Idiosyncratic Risk, Government Debt and Inflation

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Abstract

Recent Heterogeneous Agent New Keynesian (HANK) models provide for rich monetary-fiscal interactions due to their lack of Ricardian equivalence. Yet, while related frameworks are usually motivated and calibrated relating to micro-level evidence, this is insufficient to pin down a key margin of non-equivalence. I demonstrate this in a state-of-the-art 2-asset HANK model, in which subtle assumptions on asset market structure give rise to disparate effects of fiscal expansions on interest rates and inflation. This is because household heterogeneity by itself influences but doesn't pin down the liquidity value of public debt. To overcome this issue, I propose a simple model extension and discipline it using relevant macro-level evidence regarding the relationship between public debt and treasury returns. In a subsequent application to the post-2020 US, the model suggests that public debt's liquidity value played a modest role in producing the inflation peak in 2022, but is important for inflation remaining elevated thereafter.

Keywords: Monetary policy, Fiscal Policy, Inflation, HANK

JEL Classification: E31, E52, E63

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1 Introduction

In the aftermath of the Covid-19 pandemic as well as the economic shock following Russia's invasion of Ukraine, both public debt levels and inflation have rapidly risen to historic highs in many advanced countries, particularly the USA. Naturally, this has sparked renewed interest in the implications of fiscal policy for inflation and monetary policy. At the same time, the macroeconomics discipline has been rapidly adopting models with rich household heterogeneity, in particular so-called Heterogeneous Agent New Keynesian (HANK) frameworks.

Compared to standard Representative Agent (RA) models, these frameworks substantially increase the scope for fiscal expansions to matter for inflation. With an RA, transfer payments only matter for monetary policy if it is paid for with distortionary taxes or debt that is "unfunded", i.e., not backed by future government revenue. Otherwise, it does not need to affect the conduct of central bank policies. In contrast, HANK models break these implications of Ricardian Equivalence in that they provide for constrained household with a high marginal propensity to consume (MPC) out of transfer payments as well as an explicit usefulness of government debt to insure idiosyncratic risk (see, e.g., Kaplan and Violante, 2018). As summarized in Section 1.1 below, this was found to substantially increase the scope for monetary-fiscal interactions in these frameworks.

In this paper, I argue that one of these key margins of non-equivalence, the explicit usefulness of government liquidity for self-insurance, requires additional discipline to conduct joint analyses of monetary and fiscal policy with common HANK models. The issue is the following: The HA part of these frameworks is typically calibrated so that it generates certain "micro moments", e.g., regarding MPCs or the wealth distribution, for given targets of net household wealth and steady state interest rate(s). This generates an imperfectly elastic demand for liquid assets, which, in turn, makes its respective supply important. Yet, different seemingly reasonable and commonly used assumptions on the latter can generate disparate aggregate outcomes.

To make this point, I employ a rich 2-asset HANK model: In this framework, households require liquid assets to insure themselves against skill- and business risk in the face of borrowing constraints but also have access to illiquid capital assets yielding higher returns. As such, it provides for the typical features that the literature has deemed important for the analysis of fiscal policy, such as a seizable number of Wealthy Hand-to-Mouth (HtM) households as well as empirically plausible Marginal Propensities to Consume (MPCs).

However, under different assumptions on the asset market, it generates very different effects of fiscal expansions on inflation under standard "active monetary, passive fiscal" policy rules. They also notably change the set of policy rules consistent with a unique stable equilibrium and the extent to which the HANK model allows for self-financed fiscal stimulus (a result recently highlighted by Angeletos et al., 2024a). Despite the HANK literature's focus on consumption behavior, these differences are not driven by high-MPC households' consumption response but rather aggregate investment demand. In effect, the model's asset market can be of similar importance as its household block when thinking about fiscal policy's implications for central banks in HANK.

The reason is that the effect of public debt on the "natural" and "neutral" rates of interest depends crucially on the asset market structure.[1] If liquid and illiquid assets are traded on *segmented* markets, as e.g. in Kaplan et al. (2018) or Bayer et al. (2024), then higher government debt supply increases liquid bond rates *much more* in the long run than suggested by relevant empirical evidence (e.g., Laubach, 2009). In contrast, if both bonds and capital can be freely held either as liquid or illiquid asset, as e.g., in Auclert et al. (2024), then more public debt is associated with a *much weaker* rise in rates. This is despite both model variants being consistent with the same steady state micro- and macro moments. Intuitively, if public debt can easily crowd out a fraction of the much larger capital stock, interest rates and aggregate demand do not need to adjust much for asset market clearing.[2]

While the asset market structure cannot be pinned down using only household-side information alone, its importance nevertheless connects to certain micro moments. Generating the above-mentioned results requires a substantial return gap between liquid and illiquid assets. As already highlighted in the previous literature, this is a key margin to combine high MPCs with a reasonable amount and distribution of aggregate wealth in HANK models (c.f. Kaplan and Violante, 2022). Thus, consistency with certain micro-moments can be key for the liquidity margin of Ricardian non-equivalence *but only conditionally* on certain asset market assumptions.

The issue remains to discipline the HANK model's asset market structure and in turn the liquidity effect of public debt. I do so by using a simple model extension that allows to move in between the polar cases of segmented and integrated asset markets *without* changing the model's steady state. Its calibration requires a single macro-level statistic, the long-run effect of public debt on treasury returns, of which various estimates are available in the literature (see, e.g., Rachel and Summers, 2019).[3]

Ultimately, is public debt's liquidity value still a relevant channel of monetary-fiscal interaction in the properly disciplined HANK model? To gauge this issue in the light of the recent years' macroeconomic events, I extend it with an Effective Lower Bound (ELB) and filter a series of business cycle shocks that make it align with several aggregate US time series between 2020 and 2024. Through the lens of the model, the respective "debt

[1] The "natural" rate of interest is typically defined as the nominal rate consistent with a central bank's inflation target in the medium- to long term and taken to be "driven by fundamental factors in the economy, including demographics and productivity growth-the same factors that drive potential economic growth" (Powell, 2020). In contrast, the "neutral rate" is sometimes designated as the interest rate that would be consistent with target inflation in the short run (see e.g. Obstfeld, 2023).

[2] While the issue may seem to concern only 2-asset HANK models, simple 1-asset HANK models abstracting from capital implicitly also assume a form of segmented markets in that they also don't allow for a usefulness of capital to provide liquid assets.

[3] However, given that it does not affect the steady state, it should also be possible to estimate the key parameter jointly with other parameters of a models' "macro block".

inflation" is unlikely to have played a big role for generating the inflation peak in 2022, but it can quantitatively explain inflation remaining elevated in 2023 and afterwards. As an additional insight, the HANK framework supports the view of Giannone and Primiceri (2024) that the US post-Covid inflation was mostly driven by "demand-side" factors.

What does that mean for monetary policy? I show that by simply adjusting nominal rates in response to the value of public debt, central banks can implement an outcome close to an "integrated asset markets" counterfactual in which government debt's liquidity value is low and has negligible impact on inflation. In the post-2020 scenario, this achieves comparatively faster disinflation at lower nominal interest rates without substantial "real" costs.

1.1 Relation to the literature

This paper connects to a long tradition in macroeconomics studying monetary-fiscal policy interactions, going back to the seminal works of Sargent and Wallace (1981) and Leeper (1991). Leeper and Leith (2016) and Cochrane (2023) offer summaries of this literature, including its modern incarnation as Fiscal Theory of the Price Level (FTPL). As already alluded to above, these works typically required public debt to be "unfunded" to become a concern for monetary policy. A relevant recent contribution of this strand is Bianchi et al. (2023), who find unfunded fiscal policy important to explain inflation persistence in the US and also study the post-pandemic inflation.

Naturally, my work connects most closely to the sprawling HANK literature. In particular, the literature has found these frameworks to have substantially different implications of fiscal policy for both real and nominal outcomes compared to the RA benchmark. Firstly, the presence of constrained households with high MPCs can substantially amplify the aggregate effects of expansionary fiscal policy, see for example Hagedorn et al. (2019) and Auclert et al. (2024). These authors, together with Hagedorn (2021) and Angeletos et al. (2024b), also emphasize that these frameworks give rise to different patterns of equilibrium determinacy. Angeletos et al. (2024b) further argue that in response to fiscal shocks, HANK models can generate as much inflation as RA models under the FTPL. Compared to these works, my paper clarifies that in addition to households' consumption behavior, their demand for liquid assets can be crucial for HANK model's inflation responses and determinacy properties. It can (and should) be considered separately from MPCs.

Some HANK papers actually focus on how public debt's liquidity value matters for the aggregate effects of fiscal policy. This includes Bayer et al. (2023a), who focus on real outcomes, and the independent contemporary work of Campos et al. (2024) also analyzing its implications for monetary policy.[4] My work clarifies that their results depend on the assumption of certain asset market structures in addition to household heterogeneity

[4]Both this and my paper were first publicly disseminated on March 1, 2024. My earlier version remains available at the ArXiv preprint server under https://arxiv.org/abs/2403.00471v1.

itself.[5]

My insights on the importance of the asset market structure for liquid rate dynamics additionally bear resemblance to the findings by Chiang and Żoch (2023), who study a 2-asset HANK model with explicit financial intermediation. Comparing their structure with alternative settings, they find the calibration of the asset market to be important for the real effects of different policy shocks. Yet, they do not consider inflation as an outcome and assume real returns on liquid assets to be fixed.[6]

Finally, my work also connects to a set of previous studies analyzing fiscal policy in other settings deviating from Ricardian Equivalence. Related inflationary effects of "funded" government debt were also noticed by Ascari and Rankin (2013) and Aguiar et al. (2023) in the context of Overlapping Generations (OLG)-models with nominal rigidities and by Linnemann and Schabert (2010) in a New Keynesian framework assuming that public debt provides transaction services. Besides building on a different micro-foundation, my work also employs a richer, more quantitatively oriented model.

2 The Quantitative HANK model

For my analysis, I employ a 2-asset HANK model, most features of which are deliberately similar to frameworks in the previous literature, e.g., Bayer et al. (2024) and Auclert et al. (2024). While a 2-asset set-up is not necessary to make public debt matter for monetary policy via a liquidity channel, a serious quantitative investigation fo such interactions should arguably feature a somewhat realistic level and distribution of aggregate wealth and be consistent with consumption behavior that was found important for studying fiscal policy in previous work. Typical 1-asset model can't provide for these features (Kaplan and Violante, 2022).

Moreover, the 2-asset setup allows me to make my point particularly clearly in that one can change the *potential* supply of liquid assets available to households without affecting its initial steady state in any way. To this end, my set-up features a financial intermediary referred to as the *liquid asset fund* which nests different assumptions on asset market structure considered in the previous literature.

[5] While not strictly "HANK" papers, Aiyagari and McGrattan (1998), Challe and Ragot (2011) and Aguiar et al. (2024) study flexible-price incomplete markets model in which the presence of idiosyncratic risk gives rise to important liquidity effects of public debt. My work suggests that in order to assess the magnitude of the respective outcomes, it is valuable to consider the empirical plausibility of public debt's accompanying interest rate effects.

[6] Their insights may thus the be reverse of my mine: If changing liquidity supply would necessitate substantial interest rate adjustments for asset market clearing but this is prevented, then other parts of the economy have to adjust strongly.

2.1 Households

2.1.1 Idiosyncratic states

There is a unit mass of households, which I again also refer to as "agents" interchangeably. These differ ex-post by several idiosyncratic states:

- Firstly, households vary in terms of their holdings of liquid and illiquid assets a_{it} and k_{it}. k_{it} represents holdings of capital and I require that $k_{it} \geq 0$ as well as $a_{it} \geq \underline{a}$, with $\underline{a}$ representing an exogenous borrowing/short-selling limit. Capital is illiquid in that a household can change her stock k_{it} only infrequently: In particular, following Bayer et al. (2024) and Auclert et al. (2024), I assume that the opportunity to do so arises randomly in an i.i.d. fashion, in that households only gets to participate in the market for illiquid assets with probability $\lambda \in (0, 1)$ every period.

- Secondly, as in Bayer et al. (2024), the agents can be workers ($\Xi_{it} = 0$) or "entrepreneurs" ($\Xi_{it} = 1$). The former participate in the regular labor market, while the latter don't supply labor to the market but receive the profits generated by the firms (to be described below), which, for simplicity, are assumed to be shared equally among all households with $\Xi_{it} = 1$. Transitions to and out of the "entrepreneur" status are exogenous with probabilities ζ and ι, implying a time-invariant mass of $m^{\Xi} := \frac{\zeta}{\zeta+\iota}$ agents in that state.

- Worker households ($\Xi_{it} = 0$) additionally differ by their idiosyncratic labor productivity or "skill" $s_{it} \in \mathcal{S} = \{s_1, s_2, ..., s_{ns}\}$, which evolves stochastically according to a discrete Markov chain with transition probabilities $\pi^s(s_{it+1}|s_{it})$. Workers who are selected to become entrepreneurs lose their idiosyncratic s_{it} as exiting entrepreneurs draw a new s_{it} from the ergodic distribution of the Markov Chain.

2.1.2 The Household problem

Households gain utility from consumption c and disutility from their amount of hours worked according to the preference structure

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \prod_{\tau=0}^{t} (A_\tau) \left(\frac{c_{it}^{1-\xi} - 1}{1-\xi} - \varsigma \frac{N_t^{1+\gamma}}{1+\gamma} \right). \tag{1}$$

The above formulation allows for a time-varying demand shock A_t shifting all households' discount factor β, which will be used to induce consumption restraints in Section 6.[7] As, e.g., in Auclert et al. (2024), households are *not* free to choose their own labor supply. Instead, they are required to work the number of hours demanded by their employers at the wage determined by a set of labor unions as detailed below. These will be equal in equilibrium, i.e., $N_{it} = N_t \ \forall i \in [0, 1]$.

[7] This is in line with Bardóczy et al. (2024), who also use discount factor shocks in a HANK study relating to the US post-2020 period.

