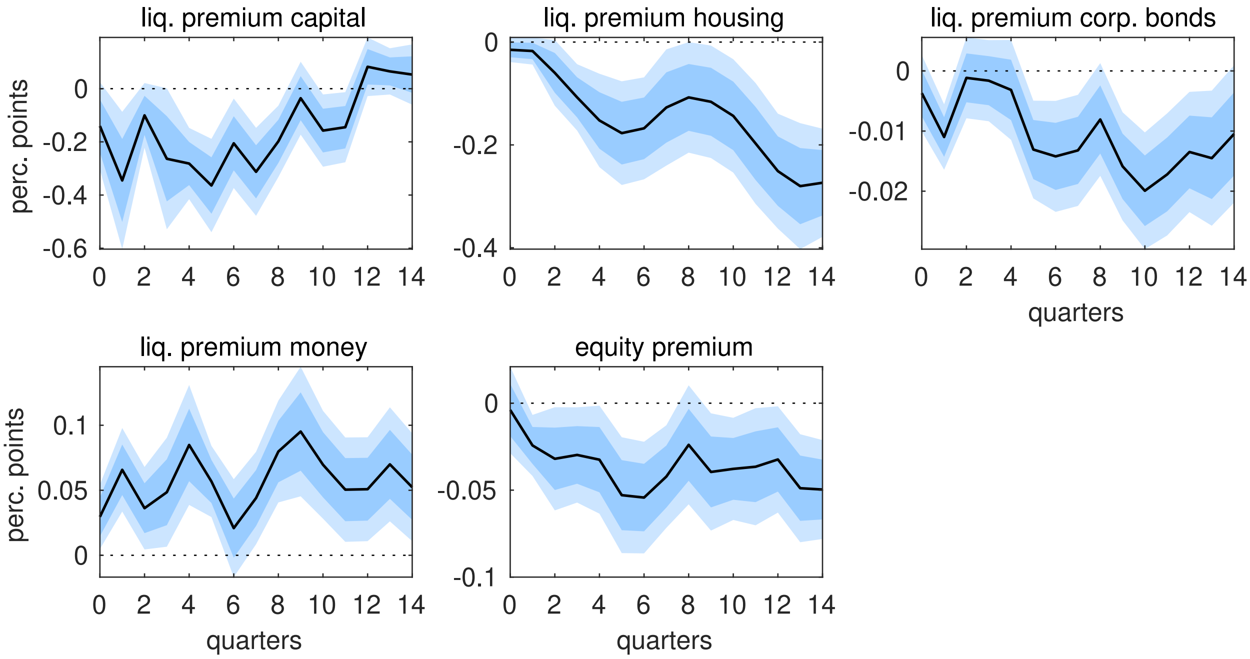
$$x_{t+h} \ = \beta_0 + \beta_1 t + \beta_2 t^2 + \psi_h \log g_t + \Gamma(L) Z_{t-1} + u_{t+h} \ . \tag{1}$$

Here, g_t is real per capita government spending in period t, and Z_{t-1} is a vector of control variables that always includes four lags of government spending, output, and debt (all three in real per capita terms), plus the real interest rate on long-term bonds and lags of the respective dependent variable if not already included. Under the Blanchard and Perotti (2002)-predeterminedness assumption, the coefficient ψ_h provides a direct estimate of the impulse response at horizon h to the government spending shock in t.[6] We also include linear and quadratic time trends, t and t^2, respectively. The error term u_{t+h} is assumed to have zero mean and strictly positive variance. We compute Newey and West (1987)-standard errors that are robust with respect to heteroskedasticity and serial correlation.

We first look at the responses of a number of standard macroeconomic variables in Figure

[6]This is equivalent to a two-step approach, where g_t is first regressed on lags of itself and additional covariates and the residual is then included in step 2 as the shock measure.

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



Notes: Impulse responses to a government spending shock. IRFs based on Blanchard and Perotti (2002)-style recursive identification; IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Newey and West (1987)-standard errors. Liq. premium capital: rate of return on capital minus long-term gov. bond rate; liq. premium housing: rate of return on housing minus long-term gov. bond rate; liq. premium corp. bonds: AAA corporate bond yield minus long-term gov. bond rate; liq. premium money: gov. bond rate minus (shadow) federal funds rate. Equity premium: Return on stocks minus long-term gov. bond rate.

1 to reconfirm that our fiscal policy shocks yield sensible aggregate results. Depicted are impulse response functions (IRFs) to a positive government spending shock that is scaled so that the maximum response of public debt is 1 percent. Government spending itself increases and follows a hump-shaped pattern, while public debt increases persistently. Output increases —at least in the short run—and investment falls, while private consumption increases with a delay. Overall, as in Ramey (2016), fiscal spending shocks have a muted effect on aggregate quantities when considering the whole post-war period. The bottom-right panel of Figure 1 shows that the real long-term government bond rate increases by 25 basis points after the fiscal expansion.[7]

The novel contribution is to estimate the response of a variety of proxies for the liquidity premium, i.e., the difference in returns of less liquid assets and long-term government

[7]We use the long-term government bond rate from Krishnamurthy and Vissing-Jorgensen (2012) with maturity of 10 years or more, see Appendix A.

bonds. The liquidity premium in the top-left panel of Figure 2 is based on the return to all capital computed by Gomme et al. (2011).[8] Next, as an alternative measure of illiquid asset returns, we use the return on housing from Jordà et al. (2019) to compute the premium (top-center panel). We also consider the liquidity premium on AAA-rated corporate bonds (the convenience yield as in Krishnamurthy and Vissing-Jorgensen, 2012). Next, we look at the federal-funds rate minus bond returns to capture the return premium over even more liquid assets as in Bredemeier et al. (2021). Finally, we include Shiller (2015)'s equity premium.

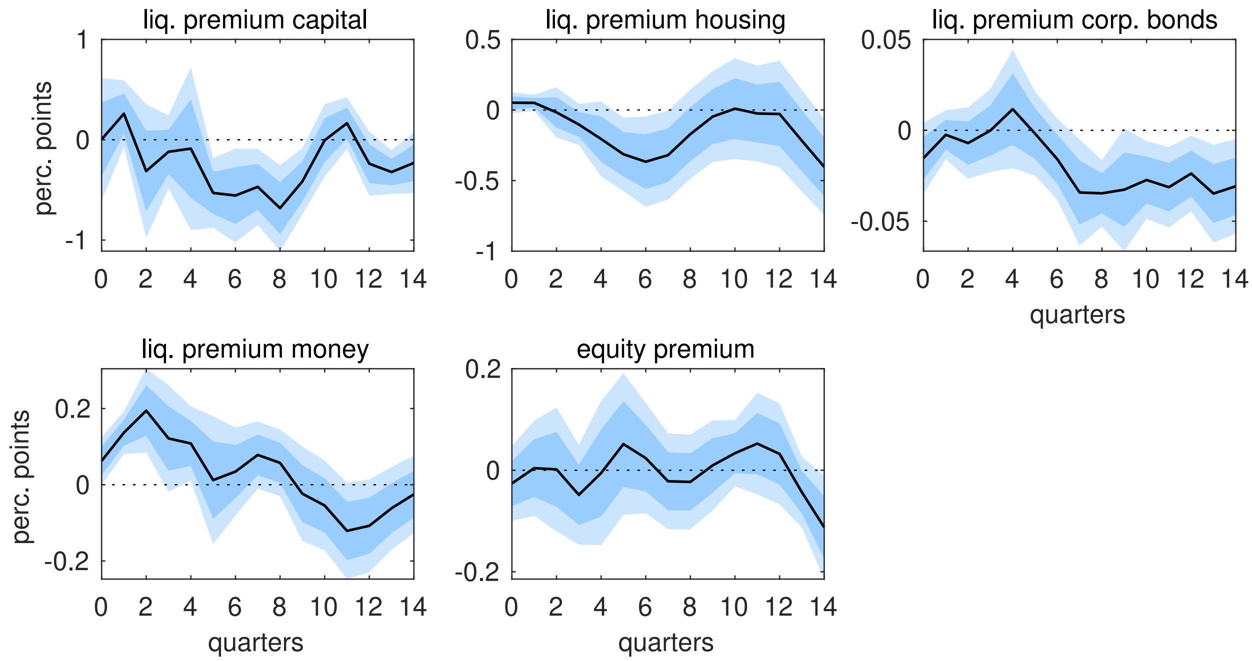
The fiscal expansion goes along with a significant fall in all liquidity premium measures (top row). The premia on capital and housing fall by around 20-35 basis points. The convenience yield falls by 2 basis points, which is the most conservative measure of the liquidity premium because it looks at the spread between very similar financial assets—government and corporate bonds—that are highly marketable. The equity premium also falls somewhat, however much less than the liquidity premia (except for the convenience yield). This is important because all return-on-capital measures, of course, include other premia besides the one on liquidity. Note that our results do not contradict the findings in Bredemeier et al. (2021), who look at the excess return of bonds over *more* liquid assets and find that this premium goes up in fiscal expansions. We can replicate their finding as is apparent from the positive response of the liquidity premium of money over government bonds shown in the lower left panel of Figure 2. In summary, we observe that the return premia of less liquid assets over bonds decrease and the return premium of bonds over more liquid assets increases after a deficit-financed spending shock.

Given the debate on the potential forecastability of Blanchard-Perotti shocks (see, e.g., Ramey, 2011, 2016), we also consider an alternative estimation in which we replace $\log g_t$ in Equation (1) by the military spending news series from Ramey (2011), deflated by the GDP deflator. We again scale the IRFs so that the maximum response of public debt is 1 percent. Results for the premia are shown in Figure 3; see Figure B.1 in the appendix for macroeconomic aggregates. The IRFs look very similar, with the fall in the liquidity premia being somewhat more drawn out but even slightly larger quantitatively in this specification.

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. We will later show that our estimated model can replicate the sign and size of the empirical responses.

[8] This combines business and housing capital. Looking at both returns separately yields similar results.

Figure 3: Empirical Responses to Military News Shocks: Return Premia



Notes: Impulse responses to a government spending shock. IRFs based on narrative identification via military news series from Ramey (2011); IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Newey and West (1987)-standard errors. Liq. premium capital: rate of return on capital minus long-term gov. bond rate; liq. premium housing: rate of return on housing minus long-term gov. bond rate; liq. premium corp. bonds: AAA corporate bond yield minus long-term gov. bond rate; liq. premium money: gov. bond rate minus (shadow) federal funds rate. Equity premium: Return on stocks minus long-term gov. bond rate.

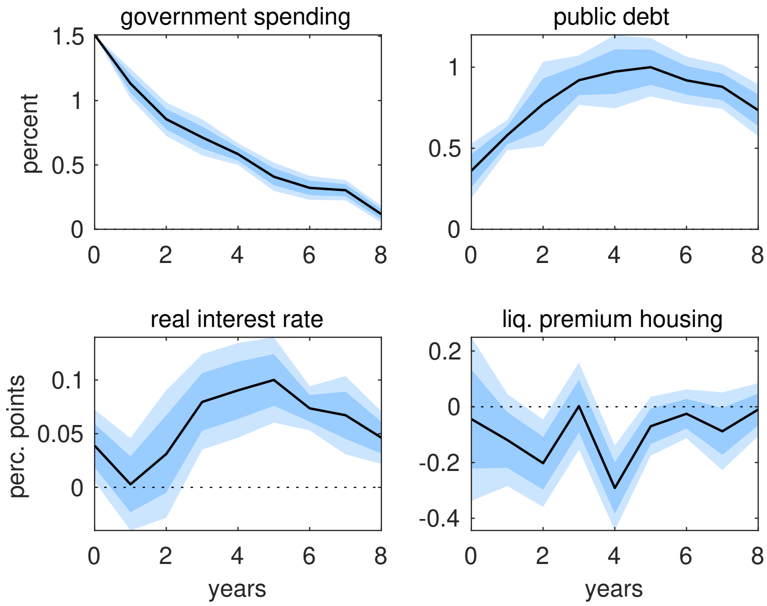
2.2 International Evidence

International panel data from the *Jordà-Schularick-Taylor Macrohistory Database* (Jordà et al., 2017) allow us to show that the response of US liquidity premia is not exceptional. What is more, we can exploit heterogeneity across countries relating the response of the liquidity premium to the amount of debt issued to finance the fiscal expansion. This relationship, we later show, is also present in our model.

Besides containing a consistent set of macroeconomic aggregates, the database also contains annual housing returns for 16 advanced economies. We start our panel in 1947 to exclude direct effects of the second world war, and the last year available in the dataset is 2016.[9] We again run the local projection, Equation (1), now at the annual level with Z_{t-1} containing the first lag of the same set of controls. Intercepts, linear and quadratic trends are

[9] See Appendix A for more details on the data and the country coverage.

Figure 4: Empirical Responses to Fiscal Spending Shocks: Country Panel



Notes: Impulse responses to a government spending shock. IRFs based on Blanchard and Perotti (2002)-style recursive identification; IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Driscoll and Kraay (1998)-standard errors. Liq. premium housing: rate of return on housing minus long-term gov. bond rate.

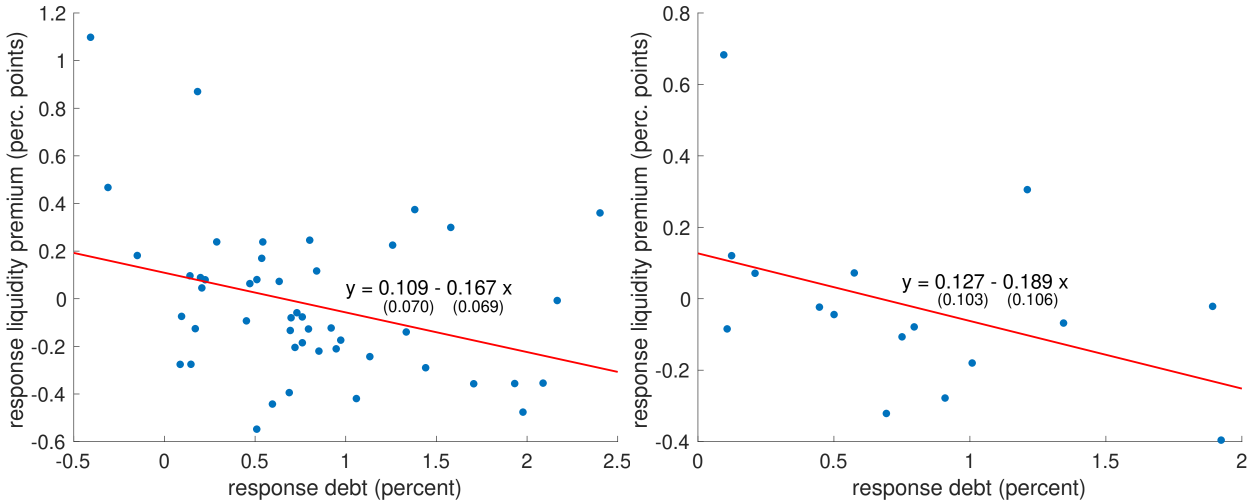
allowed to vary across countries. Given the panel dimension, we compute Driscoll and Kraay (1998)-standard errors that are robust with respect to heteroskedasticity, serial correlation, and cross-sectional correlation.

Figure 4 shows the responses to a fiscal expansion that increases real per-capita debt by 1 percent, based on the Blanchard and Perotti (2002)-style recursive identification.[10] Note that the x-axis now represents years, not quarters. The fiscal expansion leads to a persistent build-up in debt and an increase in the real interest rate on long-term bonds by about 10 basis points. Reassuringly, in this post-war country panel, we see a fall in the liquidity premium by about 20-30 basis points.

What is more, the panel regression masks an important heterogeneity. Not all countries finance the increase in government spending to the same extent by raising public debt. Some countries finance spending hikes in a more balanced-budget manner. This difference in financing behavior allows us to look at the question at hand, i.e., how does an increase in public debt change liquidity premia, through yet another angle. We run the local projections

[10] Of course, the Blanchard and Perotti (2002)-predeterminedness assumption is more restrictive at the annual than at the quarterly level. However, Born and Müller (2012) provide evidence for Australia, Canada, the UK, and the US that this assumption may not be too restrictive even for annual time-series data.

Figure 5: Debt vs. Liquidity Premium Responses



Notes: Dots represent, for each country, the debt and liquidity premium responses in years 3 to 5 (left panel) and average responses from years 3 to 5 (right panel) to a 1-percent government spending shock, based on country-by-country local projections. Standard errors for the regression line in parentheses.

country-by-country and plot in Figure 5 the change in the liquidity premium against the change in public debt around four years after the spending shock. The left panel shows the pooled responses for years 3, 4, and 5. The right panel, given the noise in the estimation, shows the average responses between years 3 and 5 for each country. The four-year horizon roughly coincides with the average peak response in public debt and ensures that more direct effects of the government spending surprises have faded out.