An agent who gets to adjust her illiquid capital stock will the face budget constraint

$$c_{it} + q_t k_{it+1} + a_{it+1} = y_{it}(s_{it}, \Xi_{it}) + (1 + r_t^a(a_{it}))a_{it} + (q_t + r_t^k)k_{it} + T_{it} \tag{2}$$

while for non-adjusters, the constraint will be of the form

$$c_{it} + a_{it+1} = y_{it}(s_{it}, \Xi_{it}) + (1 + r_t^a(a_{it}))a_{it} + r_t^k k_{it} + T_{it}. \tag{3}$$

Both budget constraint are already written in real terms. q_t denotes the time t price of capital goods, T_{it} a transfer from the government, r_t^k the real net return of capital goods and $r_t^a(a_{it})$ the real return on bonds a_{it}. The latter depends on a_{it} due to the presence of a borrowing penalty. In particular, we have

$$r_t^a(a_{it}) = \begin{cases} r_t^l & \text{if } \; a_{it} \geq 0; \\ r_t^l + \bar{R} & \text{if } \; a_{it} < 0, \end{cases} \tag{4}$$

where r_t^l is the real return on liquid savings, which will depend on the nominal central bank rate r_t^R and inflation $\pi_t = \frac{P_t}{P_{t-1}}$ as specified below. $\bar{R}$ is a real borrowing penalty.[8] Finally, y_{it} represents a household's post-tax labor- or profit income which is given by

$$y_{it}(e_{it}, s_{it}, \Xi_{it}) = \begin{cases} (1 - \tau_t^w)\left(w_t s_{it} N_t\right)^{1-\tau^p} & \text{if } \; \Xi_{it} = 0; \\ (1 - \tau_t \Xi) \frac{\Pi_t}{m_t^{\Xi}} & \text{if } \; \Xi_{it} = 1. \end{cases} \tag{5}$$

Labor income is subject to an affine tax schedule in the veins of Benabou (2002) for which the parameters τ^w and τ^p determine the level and degree of progressivity, respectively. Similarly, τ^{Ξ} is the tax rate on entrepreneurs' profit income. Both level parameters may be adjusted by the government over time and thus have a time subscript.

Letting Γ_t denote a set containing the economy's *aggregate* state at period t, we are now ready to state the Bellman equation corresponding to the households' dynamic utility maximization problem, which are

$$V^a(a_{it}, k_{it}, s_{it}, \Xi_{it}; \Gamma_t) = \max_{c_{it}, k_{it+1}, a_{it+1}} \left\{ \frac{c_{it}^{1-\xi} - 1}{1-\xi} - \varsigma \frac{N_t^{1+\gamma}}{1+\gamma} + \beta \mathbb{E}_t A_{t+1} V(a_{it+1}, k_{it+1}, s_{it+1}, \Xi_{it+1}; \Gamma_{t+1}) \right\}$$
$$\text{s.t. to (2), (5), } k_{it} \geq 0 \text{ and } a_{it} \geq \underline{a} \tag{6}$$

for an household able to adjust its capital stock and

$$V^{na}(a_{it}, k_{it}, s_{it}, \Xi_{it}; \Gamma_t) = \max_{c_{it}, a_{it+1}} \left\{ \frac{c_{it}^{1-\xi} - 1}{1-\xi} - \varsigma \frac{N_t^{1+\gamma}}{1+\gamma} + \beta \mathbb{E}_t A_{t+1} V(a_{it+1}, k_{it}, e_{it+1}, \Xi_{it+1}; \Gamma_{t+1}) \right\}$$
$$\text{s.t. to (3), (5), } k_{it} \geq 0 \text{ and } a_{it} \geq \underline{a} \tag{7}$$

for a household that is unable to do so. The ex-ante value function $V(\cdot)$ is given by

$$V(a_{it+1}, k_{it}, e_{it+1}, s_{it+1}, \Xi_{it+1}; \Gamma_{t+1}) = \lambda V^a(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t) + (1-\lambda) V^{na}(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t).$$

[8] My specification for the borrowing wedge implies that every unit of debt held by a household incurs a real resource cost of $\bar{R}$, e.g. due to costly monitoring.

2.2 Production

The model's supply side is similar to standard "medium scale" DSGE models: Production is vertically integrated. There is again a final good that can either be consumed or used by capital goods producers to produce investment goods subject to adjustment costs. This final good is assembled by a representative final goods producer, that in turn requires differentiated inputs provided by a continuum of retailers. The latter set prices in a monopolistic competitive fashion subject to nominal rigidities and require intermediate goods to produce their output. These are provided by a set of competitive intermediate goods producers that require capital and labor services as inputs. The latter are an aggregate of different labor varieties, the wage for is decided by monopolistic competitive unions that are also subject to nominal rigidities. As Bayer et al. (2024), I make the simplifying assumption that firms solving forward-looking problems (such as the retailers' price setting problem) discount the future at the households' discount parameter β.[9]

2.2.1 Final goods production

The economy's final good is produced by a representative firm that assembles a set of differentiated inputs $j \in [0, 1]$ according to the CES technology

$$Y_t = \int_0^1 y_{jt}^{\frac{\epsilon_t - 1}{\epsilon_t}} dj. \tag{8}$$

Denoting the intermediate prices as p_{jt}, this gives rise to the familiar input demand schedule

$$y_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\epsilon_t} Y_t \tag{9}$$

with optimal price index $P_t = (\int_0^1 p_{jt}^{1-\epsilon_t})^{1/(1-\epsilon_t)}$. Note that I allow the elasticity of substitution between different varieties to exogenously vary over time, i.e., I introduce what is commonly referred to as "cost-push" shocks in the literature. For notational convenience, I define $\mu_t := \frac{\epsilon_t}{\epsilon_t - 1}$ to denote the target mark-up of the retailers presented in the next section.

2.2.2 Retailers

There is a unit mass of retailers, each of which produce a given variety of the differentiated input as monopolist, taking into account demand schedule (9). Their only input are intermediate goods, which they purchase at real price mc_t (also referred to as "marginal costs") from the competitive intermediate goods producers. However, they are subject to nominal rigidities à la Calvo (1983), i.e., in any given period their nominal price remains fixed with probability λ_Y.

[9] Since I will linearize the model with respect to aggregate shocks, only the steady-state value of the discount factor in the firms' dynamic problems will matter for the dynamic model responses. Bayer et al. (2019) and Lee (2021) report that using different specifications does not significantly affect results in their 2-asset HANK models with many similar features.

If receiving a re-set opportunity, a retailer will choose a price to maximize the corresponding expected net present value of real profits

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \lambda_Y^t \left(\frac{p_{jt}^*}{P_t} - mc_t \right) \left(\frac{p_{jt}^*}{P_t} \right)^{\frac{-\mu_t}{\mu_t - 1}} Y_t.$$

Log-linearizing the first order conditions of the resulting price setting problem gives rise to the standard log-linear Phillips curve

$$\log(\pi_t) = \kappa_Y \left(mc_t - \frac{1}{\mu_t} \right) + \beta \mathbb{E}_t \log(\pi_{t+1}) \tag{10}$$

with $\kappa_Y := \frac{(1-\lambda_Y)(1-\lambda_Y \beta)}{\lambda_Y}$.

2.2.3 Intermediate goods producers

The homogeneous intermediate good is produced by a continuum of firms that use a constant-returns-to-scale technology represented by production function

$$F(u_t K_t, H_t) = F(u_t K_t, H_t) = (u_t K_t)^{\alpha} H_t^{1-\alpha}. \tag{11}$$

K_t and H_t denote the input of capital and labor services. u_t is the degree of capital utilization that determines capital depreciation according to

$$\delta(u_t) = \delta_0 + \delta_1 (u_t - 1) + \frac{\delta_2}{2} (u_t - 1)^2.$$

Taking the price h_t for labor services as well as the capital rental rate r_t and its output price mc_t as given, an intermediate goods producer solves the static profit maximization problem

$$\max_{K_t, H_t, u_t} mc_t F(u_t K_t, H_t) - h_t H_t - (r_t + q_t \delta(u_t)) K_t,$$

the solution of which can be characterized using the following first order conditions:

$$h_t = (1-\alpha) mc_t (u_t K_t)^{\alpha} H_t^{-\alpha} \tag{12}$$

$$r_t + q_t \delta(u_t) = \alpha mc_t u_t (u_t K_t)^{\alpha - 1} H_t^{1-\alpha} \tag{13}$$

$$q_t (\delta_1 + \delta_2 (u_t - 1)) = \alpha mc_t (u_t K_t)^{\alpha - 1} H_t^{1-\alpha}. \tag{14}$$

2.2.4 Capital goods producer

Capital goods producers use the final good as input and operate a technology subject to adjustment costs: Using I_t units of the final good, they can produce

$$Z_t^I \left[1 - \frac{\phi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t$$

units of capital. Investment-specific productivity Z_t^I is exogenous and potentially following a time-varying shock process. Taking the price of capital q_t as given, the producers choose I_t to maximize the net present value of real profits

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

and their optimal interior solution will fulfill first-order condition

$$1 + q_t Z_t^I \left(\frac{\phi}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - 1 + \phi \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right) = \beta q_{t+1} Z_{t+1}^I \phi \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 . \tag{15}$$

2.2.5 Labor market

The labor market follows a set-up as in Auclert et al. (2024). Labor services are produced by a representative labor packer that aggregates a range of differentiated labor inputs $u \in (0,1)$ according to

$$N_t = \left(\int_0^1 N_{ut}^{\frac{\epsilon_w - 1}{\epsilon_w}} du \right)^{\frac{\epsilon_w}{\epsilon_w - 1}}$$

and will thus demand

$$N_{ut} = \left(\frac{W_{ut}}{W_t} \right)^{-\epsilon_w} N_t \tag{16}$$

of each labor variety. Each of the differentiated labor types is supplied by a union that sets the nominal wage W_{ut} as a monopolist to maximize the utility of its members. The latter are required to work according to a uniform schedule, i.e., all u workers have to supply the same amount of hours N_{ut}. Unfortunately, every period the leadership of a union u suffers utility costs $\frac{\psi}{2} \left(\frac{W_{ut}}{W_{ut-1}} - \pi_{SS} \right)^2$ for changing the nominal wage, perhaps due the administrative burden of adjusting contracts. In turn, every union solves

$$\max_{\{W_{u\tau}\}_{\tau=t}^{\infty}} \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} \left(\int \left(u(c_{i\tau}) - \varsigma \frac{N_{i\tau}^{1+\gamma}}{1+\gamma} \right) di - \frac{\psi}{2} \left(\frac{W_{ut}}{W_{ut-1}} - 1 \right)^2 \right), \tag{17}$$

taking demand schedule (16) into account.

Households are exogenously distributed over unions in a uniform manner: Note that the law of large numbers applies thus also *within* unions so that the distribution of agents i overall and within any union u coincides.[10] Due to symmetry, the F.O.C.s of (17) then give rise to an aggregate *Wage Phillips curve* of the form

$$\begin{aligned} \pi_t^w (1 - \pi_t^w) = \kappa_w \left(\varsigma N_t^{1+\gamma} - \frac{\epsilon_w - 1}{\epsilon_w} (1 - \tau_p)(1 - \tau_t^w) \int \left(u'(c_{it}) \left(s_{it} \frac{W_t}{P_t} N_t \right)^{1-\tau_p} \right) di \right) \\ + \beta \mathbb{E}_t \pi_{t+1}^w (1 - \pi_{t+1}^w), \end{aligned} \tag{18}$$

with $w_t := W_t / P_t$ and $\pi_t^w := \frac{W_t}{W_{t-1}}$. For convenience, I define $\kappa_w := \frac{\epsilon_w}{\psi}$ to denote the slope of the Wage Phillips curve. Additional details on the derivation are provided in Appendix A.1.

2.3 Government

The government again consists of two branches, a monetary authority and a fiscal authority.

[10] Since all labor varieties will be symmetric in equilibrium, her labor type u doesn't matter for an individual's consumption-saving problem.

2.3.1 Monetary Authority

The monetary authority sets the nominal return $1 + r^R$ on a reserve asset that is in zero net supply. Specifically, it is assumed to follow a Taylor rule of the form

$$1 + r^R_{t+1} = \max\left\{(1 + r^R_{SS})\left(\frac{1 + r^R_t}{1 + r^R_{SS}}\right)^{\rho^R}\left[\left(\frac{\pi_t}{\pi_{SS}}\right)^{\theta_\pi}\left(\frac{Y_t}{Y_{t-1}}\right)^{\theta_y}\right]^{1-\rho^R}\exp\left(\epsilon^R_t\right),\ 1 + r^{LB}\right\}. \tag{19}$$

which features an Effective Lower Bound (ELB) denoted as r^{LB}. The parameter ρ^B introduces rate smoothing and if $\theta_y \neq 0$, the rule reacts to output growth in addition to inflation. ϵ^R_t represents an exogenous disturbance to the rule ("monetary policy shock"). Since the calibrations will provide for a stable steady state, $1 + r^R_{SS}$ always constitutes the true long-run natural rate of interest.

2.3.2 Fiscal Authority

The fiscal authority collects taxes, pays out transfers T_{it} and engages in government consumption G_t. It also issues nominal long-term government bonds which I introduce using a simple geometric maturity structure as in Bayer et al. (2023a). Bonds are long-lived. Every period, they pay one nominal unit of return and a random fraction δ^B of them retire without repaying the principal.[11] Denoting the nominal period t price of a bond as Q^B_t, its expected nominal return is given by $\mathbb{E}_t(Q^B_{t+1}(1 - \delta^B) + 1)$.

To state the government's budget constraint in a convenient form, let us define B^g_t to denote the value of public debt outstanding at the beginning of period t in terms of its period $t - 1$ real market value Q_{t-1}/P_{t-1}. The dynamics of public debt must then be consistent with

$$B^g_{t+1} = (1 - \delta^B)\frac{Q^B_t B^g_t}{Q^B_{t-1}\pi_t} + G_t + \int_0^1 T_{ti}di + \frac{B^g_t}{Q^B_{t-1}\pi_t} - \Upsilon_t, \tag{20}$$

i.e., the real period t market value of public debt outstanding at the end of period t equals the re-valued stock of public debt that did not retire plus the government's real spending obligations minus real tax revenues Υ_t. The latter equal

$$\Upsilon_t = \tau^\Xi_t \Pi_t + \int_{m^\Xi}^1 \left(w_t s_{it} N_t - (1 - \tau^w_t)\left(w_t s_{it} N_t\right)^{1-\tau^p}\right) di.$$

As baseline, I assume both government spending items G_t and T_{it} to be solely determined by exogenous shocks. Without any occurring, they remain fixed at $G_t = G_{SS}$ and $T_{it} = 0$.