In those countries in which public debt increases more, the liquidity premium also declines significantly more. The size of the effect is with 17–19 basis points for a 1 percent increase in debt consistent with the estimate for the US in the previous subsection. Compared to Summers and Rachel (2019)'s long-run estimates for the effect of public debt on government bond yields, the estimated short-run response of the liquidity premium is rather on the high side. However, we later show that from theory we would expect an overshooting of the liquidity premium response on impact. In the model, the short-run response of the liquidity premium to a fiscal spending shock can easily be ten times stronger than the long-run response to an increase in debt itself.

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).

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 capital goods production.

The government sector runs both a fiscal authority and a monetary authority. The fiscal authority levies taxes on labor income and 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 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. They are infinitely lived, have time-separable preferences with discount factor β, and derive felicity from consumption c_{it} and leisure. They obtain income from supplying labor, n_{it}, renting out capital, k_{it}, and earning interest on bonds, b_{it}, and potentially from profits or union transfers. Households pay taxes on labor and profit income.

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

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:

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

The shocks ϵ^h_{it} to productivity are normally distributed with constant variance. We rescale h to obtain an average productivity of 1.

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.

Concerning leisure and consumption, households have Greenwood et al. (1988)[13] (GHH)

[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 labor supply; see, e.g., Schmitt-Grohé and Uribe (2012); Born and Pfeifer (2014). It is not feasible to estimate the flexible form of preference of Jaimovich and Rebelo (2009), which also encompasses King et al. (1988) (KPR) 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. We provide a robustness check of our main results to assuming KPR preferences instead in Appendix F. The GHH assumption has been criticized by Auclert et al. (2021) on the basis of producing "too high" multipliers. We show that fiscal multipliers in our estimated model are of reasonable size both in the short and in the long run.

preferences and maximize the discounted sum of felicity:

$$\mathbb{E}_0 \max_{\{c_{it},n_{it}\}} \sum_{t=0}^{\infty} \beta^t u \left[c_{it} - L(h_{it}, n_{it})\right]. \tag{3}$$

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

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

where $x_{it} = c_{it} - L(h_{it}, n_{it})$ is household i's composite demand for goods consumption c_{it} and leisure and L measures the disutility from work. Goods consumption bundles varieties 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, $L(h_{it}, n_{it})$, determines a household's labor supply given the aggregate wage rate, w_t, and a labor income tax, τ, through the first-order condition:

$$\frac{\partial L(h_{it}, n_{it})}{\partial n_{it}} = (1-\tau) w_t h_{it}. \tag{4}$$

When the Frisch elasticity of labor supply is constant, $\frac{\partial L(h_{it},n_{it})}{\partial n_{it}} = (1+\gamma)\frac{L(h_{it},n_{it})}{n_{it}}$ with $\gamma > 0$, the disutility of labor is a constant fraction of labor income, which simplifies the expression for the composite consumption good x_{it}, making use of the first-order condition (4):

$$x_{it} = c_{it} - L(h_{it}, n_{it}) = c_{it} - \frac{(1-\tau) w_t h_{it} n_{it}}{1+\gamma}. \tag{5}$$

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 $L(h_{it}, n_{it}) = h_{it} \frac{n_{it}^{1+\gamma}}{1+\gamma}$ without further loss of generality as long as we treat the empirical distribution of income as a calibration target.[14] This functional form simplifies the household problem as h_{it} drops out and all households supply $n_{it} = N(w_t)$. Total effective labor input, $\int n_{it} h_{it} di$, is also equal to $N(w_t)$ because $\mathbb{E}h = 1$.

3.1.2 Consumption, Savings, and Portfolio Choice

Given labor income, households optimize intertemporally. They make savings and portfolio choices between liquid bonds and illiquid capital in light of a capital market friction that renders participation in the capital market 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 on liquid assets. 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).[15]

Therefore, the household's budget constraint reads:

$$\begin{aligned} c_{it} + b_{it+1} + q_t k_{it+1} =& (1-\tau)\left(h_{it} w_t N_t + \mathbb{I}_{h_{it} \neq 0} \Pi^U_t + \mathbb{I}_{h_{it}=0} \Pi^F_t\right) + \mathcal{T}_t(h_{it}) \\ &+ b_{it} \frac{R(b_{it}, R^b_t, A_t)}{\pi_t} + (q_t + r_t) k_{it}, \qquad b_{it+1} \geq \underline{B}, \quad k_{it+1} \geq 0, \end{aligned} \tag{6}$$

where $\mathcal{T}_t$ is non-distortionary transfers, 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 $R(\cdot)$ is the nominal interest rate schedule on bonds. 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.

For simplicity, we summarize all effects of all aggregate state variables, including the

[14]Hence, productivity risk can be read off from estimated income risk and both treated interchangeably.
[15]This shock follows an AR(1) process in logs and fluctuates in response to shocks, ϵ^A_t.

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 envelope value, $\mathbb{W}$, over both:

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

Expectations about the continuation value are taken with respect to all stochastic processes conditional on the current states. Maximization is subject to (6).

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 (price and wage setting and 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.[16] 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.

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 ser-

[16]Since we solve the model by a first-order perturbation in aggregate shocks, fluctuations in stochastic discount factors are irrelevant.

vices 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.

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, which, again, 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:

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

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 and q_t are the rental rate and the price of capital goods, respectively. The intermediate goods producer is a price-taker in the factor 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

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

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_t, 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}.

Optimality 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 the 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 steady state.

3.3 Government

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

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

The coefficient $\bar{R}^b \geq 0$ determines the nominal interest rate in steady state. The coefficients $\theta_\pi, \theta_Y \geq 0$ govern the extent to which the central bank attempts to stabilize inflation and output growth, while $\rho_R \geq 0$ captures interest rate smoothing.

We assume that the government follows an expenditure rule:

$$\frac{G_t}{\bar{G}} = \left(\frac{G_{t-1}}{\bar{G}}\right)^{\rho_G} \left(\frac{Y_t}{Y_{t-1}}\right)^{(1-\rho_G)\gamma_Y} \left(\frac{B_t}{\bar{B}}\right)^{(1-\rho_G)\gamma_B} D_t, \quad D_t = \epsilon^G_t \left(\epsilon^G_{t-1}\right)^{\gamma_\epsilon}, \tag{20}$$

where D_t is a government spending shock that is itself an MA(1) process.[17] We use an ARMA-process for government spending to capture the shape of expenditures in the local projections in Section 2.1. The parameters γ_B and γ_Y measure, respectively, how the spending reacts to debt deviations from steady-state and output growth. The government uses tax revenues T_t, defined below, and bonds B_{t+1} to finance expenditures, interest payments and outstanding debt.

Tax revenues are then $T_t = \tau\left(w_t N_t + \Pi^U_t + \Pi^F_t\right) - \mathcal{T}_t$, with constant tax rate τ. Here we assume that transfers are linear in h_{it}. The transfers are set to zero except for counterfactual experiments. The government budget constraint determines government bonds residually: $B_{t+1} = G_t - T_t + R^b_t/\pi_t B_t$.

There are thus two shocks to government rules: monetary policy shocks, ϵ^R_t, and government spending shocks, ϵ^G_t. 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:

$$B_{t+1} = B^d(R^b_t, A_t, r_t, q_t, \Pi^F_t, \Pi^U_t, w_t, \pi_t, \Theta_t, \mathbb{W}_{t+1}) := \mathbb{E}_t\left[\lambda b^*_{a,t} + (1-\lambda) b^*_{n,t}\right], \tag{21}$$

[17] Appendix F provides results for an AR(2) process instead.

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, $\mathbb{W}_{t+1}(\cdot)$, and the current set of prices $(R^b_t, A_t, r_t, q_t, \Pi^F_t, \Pi^U_t, w_t, \pi_t)$. 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 that 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 $\underline{B}$. We define the aggregate amount of private liquidity as $IOU_t = \int_{\bar{B}}^0 b \, d\Theta_t$, the sum over all private debt.

Last, the market for capital has to clear:

$$K_{t+1} \quad = \quad K^d(R^b_t, A_t, r_t, q_t, \Pi^F_t, \Pi^U_t, w_t, \pi_t, \Theta_t, \mathbb{W}_{t+1}) := \mathbb{E}_t[\lambda k_t{}^* + (1-\lambda)k] \ , \qquad (22)$$

such that the aggregate supply of funds from households – both those that trade capital, λk^*_t, and those that do not, $(1-\lambda)k$ – equals the capital used in production. Again k^*_t is a function of the current prices and continuation values. The goods market then clears due to Walras's 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 $\{x^*_{a,t}, x^*_{n,t}, b^*_{a,t}, b^*_{n,t}, k^*_t\}$, of value functions $\{V^a_t, V^n_t\}$, of prices $\{w_t, w^F_t, \Pi^F_t, \Pi^U_t, q_t, r_t, R^b_t, \pi_t, \pi^W_t\}$, of stochastic states A_t, Ψ_t, Z_t and shocks $\epsilon^R_t, \epsilon^G_t, \epsilon^A_t, \epsilon^Z_t, \epsilon^\Psi_t, \epsilon^{\mu W}_t, \epsilon^{\mu Y}_t$, 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 $\mathbb{W}_{t+1}$ 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 $\{V^a_t, V^n_t\}$ 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 policy is set according to the fiscal rule, and stochastic processes evolve according to their laws of motion.

4. Expectations are model consistent.

4 Calibration and Estimation

We follow a two-step procedure to estimate the model. First, we calibrate 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 parameters, Table 2 shows the calibration targets, 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 1947 to 2019.

4.1 Calibration

We fix a number of parameters either following the literature or targeting steady-state ratios; see Table 1. 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), and set $\rho_h = 0.98$ and $\sigma_h = 0.12$. Guvenen et al. (2014) provide the probability that a household will fall out of the top 1 percent of the income distribution in a given year, which we take as the transition probability from entrepreneur to worker, $\iota = 6.25$ percent.

Table 2 summarizes the calibration of the remaining household parameters. We match 4 targets: (1) average illiquid assets ($K/Y = 11.48$), (2) public liquidity ($B/Y = 2.36$), (3) private liquidity ($IOU/Y = 0.56$), and (4) the average top 10 percent share of wealth, which is 68 percent. This yields a discount factor of 0.983, a portfolio adjustment probability of 6.4 percent, a borrowing penalty of 1.0 percent quarterly (given a borrowing limit of one-time average annual income), and a transition probability from worker to entrepreneur of 0.05 percent.[18]

The total supply of liquid assets, $IOU + B$, in our calibration is 25 percent larger than the supply of liquidity through government bonds alone. As in Huggett (1993), when some households borrow, they create liquid assets for others to save in. We match this private liquidity to the aggregate amount of unsecured consumer credit in the flow of funds.

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

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

Table 1: Calibrated Parameters (Quarterly Frequency)

Parameter	Value	Description	Target
Households			
β	0.983	Discount factor	see Table 2
ξ	4.00	Relative risk aversion	Kaplan et al. (2018)
γ	2.00	Inverse of Frisch elasticity	Chetty et al. (2011)
λ	6.40%	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	0.05%	Trans.prob. from W. to E.	see Table 2
ι	6.25%	Trans.prob. from E. to W.	Guvenen et al. (2014)
$\bar{R}$	1.00%	Borrowing penalty	see Table 2
Firms			
α	0.68	Share of labor	62% labor income
δ_0	1.75%	Depreciation rate	7.0% p.a.
$\bar{\eta}$	11	Elasticity of substitution	Price markup 10%
$\bar{\zeta}$	11	Elasticity of substitution	Wage markup 10%
Government			
τ	0.28	Tax rate level	$G/Y = 20\%$
$\bar{R}^b$	1.00	Nominal rate	see text
$\bar{\pi}$	1.00	Inflation	see text

The tax rate, τ, is set to clear the government budget constraint that corresponds to a government share of $G/Y = 20$ percent. We set steady-state inflation to zero as we have assumed indexation to the steady-state inflation rate in the Phillips curves. We set the steady-state net interest rate on bonds to 0.0 percent, in order to capture the average federal funds rate relative to nominal output growth over 1947 – 2019.

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, frictions, and the policy rules.[19] We use quarterly US data from 1947Q1 to 2019Q4 and include the following eight (demeaned) observable time series: the growth rates of per capita GDP, private consumption, investment, and wages, all in real terms, the log difference of the GDP deflator, and the logarithm of the levels of per capita hours worked, the (shadow) federal funds rate, and the measure of the liquidity premium based on the Gomme et al. (2011) data.[20]

[19]See Appendix C and Bayer et al. (2020) for details on the estimation technique.

[20]The liquidity premium is available until 2015Q4 only, see Appendix A, but our estimation approach allows for missing values in the observed time series.

Table 2: Calibration Targets

Targets	Model	Data	Source	Parameter
Mean illiquid assets (K/Y)	11.48	11.48	NIPA	Discount factor
Public liquidity (B/Y)	2.36	2.36	FRED	Port. adj. probability
Private liquidity (IOUs/Y)	0.56	0.56	FOF	Borrowing penalty
Top 10% wealth share	0.68	0.68	WID	Fraction of entrepreneurs

Notes: Targets that are shares of GDP are computed relative to *quarterly* GDP.

Columns 1–4 of Table 3 present the parameters we estimate and their assumed prior distributions. We use prior values that are standard in the literature and independent of the underlying data, closely following Smets and Wouters (2007). We allow for measurement error in the liquidity premium.

Columns 5–8 of Table 3 report the posterior distributions of the estimated parameters.[21] The parameter estimates are broadly in line with the representative-agent 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 quarters on average. The estimated Taylor rule is also in line with the literature. The coefficients on inflation and output growth are 1.7 and 0.36, respectively, and there is substantial inertia of 0.82. The fiscal rule that governs government spending exhibits a sizable countercyclical response to output deviations, −9.92, sluggish debt stabilization, −0.33, and inertia, 0.73. The MA component, 0.39, is positive and sizable—producing a hump-shaped response to government spending shocks as in the local projections of Section 2.

[21] The estimation is conducted with five parallel chains starting from an over-dispersed target distribution after an extensive mode search. After burn-in, 150,000 draws from the posterior are used to compute the posterior statistics. The acceptance rates across chains are between 20 and 30 percent. Appendix D.1 provides convergence statistics and traceplots of individual parameters. Appendix D.2 compares observed data and model predictions based on the Kalman smoother.

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	0.499	0.086	0.363	0.645
ϕ	Gamma	4.00	2.00	0.117	0.017	0.090	0.146
κ	Gamma	0.10	0.01	0.111	0.010	0.096	0.128
κ_w	Gamma	0.10	0.01	0.099	0.011	0.082	0.117
			Monetary policy rule				
ρ_R	Beta	0.50	0.20	0.820	0.012	0.800	0.839
σ_R	Inv.-Gamma	0.10	2.00	0.230	0.011	0.213	0.250
θ_π	Normal	1.70	0.30	1.704	0.086	1.567	1.846
θ_Y	Normal	0.13	0.05	0.360	0.041	0.293	0.428
			Spending rule				
γ_B	Normal	0.00	1.00	-0.335	0.094	-0.493	-0.186
γ_Y	Normal	0.00	1.00	-9.925	0.637	-11.00	-8.902
ρ_G	Beta	0.50	0.20	0.727	0.024	0.686	0.766
γ_ϵ	Beta	0.50	0.20	0.385	0.043	0.312	0.454
σ_G	Inv.-Gamma	0.10	2.00	4.689	0.285	4.245	5.178
			Structural shocks				
ρ_A	Beta	0.50	0.20	0.976	0.008	0.961	0.989
σ_A	Inv.-Gamma	0.10	2.00	0.177	0.018	0.148	0.207
ρ_Z	Beta	0.50	0.20	0.972	0.006	0.963	0.981
σ_Z	Inv.-Gamma	0.10	2.00	0.803	0.035	0.749	0.862
ρ_Ψ	Beta	0.50	0.20	0.936	0.008	0.922	0.950
σ_Ψ	Inv.-Gamma	0.10	2.00	1.868	0.112	1.692	2.058
ρ_μ	Beta	0.50	0.20	0.854	0.018	0.824	0.882
σ_μ	Inv.-Gamma	0.10	2.00	1.938	0.138	1.723	2.174
$\rho_{\mu w}$	Beta	0.50	0.20	0.786	0.026	0.742	0.828
$\sigma_{\mu w}$	Inv.-Gamma	0.10	2.00	7.175	0.757	6.036	8.516
			Measurement error				
σ_{LP}^{me}	Inv.-Gamma	0.05	0.01	1.885	0.091	1.741	2.040

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

5 The Short Run: Government Spending Shocks

In this section, we look at the aggregate effects of transitory government spending shocks that increase public debt in their aftermath. First, we show that the estimated model replicates the evidence from the local projections in Section 2, in particular the response of liquidity premia. Second, we discuss the importance of the liquidity channel for the transmission of fiscal policy.