To ensure public debt stability in the face of various business cycle shocks, the fiscal authority is furthermore assumed to adjust taxes as $\tau^w_t = \tau_t \tau^w_{ss}$ and $\tau^\Xi_t = \tau_t \tau^\Xi_{ss}$. The tax level τ_t evolves according to

$$\left(\frac{\tau_t}{\tau_{ss}}\right) = \left(\frac{\tau_{t-1}}{\tau_{ss}}\right)^{\rho_\tau}\left(\frac{B^g_t}{B^g_{ss}}\right)^{(1-\rho_\tau)\psi_B}, \tag{21}$$

[11] Equivalently, such a setting can be interpreted as featuring infinitely-lived bonds with geometrically declining coupon payments. See Woodford (2001).

a functional form also used in Bianchi et al. (2023). Adjusting all tax levels proportionally by the same factor aims to reduce the distributional impact of fiscal consolidation in order to better isolate the role of the public debt level. Otherwise, the fiscal authority issues any amount of bonds B^g_{t+1} necessary to fulfill its budget constraint (20). Intuitively, policy rule (21) means that the government will eventually raise taxes to pay back debt in surplus of its long-run target, but may do so only slowly. In Appendix C, I will additionally consider the alternative scenario in which the fiscal authority consolidates its budget by adjusting spending G instead of taxes τ_t.

2.4 Liquid Asset Provision

While I assume a centralized market for claims to (illiquid) capital, households obtain liquid assets from a set of competitive *liquid asset funds* (LAFs). In contrast to households, these funds are able to trade claims to capital every period and also have access to a technology to short-sell any asset. Their objective is to maximize expected real returns by investing the liquid savings A^l_{t+1} they receive from the households in capital, government bonds and reserves. In particular, the LAFs solve

$$\max_{B^l_{t+1},R^l_{t+1}} \Bigg\{ \mathbb{E}_t \left[(r^k_{t+1} + q_{t+1}) \frac{A^l_{t+1} - B^l_t - R^l_t}{q_t} + \frac{Q^B_{t+1}(1-\delta^B)+1}{\pi_{t+1}} \frac{B^l_{t+1}}{Q^B_t} + \frac{1+r^R_{t+1}}{\pi_{t+1}} R^l_{t+1} \right] \\ - A^l_{t+1} \left(\varphi + \frac{\Psi}{2} \left(1 - \frac{B^l_{t+1} + R^l_{t+1}}{A^l_{t+1}} \right)^2 \right) \Bigg\}, \tag{22}$$

where A^l_{t+1} denotes the total amount of assets intermediated by the LAF and B^l_t and R^l_t the amount of government debt and reserves it chooses to acquire. A fund faces costs for each unit of liquid asset it invests on behalf of the households. This involves a linear component φ and a part $\frac{\Psi}{2}\left(1 - \frac{B^l_t + R^l_t}{A^l_t}\right)^2$ that increases in the relative amount of the fund's asset positions that are *not* in liquid government assets. This structure implies that the equilibrium government bond prices Q^B must fulfill the no-arbitrage condition

$$\mathbb{E}_t \frac{1 + r^R_{t+1}}{\pi_{t+1}} = \mathbb{E}_t \frac{Q_{t+1}(1-\delta^B)+1}{\pi_{t+1} Q^B_t}.$$

Furthermore, the LAFs' aggregate portfolio choice can be determined from the corresponding F.O.C.

$$\mathbb{E}_t \left(\frac{r^k_{t+1} + q_{t+1}}{q_t} \right) - \Psi \left(1 - \frac{B^l_{t+1}}{A^l_{t+1}} \right) = \mathbb{E}_t \left(\frac{1 + r^R_{t+1}}{\pi_{t+1}} \right) \tag{23}$$

and the ex-post real return to household's liquid savings will be given by

$$1 + r^l_t = \frac{q_t + r^k_t}{q_{t-1}} \frac{A^l_t - B^l_t}{A^l_t} + \frac{Q^B_t(1-\delta^B)+1}{\pi_t Q^B_{t-1}} \frac{B^l_t}{A^l_t} - \varphi - \frac{\Psi}{2} \left(1 - \frac{B^l_t}{A^l_t} \right)^2 \tag{24}$$

(anticipating that in equilibrium $R^l_t = 0$ as reserves are in 0 net supply).

A few words on the above assumptions are in order: Although the quadratic portfolio

cost in (22) is reminiscent of some DSGE models featuring a financial sector (for example Gerali et al., 2010), its aim is *not* to provide a particularly realistic model of financial intermediation. Rather, it introduces a parsimonious way to flexibly move between various assumptions on liquid asset supply in the literature. For this purpose, the parameter Ψ has a simple interpretation as determining how easily capital assets can be used for liquidity provision. In case $\Psi \to \infty$, the model nests the assumption of *segmented* markets for liquid and illiquid assets as in Kaplan et al. (2018) or Bayer et al. (2024), who assume that government bonds can *only* be held as a liquid asset and capital *only* as an illiquid asset. That means capital is practically useless for the provision of liquid assets. In contrast, for $\Psi \to 0$ it nests a completely *integrated* market as in Auclert et al. (2024), who assume that both capital and public debt can be held in either liquid or illiquid form. If that is the case, capital is a perfect substitute for government bonds for the purpose of liquidity provision and (23) collapses to a standard no-arbitrage condition. As will become clear below, being able to move between either extreme will be crucial for the model results.
While a micro-founded models of financial intermediation, building e.g. on Gertler and Karadi (2011), could also provide for imperfect usefulness of capital for liquidity provision, the above formulation has several benefits: Most importantly, if the model's Steady State (SS) is calibrated so that the household sector's net liquid asset holdings equal the net supply of government bonds, one can move "in between" the above-mentioned assumptions on asset market structure *without* changing its SS. In the context of a HANK model, allowing for varying degrees of liquidity transformation typically impacts the steady state by requiring different financial sector net worth or similar. Besides, my simple structure makes it particularly transparent how varying the usefulness of capital for liquidity provision is achieved.

2.5 Market clearing conditions and equilibrium

The Definition of Equilibrium is standard, but tedious, given that the quantitative model features multiple markets and also requires keeping track of the evolution of the aggregate distribution. In turn, I relegate these details to Appendix A.2.

2.6 Numerical Approach

To approximate the dynamic equilibrium of the model, I use established techniques that conduct first-order perturbation around the economy's non-stochastic steady state, specifically the Sequence Space Jacobian (SSJ)-method proposed by Auclert et al. (2021) and the State Space method employed by Bayer et al. (2024). Both have comparative advantages for different purposes: For example, the Sequence Space method can more conveniently handle a binding ELB relevant for the analysis described in Section 6.2, as one can impose the lower bound on nominal rates via monetary news shocks as in McKay and Wieland (2021). As we see below, representing the linearized model in terms of Impulse Response Functions (IRFs) will also be useful to isolate the "debt inflation" in that Section's complex scenario. In contrast, the State Space method allows to easily check whether the model admits a unique and stable solution for a given parameterization via the Blanchard-Kahn-conditions and proved conveniently fast for exercises requiring the model to be solved many times.

For obtaining the model's steady state, I use a multidimensional Endogenous Grid Method similar to the algorithm described in Bayer et al. (2019) to solve the households' dynamic programming problem. The joint income- and asset distribution is approximated as a histogram using the "lottery"-method proposed by Young (2010). Further details on the numerical implementation are provided in Appendix A.3.

3 Calibration of the quantitative model

A period is interpreted to be a quarter. I aim for the model to be consistent with the most relevant features of the US economy and the key empirical moments emphasized by the HANK literature, such as a plausible income- and wealth distribution, the presence of poor and wealthy "Hand-to-Mouth" (HtM) households and in turn a fairly high aggregate MPC. To do so, I first set a range of parameters exogenously, relying on the previous literature: In addition to standard preference- and technology parameters, this includes some parameters exclusively affecting the dynamic model response to aggregate shocks, for which I rely on previous papers estimating HANK models. Note that the robustness of the main results with regard to these choices is analysed in Appendix C. Afterwards, the remaining parameter values are chosen to match several steady state moments of the household wealth distribution.

3.1 Externally calibrated

The model's externally calibrated parameters are displayed in Table 1: I set the households' risk aversion parameter to $\xi = 1.5$, within the range of standard values used in the literature. Regarding technology, I use the standard values of $\alpha = 0.33$ for the Cobb-Douglas parameter for capital and set a quarterly depreciation rate for capital of $\delta = 0.0175$, implying approx. 7% annual depreciation. Similar, I set μ_t to a conventional value of 1.1, resulting in a steady state markup of 10%. The elasticity of substitutions between different labor varieties is assumed to be the same as for goods and thus $\epsilon_w = 11$.[12] The slope of the price Phillips curve is set to $\kappa_Y = 0.06$, in line with the recent evidence by Gagliardone et al. (2023). In the HANK literature, wages are often assumed to be substantially stickier than prices, even though estimated DSGE models do not always support this. I set $\kappa_w = 0.015$ to be consistent with the former, a value based on the estimate of Auclert et al. (2020). However, given the empirical controversies surrounding these parameters, related robustness checks will be discussed in Appendix C.

[12]Since I set κ_w independently of ϵ_w and calibrate ς to achieve $N_{ss} = 1$, the value of this parameter is practically of limited importance.

Several other parameters governing the economy are calibrated following Bayer et al. (2024): First, I also set the probability of exiting the $\Xi = 1$ state within a given period to be 6.25% and adopt their tax progressivity parameter $\tau_p = 0.12$. The investment adjustment cost is chosen to be 3.5 and the ratio δ_2/δ_1 set to be 1, reflecting the results of their model estimation. For a given δ_2/δ_1-ratio, I always set δ_1 and δ_2 to achieve $u_t = 1.0$ in steady state. Again, since estimates for the investment- and utilization adjustment parameters also vary in the literature, these values will be subjected to robustness tests as well.

Regarding monetary policy, I parameterize the model's interest rule with standard values also employed by Bayer et al. (2023b) to study post-2020 macroeconomic dynamics in the US. In particular, this includes setting the Central Bank's inflation reaction parameter to the value $\theta_\pi = 1.5$ first proposed by Taylor (1993), making it clear that monetary policy is "active" in my model. The ELB is set to be 2 percentage points (in annual terms) below the steady state policy rate r^R_{SS}, given that an exercise in Section 6 effectively assumes the model to be in steady state before 2020. In that year, the nominal rate was around 2% and the ELB thus 2 p.p. below it.

On the fiscal side, the steady labor tax level τ is chosen to be consistent with $G/Y \approx$ 17.5% given the model's other targets, in line with the average ratio of government consumption and investment to GDP in 2014-2019. The tax rate on the "entrepreneurs"'s profit incomes are set to 24%, reflecting the top tax bracket for qualified dividends in the US. Bianchi et al. (2023) report the average maturity of US treasury debt to typically vary between 4.5-5.5 years, so I chose $\delta^B = 0.05$ to be consistent with an average 5-year (20 quarter) duration.

Initially, I set $\rho_\tau = 0.85$ and $\psi_B = 1.25$, ad hoc values that result in a moderately drawn-out public debt responses. In particular, these parameters imply that for a simple transfer shock as studied in Section 4, public debt will start to clearly decline after approx. 2 years. As will become clear below, different combinations of parameters yield similar results as long as they provide for public debt responses of comparable magnitude.

3.2 Internal calibration

The remaining parameters are chosen so that the model matches various targets in the non-stochastic steady state. To clarify how they come about, I present for each parameter the moment I use to identify it. While in principle any parameter will somewhat affect any of the stationary equilibrium's target moments, it nevertheless turns out that achieving a good fit with the target relies mostly on the stated parameter.

Several parameters are disciplined by moments related to the steady state wealth distribution. I choose the household discount factor β to match a ratio of average steady state capital holdings to output of 11.22 as in Bayer et al. (2024), resulting in $\beta = 0.9838$. The probability ζ determines the amount of "super rich" entrepreneur households and I use it to target a Top 10% wealth share of 70%, approximately the value computed by Krueger

Parameter	Description	Value	Source
ξ	Risk aversion	1.5	Standard
ι	Exit prob. entrepreneurs	1/16	Bayer et al. (2024)
α	Cobb-Douglas parameter	0.33	Standard
δ_0	Steady State depreciation	0.0175	Standard
μ	SS Goods markup	1.1	Standard
κ_Y	Slope of price Phillips curve	0.06	Gagliardone et al. (2023)
κ_w	Slope of wage Phillips curve	0.015	Auclert et al. (2020)
ϵ_w	EOS labor varieties	11	Standard
ϕ	investment adjustment cost	3.5	Bayer et al. (2024)
δ_2/δ_1	utilization parameters	1.0	Bayer et al. (2024)
γ	Inverse Frisch	1.0	Standard
δ^B	Government debt duration	0.05	5 years avg. maturity
τ	Tax level	0.2	$G/Y \approx 17.5\%$
τ^p	Tax progressivity	0.12	Bayer et al. (2024)
τ^Ξ	Profit Tax	0.24	US Tax Code
$(\rho_R, \theta_\pi, \theta_y)$	Taylor rule parameters	(0.8,1.5,0.2)	Bayer et al. (2023b)
R^{LB}	Effective Lower Bound	$r^R_{SS} - 0.005$	2 p.p. below r^R_{SS}
(ρ_τ, ψ_B)	Tax rule parameters	(0.85, 1.25)	See text

Table 1: Externally set parameters

et al. (2016) using SCF data. This requires a value of approx. 0.0005.
λ determines the (il-)liquidity of capital and thus how many liquid assets agents wish to additionally hold for self-insurance purposes: I use it to target net liquid asset holdings by households to equal 1.8 times quarterly GDP. Firstly, it is in line with the amount of *domestically* held public debt in the US before the start of the 2020 Covid pandemic, the arguably relevant measure in my closed-economy model. However, the target is also close the average *overall* debt-to-GDP ratio for the US over the period 1970-2019 and can thus also be interpreted in this way.[13] Additionally, it is of a roughly similar magnitude as the average net amount of liquid assets held by US households (HHs) over the 2014-2019 period.[14]

Regarding household borrowing, I follow Kaplan et al. (2018) by assuming the borrowing limit to equal the average quarterly (post-tax) labor income and set the borrowing penalty $\bar{R}$ so as end up with 16% of households having $a \leq 0$ in SS. The return wedge φ is

[13]The statement regarding *domestically-held debt* is based on subtracting FRED series FDHBFIN (Federal Debt held by foreign and international investors) from FYGFDPUN (Federal Debt Held by the Public), while the overall debt-to-GDP ratio is taken from FYGFGDQ188S.