5.1 Model Dynamics

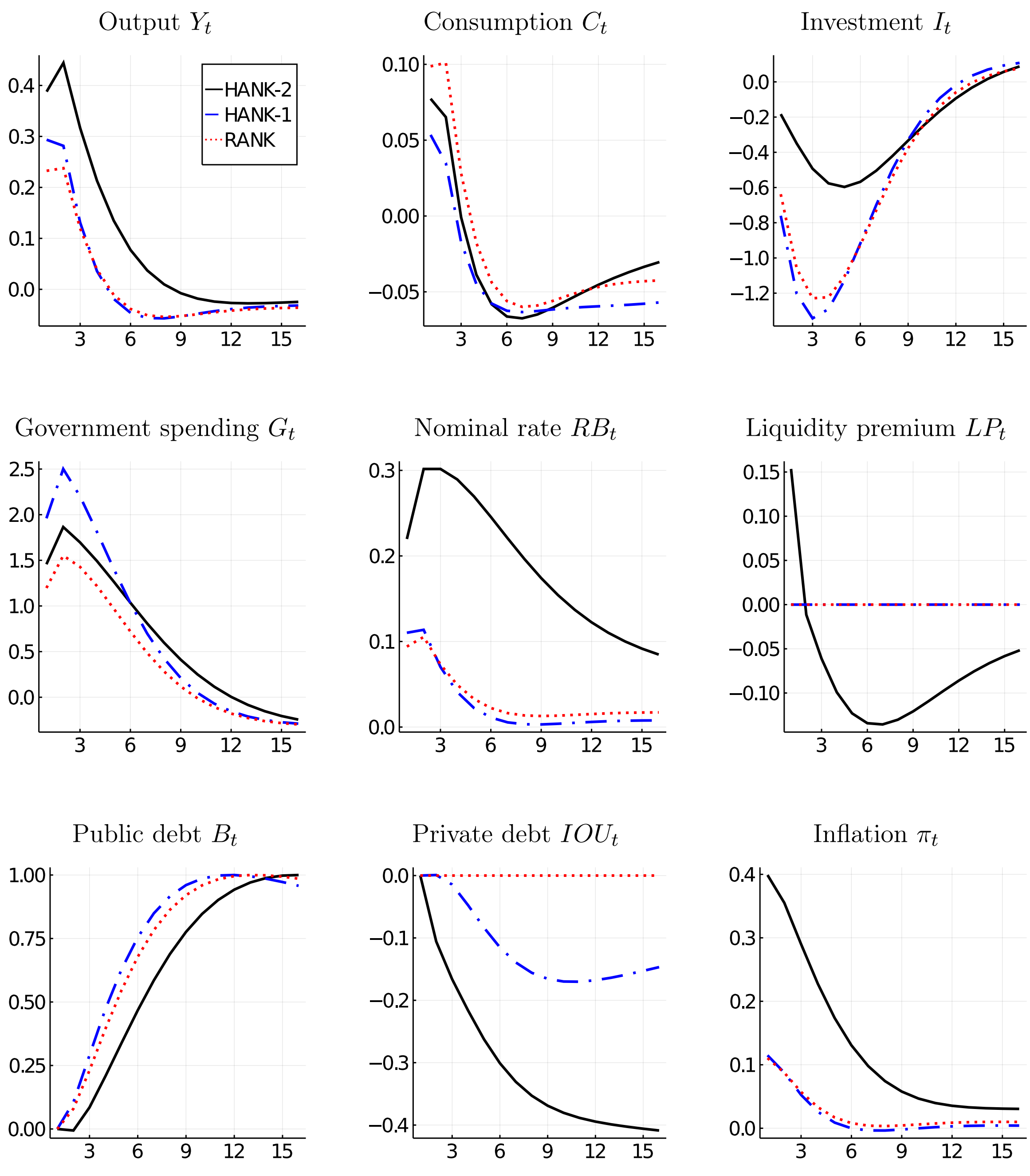
Figure 6 (black solid lines, "HANK-2") shows the impulse responses to a government spending shock in the estimated model.[22] The estimated shock is very similar to the shock identified with the Blanchard and Perotti (2002)-approach in Section 2. Again, we normalize the size of the shock to yield a 1 percent debt increase at the peak. Government spending persistently goes up, peaking at around 1.87 percent at quarter 2 and falls below its steady-state level after 12 quarters in order to stabilize public debt thereafter.

In response to higher government spending, output and consumption increase. The maximum output response is 0.44 percent in period 2. This leads to inflationary pressures and the policy rate increases by 22 basis points (annualized) on impact and further to 30 basis points at peak, with a peak inflation response of 40 basis points in period 1. Investment, by contrast, falls by 0.6 percent with the trough at 4 quarters. The dynamics of the investment response match the local-projection evidence and the size is well within the confidence bounds. The response of output and consumption is somewhat stronger in the model but less persistent.

The increased public spending crowds out capital not only because reducing investment allows the economy as a whole to provide the resources absorbed by the government without cutting back consumption but also because now, with increasing public debt, further savings devices become available to households. Similarly, the supply of private liquidity is crowded out and falls by 0.4 percent. Nonetheless, total liquidity increases because the increase in government bonds is ten times larger in absolute terms than the decline in IOUs. Consequently, the bond rate rises to make households absorb the extra liquidity. It does so more than the return on capital and, therefore, the liquidity premium falls by 14 basis points (annualized) after 6 quarters. This model-implied response of the liquidity premium lines up well with the local projections where we find a decline between 2 and 35 basis points; see Figure 2, even if it is slightly smaller than the estimated one for Gomme et al. (2011)'s

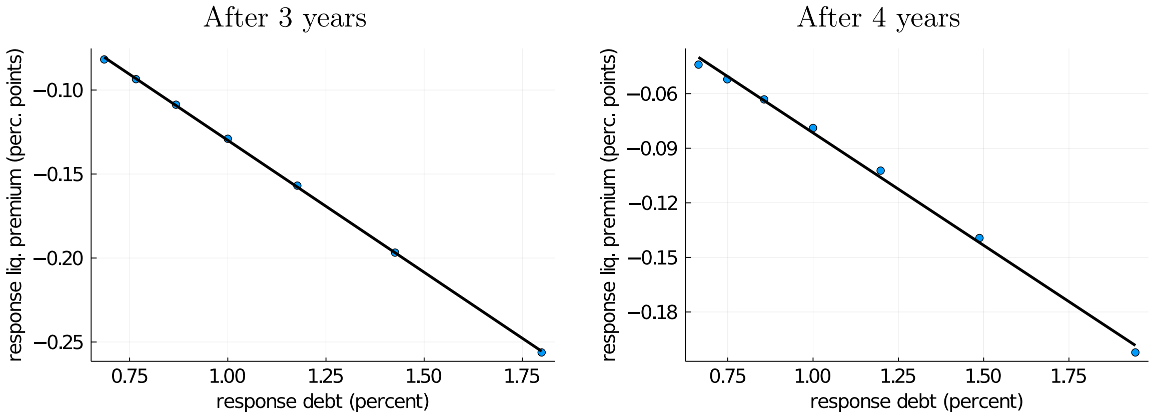
[22] We show selected impulse responses that highlight the key mechanisms in this section. Impulse responses for more variables and all shocks are in Appendix E.

Figure 6: Impulse Response Functions to a Government Spending Shock



Notes: Impulse responses to the estimated government spending shock. Black solid line: Baseline model, HANK-2. Blue dash-dotted: Liquid-capital model, HANK-1. Red dotted line: Complete-markets model, RANK. Both alternative models under baseline parameters. Y-axis: Percent deviation from steady state, except for RB_t, π_t, and LP_t that are in annualized percentage points. X-axis: Quarters.

Figure 7: Debt vs. Liquidity Premium in the Model



Notes: Dots represent the response of public debt (x-axis) and the liquidity premium at horizons 12 quarter (left panel) and 16 quarter (right panel) to a spending shock for alternative solutions of the model, in which we vary the degree of debt-financing. The lines represent a linear regression. See main text for details.

capital returns. In sum, the model matches the local projections for the US from Section 2.

Moreover, the model also reproduces the cross-country evidence from Figure 4. To show this, we vary transfers and the tax rate according to $\mathcal{T}_t\bar{Y} = \left(\frac{B_{t+1}}{B_t}\right)^{2/3\gamma_B^{\tau}}$ and $\frac{\tau_t}{\bar{\tau}} = \left(\frac{B_{t+1}}{B_t}\right)^{\gamma_B^{\tau}}$. We consider a range of values for γ_B^{τ} form -7.5 to 7.5. The higher the value for γ_B^{τ}, the more the government finances spending shocks in a balanced budget manner. The parameterization is such that transfers and taxes contribute by equal amounts to the debt stabilization. In the baseline model, this response is absent. Here, it allows us to obtain variations in the size of the public debt response to a fiscal spending shock. Figure 7 displays the results of this exercise. For an additional increase in debt of 1 percent, the liquidity premium falls by roughly 16 basis points after 3 years and by 12 basis points after 4 years. The slope of this relationship in the model is well within the confidence bounds of the empirical exercise in Section 2.2.

5.2 The Role of Liquidity

How important is the liquidity injection that is generated by the fiscal shock for its aggregate effects? How important is the portfolio choice between liquid and illiquid assets in our model? And how does the model compare to a setting with complete markets? To answer these questions and quantify the liquidity channel of fiscal policy, we run the same shock in two alternative specifications of the model under the baseline (HANK-2) parameterization. First, we look at the shock in an incomplete markets model in which all assets are liquid and thus, up to first order, the return difference between capital and bonds is constant (HANK-1).[23] Second, we look at a version of the model with a representative agent, i.e., with complete markets (RANK). IRFs for these model variants are also displayed in Figure 6.

Except for the flat liquidity premium, the signs of the impulse responses remain the same as before. However, the impact fiscal multiplier decreases by up to 40 percent—1.28 (HANK-2) vs. 0.77 (HANK-1) vs. 1.11 (RANK)—and as a result also the size of the spending shock differs in Figure 6 because we normalize to a debt increase of 1 percent at peak.[24] When there is no movement in the liquidity premium, the decline of investment is very similar between the incomplete markets and the complete markets model. It is, however, much stronger compared to our baseline, in which capital is illiquid from the point of view of the household. Without portfolio choice and thus without an endogenous response of the liquidity premium, there is more crowding out of capital. Conversely, bond rates increase less and there is less crowding out of private bonds. The stronger decline of investment in RANK and HANK-1 also has consequences for the fiscal multiplier at longer horizons because capital falls less in HANK-2. After 3 years, when government spending is back at zero, the cumulative multipliers are 0.73 in HANK-2, 0.21 in HANK-1, and 0.30 in RANK.

5.3 Robustness

In Appendix F, we show that the model behavior is robust to re-estimating the model under the assumption of King et al. (1988) preferences, under the assumption of a degree of risk aversion of 2 instead of 4, and under the assumption of the spending process being AR(2) instead of ARMA(1,1). In all versions, there is a significant decline in the liquidity premium after the spending shock. KPR preferences yield consumption crowding out, a more immediate decline in investment and thereby multipliers that are somewhat lower. Therefore, interest rate movements are also muted under KPR, but otherwise results are very similar. Compared to the evidence from the local projections, the liquidity premium falls too little under KPR preferences, and also a comparison of marginal data densities favors the GHH preference specification over the KPR one. A lower degree of risk aversion/higher intertemporal substitution results in somewhat less investment crowding out and hence higher multipliers and a slightly stronger liquidity premium response. An AR(2) process leads to virtually indistinguishable results compared to our baseline, except for a slight difference in the dynamics of spending but has a slightly lower marginal data density.

[23] We set the steady-state value of A_t, the intermediation efficiency or "risk premium", such that the steady-state returns coincide with the baseline model (HANK-2).

[24] The absolute size of the multiplier depends on the assumed GHH preferences and wage and price stickiness. However, the focus here is on the additional effect coming from the liquidity channel. Note that, under our estimated parameters, our model does not suffer from the potential problem of unrealistically high multipliers under incomplete markets and GHH preferences highlighted in Auclert et al. (2021).

6 The Long Run: Public Debt and Interest Rates

In the previous section, we have shown that our estimated model is capable of explaining the short-run dynamics of the liquidity premium, matching our local-projection evidence. Next, we use it to investigate a more permanent change in fiscal policy, for which empirical evidence is, almost by definition, very limited. In particular, we analyze the effects of a quasi-permanent increase in public debt on interest rates, the capital stock, and inequality. Analyzing the interest rate movements equips us with a simple approximation for the fiscal burden of public debt.

6.1 The Economic Consequences of Increasing the Debt Target

We assume that the government increases its debt target by 10 percent. This increase is quasi permanent and implemented over 10 years.[25] We distribute the receipts (and long-term costs) to the households through the non-distortionary transfer $\mathcal{T}$.[26] Figure 8 shows the model responses to the change in the debt target over 50 years. Again we display and compare results across the HANK-2, HANK-1, and RANK variants of our model. The RANK model, we only display for completeness as it features Ricardian equivalence and, hence, the increase in public debt has no aggregate or price consequences whatsoever.[27]

Our main finding is that the higher public-debt target has a persistent and strong effect on the real interest rate of public debt in the HANK-2 model. A 10 percent increase (i.e., an increase in the initially targeted (annual) public-debt-to-output ratio of roughly 6 percentage points) increases the (annualized) nominal rate by 62 basis points and inflation by 37 basis points in the long run. Hence, we find a semi-elasticity of the real rate with respect to public debt of 0.025. This number aligns with Summers and Rachel (2019), who summarize the literature with a semi-elasticity of 0.021.[28] At the same time, the marginal product of capital hardly moves and capital declines only mildly by 0.2 percent.

After 50 years, this leads to a pronounced difference to the standard incomplete markets version, in which all assets are liquid and the liquidity premium is constant. In the HANK-1 model, capital falls by 1.2 percent and output falls by 0.2 percent. In the long-run, higher

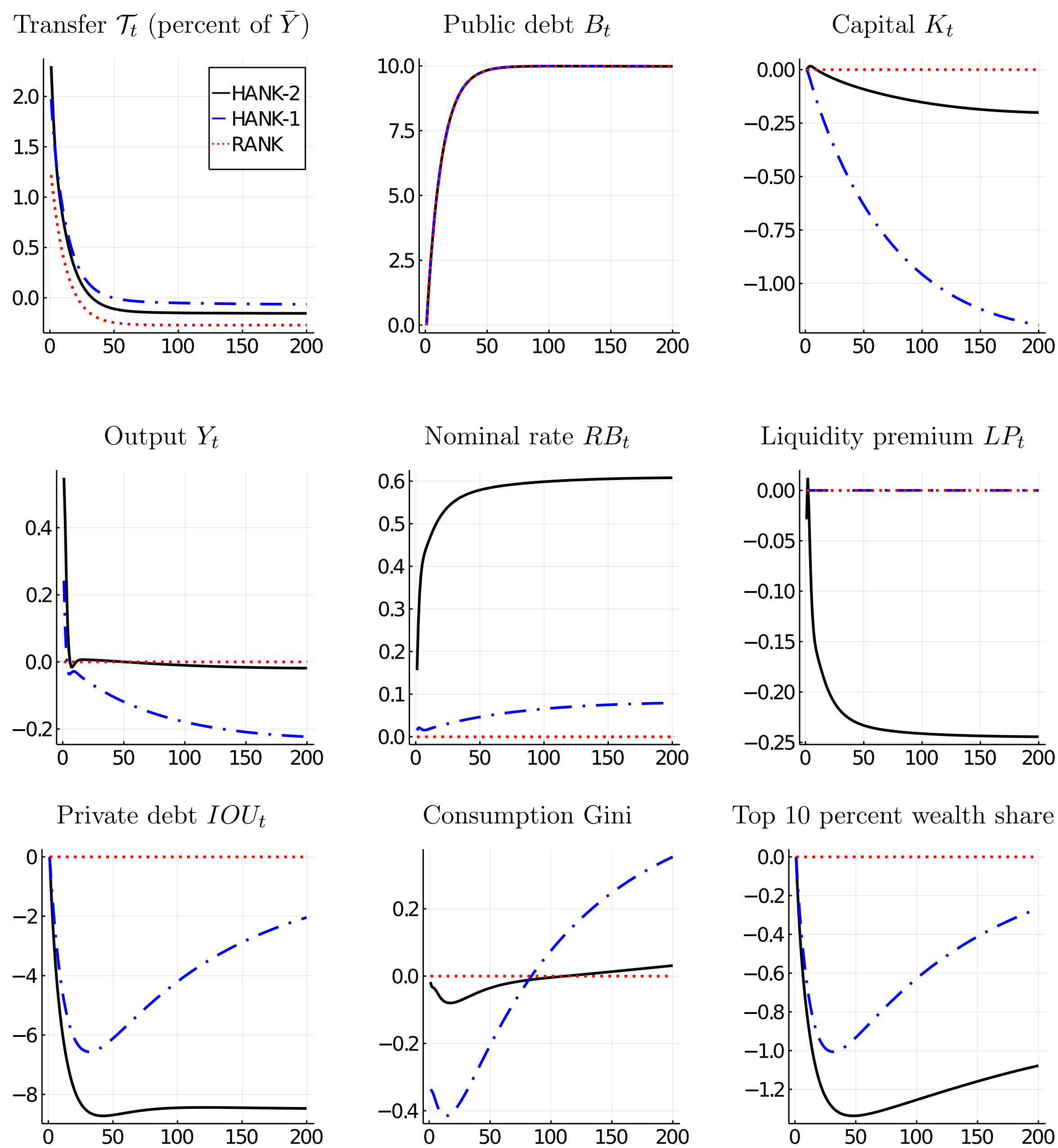
[25] The speed of this transition is not important for the long-run results. The debt target shock has a persistence of 0.9999. We increase the number of DCT coefficients for the value functions to capture the very persistent nature of this shock. Long-term effects are similar to steady-state comparisons.

[26] We set the transfers proportional to a household's productivity in order to keep income risk constant in this exercise. We shut down any response of government spending to the debt target and cycle $\gamma_B = \gamma_Y = 0$.

[27] We also consider adjustment through government spending, such that there is no Ricardian equivalence in RANK. The IRFs are displayed in Appendix G. The findings are similar.

[28] See their Table 2, which reports a 3.5 basis point increase for a 1 percentage point increase in the debt-to-output ratio.

Figure 8: Response to an Increase in the Debt Target



Notes: Impulse responses to a 10 percent debt-target shock financed by non-distortionary transfers. Black solid line: Baseline model, HANK-2. Blue dash-dotted: Liquid-capital model, HANK-1. Red dotted line: Complete-markets model, RANK. Y-axis: Percent deviation from steady state, except for $\mathcal{T}_t/\bar{Y}$, RB_t, and LP_t that are in annualized percentage points. X-axis: Quarters.

interest rates have little impact on wealth inequality in HANK-1, because households are not affected differently across the wealth distribution. This in stark contrast to the HANK-2 version. Poor households that primarily save in liquid form profit from the higher returns on these liquid assets more than rich households do (see Bayer et al., 2019, for the distribution of portfolio liquidity across the wealth distribution). As a result, poor households increase their savings more than rich households, and wealth inequality persistently decreases. While wealth inequality falls, consumption inequality rises in the long run. Lower wages drive the increase in consumption inequality. However, because of the muted crowding-out of capital in HANK-2, the consumption inequality response is small.

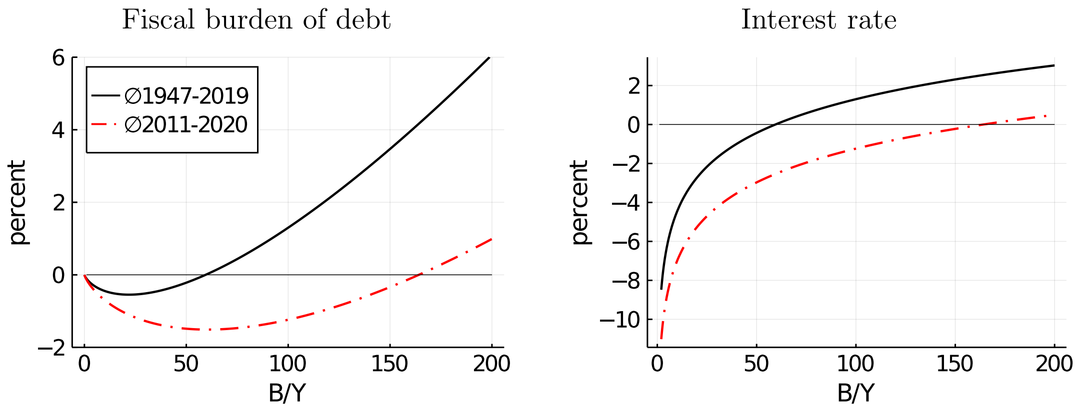
While the crowding out of capital is smaller in HANK-2 compared to HANK-1, the crowding out of private liquidity is stronger, and it is also two times stronger than in the short-run exercise of Section 5. IOUs fall by 8.5 percent in HANK-2 and 2 percent in HANK-1. However, since IOUs make up only a fifth of total liquid assets (in HANK-2), the total supply of liquid assets (public plus private debt) still increases by 4.8 percentage points of annual output. Taking also into account the crowding out of capital, the total amount of assets still increases by 4.2 percentage points. In contrast, when capital is liquid (HANK-1), the total amount of assets in the economy increases by much less. The increase is only 2.3 percentage points relative to annual output because the 6 percentage points increase in public debt crowds out 3.4 percentage points of capital and 0.3 percentage points of private debt.

The increase in interest rates implies that the government needs to pay more on its outstanding debt and, therefore, the transfers in the future need to fall. In HANK-1, this channel is muted because interest rates increase less. There, however, the tax base becomes smaller as capital and, hence, output declines. For this reason, in both incomplete markets models, transfers become negative as debt increases in the long-run even though the steady-state return on bonds is zero.

6.2 The Fiscal Implications of Public Debt

As alluded to above, the substantial elasticity of the real interest rate to persistent public debt movements has important fiscal implications. The fiscal burden of rolling over public debt is $\mathcal{R}(B)B$, where $\mathcal{R} = R^b_t/\pi_t - \log(Y_{t+1}/Y_t)$ is the differential of the real rate on public debt and output growth. Since the interest-growth difference is an increasing function of public debt, the fiscal burden of debt increases by more than the (marginal) interest rate upon an increase of debt. The government also has to pay a higher interest rate on all debt that is already outstanding. Expressed differently, like a monopolist for the provision of

Figure 9: Fiscal Implications of Public Debt



Notes: Left panel: Interest-burden-to-GDP ratio vs. public-debt-to-GDP ratio (both in annual percent). Right panel: Interest rate-growth differential vs. public-debt-to-GDP ratio (both in annual percent). Black solid line: US data from 1947 to 2019; red dashed line: US data from 2011 to 2020.

aggregate liquidity, the government is not a price taker in our closed-economy model.

Log-linearization yields an interest-growth differential with a constant semi-elasticity,

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

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

$$\frac{\partial(\mathcal{R}(B)B)}{\partial B} = \mathcal{R}(B) + \eta_B \approx \mathcal{R}(\bar{B}) + \eta_B \left[\ln\left(\frac{B}{\bar{B}}\right) + 1\right]. \tag{24}$$

Our estimate of the semi-elasticity η_B is 2.5 percent, which is then also the marginal fiscal burden from higher public debt even though in steady state the interest-growth differential is $\mathcal{R}(\bar{B}) = 0.0$ percent. This burden increases with higher debt.

Vice versa, (24) implies that, if there is a positive level of debt at which the interest-growth differential is zero, the fiscal burden of public debt becomes a fiscal gain for some positive debt level. In a sense, there is a Laffer curve of debt. At zero debt the cost/gain from rolling over debt is null at any finite interest-growth differential. It is also null when the interest-growth differential is zero. In-between the two debt levels, the fiscal burden of debt is negative, i.e., the government generates revenues from rolling over debt. Importantly, this implies that there is an internal fiscal optimum. Lowering public debt beyond a certain positive threshold reduces the revenues from rolling over the debt. A lower debt level than this revenue maximizing one seems therefore both fiscally as well as from a liquidity-provision point of view inefficient.

Our log-linear approximation (24) equips us with a simple formula for this revenue-maximizing level of debt, B_t^* at time t. Replacing $\bar{B}$ and $\mathcal{R}(\bar{B})$ by time-t values, we obtain

$$\ln B_t^* = \ln B_t - 1 - \tfrac{\mathcal{R}_t}{\eta_B}. \tag{25}$$

Figure 9 summarizes this graphically. It shows the fiscal burden of public debt, $\mathcal{R}(B)B/Y$, left panel, and the interest-growth differential, $\mathcal{R}(B)$, right panel, both plotted against the level of public debt, B/Y (all 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 of the fiscal burden of debt with zero: at $B/Y = 0$ and at $B/Y = 59$ percent. The second point corresponds to our steady state, which has at zero interest-growth differential a zero fiscal burden of debt. A higher debt-to-GDP ratio increases the interest rate burden, while a lower ratio decreases the burden at first. As interest rates become negative, the government generates revenues from rolling over debt, but as debt vanishes so do these revenues from rolling over.

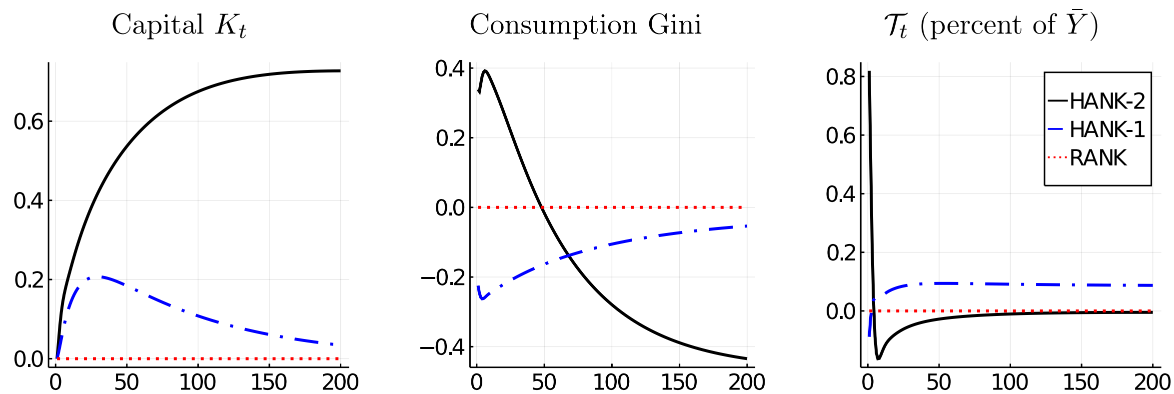
For the US over the last seven decades, this revenue-maximizing debt level has been at 21 percent of GDP on average (black solid line, in Figure 9). Any target below this level provides less liquidity to the private sector and less revenues to the government. If we apply the formula to the most recent decade (2011-2020, red dashed line), however, the results look very different even though it includes the worst recession after the second world war. For this period, the US interest-growth differential is $\mathcal{R} = -1$ percent and the average debt-to-GDP ratio is roughly 110 percent.[29] This implies that any debt-to-GDP ratio below 60 percent leads 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 $\ln B_t^0 = \ln B_t - \frac{R_t}{\eta_B}$. Hence, to achieve an interest rate equal to the growth rate, US public debt needs to be roughly 160 percent of GDP today.

6.3 Debt-Financed Investment Programs

Several governments, including the current US administration, are discussing large-scale investment programs both in terms of private and public capital. Some European commentators have suggested building up a well-diversified sovereign wealth fund (SWF) that

[29]We take the 10-year bond yield minus nominal GDP growth. In terms of the model, a risk premium shock, A_t, for example, might have lowered the interest rate.

Figure 10: Response to an Increase in the Debt Target to Finance a Sovereign Wealth Fund



Notes: Impulse responses to a 10 percent debt-target shock to finance a sovereign wealth fund buying private capital. Non-distortionary transfers adjust to clear the government's budget if necessary. Black solid line: Baseline model, HANK-2. Blue dash-dotted: Liquid-capital model, HANK-1. Red-dotted line: Complete-markets model, RANK. Y-axis: Percent deviation from steady state, except for $\mathcal{T}_t/\bar{Y}$ that is in annualized percentage points. X-axis: Quarters.

buys private capital.[30] At a first glance, the return difference of 1.5 percent (annualized) between public debt and capital in our model seems to be an argument in favor of such programs.[31] However, the marginal fiscal burden is equal to the estimated semi-elasticity of 2.5 percent and thus larger than the liquidity premium of 1.5 percent, which suggests that the government would need to raise revenues to finance such a fund.

However, such a simple comparison of η_B and the liquidity premium might be misleading because the fund increases capital. This in turn improves government tax revenues by raising output. Figure 10 shows that an SWF that buys capital by issuing public debt is almost self-financing in our estimated model. It can increase the capital stock of the economy even in the long run and thereby wages. It also increases bond yields and lowers the liquidity premium. For this reason, it reduces both consumption and wealth inequality. The latter even more so than just an increase in public debt already does because now also capital returns fall. With liquid capital, i.e., in HANK-1, the crowding out works against the capital increase through the SWF. In fact, the fund has no effect on capital or output in the long-run because, eventually, it is irrelevant to the households whether they hold capital directly or indirectly through government bonds (see also the irrelevance in RANK).

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

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

7 Conclusion

We highlight the importance of the liquidity channel of public debt in understanding the effects of fiscal policy. We provide novel empirical evidence that fiscal expansions that result in higher public debt lower liquidity premia. We replicate this evidence in an estimated monetary business cycle model with heterogeneous agents, incomplete markets, and portfolio choice. We then use this model as a framework to quantify the liquidity channel of fiscal policy. We find the liquidity channel important in the transmission of transitory and permanent changes in fiscal policy. In the short run, fiscal multipliers are larger because there is less crowding out of capital once the liquidity role of public debt is taken into account. In the long run, and in line with the theoretical argument in Woodford (1990), we find very little impact on the private capital stock as well. However, as a fiscal expansion increases the interest rate on existing public debt, it has a strong impact on the government's budget.

In turn, it is insufficient to only look at current bond yields to assess the fiscal consequences of increasing public debt. We provide a simple formula to approximate the marginal fiscal burden of debt and to calculate both a revenue maximizing level of public debt and the level of debt that equates the rates of interest and growth. We exemplify the fiscal cost of public debt in excess of the current interest rate by looking at an increase in public debt that either finances a transfer program or finances a sovereign wealth fund. Even though the returns this fund makes on its investment in capital are higher than its financing cost, the government's budget in total worsens by the introduction of such a fund. The fiscal cost is lower in the second scenario because the capital stock increases. What is more, an increase in public debt by compressing the liquidity premium lowers wealth inequality.

Our analysis restricts itself to the positive assessment of public debt expansions. The importance of the liquidity channel therein, of the return differential between more and less liquid assets and the limited crowding out of capital, calls for a reassessment of the welfare consequences of public debt. Of course, one needs to take into account that the model economy we look at is a closed economy. For many economies smaller than the US, the estimated elasticity of the interest rate on bonds is potentially too high. We leave this open economy perspective and the more normative question of optimal public debt policy for future work.

References

Acikgöz, Ö., Hagedorn, M., Holter, H., and Wang, Y. (2018). The optimum quantity of capital and debt. *CEPR Discussion Paper*, No. DP12952.

Aiyagari, S. R. (1994). Uninsured idiosyncratic risk and aggregate saving. *The Quarterly Journal of Economics*, 109(3):659–684.

Aiyagari, S. R. and McGrattan, E. R. (1998). The optimum quantity of debt. *Journal of Monetary Economics*, 42(3):447–469.

An, S. and Schorfheide, F. (2007). Bayesian analysis of DSGE models. *Econometric Reviews*, 26(2-4):113–172.

Angeletos, G.-M., Collard, F., and Dellas, H. (2016). Public debt as private liquidity: Optimal policy. NBER Working Papers 22794.

Auclert, A., Bardóczy, B., and Rognlie, M. (2021). MPCs, MPEs, and multipliers: A trilemma for New Keynesian models. *Review of Economics and Statistics*, forthcoming.

Auclert, A., Rognlie, M., and Straub, L. (2018). The intertemporal Keynesian Cross. NBER Working Papers 25020.

Auclert, A., Rognlie, M., and Straub, L. (2020). Micro jumps, macro humps: Monetary policy and business cycles in an estimated HANK model. NBER Working Papers 26647.

Azzimonti, M. and Yared, P. (2019). The optimal public and private provision of safe assets. *Journal of Monetary Economics*, 102(C):126–144.

Bassetto, M. and Cui, W. (2018). The fiscal theory of the price level in a world of low interest rates. *Journal of Economic Dynamics and Control*, 89:5–22. Fed St. Louis-JEDC-SCG-SNB-UniBern Conference, titled: "Fiscal and Monetary Policies".

Bayer, C., Born, B., and Luetticke, R. (2020). Shocks, frictions, and inequality in US business cycles. *CEPR Discussion Paper No. DP14364*.

Bayer, C. and Luetticke, R. (2020). Solving heterogeneous agent models in discrete time with many idiosyncratic states by perturbation methods. *Quantitative Economics*, 11:1253–1288.

Bayer, C., Luetticke, R., Pham-Dao, L., and Tjaden, V. (2019). Precautionary savings, illiquid assets, and the aggregate consequences of shocks to household income risk. *Econometrica*, 87(1):255–290.

Bhandari, A., Evans, D., Golosov, M., and Sargent, T. J. (2017). Public debt in economies with heterogeneous agents. *Journal of Monetary Economics*, 91:39–51.

Blanchard, O. J. (2019). Public debt: Fiscal and welfare costs in a time of low interest rates. Working Paper 19-4, Peterson Institute.

Blanchard, O. J. and Perotti, R. (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *Quarterly Journal of Economics*, 117(4):1329–1368.

Born, B. and Müller, G. J. (2012). Government spending shocks in quarterly and annual time series. *Journal of Money, Credit and Banking*, 44(2–3):507–517.

Born, B. and Pfeifer, J. (2014). Policy risk and the business cycle. *Journal of Monetary Economics*, 68:68–85.