[14]For the purpose of this calculation, I take net liquid asset holdings to be the sum of cash and checkable deposits, money market funds and direct treasury security holdings minus revolving consumer credit and credit card debt. According to the Federal Reserve's Financial Accounts of the United States, on average the holdings of HHs and Non-Profit Organizations (NPOs) equalled 54% of quarterly GDP over that period. Since NPO assets are not necessarily liquid from the point of view of HHs, holdings of the latter should be somewhat lower.

Parameter	Description	Value	Target
β	Time discounting	0.9838	$K/Y = 11.44$
ζ	prob. entrepreneur state	0.0005	Wealth share top 10
λ	prob. illiquid asset adjustment	0.0363	$B/Y = 1.8$
$\bar{R}$	Borrowing penalty	0.0355	16% borrower share
$\underline{a}$	Borrowing limit	-1.4491	100 % avg. quart. income
G_{ss}	Government consumption	0.5649	Budget clearing (20)
φ	Liquidity Fixed Cost	0.0092	$r^l_{ss} = 0.0$
Ψ	Liquidity Supply		See Section 5.4

Table 2: Internally calibrated parameters

chosen so that the real return to liquid savings is 0 in SS as in Bayer et al. (2023b), which requires setting φ equal to the steady state return on capital, equal to 0.0092 in the Baseline model (a return of 3.7% in annual terms). Initially, I entertain previous assumptions on asset market segmentation, i.e. $\Psi = 0$ and $\Psi \to \infty$. Section 5.4 below will eventually propose an explicit calibration strategy.

3.3 Distributional Moments

In this section, I validate the internal calibration by analyzing various model-generated moments that were not directly targeted.

Table 3 compares various untargeted moments of the model's Steady State income- and wealth distributions with their empirical counterparts as reported by Krueger et al. (2016). The latter are based on the 2006 Panel Survey of Income Dynamics (PSID) and the 2007 Survey of Consumer Finance (SCF), respectively.[15] Arguably, the model achieves a fairly good fit, in particular for Net Worth.

Since I am employing a two-asset model, it is not only relevant to assess how closely the framework matches data moments related to the distribution of overall net worth, but also the different asset classes held by the households. I do so in Table 4: First, I am considering moments of the illiquid- and liquid wealth distribution separately. In particular, I compare them with statistics reported by Kaplan et al. (2018), who rely on the 2004 SCF. As in the data, the model generates a more unequal distribution of liquid assets and ownership of both asset classes is concentrated in their respective Top 10%, with the bottom 50% holding hardly any. Also, the model moments of the illiquid asset distribution are close to the data, mildly under-predicting the share of the Top 10%. However, for liquid assets, I generate a comparably more equal asset distributions, with the share held by the Top 10% not as high and the share of the Next 40% substantially larger than in the SCF data. But, as noted by Kaplan et al. (2018), it is "notoriously challenging" to match the extreme right tail of wealth distributions with income risk alone. From that perspective, I view

[15] In the data, disposable income is defined as the sum of after-tax earnings, income generated by assets held as well as unemployment benefits. In the model, it only compromises the first two as there is unemployment. In both model and data, Net Worth relates to both liquid and illiquid assets.

	Disposable Income		Net Worth	
	Model	Data	Model	Data
Quint. 1	6.8	4.5	0.0	-0.2
Quint. 2	10.8	9.9	1.2	1.2
Quint. 3	14.8	15.3	4.2	4.6
Quint. 4	20.6	22.8	11.0	11.9
Quint. 5	46.9	47.5	83.8	82.5
Gini	0.40	0.42	0.80	0.78

Note: "Data" refers to moments computed by Krueger et al. (2016) using PSID and SCF.

Table 3: Distributional moments comparison

Moments	Model	Data (incl. source)
Illiquid asset shares		(from Kaplan et al., 2018)
Top 10%	67.1	70
Next 40%	31.4	27
Bottom 50%	1.5	3
Liquid asset shares		(from Kaplan et al., 2018)
Top 10%	74.7	86
Next 40%	24.6	18
Bottom 50%	0.7	-4
Hand-to-Mouth (HtM) Status		(from Kaplan et al., 2014)
Share HtM	29.0	31.2
Share Wealthy HtM	17.6	19.2
Share Poor HtM	11.4	12.1

Table 4: Portfolio moments: Model vs. Data

my model's performance as satisfactory.

Finally, I analyze how many households are *Hand-to-Mouth* (HtM) in the sense of Kaplan et al. (2014), i.e., whether their liquid asset holdings are less than 2 weeks ($\approx 1/6$ of a model period) of current household income above of either 0 or the borrowing constraint. I also classify them as "Wealthy HtM" if they additionally hold illiquid assets and "Poor HtM" if they do not. The model matches the empirical evidence on the size of either group of agents well. As visualized in Figure 1, these low liquid-wealth agents tend to have particularly high MPCs. In turn, my framework is able to generate an average quarterly MPC of 15.8% and an average annualized MPC of 36.7%.[16] The former is of a similar magnitude as the corresponding value reported by Kaplan et al. (2018).

[16] I compute individuals' annualized MPCs $aMPC$ as $aMPC = 1-(1-qMPC)^4$ following Carroll et al. (2017). Note that these *annualized* MPCs will not exactly equal individuals' *annual* MPCs.

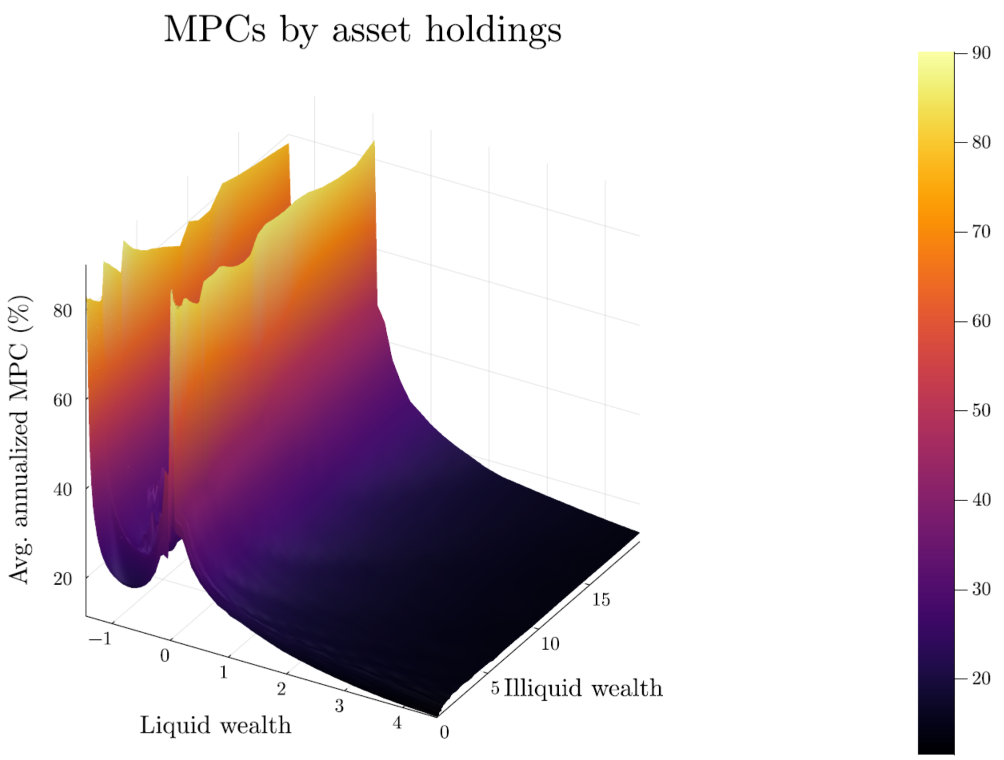


Figure 1: Model MPC distribution

4 Fiscal implications for monetary policy

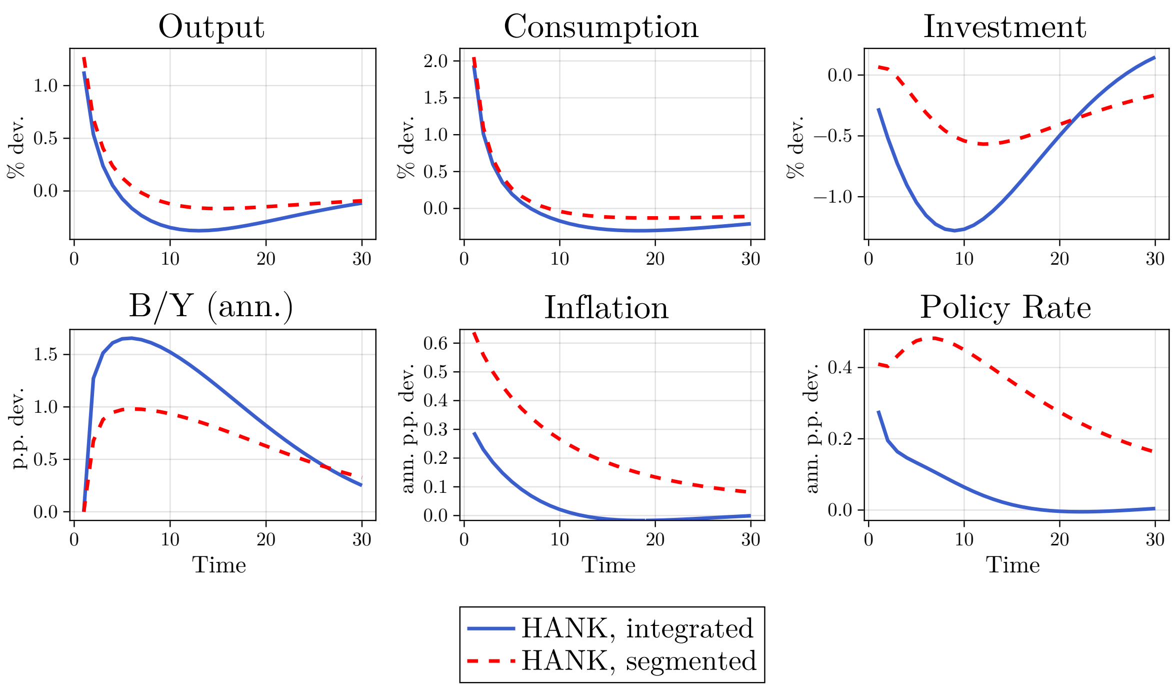
Armed with the suitably calibrated model, we are now ready to study the aggregate effects of fiscal policy and monetary-fiscal interactions in the model. For this purpose, I first study the aggregate response to expansionary fiscal policy shock before turning to the models determinacy properties and the self-financing result highlighted in the previous literature. Additional robustness checks of the main insigts are provided in Appendix C.

4.1 Aggregate effects of fiscal stimulus

To keep the analysis in this subsection as transparent as possible, I consider a particular simple fiscal policy shock: The only exogenous disturbance will be a one time-shock to government transfers T_t without any persistence, which may be viewed as the government sending out "stimulus checks". To aid this interpretation, I choose the size of the shock to amount to 2% of Steady State GDP. In terms of the USA's 2019 GDP, this would amount to circa USD 1,300 per capita, roughly the size of the one-time payments distributed under the CARES act in 2020.

The response of key aggregate variables to the fiscal stimulus is depicted in Figure 2, both for the cases with integrated and segmented asset markets. Qualitatively, the responses under either model version align: The response of consumption looks as we would expect in a model featuring a high of amount of HtM-households with high MPCs, increasing substantially at impact and fading out after a few quarters. Output and inflation simi-

Figure 2: Model IRFs to transfer shock



Note: B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State. An expanded figure with more IRFs is provided as Figure F.5 in Appendix F.

larly increase at impact, causing the central bank to raise its nominal rate. At the same time, investment decreases, which reflects crowd-out amid higher real interest rates after the shock. This, in combination with slowly increasing taxes to combat the now-higher public debt, causes the output- and consumption-responses to turn negative after a few quarters.

Quantitatively, however, we see stark differences: Inflation and the policy rate rise much more in the segmented $\Psi \to \infty$ scenario, which causes the market value of public debt to increase less to the devaluation of the nominal long-term debt. Additionally, investment declines much less, which stabilizes the output responses after a few quarters. This contrasts with the consumption response, which looks very similar in either case. Thus, in my overall conventional 2-asset HANK model, the asset market structure is a key driver of fiscal policy's impact on inflation and equilibrium interest rates. It does not seem work through the consumption behavior usually emphasized by the HANK literature, but through the extent to which investment is crowded out by higher public debt.

4.2 Policy rules and determinacy

The literature on monetary-fiscal policy interactions has traditionally also been concerned with the issue which combinations of monetary and fiscal policy rules can ensure macroeconomic stability by ruling out explosive equilibrium paths or equilibrium multiplicity.

Here, I conduct such an exercise for my HANK model under both integrated and segmented asset markets. Specifically, I ask which combinations of θ_π (the inflation reaction of the central bank) and ψ_B (the response of the tax level to public debt) give rise to a unique and non-explosive equilibrium. For comparability with the previous literature, I assume here that $\theta_y = 0$, i.e. that the central bank does not respond to output directly.
The results of that exercise are displayed in Figure 3, where the outcomes for the alternative scenarios are contrasted with the ones of a RA version of the model.[17] Clearly, the latter provides for the classical Leeper (1991)-dichotomy that a unique and determinate equilibrium requires either an inflation reaction above 1 if the fiscal authority is committed to stabilize its debt - the “active monetary, passive fiscal” (AM-PF) regime - or a reaction below 1 if that is not the case - the “passive monetary, active fiscal” (PM-AF) regime. With integrated asset markets, we see that in the ψ_B-range consistent with active fiscal policy in RANK, macroeconomic stability can be achieved with an inflation reaction slightly above one. Moreover, some values in the RANK’s “passive fiscal” region work with a θ_B slightly below one. Overall, though, the model’s determinacy patters are rather close to a standard RANK economy.
The picture changes completely under segmented assets. In this case, we see a single connected determinacy region in the (θ_π, ψ_B)-space not resembling the AM-PF and PM-AF quadrants in RANK. We also notice the set of ψ_B inconsistent with a strong central bank response to inflation is noticeably expanded. Overall, it seems that asset market structure is also crucially for whether a given monetary-fiscal policy mix can achieve macroeconomic stability, and particularly for the extent to which that differs between HANK and RANK.