Bredemeier, C., Juessen, F., and Schabert, A. (2021). Why are fiscal multipliers moderate even under monetary accomodation. Mimeo, University of Cologne.

Broer, T., Hansen, N.-J. H., Krusell, P., and Öberg, E. (2019). The New Keynesian transmission mechanism: A heterogenous-agent perspective. *The Review of Economic Studies*, 87(1):77–101.

Brook, A.-M. (2003). Recent and prospective trends in real long-term interest rates: Fiscal policy and other drivers. Technical Report 367, OECD Economics Department Working Papers.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12(3):383–398.

Castaneda, A., Diaz-Gimenez, J., and Rios-Rull, J.-V. (1998). Exploring the income distribution business cycle dynamics. *Journal of Monetary Economics*, 42(1):93 – 130.

Challe, E. and Ragot, X. (2011). Fiscal policy in a tractable liquidity-constrained economy. *The Economic Journal*, 121(551):273–317.

Challe, E. and Ragot, X. (2015). Precautionary saving over the business cycle. *The Economic Journal*, 126(590):135–164.

Chetty, R., Guren, A., Manoli, D., and Weber, A. (2011). Are micro and macro labor supply elasticities consistent? A review of evidence on the intensive and extensive margins. *The American Economic Review*, 101(3):471–475.

Cui, W. (2016). Monetary–fiscal interactions with endogenous liquidity frictions. *European Economic Review*, 87:1–25.

Den Haan, W. J., Rendahl, P., and Riegler, M. (2017). Unemployment (fears) and deflationary spirals. *Journal of the European Economic Association*, 16(5):1281–1349.

Driscoll, J. C. and Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, 80(4):549–560.

Durbin, J. and Koopman, S. J. (2012). *Time Series Analysis by State Space Methods*. Oxford University Press.

Engen, E. M. and Hubbard, R. G. (2004). Federal government debt and interest rates. In *NBER Macroeconomics Annual*, volume 19, pages 83–160.

Fernández-Villaverde, J. (2010). The econometrics of DSGE models. *SERIEs*, 1(1):3–49.

Floden, M. (2001). The effectiveness of government debt and transfers as insurance. *Journal of Monetary Economics*, 48(1):81–108.

Fratzscher, M. (2019). Ein Deutschlandfonds statt Aktien für Arme. *Die ZEIT*.

Gelman, A. and Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Statistical Science*, 7(4):457–472.

Geweke, J. (1992). Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. In Bernardo, J. M., Berger, J. O., Dawid, A. P., and Smith, A. F. M., editors, *Bayesian Statistics*, volume 4, pages 641–649. Clarendon Press, Oxford.

Gomme, P., Ravikumar, B., and Rupert, P. (2011). The return to capital and the business cycle. *Review of Economic Dynamics*, 14(2):262–278.

Gornemann, N., Kuester, K., and Nakajima, M. (2012). Monetary policy with heterogeneous agents. *Philadelphia Fed Working Paper 12-21*.

Gottardi, P., Kajii, A., and Nakajima, T. (2015). Optimal taxation and debt with uninsurable risks to human capital accumulation. *American Economic Review*, 105(11):3443–70.

Greenwood, J., Hercowitz, Z., and Huffman, G. W. (1988). Investment, capacity utilization, and the real business cycle. *American Economic Review*, 78(3):402–417.

Gros, D. and Mayer, T. (2012). A German sovereign wealth fund to save the euro. *CEPR VOXEU*.

Guerrieri, V. and Lorenzoni, G. (2017). Credit crises, precautionary savings, and the liquidity trap. *The Quarterly Journal of Economics*, 132(3):1427–1467.

Guvenen, F., Kaplan, G., and Song, J. (2014). How risky are recessions for top earners? *The American Economic Review*, 104(5):148–153.

Hagedorn, M., Manovskii, I., and Mitman, K. (2019). The fiscal multiplier. *NBER Working Paper*, No. 25571.

Heathcote, J. (2005). Fiscal policy with heterogeneous agents and incomplete markets. *The Review of Economic Studies*, 72(1):161–188.

Huggett, M. (1993). The risk-free rate in heterogeneous-agent incomplete-insurance economies. *Journal of Economic Dynamics and Control*, 17(5-6):953–969.

Jaimovich, N. and Rebelo, S. (2009). Can news about the future drive the business cycle? *American Economic Review*, 99(4):1097–1118.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, 95(1):161–182.

Jordà, Ò., Knoll, K., Kuvshinov, D., Schularick, M., and Taylor, A. M. (2019). The rate of return on everything, 1870–2015. *The Quarterly Journal of Economics*, 134(3):1225–1298.

Jordà, Ò., Schularick, M., and Taylor, A. M. (2017). Macrofinancial history and the new business cycle facts. *NBER Macroeconomics Annual*, 31(1):213–263.

Justiniano, A., Primiceri, G. E., and Tambalotti, A. (2010). Investment shocks and business cycles. *Journal of Monetary Economics*, 57(2):132 – 145.

Justiniano, A., Primiceri, G. E., and Tambalotti, A. (2011). Investment shocks and the relative price of investment. *Review of Economic Dynamics*, 14(1):101–121.

Kaplan, G., Moll, B., and Violante, G. L. (2018). Monetary policy according to HANK. *American Economic Review*, 108(3):697–743.

King, R. G., Plosser, C. I., and Rebelo, S. T. (1988). Production, growth and business cycles: I. The basic neoclassical model. *Journal of Monetary Economics*, 21(2):195 – 232.

Kinoshita, N. (2006). Government debt and long-term interest rates. IMF Working Paper WP/06/63.

Koopman, S. J. and Durbin, J. (2000). Fast filtering and smoothing for multivariate state space models. *Journal of Time Series Analysis*, 21(3):281–296.

Krishnamurthy, A. and Vissing-Jorgensen, A. (2012). The aggregate demand for Treasury debt. *Journal of Political Economy*, 120(2):233–267.

Laubach, T. (2009). New evidence on the interest rate effects of budget deficits and debt. *Journal of the European Economic Association*, 7(4):858–885.

Luetticke, R. (2021). Transmission of monetary policy with heterogeneity in household portfolios. *American Economic Journal: Macroeconomics*, 13(2):1–25.

McKay, A., Nakamura, E., and Steinsson, J. (2016). The power of forward guidance revisited. *The American Economic Review*, 106(10):3133–3158.

Mertens, K. and Ravn, M. O. (2012). Empirical evidence on the aggregate effects of anticipated and unanticipated US tax policy shocks. *American Economic Journal: Economic Policy*, 4(2):145–81.

Newey, W. K. and West, K. D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3):703–708.

Ramey, V. A. (2011). Identifying government spending shocks: It's all in the timing. *Quarterly Journal of Economics*, 126(1):1–50.

Ramey, V. A. (2016). Macroeconomic shocks and their propagation. *Handbook of Macroeconomics*, 2:71–162.

Reis, R. (2021). The constraint on public debt when r$<$ g but g$<$ m. *CEPR Discussion Paper*, No. DP15950.

Röhrs, S. and Winter, C. (2017). Reducing government debt in the presence of inequality. *Journal of Economic Dynamics and Control*, 82:1–20.

Romer, C. D. and Romer, D. H. (2010). The macroeconomic effects of tax changes: estimates based on a new measure of fiscal shocks. *American Economic Review*, 100(3):763–801.

Schmitt-Grohé, S. and Uribe, M. (2012). What's news in business cycles. *Econometrica*, 80(6):2733–2764.

Shiller, R. J. (2015). *Irrational exuberance: Revised and expanded third edition*. Princeton university press.

Smets, F. and Wouters, R. (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review*, 97(3):586–606.

Sterk, V. and Tenreyro, S. (2018). The transmission of monetary policy through redistributions and durable purchases. *Journal of Monetary Economics*, 99:124–137.

Storesletten, K., Telmer, C. I., and Yaron, A. (2004). Cyclical dynamics in idiosyncratic labor market risk. *Journal of Political Economy*, 112(3):695–717.

Summers, L. H. and Rachel, L. (2019). On falling neutral real rates, fiscal policy and the risk of secular stagnation. In *Brookings Papers on Economic Activity BPEA Conference Drafts, March 7-8*.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester Conference Series on Public Policy*, volume 39, pages 195–214. Elsevier.

Wong, A. (2019). Refinancing and the transmission of monetary policy to consumption. Mimeo, Princeton University.

Woodford, M. (1990). Public debt as private liquidity. *American Economic Review*, 80(2):382–388.

Wu, J. C. and Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking*, 48(2-3):253–291.

A Data

A.1 Data for Local Projections

Unless otherwise noted, all series are available at quarterly frequency from 1947Q1 to 2019Q4 from the St.Louis FED - FRED database (mnemonics in parentheses).[32] Corresponding series for the annual country panel (1947–2016) are taken from the *Jordà-Schularick-Taylor Macrohistory Database* (Jordà et al., 2017).[33]

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).

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

Nominal interest rate. Quarterly average of the effective federal funds rate (FED-FUNDS). From 2009Q1 till 2015Q4 we use the Wu and Xia (2016) shadow federal funds rate. Before 1954Q3, we use the 3-month t-bill rate (TB3MS).

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).

Return to capital. After-tax returns to all capital taken from Gomme et al. (2011) and available till 2015Q4.

Return to housing. Annual return to housing from Jordà et al. (2019), available at annual frequency until 2016 and interpolated to quarterly frequency via cubic splines.

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

Liquidity premium on corporate bonds. Convenience yield: Spread between Moody's Aaa-rated corporate bond yield and the long-term rate on government bonds.

[32]In the quarterly regressions, we use only data until 2015Q4 to have a consistent sample across all dependent variables. The constraining factor is the availability of some of the liquidity premia after 2015.

[33]Countries covered are Australia, Belgium, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Italy, Japan, Netherlands, Norway, Portugal, Sweden, and the USA.

Liquidity premium on money. Spread between the long-term rate on government bonds and the (shadow) federal funds rate.

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

Military spending shocks. Ramey (2011)-series of narratively-identified defense news shocks. Series available from 1947Q1 to 2015Q4 on Valerie Ramey's homepage (`https://econweb.ucsd.edu/~vramey/research.html`).

Tax shocks. Romer and Romer (2010)-series of narratively-identified exogenous tax changes which are measured as total revenue impact as a ratio of GDP in the previous quarter. We focus on those classified as unanticipated by Mertens and Ravn (2012). Series available from 1948Q1 to 2007Q3 on Karel Mertens' homepage (`https://karelmertens.com/research/`).

Tax revenues. Federal government current tax receipts (W006RC1Q027SBEA) divided by the GDP deflator (GDPDEF).

A.2 Data for Calibration

Mean illiquid assets. Private fixed assets (NIPA table 1.1) over quarterly GDP, averaged over 1947-2019.

Public liquidity. Gross federal debt (MVGFD027MNFRBDAL) over quarterly GDP, averaged over 1947-2019.

Private liquidity. Private unsecured credit (HCCSDODNS) from the flow of funds over quarterly GDP, averaged over 1947-2019.

Average top 10 percent share of wealth. Source is the World Inequality Database (1947-2019).

A.3 Data for Model Estimation

Unless otherwise noted, all series are available at quarterly frequency from 1947Q1 to 2019Q4 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) divided by the GDP deflator (GDPDEF) and the civilian noninstitutional population (CNP16OV).

Consumption. Sum of personal consumption expenditures for nondurable goods (PCND), durable goods (PCDG) and services (PCESV) 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).

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

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.

Liquidity premium. After-tax returns to all capital taken from Gomme et al. (2011) and available till 2015Q4 minus 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).

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

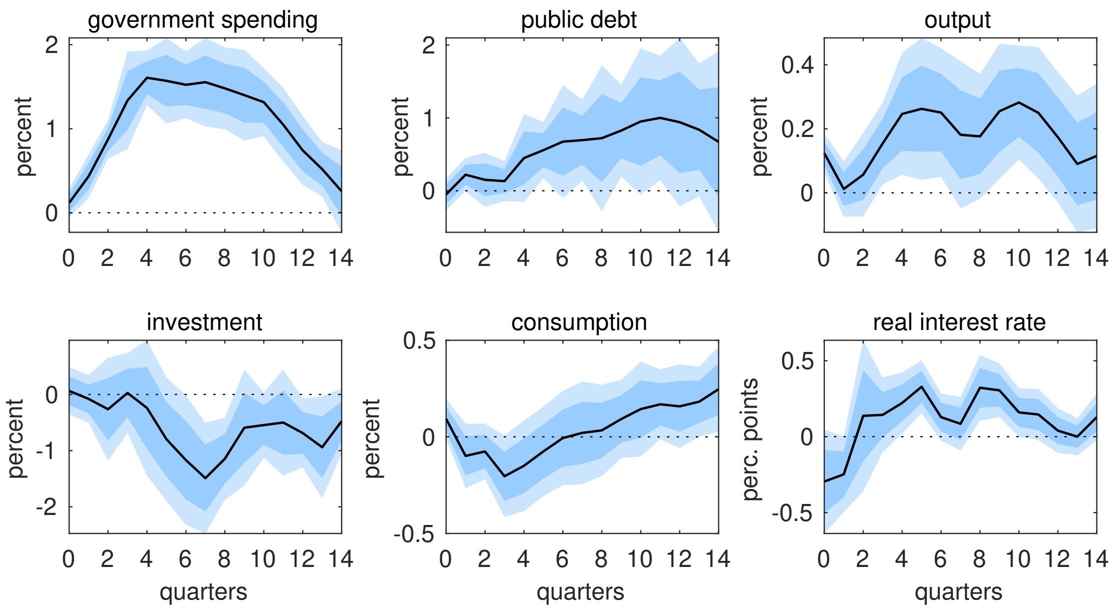
$$OBS_t = \begin{bmatrix} \Delta \log (Y_t) \\ \Delta \log (C_t) \\ \Delta \log (I_t) \\ \Delta \log \left(w_t^F\right) \\ \log (N_t) \\ \log \left(R_t^b\right) \\ \log (\pi_t) \\ \log (LP_t) \end{bmatrix} - \begin{bmatrix} \overline{\Delta \log (Y_t)} \\ \overline{\Delta \log (C_t)} \\ \overline{\Delta \log (I_t)} \\ \overline{\Delta \log \left(w_t^F\right)} \\ \overline{\log (N_t)} \\ \overline{\log \left(R_t^b\right)} \\ \overline{\log (\pi_t)} \\ \overline{\log (LP_t)} \end{bmatrix}$$

where Δ denotes the temporal difference operator, bars above variables denote time-series averages, and we allow for measurement error in LP_t (not depicted here).

B Additional Empirical Results

B.1 Aggregate Responses to Military News Shocks

Figure B.1: Empirical Responses to Military News Shocks: Aggregates



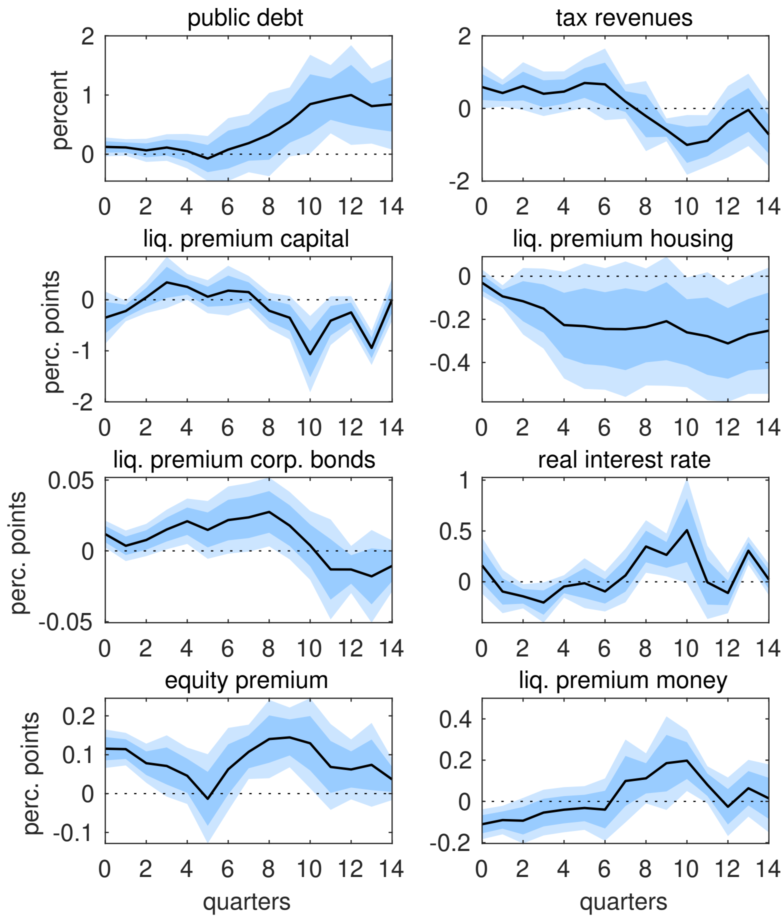
Notes: Impulse responses to a government spending shock. IRFs based on narrative identification via military news series from Ramey (2011); IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Newey and West (1987)-standard errors.