4.3 Self-financing

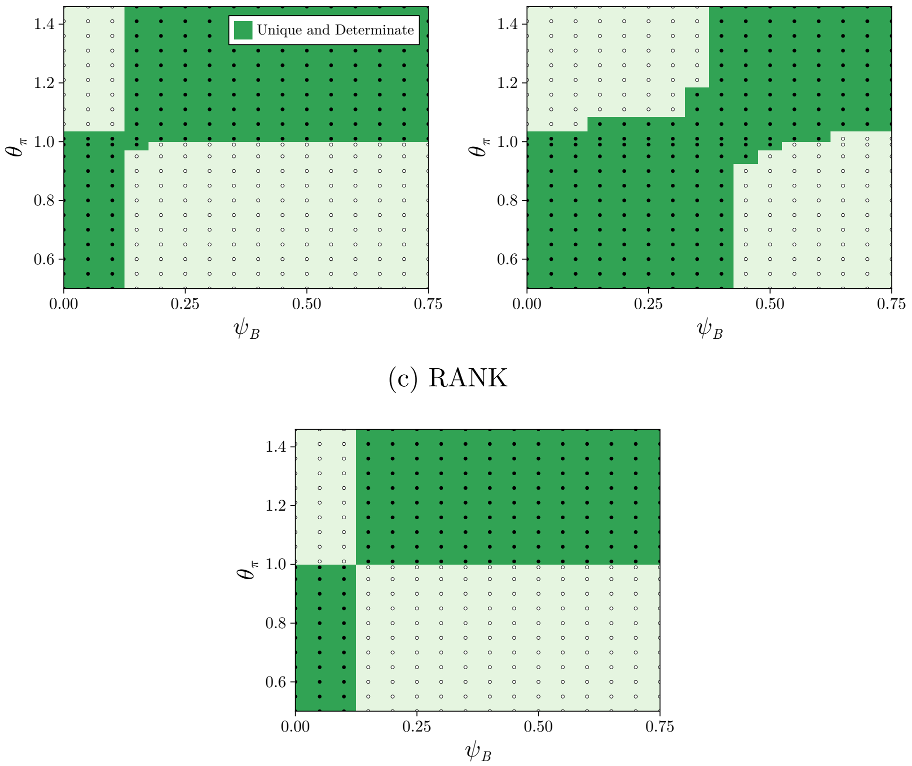
The recent work by Angeletos et al. (2024a) demonstrated that non-Ricardian New Keynesian models such as HANK potentially allow for fiscal stimulus that is self-financed: If monetary policy doesn’t lean strongly against inflation, then the government can finance fiscal expansions (almost) without increasing tax rates or decreasing spending. Inflation-driven debt devaluations and a higher tax base due to the expansion can be sufficient.
Above in Section 4.1, we already saw that the HANK model’s asset market structure matters significantly for either margin. Therefore, it should also be important for the possible extent of self-financing. To make this more obvious, Figure 4 follows Angeletos et al. (2024a) by considering a scenario with a small monetary response to inflation, $\theta_\pi = 1.05$. To ease comparability with other work, I again set $\theta_y = 0$ as well. Note that this scenario would still correspond to “active” monetary policy in a RANK economy.
Under segmented markets, the response of output is noticeably stronger compared to the

[17] In the RA version, all parameters are unchanged, while the household block is replaced with a representative agent with discount factor $1/(1 + r_(ss)^k)$. Since a no-arbitrage condition between capital and public debt has to hold in an RA framework, it furthermore assumes integrated asset markets with $\varphi = 0$.

Figure 3: Determinacy analyses

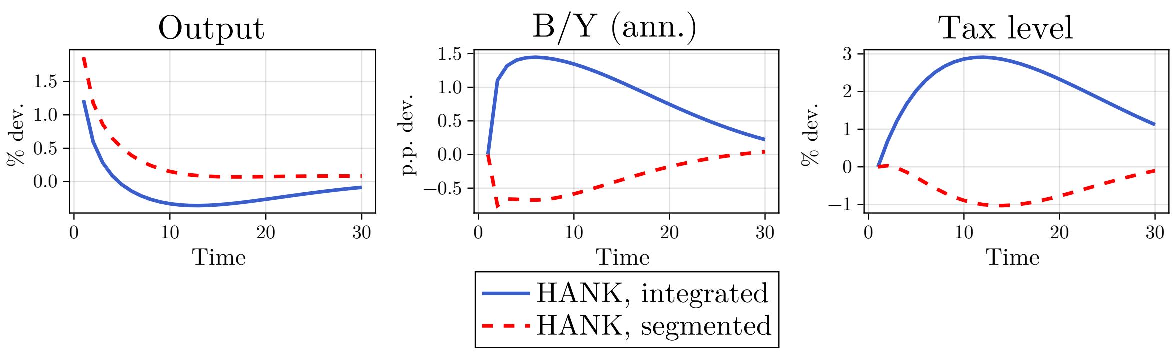
(a) Integrated markets $\Psi = 0$ (b) Segmented markets $\Psi \to \infty$

(c) RANK



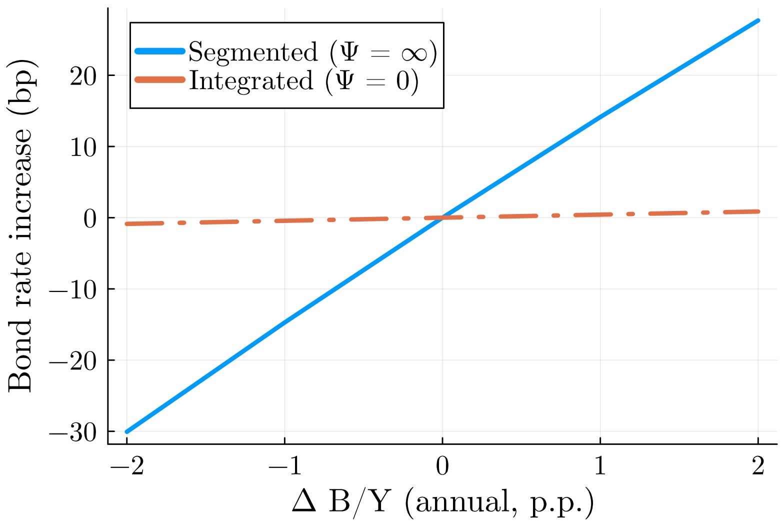
Note: Dots indicate the evaluated parameter combinations.

Figure 4: Model IRFs: Self-financing



Note: The figure displays IRFs to a one-time transfer shock under $\theta_\pi = 1.05$ and $\theta_y = 0$. B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State.

Figure 5: Model: Long-run effects of gov't debt on bond returns



Note: $\Delta B/Y$ denotes the change in the gov't debt-to-GDP ratio compared to the Baseline Steady State.

baseline and we notice self-financing features: The real value of public debt even declines at impact, which the fiscal authority's instrument rule translates into even lower net tax rates. This is, however, accompanied by high and persistent inflation. It contrasts clearly with the response under integrated asset markets: Output eventually declines below its original level due to the capital crowd-out and we still need noticeable tax increases to stabilize public debt. Clearly, the remarkable possibility of self-financing fiscal stimulus seems to also depend on macro-level assumptions on liquid asset supply and not just the (again identical) micro-level patterns of consumer behavior emphasized by Angeletos et al. (2024a).

5 Liquidity Supply and Fiscal Inflation in HANK

In the previous Section, we found that the HANK model's asset market structure crucially shaped its aggregate response to fiscal shocks as well as its determinacy properties. Why is that? As I will elaborate in this section, the key is that the differing scope for public debt to crowd-out capital strongly affects the impact of public debt on the "natural" or "neutral" rate of interest.

5.1 Public debt and the natural rate

To illustrate the effect of public debt supply on the natural rate in a way abstracting from the model's real and nominal adjustment frictions, I analyze how the return to government bonds changes with public debt in the long run. In either model version, this is equivalent to the change in the long-run natural rate of interest. The exercise involves computing new steady states for higher and lower Debt-to-GDP ratios under the parameterization specified in Section 3 and yields Figure 5.[18]

We clearly see very different impacts of government's debt to supply on the return to its bonds. Under segmented asset markets, a 1 p.p. higher annual Debt-to-GDP ratio causes the annual steady state real treasury return $1/Q^B + (1-\delta^B)$ to increase strongly by approx. 15 bp. In case of the integrated asset market ($\Psi \to 0$), we have the opposite: The response of the real liquid rate is hardly noticeable.

Considering empirical attempts to estimate the effects of public debt supply, does either of these effects plausible? According to a summary in Rachel and Summers (2019), such estimates indicate medium- to long-term effects of 3 and 6 basis points (bp) per percentage point increase in the Debt-to-GDP ratio. Under the segmented market assumption ($\Psi \to \infty$) the effect is much stronger, almost 3 times *more* than the upper end of the empirical estimates. In the integrated asset market part, it is much *smaller*, amounting to not even a third of the empirical estimates' lower range (dashed line).

These results encapsulate insights that should be of interest beyond the immediate focus of this paper on monetary-fiscal interactions: Firstly, it indicates that assumptions on asset markets are of first-order importance for model-based analyses of secular interest rate changes (such as Platzer and Peruffo, 2022). Secondly, a stronger response of interest rate to public debt is supply is often taken to imply a stronger crowd-out of capital (see, e.g., Laubach, 2009). The comparison above shows that this does not need to be the case in 2-asset models, as the segmented asset market version provides for less crowd-out than the integrated one.

5.2 The mechanism

Having established that the asset market structure is key for public debt's effect on the long-run natural rate, why should that matter much for the differences in aggregate responses and determinacy? The different investment responses are easy to rationalize, as public debt can freely crowd out capital under integrated but not under segmented markets. But why the differences in inflation?

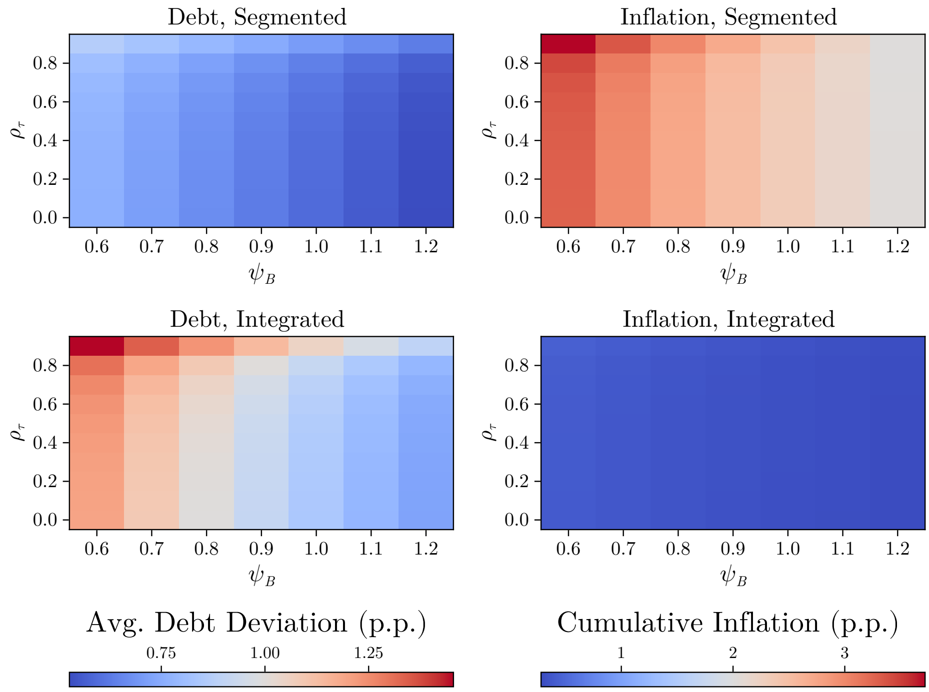
In that regard, it is useful to consider a simplified version of the model's central bank reaction function, a textbook Taylor rule of the form

$$1 + i_t = \pi^* R^* + \theta_\pi(\pi_t - \pi^*), \tag{25}$$

allowing for a positive net inflation target π^*. R^* denotes the natural (gross) rate consistent with the steady state level of government debt B^g_{ss}. Now, the amount of government debt in circulation rises temporarily to $B^g_1 > B^g_{ss}$. Notice that we can add and substract a term

[18] For the exercise, the following assumptions on government policy are made: The central bank adjusts its nominal rate target so that $\pi_{ss} = 1$ is also achieved in the new steady state. At the same time, the fiscal authority keeps G_{ss} at the same value as in the Baseline SS and adapts the tax level τ_t to clear its budget.

Figure 6: Debt and Inflation under alternative fiscal policy



Note: The panels on the left-hand size indicate the average percentage-point (p.p.) deviation of public debt (market value) relative to annualized GDP during the first 40 quarters after a one-time transfer shock as in Section 4. The panels on the right-hand side indicate cumulative inflation during the same period.

$\tilde{R}(B_1^g)$ to (25) and re-write it as

$$1 + i_t = \tilde{\pi}_1 \tilde{R}(B_1^g) + \theta_\pi(\pi_t - \tilde{\pi}_1) \quad \text{with} \quad \tilde{\pi}_1 := \pi^* \frac{\theta_\pi - R^*}{\theta_\pi - \tilde{R}(B_1^g)}. \tag{26}$$

If $\tilde{R}(B_1^g) > R^*$, then $\tilde{\pi}_1 > \pi^*$ as long as $\theta_\pi > \tilde{R}(B_1^g)$. So, if public debt rises and the central bank sticks to rule (25) while the current debt-dependent neutral rate $\tilde{R}$ is de facto higher than R^*, the central bank would seem to operate as if having a higher "implicit" inflation target. This effect is the stronger the more equilibrium interest rates depend on public debt supply and active even if the public debt level eventually returns to its original value (and the long-run natural rate doesn't actually change).

To back up that argument, I re-solve the model under various combinations of the parameters ρ_τ and ψ_B that determine the persistence of the tax level and its responsiveness to the value of public debt, respectively.[19] For the same transfer shock as in the previous Section 4, Figure 6 indicates for each of these combinations the induced average deviation of public debt during the first 40 quarters (10 years) as well as cumulative inflation under the that period: The results for the segmented HANK model are displayed in the upper panels and the ones for the integrated $\Psi = 0$ version in the lower ones.