B.2 Tax Shocks

As discussed in Section 2, we are not interested in government spending shocks per se, but rather use them as a vehicle to study how an increase in public debt affects liquidity premia. Of course, increases in government spending are not the only causes for changes in the level of debt. In this appendix, we study whether increases in debt induced by tax changes show a similar link between debt and liquidity premia.

To this end, we employ the Romer and Romer (2010)-series of narratively-identified exogenous tax changes, focusing on those classified as unanticipated by Mertens and Ravn (2012), which is available from 1948 till 2007. We replace $\log g_t$ in Equation (1) by the exogenous tax shock measure and include as additional control lags of real federal tax revenues. Results are shown in Figure B.2, where we again scale the IRFs so that the maximum response of public debt is 1 percent. Public debt takes some time to build up but once it does, premia start to fall. So the negative link between public debt and liquidity premia also holds true if the increase in debt comes from the revenue and not the expenditure side of the government budget constraint. Focusing on the liquidity premium on housing, we see that the elasticity is quantitatively in the same ballpark.[34]

Figure B.2: Empirical Responses to Romer-Romer Narrative Tax Shocks



Notes: Impulse responses to a tax shock. IRFs based on Romer and Romer (2010)-narrative tax changes; IRFs scaled so that the maximum debt response is 1 percent. Light (dark) blue areas are 90 percent (68 percent) confidence bounds based on Newey and West (1987)-standard errors.

[34]Interestingly, a tax cut in our sample is self financing through an increase in economic activity and leads to a fall in debt. Given that we are only interested in the link between debt and liquidity premia, we flip all IRFs to facilitate comparison with the other experiments.

C 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 (2020). 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 80x80x11 points for liquid assets, illiquid assets, and income, respectively. The dimensionality-reduced number of states and controls in our system is roughly 1000.

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

$$\mathbb{E}_t F(x_t, X_t, x_{t+1}, X_{t+1}, \sigma \Sigma \epsilon_{t+1}), \tag{26}$$

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 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).

D Estimation Diagnostics

D.1 Convergence Checks

We estimate each model using five parallel RWMH chains starting from an over-dispersed target distribution after an extensive mode search. After burn-in, 150,000 draws from the posterior distribution are used to compute the posterior statistics. The acceptance rates across chains are between 20 and 30 percent. Here, we provide Gelman and Rubin (1992) and Geweke (1992) convergence statistics as well as traceplots of individual parameters for the baseline model. The Gelman and Rubin (1992) approach is based on comparing the estimated between-chains and within-chain variances for each model parameter. Large differences between these variances indicate non-convergence. Table D.1 reports the Gelman and Rubin potential scale reduction factor (PSRF) and its 97.5 percent quantile based on five chains. A common rule-of-thumb declares convergence if $PSRF < 1.1$. Geweke (1992) tests the equality of means of the first 10 percent of draws and the last 50 percent of draws (after burn-in). If the samples are drawn from the stationary distribution of the chain, the two means are equal and Geweke's statistic has an asymptotically standard normal distribution. Table D.2 reports the Geweke z-score statistic and the p-value for the pooled chains of each parameter. Taking the evidence from Geweke (1992), Gelman and Rubin (1992), and traceplot graphs together, we conclude that our chains have converged.

Table D.1: Gelman and Rubin (1992) Convergence Diagnostics

	HANK (base)		HANK (AR2)		HANK (RA2)		HANK (KPR)	
Parameter	PSRF	97.5%	PSRF	97.5%	PSRF	97.5%	PSRF	97.5%
δ_s	1.001	1.002	1.006	1.016	1.009	1.023	1.031	1.078
ϕ	1.005	1.012	1.001	1.004	1.002	1.004	1.010	1.023
κ	1.004	1.011	1.001	1.003	1.000	1.001	1.012	1.031
κ_w	1.002	1.005	1.002	1.006	1.002	1.005	1.005	1.011
ρ_A	1.004	1.009	1.002	1.006	1.003	1.008	1.007	1.016
σ_A	1.004	1.011	1.002	1.005	1.004	1.009	1.016	1.041
ρ_Z	1.001	1.003	1.002	1.005	1.001	1.002	1.002	1.005
σ_Z	1.002	1.005	1.001	1.004	1.001	1.003	1.002	1.006
ρ_Ψ	1.003	1.007	1.010	1.017	1.002	1.004	1.017	1.044
σ_Ψ	1.002	1.006	1.001	1.002	1.001	1.003	1.006	1.015
ρ_μ	1.003	1.008	1.003	1.007	1.003	1.007	1.005	1.011
σ_μ	1.003	1.006	1.002	1.006	1.002	1.006	1.004	1.011
$\rho_{\mu w}$	1.003	1.007	1.005	1.013	1.005	1.012	1.008	1.021
$\sigma_{\mu w}$	1.002	1.006	1.005	1.014	1.002	1.005	1.004	1.011
ρ_R	1.002	1.006	1.001	1.001	1.001	1.004	1.034	1.091
σ_R	1.001	1.002	1.002	1.005	1.001	1.002	1.017	1.046
θ_π	1.003	1.008	1.004	1.010	1.007	1.019	1.044	1.111
θ_Y	1.006	1.015	1.001	1.002	1.004	1.011	1.010	1.025
γ_B	1.002	1.005	1.008	1.020	1.015	1.037	1.011	1.028
γ_Y	1.001	1.002	1.001	1.001	1.017	1.044	1.047	1.121
ρ_G	1.003	1.007	1.004	1.012	1.005	1.012	1.019	1.051
γ_ϵ	1.005	1.014	1.003	1.007	1.007	1.020	1.064	1.159
σ_G	1.004	1.010	1.001	1.001	1.003	1.007	1.007	1.020
σ_{LP}^{me}	1.003	1.007	1.001	1.003	1.001	1.002	1.003	1.008

Note: Gelman and Rubin (1992) potential scale reduction factor (PSRF) and 97.5 percent quantile. A common rule-of-thumb declares convergence if $PSRF < 1.1$. For HANK (AR-2), $\rho_{G1} = \gamma_\epsilon - \rho_G$ and $\rho_{G2} = \rho_G$.

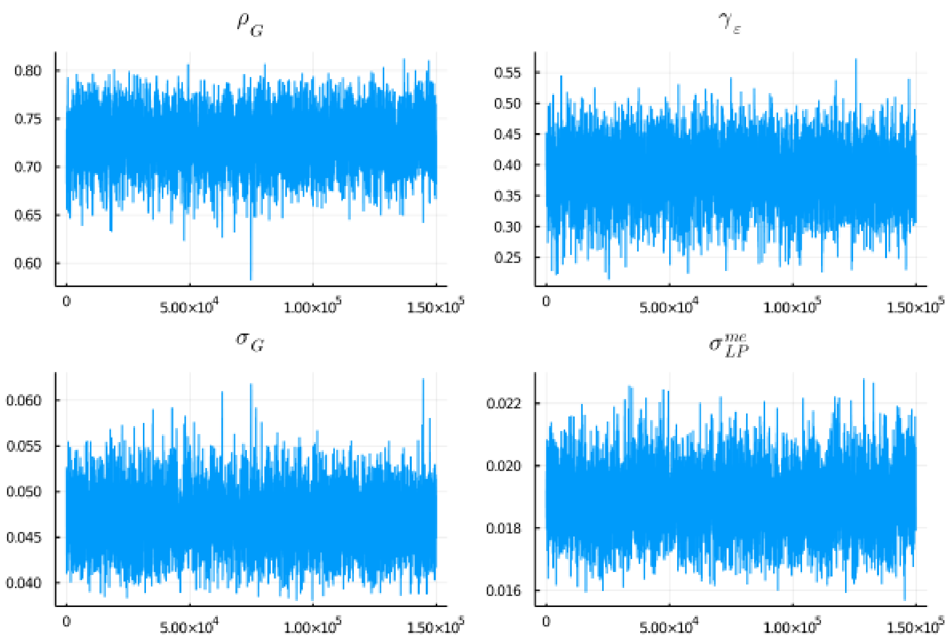
Table D.2: Geweke (1992) Convergence Diagnostics

	HANK (base)		HANK (AR2)		HANK (RA2)		HANK (KPR)	
Parameter	z-score	p-value	z-score	p-value	z-score	p-value	z-score	p-value
δ_s	0.366	0.714	0.613	0.540	-1.657	0.098	0.356	0.722
ϕ	-0.447	0.655	-0.311	0.756	-0.033	0.973	1.623	0.105
κ	0.770	0.441	0.184	0.854	-1.099	0.272	1.225	0.221
κ_w	-1.368	0.171	-1.859	0.063	-1.223	0.221	0.981	0.326
ρ_A	-0.147	0.883	1.349	0.177	0.752	0.452	-0.083	0.934
σ_A	-0.688	0.492	0.987	0.324	-0.50	0.617	1.884	0.060
ρ_Z	-0.235	0.814	0.854	0.393	0.522	0.602	-1.871	0.061
σ_Z	-0.368	0.713	-1.735	0.083	0.015	0.988	-0.493	0.622
ρ_Ψ	1.222	0.222	-0.501	0.617	0.394	0.694	-0.108	0.914
σ_Ψ	0.240	0.811	-0.265	0.791	-0.892	0.372	1.664	0.096
ρ_μ	0.464	0.643	1.941	0.052	0.517	0.605	1.616	0.106
σ_μ	-0.519	0.604	-1.05	0.294	0.329	0.742	-1.574	0.115
$\rho_{\mu w}$	-0.618	0.537	-2.412	0.016	-0.697	0.486	-0.17	0.865
$\sigma_{\mu w}$	1.201	0.230	2.233	0.026	1.477	0.140	-0.437	0.662
ρ_R	-0.098	0.922	1.287	0.198	-0.803	0.422	2.214	0.027
σ_R	0.003	0.998	-1.671	0.095	-0.313	0.754	-2.555	0.011
θ_π	0.012	0.991	1.184	0.236	-0.759	0.448	1.514	0.130
θ_Y	1.044	0.296	1.512	0.131	1.166	0.244	-0.362	0.717
γ_B	1.334	0.182	-0.318	0.750	2.121	0.034	-0.594	0.552
γ_Y	0.894	0.371	0.628	0.530	-0.473	0.636	1.305	0.192
ρ_G	-0.747	0.455	1.685	0.092	-0.013	0.990	0.998	0.318
γ_ϵ	0.090	0.929	0.363	0.716	0.391	0.696	0.607	0.544
σ_G	2.190	0.029	-0.791	0.429	-0.392	0.695	-1.483	0.138
σ_{LP}^{me}	1.273	0.203	0.241	0.810	0.270	0.787	1.514	0.130

Note: Geweke (1992) equality of means test of the first 10 percent vs. the last 50 percent of draws. Failure to reject the null of equal means indicates convergence. For HANK (AR-2), $\rho_{G1} = \gamma_\epsilon - \rho_G$ and $\rho_{G2} = \rho_G$.

Figure D.3: MCMC draws of baseline HANK-2 model

Figure D.4: MCMC draws of baseline HANK-2 model

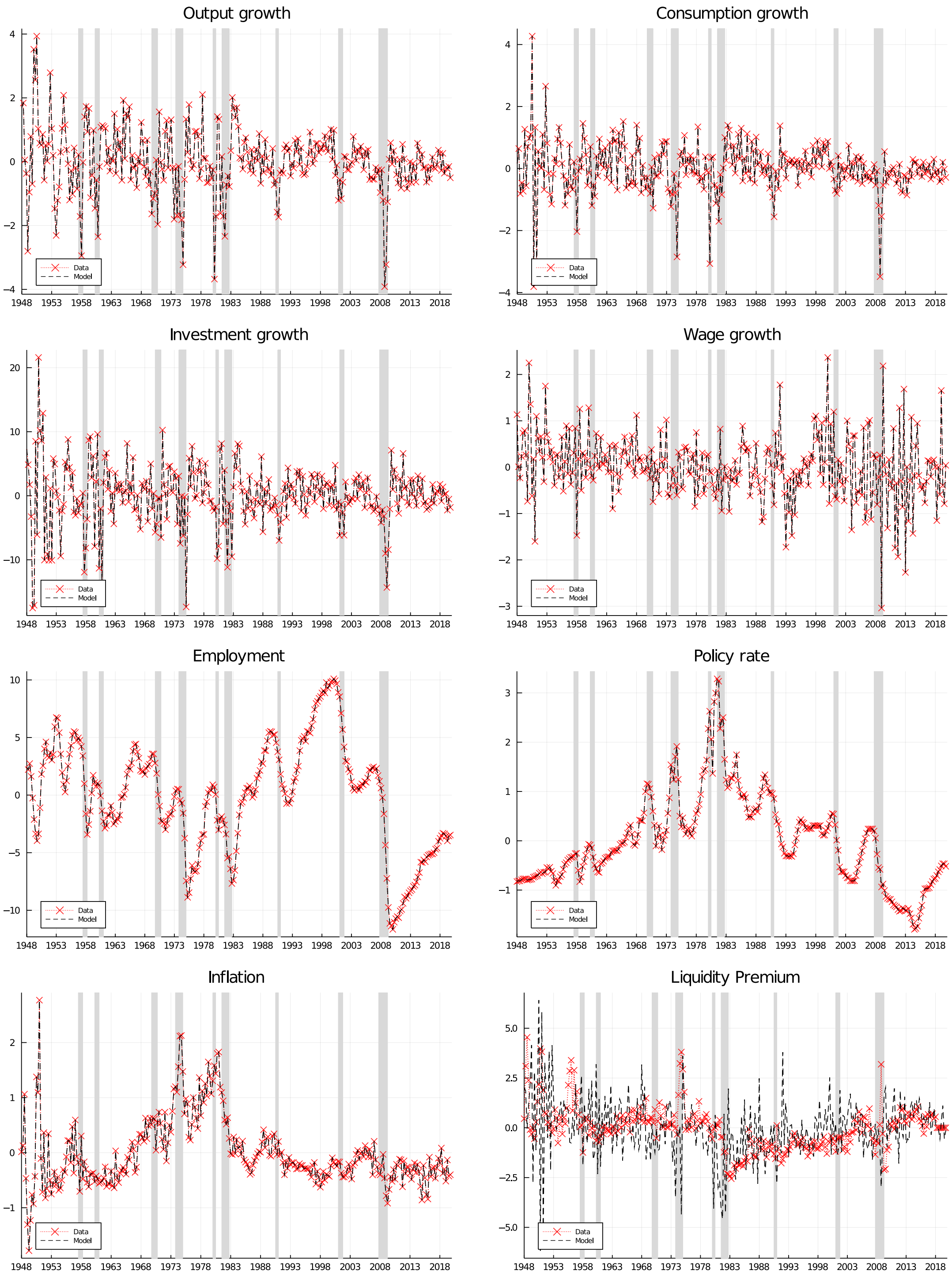


D.2 Observed Data vs. Model Predictions

Figure D.5 plots the observable time-series used in the estimation against the predictions from the estimated model obtained via the Kalman smoother. Our estimation includes seven aggregate shocks, the same as in Smets and Wouters (2007), and 7 standard observables included without measurement error, also as in Smets and Wouters (2007). In addition, we include as observable a proxy of the liquidity premium with measurement error. The estimation does a good job in replicating the medium- and long-run movements in the liquidity premium, while predicting a too high volatility in the short-run.

We also estimated the model without including the liquidity premium as observable and obtain very similar results.

Figure D.5: Estimation: Observables vs Model Predictions

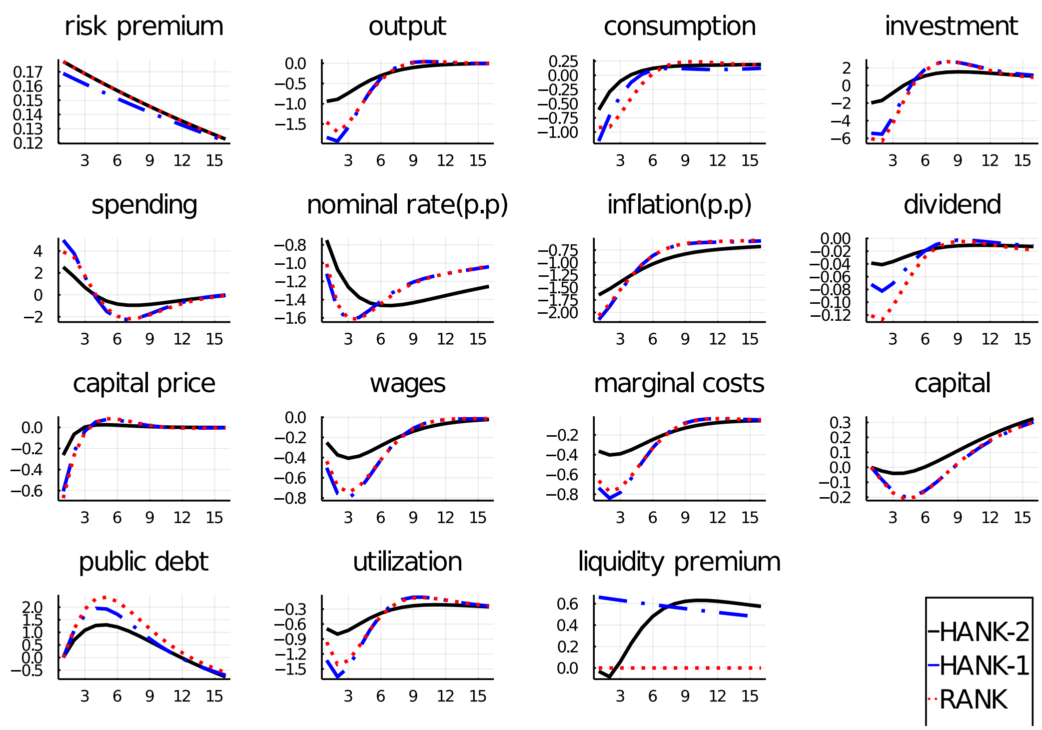


Notes: Observable time-series used in the estimation (red crosses) and Kalman smoother from the estimated model (black dashed line). Shaded areas correspond to NBER-dated recessions.

E Further Impulse Responses

Figures E.6, E.7, E.8, and E.9 plot impulse responses for all key variables for all seven shocks included in the estimation of the baseline model. We also include the impulse responses for the HANK-1 and RANK models under the same parameterization as HANK-2 for comparison.

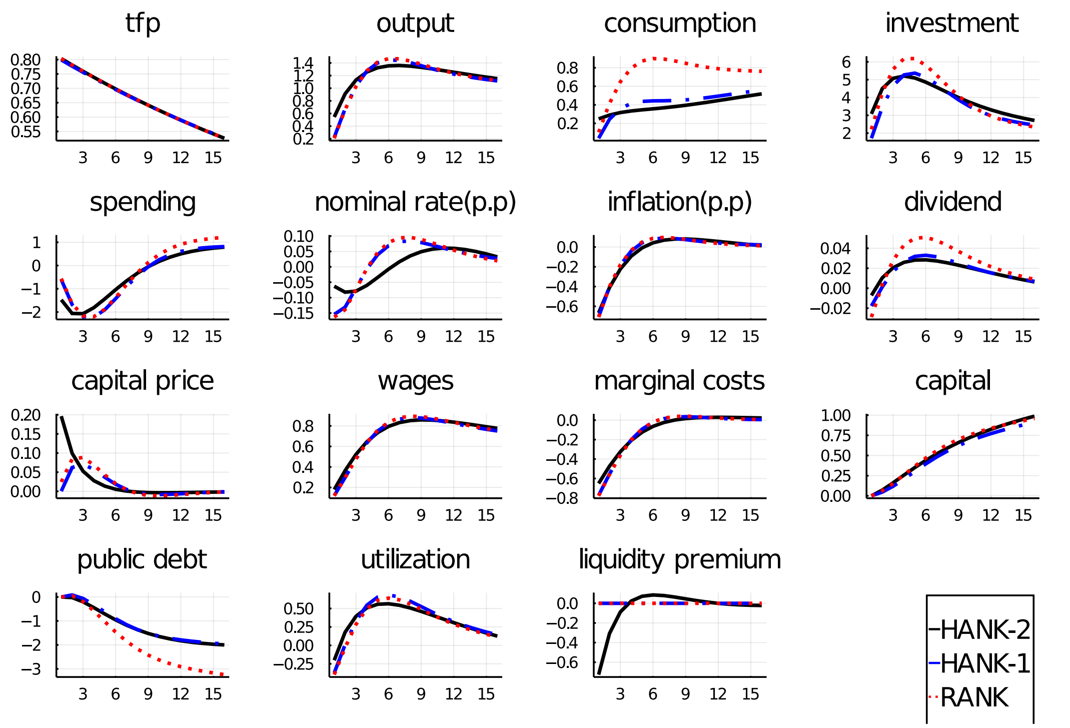
Figure E.6: Further Impulse Response Functions



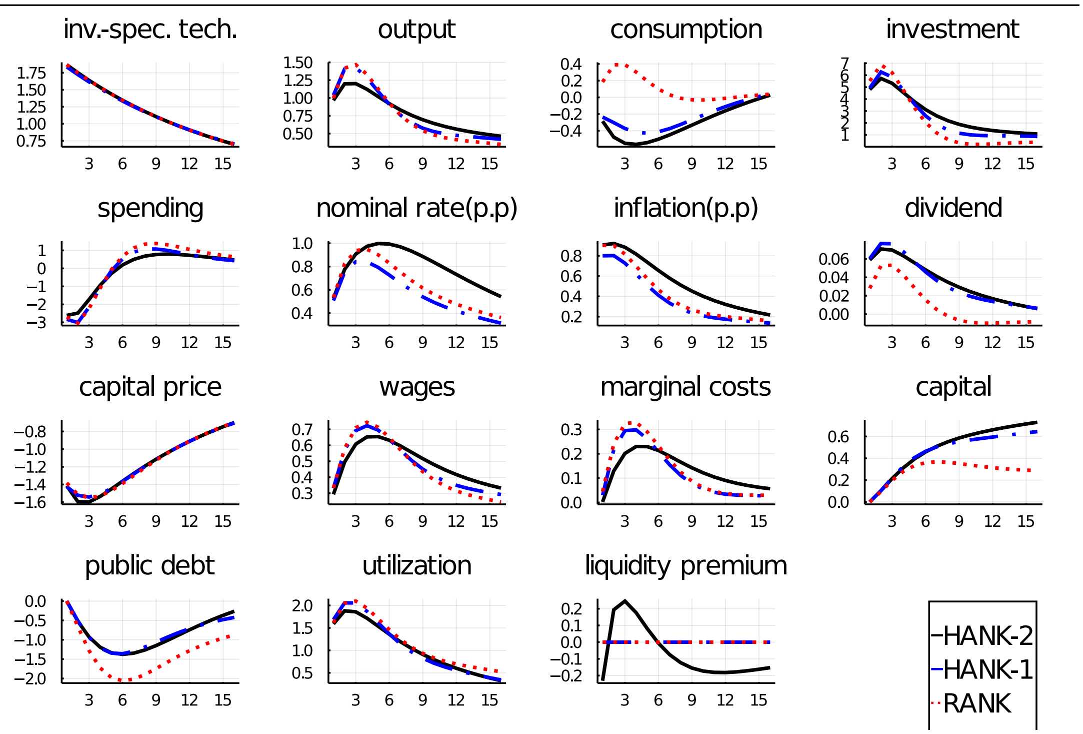
Risk premium shock

Notes: Impulse responses to the estimated risk premium shock in the HANK-2 model (black solid line). IRFs for HANK-1 (blue dash-dotted line) and RANK (red dotted line) under the same parameters as HANK-2.

Figure E.7: Further Impulse Response Functions



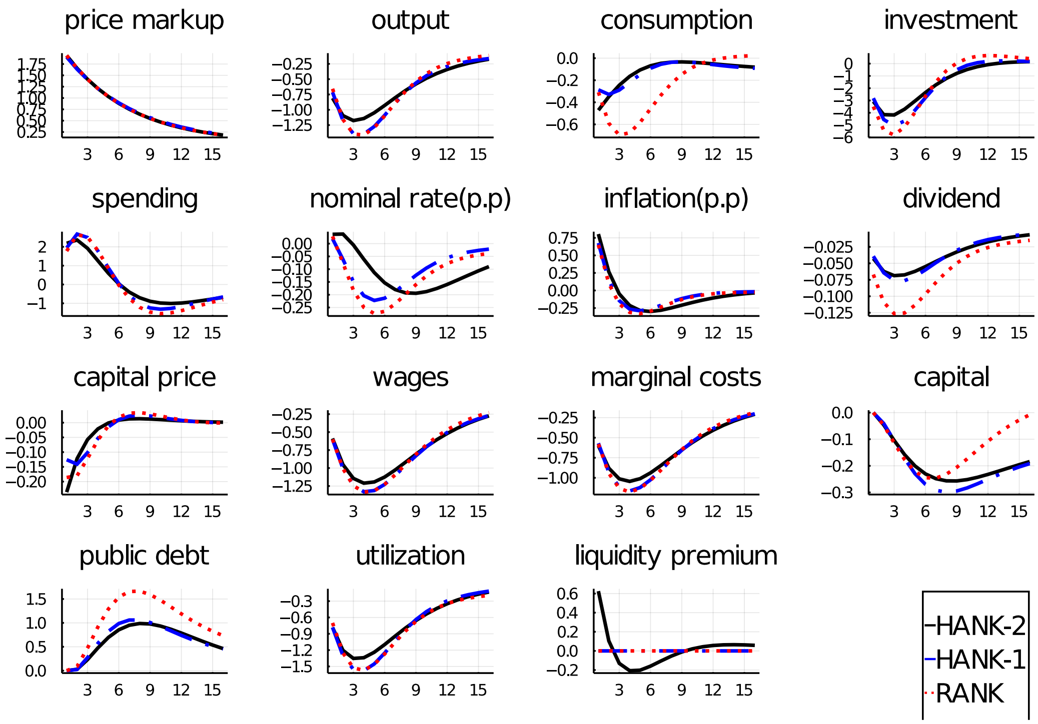
Total factor productivity shock



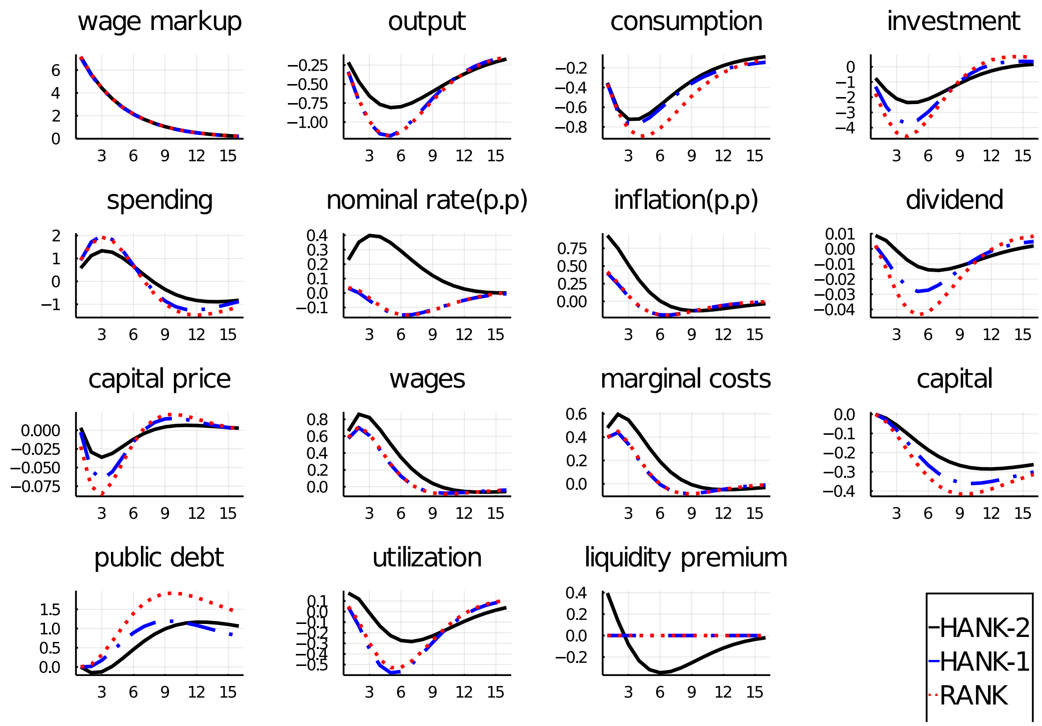
Marginal efficiency of investment shock

Notes: Impulse responses to the estimated TFP and MEI shocks in the HANK-2 model (black solid line). IRFs for HANK-1 (blue dash-dotted line) and RANK (red dotted line) under the same parameters as HANK-2.

Figure E.8: Further Impulse Response Functions



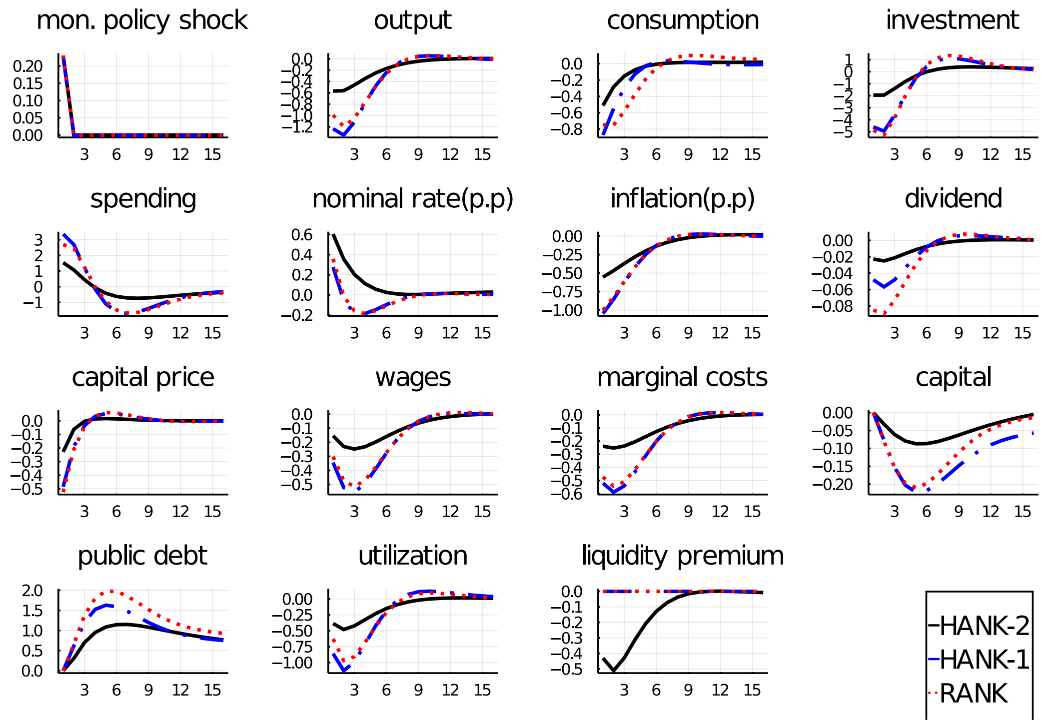
Price markup shock



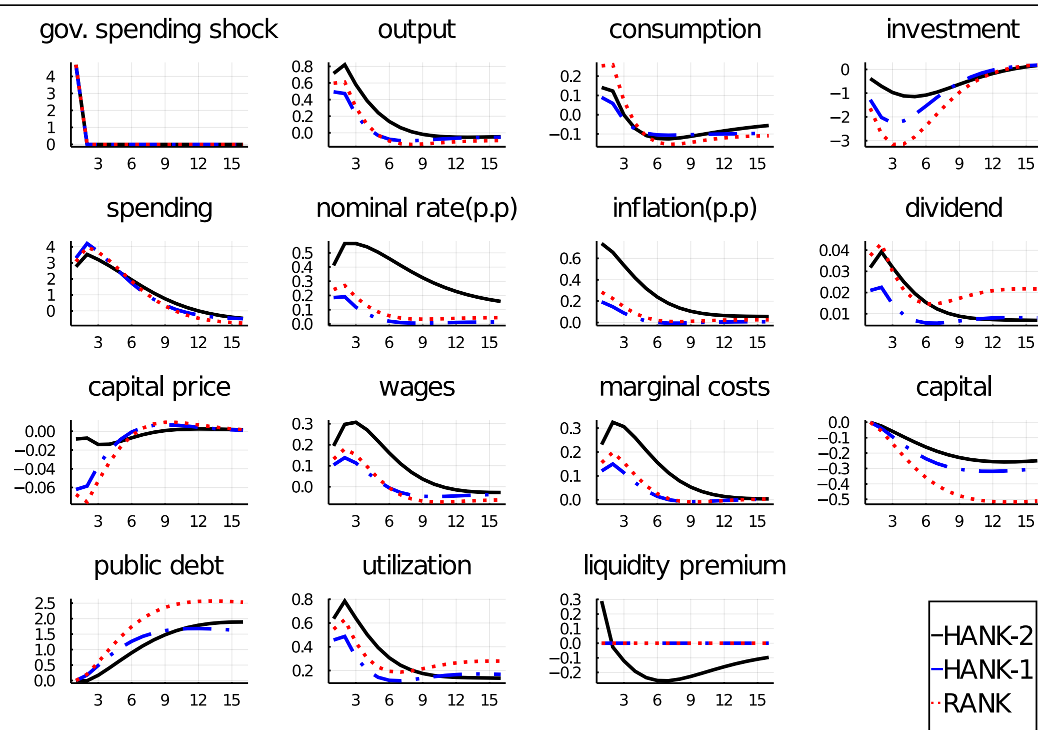
Wage markup shock

Notes: Impulse responses to the estimated price and wage markup shocks in the HANK-2 model (black solid line). IRFs for HANK-1 (blue dash-dotted line) and RANK (red dotted line) under the same parameters as HANK-2.