Unsurprisingly, combinations of high ρ_τ and low responsiveness ψ_B result in higher public debt. In the segmented asset market HANK, this is systematically associated with signif-

[19] All considered combination result in stable and determinate equilibria.

icantly stronger increases in the price level. In comparison, in the $\Psi = 0$ case with very small effects of public debt supply on liquid interest rates, we always see lower inflation and a much less pronounced association with public debt. This affirms that the combination of a higher value of public debt and a high responsiveness of the neutral rate to its supply is crucial for the model's inflation response.

Finally, equation (26) is also useful to understand the differences in model determinacy properties. We have

$$\frac{d\tilde{\pi}_1}{d\pi_t} = \frac{\theta_\pi - R^*}{(\theta_\pi - \tilde{R}(B_1^g))^2} \frac{d\tilde{R}(B_1^g)}{dB_1^g} \frac{dB_1^g}{d\pi_t} \tag{27}$$

so if the neutral rate increases in public debt, inflation-induced debt devaluations $\frac{dB_1^g}{d\pi_t}$ increase (decrease) the "implicit" monetary policy stance $\tilde{\pi}_1$ if $\theta_\pi > R^*$ ($\theta_\pi < R^*$). This counteracts the extent to which the central bank induces higher (lower) real interest rates in response to inflation and thus results in a fuzzy separation between "active" and "passive" monetary policy. (27) furthermore suggests this to become more pronounced the stronger the effect of public debt on the neutral rate, i.e. the higher $\frac{d\tilde{R}(B_1^g)}{dB_1^g}$ is, which rationalizes the stronger deviation from RANK under segmented markets. Additionally, consider that if $\frac{d\tilde{R}(B_1^g)}{dB_1^g}$ is high, positive deviatons of public debt raise fiscal authority's real refinancing costs more strongly and a higher ψ_B is necessary to stabilize debt in the absence of a favorable monetary policy stance.

5.3 The role of household heterogeneity

Above, we saw that different asset market structures in HANK models importantly shape their implications for monetary and fiscal interactions. Yet, it is unrelated to household heterogeneity in that various assumptions are consistent with the same steady state micro moments. How do these effects not present in typical RA models come about then? And are these (perhaps surprising) implications simply a peculiarity of the model proposed in this paper or a more general feature of (2-asset) HANK models?

Investigating the sources of this result suggests there to be both a subtle relation to the model's micro moments and the results being relevant for a broader class of models: As is well known, such frameworks need to feature a sufficiently high gap between the return on liquid and illiquid assets to give rise to relatively high MPCs (c.f. Kaplan and Violante, 2022). With that, the model can generate a substantial number of Wealthy HtM agents as households are incentivized to forego holding large amounts of liquidity in order to reap the illiquid assets' higher returns. In that case, however, it also seems intuitive that if agents are to hold more liquid government bonds, they will have to be compensated with substantially higher returns. This argument, in turn, predicts the interest rate effects of public debt in 2-asset HANK models with *segmented* asset markets to be closely linked to their initial return gap and MPCs. On the other hand, with *integrated* markets, public debt can just crowd out a bit of the much larger capital stock and does not necessarily require households to hold substantially more liquid assets. Therefore, there is no reason to expect a strong connection.

To analyze the link between the initial return gap and interest rate effects of public debt supply in the segmented $\Psi = \infty$ case more formally, I re-calibrate my baseline framework to provide for lower steady state return gaps. In particular, I aim for the new parameterization to remain consistent with the aggregate moments targeted in 3.2 and just increase the long-run rate of capital depreciation δ_0: Keeping all other externally-set parameters the same and matching the same targets, increasing δ_0 in several steps from 0.0175 to 0.025 (still a common calibration choice) will yield substantially lower capital returns and thus rate gaps in the resulting stationary equilibria.[20] A summary of the respective parameter results is provided in Appendix Table E.1: Overall, if the model is to remain compatible with the same moments under a lower returns gap, it requires a higher λ (i.e., capital to be less illiquid) and households to be more patient (higher β). The former is because the lower rate gap makes capital relatively less attractive, so it needs to be less illiquid for the aggregate household portfolio to remain the same. In turn, the latter is necessary as a higher δ_0 decreases the returns of capital. This obliges households to be more patient if they are to still hold the same amount.

Figure 7 then visualizes the implications of different initial return gaps: In Panel 7a, we see that calibrating the model to be consistent with a lower initial return gap indeed decreases the elasticity of government bond returns with respect to bond supply in the case of segmented asset market (solid line). In fact, it can even generate a response within the 3-6 b.p. range if the return gap is low enough. But as Panel 7b illustrates, this will render the model unable to generate high average MPCs and substantial amounts of HtM households. In line with the arguments above, under *integrated* asset markets, the response of interest rates to public debt supply doesn't change much with the calibration and is always low (dashed line in Panel 7a).

The above results also suggest a tension in the HA(NK) literature on fiscal policy: While both high MPCs and their liquidity supply effects were previously argued to be important for the aggregate effects of fiscal policy, the common assumptions of segmented or integrated markets prevent both mechanisms exerting plausible effects at the same time. [21]

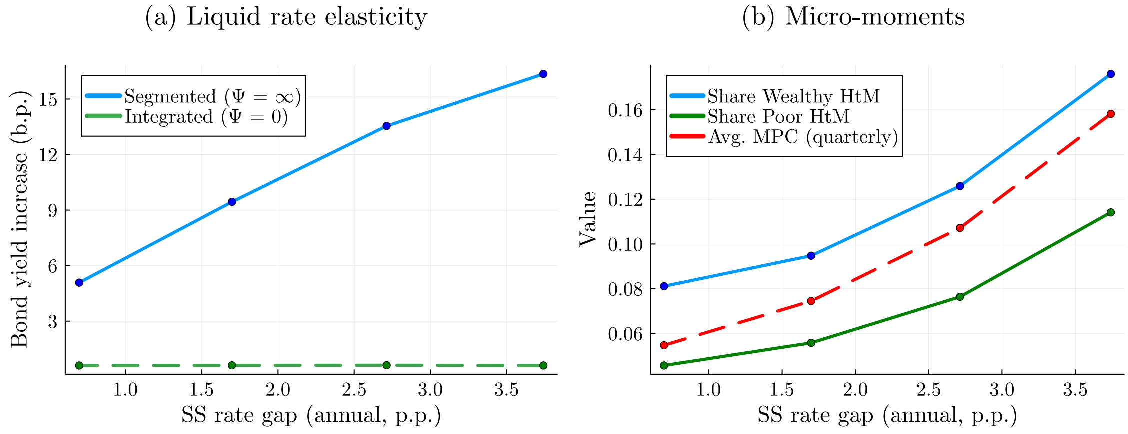
5.4 Disciplining the asset market

Overall, the above results for the off-the-shelf assumptions on asset market structure are somewhat unsatisfying. This is not only because they fail to generate certain results but also indicate a drawback of heterogeneous agent business cycle theory: While related

[20] This exploits the close connection between capital returns and the (targeted) K/Y-ratio in Cobb-Douglas production functions: In steady state, (13) requires $r_t^k = \alpha \frac{1}{\mu_{ss}} \frac{Y}{K} - \delta_0$.

[21] While e.g. Bayer et al. (2023a) report their framework to generate a long-run response of liquid rates to public debt supply in line with the Rachel and Summers (2019) summary, their calibration seems to imply a rate gap of only 1.5% annually as well as an average quarterly MPC of less than 5%, i.e., their framework does not seem to escape the calibration trade-off.

Figure 7: Implications of steady state return gaps



Note: "Bond Yield Increase" refers to the difference of the annualized bond yield $\frac{1}{Q^b} + (1 - \delta^B)$ from the calibrated Steady State after solving for a new stationary equilibrium with 1 p.p. higher annual Debt-to-GDP ratio. "SS rate gap" denotes the difference between annualized r^k and r^l in the calibrated steady state.

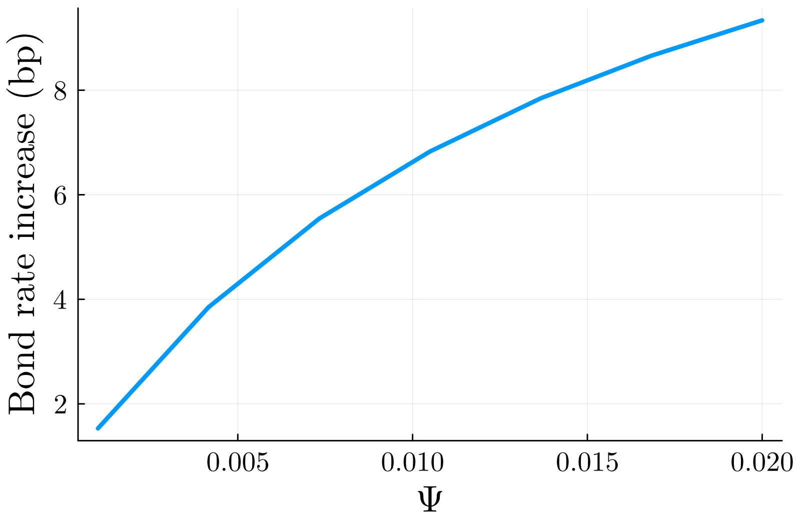
frameworks can relate to rich cross-sectional evidence, they may also require subtle modelling choices that matter for aggregate outcomes but cannot be disciplined by micro-data alone. Instead, further macro-discipline is required as well.

Of course, my set-up casting the model's asset market structure in terms a single parameter Ψ immediately suggests a resolution for the particular issue at hand: If the effects of public debt supply on its returns are overly strong for $\Psi \to \infty$ and overly weak for $\Psi \to 0$, then a value in between will presumably result in a reasonable magnitude. To explore this possibility, Figure 8 displays, for different values of Ψ, how much the steady state return of treasury securities changes after a long-run 1 p.p. increase in the Debt-to-GDP ratio. We see that for values between 0.003 and 0.0075, the liquid return reaction in the model economy is indeed in line with the range from Rachel and Summers (2019). As baseline calibration, I will adopt $\Psi = 0.005$, which results in a response close to Laubach (2009)'s estimate of 4 basis points.

6 How relevant is public debt's liquidity value for monetary policy?

Having proposed a calibration for the HANK's model asset market segmentation in Section 5, we can now examine whether the liquidity margin of Ricardian equivalence still provide for meaningful monetary-fiscal interactions once reasonably disciplined. In that regard, I start with the simple fiscal shock and determinacy exercise familiar from Section 4, before moving on to a richer scenario inspired by the US post-2020 episode.

Figure 8: Treasury return responses by Ψ



Note: "Bond rate increase" refers to the difference of the annualized bond yield $\frac{1}{Q^b} + (1 - \delta^B)$ from the calibrated Steady State after solving for a new stationary equilibrium with 1 p.p. higher annual Debt-to-GDP ratio.

6.1 Simple fiscal shock and determinacy

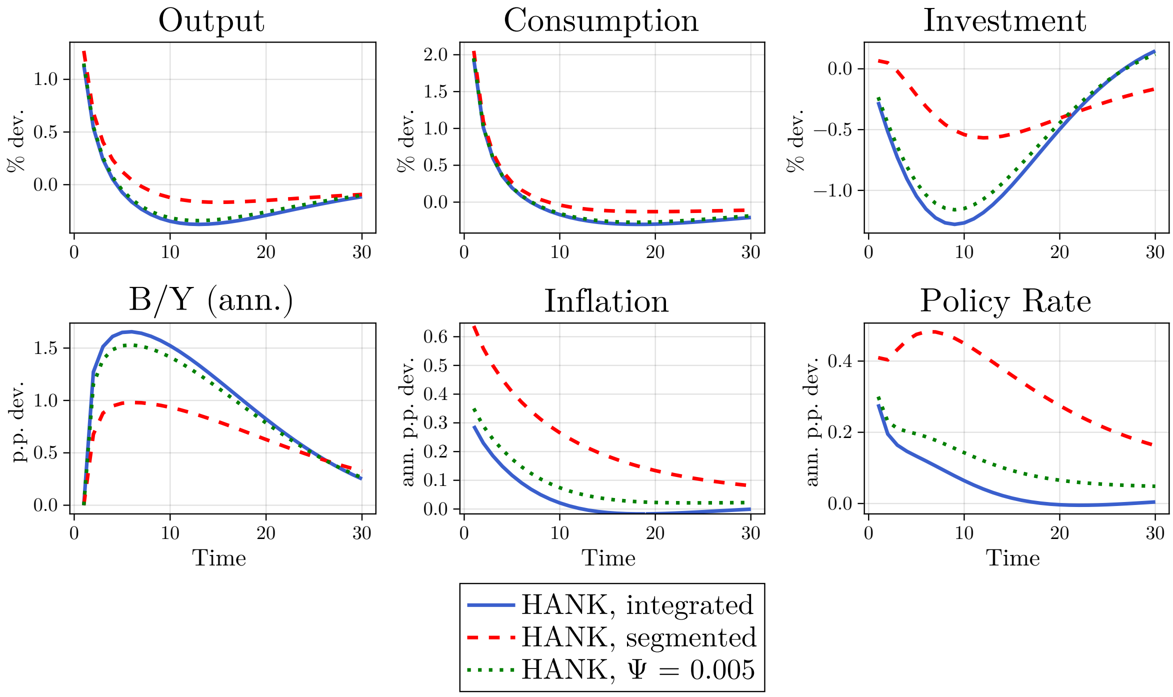
Figure 9 provides the model responses already analyzed in Section 4 and contrasts them with the calibrated model version featuring $\Psi = 0.005$. Overall, the responses resemble the model version with integrated $\Psi = 0$ asset market much more than the segmented case. Compared to the former, investment turns out slightly higher while inflation and the policy rate remain low-key elevated following the shock. Naturally, the latter is due to the still-elevated public debt exerting upward pressure on the neutral rate. Overall, while the calibrated version naturally retains the fiscal non-neutrality stemming from the presence of constrained households, the additional relevance of government-provided liquidity seems rather moderate. Of course, this is for a scenario in which the overall increase in debt is moderate and expected to be reined in within a few years.