Figure E.9: Further Impulse Response Functions



Monetary shock



Government spending shock

Notes: Impulse responses to the estimated monetary and fiscal shocks in the HANK-2 model (black solid line). IRFs for HANK-1 (blue dash-dotted line) and RANK (red dotted line) under the same parameters as HANK-2.

F Robustness

Figure F.10 shows robustness of our main results to variations in the fiscal spending rule, risk aversion, and KPR preferences. For the latter two, we need to recalibrate the steady state to match the capital-to-output ratio, the public-debt-to-output ratio, the private-debt-to-output ratio, and the wealth held by the top 10 percent as reported in Table 2.

For GHH with risk aversion parameter of 2, this yields a discount factor of $\beta = 0.9905$, a portfolio adjustment probability of $\lambda = 4.8$ percent, a borrowing penalty of $\bar{R} = 1.0$ percent, and a probability of becoming an entrepreneur of 1/1700.

For KPR preferences, this yields a discount factor of $\beta = 0.9855$, a portfolio adjustment probability of $\lambda = 9$ percent, a borrowing penalty of $\bar{R} = 1.0$ percent, and a probability of becoming an entrepreneur of 1/1600. The felicity function u now reads:

$$u(c_{it}, n_{it}) = \frac{c_{it}^{1-\xi} - 1}{1-\xi} - \Gamma \frac{n_{it}^{1+\gamma} - 1}{1+\gamma},$$

with risk aversion parameter $\xi > 0$ and inverse Frisch elasticity $\gamma > 0$. The first-order condition for labor supply is:

$$n_{it} = \left[\frac{1}{\Gamma} u'(c)(1-\tau_t)(w h_{it}) \right]^{\left(\frac{1}{\gamma}\right)}.$$

Table F.3 shows the posterior distributions of the estimated parameters for all variants.

Table F.3: Prior and Posterior Distributions of Estimated Parameters

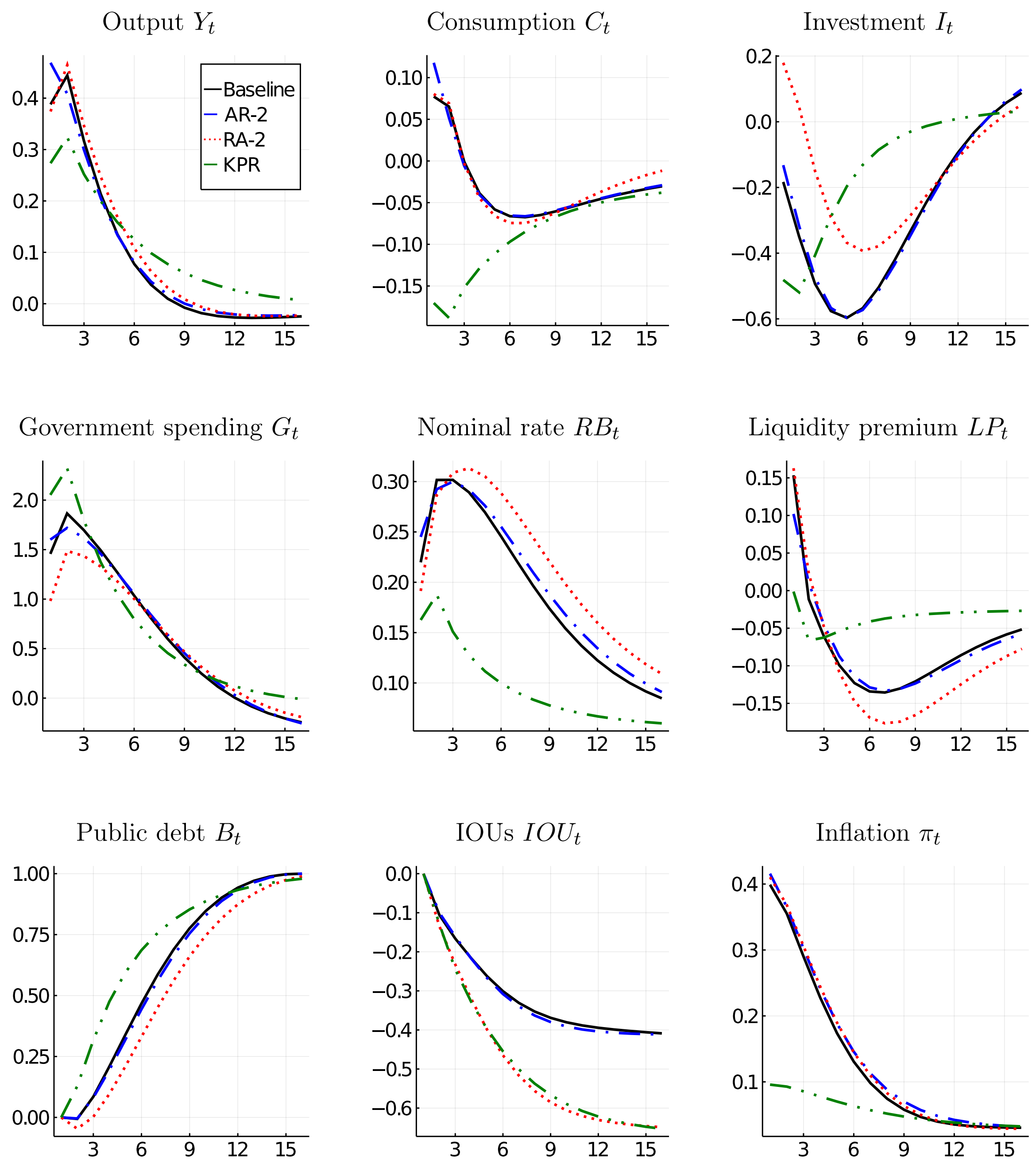
Parameter		Prior		Posterior			
	Distribution	Mean	Std. Dev.	HANK (base)	HANK (AR2)	HANK (RA2)	HANK (KPR)
				Frictions			
δ_s	Gamma	5.00	2.00	0.499	0.635	0.633	0.172
				(0.363, 0.645)	(0.628, 0.641)	(0.513, 0.764)	(0.140, 0.206)
ϕ	Gamma	4.00	2.00	0.117	0.114	0.043	0.054
				(0.090, 0.146)	(0.083, 0.148)	(0.026, 0.063)	(0.038, 0.074)
κ	Gamma	0.10	0.01	0.111	0.094	0.086	0.080
				(0.096, 0.128)	(0.080, 0.109)	(0.072, 0.101)	(0.070, 0.091)
κ_w	Gamma	0.10	0.01	0.099	0.109	0.099	0.119
				(0.082, 0.117)	(0.093, 0.127)	(0.083, 0.116)	(0.102, 0.137)
				Monetary policy rule			
ρ_R	Beta	0.50	0.20	0.820	0.839	0.846	0.746
				(0.800, 0.839)	(0.821, 0.856)	(0.826, 0.864)	(0.712, 0.776)
σ_R	Inv.-Gamma	0.10	2.00	0.230	0.248	0.223	0.298
				(0.213, 0.250)	(0.228, 0.270)	(0.207, 0.241)	(0.268, 0.332)

Table F.3: Prior and posterior distributions of estimated parameters - continued

Parameter	Prior			Posterior			
	Distribution	Mean	Std. Dev.	HANK (base)	HANK (AR2)	HANK (RA2)	HANK (KPR)
θ_π	Normal	1.70	0.30	1.704	2.365	1.914	1.905
				(1.567, 1.846)	(2.250, 2.482)	(1.774, 2.070)	(1.805, 2.017)
θ_Y	Normal	0.13	0.05	0.360	0.319	0.313	0.444
				(0.293, 0.428)	(0.254, 0.384)	(0.245, 0.379)	(0.409, 0.482)
				Spending rule			
γ_B	Normal	0.00	1.00	-0.335	-0.445	-0.301	-0.103
				(-0.493, -0.186)	(-0.516, -0.379)	(-0.383, -0.228)	(-0.131, -0.086)
γ_Y	Normal	0.00	1.00	-9.925	-11.343	-11.07	-9.581
				(-11.0, -8.902)	(-11.516, -11.172)	(-12.128, -10.041)	(-9.927, -9.212)
ρ_G	Beta	0.50	0.20	0.727	-0.239	0.712	0.695
				(0.686, 0.766)	(-0.263, -0.216)	(0.677, 0.744)	(0.660, 0.731)
γ_ϵ	Beta	0.50	0.20	0.385	0.816	0.494	0.366
				(0.312, 0.454)	(0.792, 0.839)	(0.429, 0.556)	(0.296, 0.432)
σ_G	Inv.-Gamma	0.10	2.00	4.689	5.100	4.351	5.349
				(4.245, 5.178)	(4.684, 5.553)	(3.948, 4.802)	(4.872, 5.856)
				Structural shocks			
ρ_A	Beta	0.50	0.20	0.976	0.956	0.979	0.975
				(0.961, 0.989)	(0.944, 0.966)	(0.969, 0.988)	(0.962, 0.988)
σ_A	Inv.-Gamma	0.10	2.00	0.177	0.321	0.216	0.145
				(0.148, 0.207)	(0.295, 0.348)	(0.190, 0.243)	(0.130, 0.162)
ρ_Z	Beta	0.50	0.20	0.972	0.986	0.992	0.885
				(0.963, 0.981)	(0.982, 0.990)	(0.987, 0.996)	(0.872, 0.897)
σ_Z	Inv.-Gamma	0.10	2.00	0.803	0.603	0.629	2.404
				(0.749, 0.862)	(0.558, 0.650)	(0.585, 0.676)	(2.223, 2.598)
ρ_Ψ	Beta	0.50	0.20	0.936	0.998	0.895	0.918
				(0.922, 0.950)	(0.994, 0.999)	(0.860, 0.927)	(0.896, 0.940)
σ_Ψ	Inv.-Gamma	0.10	2.00	1.868	1.585	1.274	0.930
				(1.692, 2.058)	(1.417, 1.768)	(1.141, 1.418)	(0.832, 1.043)
ρ_μ	Beta	0.50	0.20	0.854	0.876	0.918	0.910
				(0.824, 0.882)	(0.846, 0.904)	(0.890, 0.943)	(0.887, 0.932)
σ_μ	Inv.-Gamma	0.10	2.00	1.938	2.261	2.226	1.135
				(1.723, 2.174)	(2.004, 2.551)	(1.966, 2.527)	(0.968, 1.321)
$\rho_{\mu w}$	Beta	0.50	0.20	0.786	0.893	0.850	0.700
				(0.742, 0.828)	(0.848, 0.936)	(0.813, 0.885)	(0.662, 0.738)
$\sigma_{\mu w}$	Inv.-Gamma	0.10	2.00	7.175	5.442	6.198	5.731
				(6.036, 8.516)	(4.708, 6.319)	(5.345, 7.184)	(4.916, 6.634)
				Measurement errors			
σ_{LP}^{me}	Inv.-Gamma	0.05	0.01	1.885	1.588	1.489	1.231
				(1.741, 2.040)	(1.475, 1.711)	(1.381, 1.605)	(1.143, 1.325)

Notes: The standard deviations of the shocks and meas. error have been transformed into percentages by multiplying by 100. HANK (AR2) denotes HANK model with AR(2) process for government spending shock instead of ARMA(1,1), HANK (RA2) denotes HANK model with risk aversion 2 instead of 4, HANK (KPR) denotes HANK model with KPR instead of GHH preferences. For HANK (AR-2), $\rho_{G1} = \gamma_\epsilon - \rho_G$ and $\rho_{G2} = \rho_G$.

Figure F.10: Impulse Response Functions (robustness)

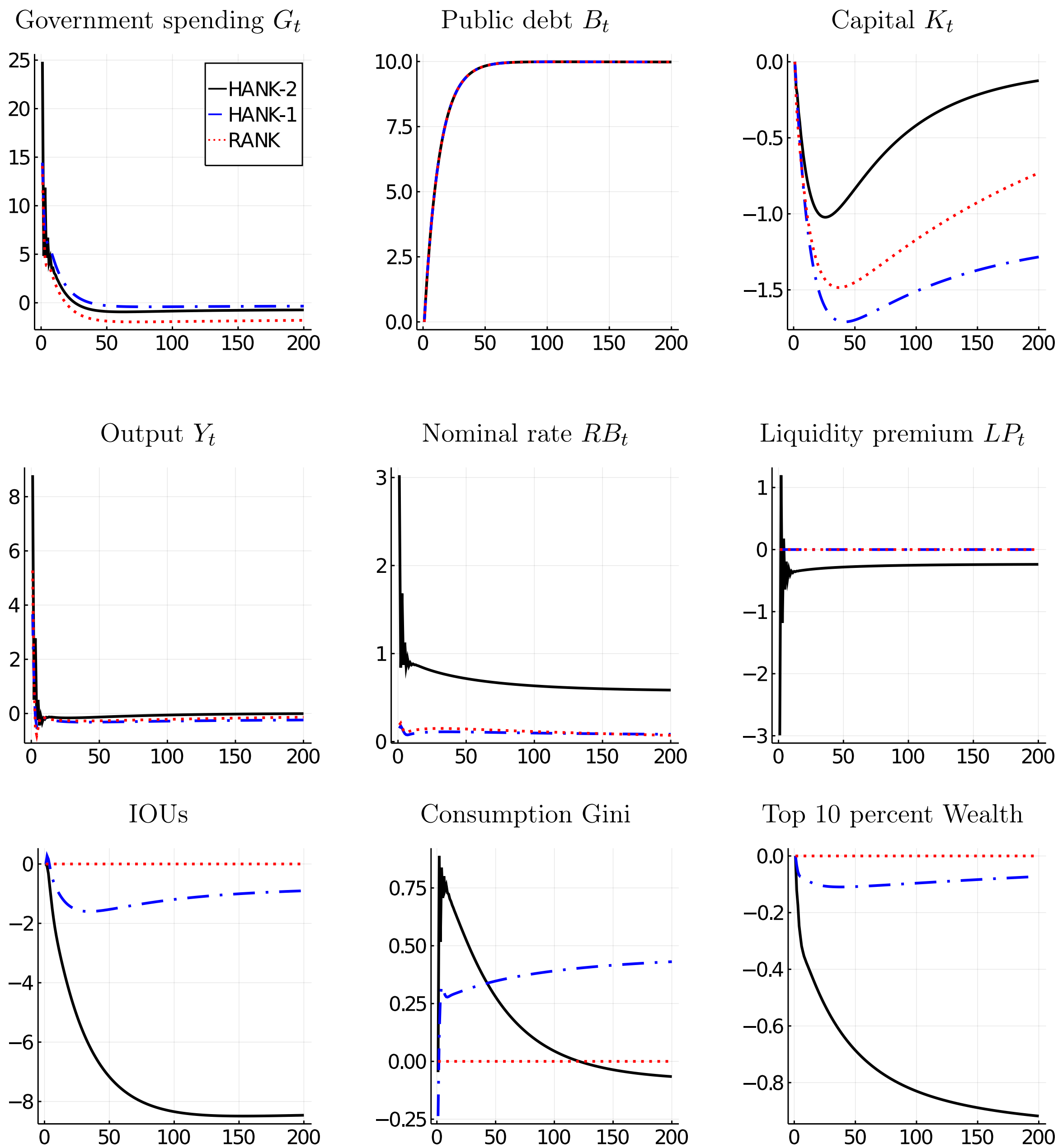


Notes: Impulse responses to the estimated government spending shocks in the baseline model (black - solid line), model with G_t following an AR(2) process (blue dash-dotted line), model with risk aversion of 2 (red dotted line), and model with KPR preferences (green dot-dot-dashed line.) Y-axis: Percent deviation from steady state for Y_t, C_t, I_t, G_t, B_t, and IOU_t, and annualized percentage points for RB_t, π_t and LP_t. X-axis: Quarters.

G Increasing the Debt Target to Finance Expenditures

Figure G.11 shows the impulse responses for a 10 percent increase in the debt target used for government spending. In response, as in the baseline in which adjustment is done via non-distortionary transfers, the liquidity premium falls by around 25 basis points. This leads to less crowding out of capital in comparison to models with liquid capital (HANK-1 and RANK). In the long run, capital falls by around 0.12 percent — slightly less than in the baseline experiment. Similarly, wealth inequality falls in the long run because of the decline in the liquidity premium. What is different with adjustment via government spending is that also consumption inequality slightly falls in the long run, while it slightly increases with adjustment via non-distortionary transfers. Behind this is the smaller decrease in the capital stock and hence wages fall less while returns on portfolios of relatively poor households increase. The government-spending-to-output ratio falls below its steady-state value in the long run.

Figure G.11: Response to an Increase in the Debt Target (G adjusts)



Notes: Impulse responses to a 10 percent debt target shock financed by government spending. Black solid line: Baseline model, HANK-2. Blue dash-dotted: Liquid-capital model, HANK-1. Red dotted line: Complete markets model, RANK. Y-axis: Percent deviation from steady state, except for RB_t and LP_t that are in annualized percentage points. X-axis: Quarters.