The similarity between the calibrated and fully integrated asset market setups also carries over to the self-financing exercise: Compare Appendix Figure F.6. Turning to determinacy, the related results are displayed in Figure 10. As for the fiscal IRFs, the result is "in between" the ones for the segmented and inegrated cases. Nevertheless, the parameter region providing for a unique stable equilibrium doesn't closely resemble the four RANK quadrants provided as in Figure 3c. So, even the reasonably calibrated liquidity value of public debt provides for a noticeable deviation from the RA case.

6.2 An application to the post-2020 US

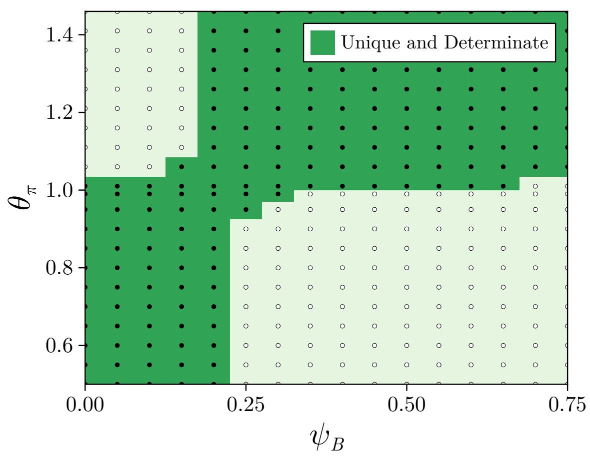
The liquidity effect of public debt supply seemed to be of limited relevance for monetary policy in the simple scenario above. Does that change in a situtation with a large and longer-lived fiscal expansion? To provide an answer connecting to real-world events, I

Figure 9: Model IRFs to transfer shock



Note: B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State.

Figure 10: Determinacy analysis with $\Psi = 0.005$



Note: Dots indicate the evaluated parameter combinations.

apply my model to the post-2020 US in a stylized experiment.

To analyze and conduct counterfactuals for this episode, we need the model to generate a situation in line with the economic dynamics of that time. Hence, I use the filtering algorithm proposed by McKay and Wieland (2021) to obtain sequences of the model's 5 business cycle shocks that make the framework match the evolution of 5 aggregate variables during the period 2020:Q1-2024:Q2.[22] The method can account for an ELB and is described in more detail in Appendix A.3.

Recall that the HANK model's 5 shocks contain two supply shocks (investment technology, "cost push"/markup), a demand shock (discount factor) and two policy shocks (monetary policy, transfers). Under the assumption that the economy was in steady state in 2019, these exogenous disturbances will be used to replicate the subsequent evolution of aggregate output, investment, inflation, the central bank's policy rate as well as government transfer spending. For the real variables subject to trend growth, this refers to the relative deviation from their pre-pandemic trends instead of levels.[23] For further information on the construction of the targeted variables, please refer to Appendix B.

The choice of the 5 business cycle shocks mentioned above is motivated as follows: The discount factor shock is supposed to induce pandemic-related consumption restraints as in Bardóczy et al. (2024), which requires additional investment shocks to not give rise to counterfactual higher capital accumulation. The monetary policy- and transfer shocks are needed to replicate the time-paths of the policy rate and transfer payments while the "cost-push" introduces another source of supply side inflation. I intentionally do not model other Covid-related spending programs such as support for corporations as it is less clear to whom these should be assigned in my framework. Given that this will result in my model generating less public debt than in the data, I view this as a conservative choice.

Since the number of shocks equals the number of target variables, the McKay and Wieland (2021) filtering method does not require me to take a stance on the variance of the business cycle shocks. However, assuming that all shocks follow $AR(1)$-processes, I still need to make assumptions on their persistence in order to compute the necessary IRFs. My calibration choice is presented in Table 5: The values for the supply shocks (μ, Z^I) and the discount factor disturbance (A) are set to salient values in the ballpark of Bayer et al. (2024)'s estimates. Since many of the big transfer expansions during the pandemic period were designed to be short-lived, I further assume the autoregressive parameter of the transfer shock to be a low 0.5. As the rate smoothing term of the monetary policy rule (19) already provides for a persistent impact of the rate shock ϵ^R, the latter does not depend on its previous value. To ensure that the short-lived transfer shocks result in a long-lived debt response, I furthermore reduce fiscal responsiveness to for $(\rho_\tau, \psi_B) = (0.94, 0.5)$.

[22]This period was chosen to sidestep the challenge of having to relate to the numerous economic governance changes due to the re-election and inauguration of US President Trump.

[23]Strictly speaking, I cannot match transfer spending's relative deviation from trend in my model as transfer payments are zero in its stationary equilibrium. Instead, I match the deviation of transfers relative to trend output.

	Z^I	μ	ϵ^R	A	T
AR(1) persistence	0.75	0.9	0.0	0.9	0.5

Table 5: Assumed persistence of model shocks

These values were chosen so that public debt does not noticeable decline before 2026 in the filtered baseline scenario.

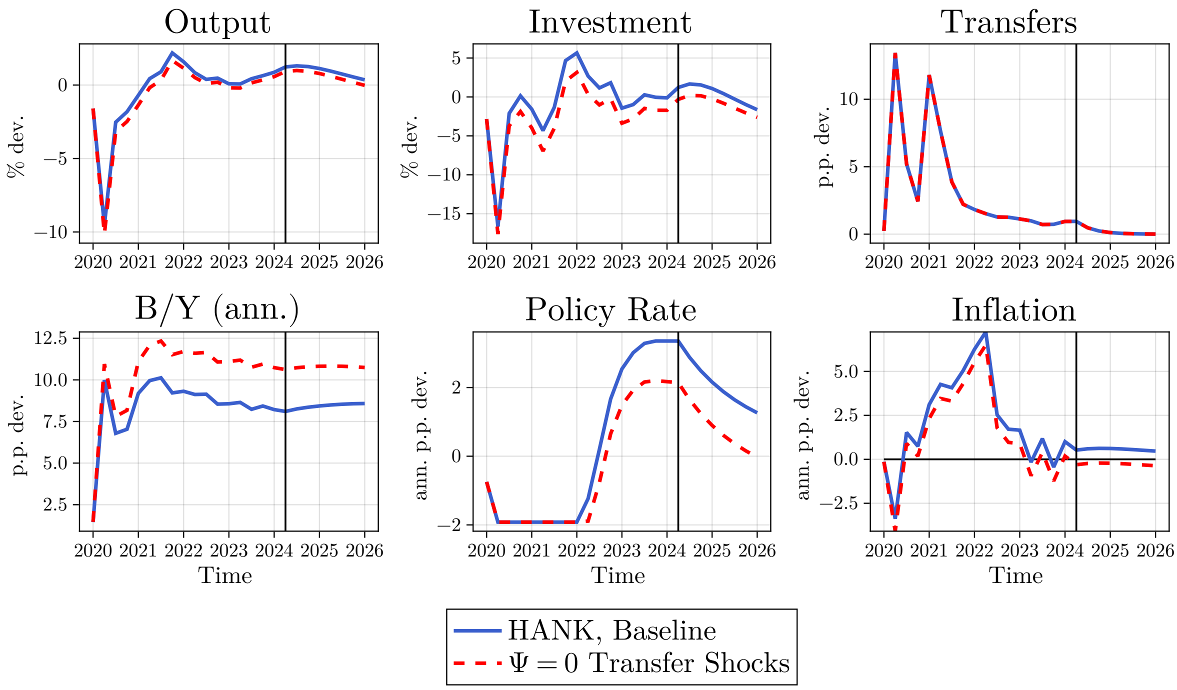
Naturally, the resulting analyses will have various caveats. Firstly, my model doesn't feature any Covid-related features such as lock-downs but rather assigns the observed aggregate dynamics during 2020-2021 to standard business cycle shocks. While in line with other DSGE model-based investigations of the post-pandemic inflation (e.g. Gagliardone and Gertler, 2023; Bianchi et al., 2023), the model does thus only provide a simplistic account of various pandemic-specific phenomena. This includes the nature of transfer payments made by the government, which are assumed to consist solely of uniform lump-sum payments for the purpose of this exercise: Since transfers specifically aimed at poor agents with high MPCs tend to have larger effects in HANK models, this simplification can again be seen as a conservative choice. Secondly, the fact that the analysis is based on a linearized model means that we will miss out on non-linearities that may be relevant for the large shocks occurring during the period under consideration. Again, my analysis shares this reservation with numerous other studies of the US post-2020 period (including the two cited previously). Finally, all the results obviously depend on the assumption of underlying policy rules: Under different ones, e.g., a partly active fiscal policy regime as in Bianchi et al. (2023) instead of the active Taylor rule, the same aggregate dynamics might be assigned to different shocks.

Post-2020 US: Aggregate dynamics

Using the set of aggregate shocks obtained as described above, we can now simulate the model from 2020:Q1 forward: The dynamics of several key macroeconomics aggregates are displayed as the blue solid line ("Baseline") in Figure 11. Note that by construction, the time paths of all displayed variables except the public debt variable (B/Y) and consumption equal their counterparts in the data until my sample ends in 2024:Q2 (indicated by the black vertical line). Beyond that point, the model is simulated forward without any additional shocks hitting, implying the targeted variables deviate from their empirical counterparts.

In the beginning of 2020, we see real variables such as output and investment take a big hit, accompanied by declining inflation and the central bank's policy rate hitting its ELB. Through the lens of the model, this is mostly due to a combination of households' Covid-related consumption restraints (i.e., the discount factor shock) and an unfavorable investment technology disturbance. At the same time, public debt relative to GDP jumps up, both due to the decline in the denominator and a big shock to transfers, the targeted

Figure 11: Aggregate dynamics using filtered shocks



Note: B/Y represents the market value of public debt B^g over annualized GDP.

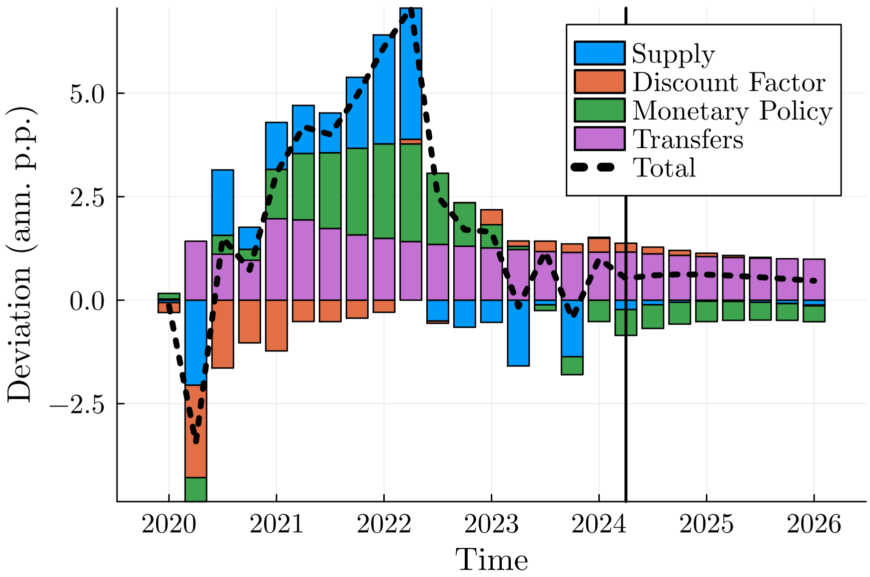
time path of which is displayed in the top-right panel. Of course, as I also illustrate in Appendix D.1, the model increase in debt is smaller than its relevant counterpart in the data, given that I only target transfer spending.

Afterwards, the economy recovers quite quickly: In the HANK model, this is partly due to the initial shocks easing quicker than expected, i.e., expansionary discount factor- and investment technology innovations, and also aided by accommodative monetary policy as well as another spike of transfers at the beginning of 2021 (the American Rescue Plan Act). Eventually, inflation starts to rise precipitously amid output and consumption above their pre-covid trends, inducing the Federal Reserve (Fed) to start raising its nominal rate in the beginning of 2022. Price pressures ease quickly initially, but inflation remains elevated above target and is indeed predicted to do so for quite some time into the future. At the same time, the model's value of public debt relative to GDP has not substantially declined since its peak at the beginning of the pandemic.[24] Naturally, by now we expect the final two phenomena to be linked.

Are the implied model dynamics plausible considering non-targeted model moments and subsequent (non-matched) macroeconomic dynamics for the US? A respective analysis is provided in Appendix D.1. To briefly summarize its results, the model has difficulties relating to some labor market moments during the Covid-pandemic and recovery thereof. This is arguably not surprising, as its simple labor-market setup is ill-suited to capture the specifics of the Covid unemployment surge. Nevertheless, the fact that it matches

[24]Under the fiscal rule in place, public debt starts declining in late 2026.

Figure 12: Decomposition of inflation



Note: "Supply" collects the impact of both the "cost-push"- and the investment technology shock.

later developments in aggregate labor compensation suggests that it captures important economic drivers of the later inflationary period. Additionally, the model's unconditional forecasts of the time paths of inflation and the Fed funds rate beyond 2024:Q2 seem roughly in line with expectations at the time.

6.3 Post-2020 US: Model-implied determinants of Inflation

To better understand to what extent the neutral-rate driven "debt inflation" is related to the persistent last mile inflation in the model, Figure 12 exploits the linearity of the model solution to decompose the inflation response into the contribution of different shocks. As already explained above, the deflation at the beginning of the Covid pandemic is due to a combination of discount factor- and supply shocks, partly counteracted by the strong increase in transfers.[25] Interestingly, while the McKay and Wieland (2021) filtering method assigns the 2022 peak in inflation to adverse supply shocks, it also suggests the combination of government transfers and accommodative monetary policy to be the key drivers of inflation during 2021-2022. My model exercise thus supports the findings of Giannone and Primiceri (2024) who argue such "demand side" factors to be the most important determinants of the post-Covid price pressures. Incidentally, the strong decline of inflation in 2022:Q3 is interpreted to be due to an unexpected easing (negative innovations) of the "cost push"-shocks, perhaps reflecting the decrease of the oil price and an easing of supply chain bottlenecks at the time.

From the perspective of this paper's topic though, the most interesting observation is the persistent impact of the transfer shocks. Additionally, considering the time path

[25] The negative contribution of Monetary Policy reflects the binding nominal interest ELB.

for transfers as on Figure 11, we see that they retain a strong influence on inflation for an extended period of time after their peaks in 2020 and 2021. Indeed, the model suggests them to be the sole reason for inflation staying above target after 2023 and the continuing upward pressure on inflation going forward. To what extent is this due to transfers remaining above trend at the time as compared to the interest rate pressure exerted by the public debt stemming from previous transfers?

To gauge the importance of the transfer-induced debt as compared to current transfer levels, I again make use of the linearity of my model solution, which provides for a $MA(\infty)$-representation in that the time path of a variable model variable x_i can be expressed as

$$x_{it} = \bar{x} + \sum_{e=1}^{n_e} \sum_{i=0}^{\infty} \Theta_x^e(i) \epsilon_{t-i}^e \quad ,$$

where $\Theta_x^e(i)$ denotes the i'th entry of the IRF of variable x with respect to shock e. Specifically, I simulate my model using that representation but propagate the transfer shocks according to the "wrong" IRF from the $\Psi = 0$ economy with integrated asset markets: This attempts to (almost) "shut down" the effect of transfer-related public debt supply on aggregate demand and liquid asset returns. The result of this model exercise is displayed as the red-dashed line in Figure 11. We see that in the absence of that channel, the post-Covid inflation would have practically been over in the beginning of 2023 and remain at or below the Fed's target afterwards. As in Section 6.1 above, this is accompanied by a less pronounced central bank reaction, lower investment as well as a more pronounced increase in the value of government debt. While the differences in inflation may seem small compared to the very high inflation peaks in 2022, Figure 13 indicates them to be of a relevant size, amounting to more than 0.8 p.p. in annualized terms at the end of 2023.

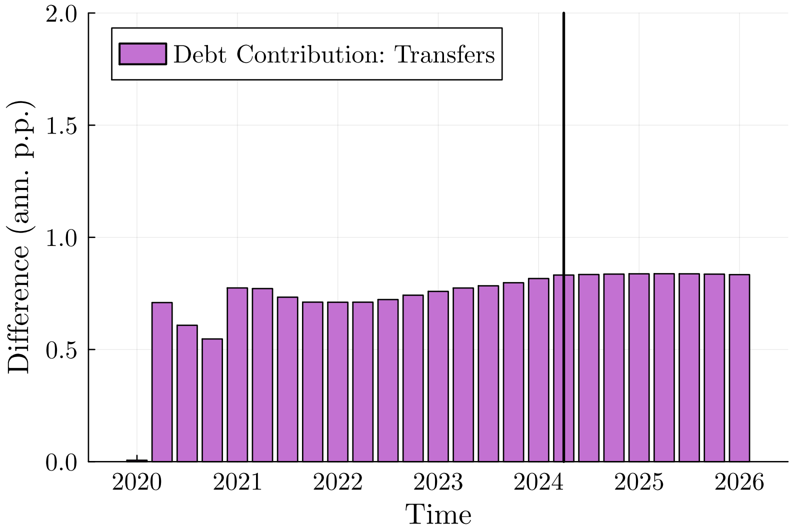
We can further back up that result by re-doing the entire exercise for the $\Psi = 0$ economy: In that case, the corresponding inflation decomposition (relegated to Appendix Figure F.7) assigns much less importance to the transfers but rather attributes the realized inflation to other shocks. It also predicts less inflation persistence going forward. Overall, the model thus suggests that public debt-driven demand pressure may plausibly exert relevant inflationary effects in the aftermath of big fiscal expansions, to the extent that it could quantitatively generate the US's post-2023 last mile inflation persistence.

6.4 Implications for monetary policy

After the previous analyses indicating relevant effects of elevated public debt levels on inflation under Taylor rule-type monetary policy, the question in which ways such feedback should and could be prevented obviously arises. Here, I shall briefly elaborate on some considerations regarding the latter, noting that welfare-optimal policy may involve complex distributional considerations in HANK models such as this.

If preventing the "debt inflation" is supposed to be achieved by building on a parsimonious policy rule, a very targeted way to do so is for monetary policy to *directly* react to

Figure 13: Inflation differences



Note: This figure displays the difference between inflation in the Baseline model and the scenario with counterfactual propagation of the Transfer shocks, i.e., the difference between the blue and red-dashed line in the "Inflation" panel of Figure 11.

public debt: Recall that the cause of the liquidity supply-driven inflation is that, under a Taylor rule, higher real interest rates on liquid assets can only come about if inflation is also higher. This mechanism is broken if, in response to higher public debt, the central bank sets a higher nominal rate at *any* given inflation level. For the purpose of this section, I shall implement this idea by replacing the $\log(1 + r^R_{ss})$-terms in the HANK model's interest rule (19) with an approximated "debt-corrected" natural rate

$$\log \tilde{R}_t = \log(1 + r^R_{ss}) + \theta^B \left(\log(B^g_{t+1}/Y_t) - \log(B^g_{ss}/Y_{ss})\right). \tag{28}$$

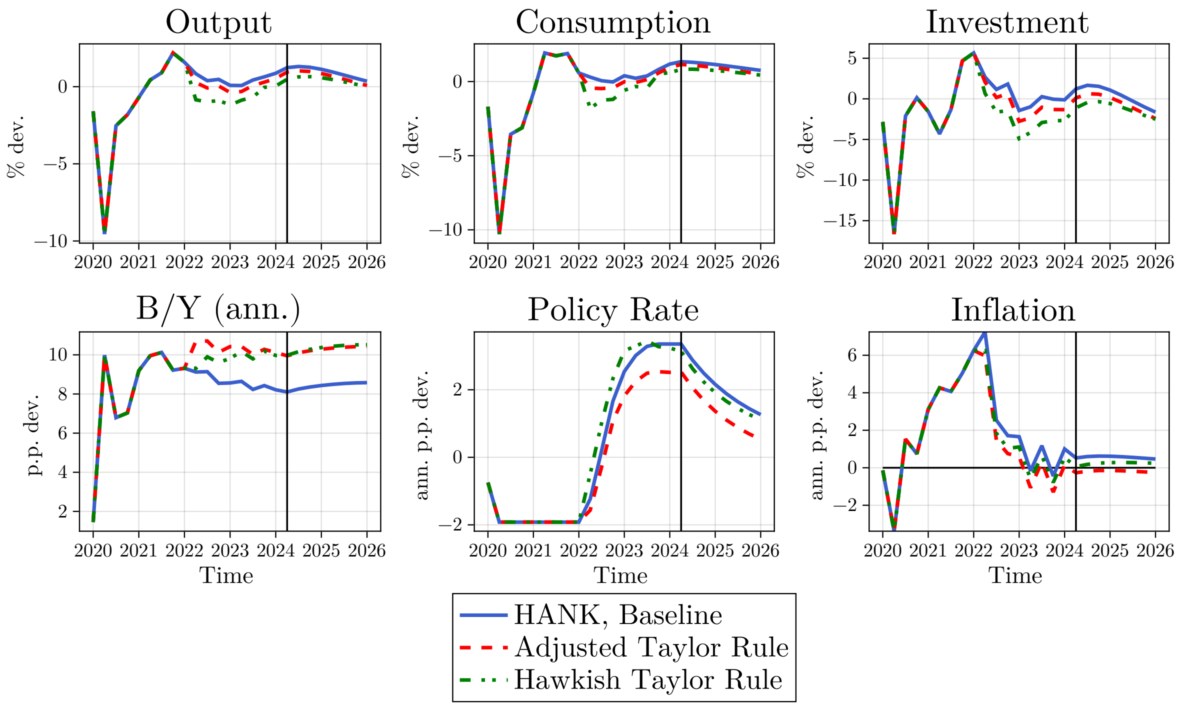
Here, θ^B denotes the approximate steady state elasticity of the gross liquid return with respect to the quarterly Debt-to-GDP ratio, which amounts to 0.0047.[26]

In addition to this adjusted Taylor rule, I consider the effects of monetary policy trying to counteract the "debt inflation" in the seemingly more conventional way of reacting stronger to changes in the price level. As a potential implementation of that approach, I assume a counterfactual in which the central bank operates rule (19) with a "hawkish" reaction coefficient of $\theta_\pi = 2.5$.

To assess the respective performance of the considered rules, I study the following scenario: In the Baseline HANK subject to the shocks obtained as in Section 6.2, the interest rate rule switches to one of the alternative rules as of 2022:Q1 when interest rates started to rise after the pandemic, perhaps reflecting policymakers' concerns about fiscal influence on the neutral rate going forward. The chosen time allows me to sidestep the issues that a) the size of the filtered monetary policy shocks are not uniquely identified under the ELB period before and b) the model does not capture the initial pandemic

[26] In their model, Bayer et al. (2023a) also allowed the central bank to react to public debt according to a different specification.

Figure 14: Post-2020 aggregate dynamics under alternative rules



Note: B/Y represents the market value of public debt B^g over annualized GDP.

recession in 2020 as well. How well would that have counteracted the suggested "debt inflation" and at what costs?

The results as displayed in Figure 14 shows that in the model, implementing the Taylor rule adjusted for the natural rate effects of public debt supply (red-dashed line) results in an outcome very similar to the counterfactual conducted in Section 6.3. In particular, it allows the central bank to avoid elevated inflation post-2023 while raising the nominal rate less. This outcome entails limited costs in terms of output and an actually higher value of public debt. The latter is again due to less pronounced devaluations.

The "hawkish" rule, in turn, achieves less effective disinflation at higher nominal rates which also happen to involve somewhat higher costs in terms of lower consumption and investment. Hence, I take the conducted exercises to suggest that direct central bank reactions to public debt may have appealing properties for tackling inflationary effects of public debt's impact on the natural rate. In particular, doing so allows the central bank to implement an outcome close to a counterfactual economy in which public debt's liquidity value and impact on inflation is very limited. In an analysis relegated to Appendix D.2, I further argue that the adjusted rule compares favorably to a Orphanides and Williams (2002)-style "Difference rule" as recently studied by Campos et al. (2024).

7 Concluding Remarks

This paper studied monetary-fiscal interactions in a quantitative HANK model. While previous works emphasized the implications of household consumption- and savings behavior of such models, I highlight that several key outcomes depend substantially on typically less prominent assumptions on the asset market. In particular, this is the case for the inflationary effects of fiscal policy, model determinacy properties and the costs of fiscal stimulus. Effectively, it does not just matter whether households have high MPCs and hold little liquid assets, but also how fundamentally scarce these liquid assets are. While the potential importance of the latter depends on the micro-moments a model aims to generate, it cannot be determined from them and thus needs to be disciplined separately. Doing so restricts the liquidity supply channel of Ricardian non-equivalence, but not enough to render it irrelevant for policy. In a stylized model experiment on the US post-Covid inflation, it is strong enough to generate the elevated "last mile" inflation in 2023 and afterwards. A central bank can, however, effectively counteract it by reacting directly to the stock of public debt.

Regarding future work, my paper pinpoints a need to thoroughly assess and discipline the asset market structure of rich heterogeneous agent models. While I address this with a simple model extension, more detailed micro-foundations may provide for interesting policy implications. Additionally, it remains an open question how optimal central bank policy should account for the liquidity effects of public debt.

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A Details on Section 2

A.1 Derivation of the wage Phillips curve

Given the uniform hours $N_{it} = N_{ut}$ for all union members and demand schedule (16), we have

$$\frac{\partial}{\partial W_{ut}} N_{ut} = -\epsilon_w \frac{N_{ut}}{W_{ut}}$$

and

$$\frac{\partial}{\partial W_{ut}} u(c_{it}) = u'(c_{it})(1-\tau_p)(1-\tau_w)\left(s_{it}\frac{W_{ut}}{P_t}N_{ut}\right)^{-\tau_p} s_{it}\frac{N_{ut}}{P_t}(1-\epsilon_w) \quad ,$$

the latter reflecting that due to the envelope theorem, the marginal utility of additional resources should equal the marginal utility of consumption. In turn, the F.O.C. corresponding to (17) is

$$(1-\tau_p)(1-\tau_w)\frac{1-\epsilon_w}{W_{ut}} \int \left(u'(c_{it}) \left(s_{it}\frac{W_{ut}}{P_t}N_{ut}\right)^{1-\tau_p}\right) di + \frac{\epsilon_w}{W_{ut}} \varsigma N_{u_t}^{1+\gamma}$$
$$-\psi\left(\frac{W_{ut}}{W_{ut-1}} - 1\right)\frac{1}{W_{ut-1}} + \beta \mathbb{E}_t \psi \left(\frac{W_{ut+1}}{W_{ut}} - 1\right)\frac{W_{ut+1}}{(W_{ut})^2} = 0 \quad .$$

If we now use that unions are symmetric and thus $N_{ut} = N_t$ and $W_{ut} = W_t$, re-arranging yields

$$\pi_t^w(1-\pi_t^w) = \frac{\epsilon_w}{\psi}\left(\varsigma N_t^{1+\gamma} - \frac{\epsilon_w - 1}{\epsilon_w}(1-\tau_p)(1-\tau_w)\int \left(u'(c_{it})\left(s_{it}\frac{W_t}{P_t}N_t\right)^{1-\tau_p}\right) di\right)$$
$$+ \beta \mathbb{E}_t \pi_{t+1}^w (1-\pi_{t+1}^w) \quad .$$

A.2 Definition of equilibrium

Definition 1. *A **Recursive Equilibrium** of the model consists of*

- *value functions* $V^a(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$, $V^{na}(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$
- *household policies* $a^a(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$, $a^{na}(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$, $k(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$ *and* $c^a(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$, $c^{na}(a_{it}, k_{it}, s_{it}, \Psi_{it}; \Gamma_t)$,
- *firm- and union policies* I_t, K_t, H_t, Y_t, u_t, B_t^l, Π_t, $y_{jt} \forall j \in [0,1]$, w_t
- *prices* h_t, r_t, q_t, r_t^l, mc_t
- *inflation* π_t
- *government policies* $G_t, B_{t+1}^g, \tau_t, r_{t+1}^R$,

so that

1. *Given prices* r_t^l, r_t, q_t, *wages* w_t *and profits* Π_t, *the value functions* $V^a(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t)$, $V^{na}(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t)$ *solve the households' Bellman equations in* (6) *and* (7) *and* $a(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t)$, $k(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t)$, $c(a_{it}, k_{it}, e_{it}, s_{it}, \Xi_{it}; \Gamma_t)$ *are the resulting optimal policy functions.*

2. *Expectations are model-conistent.*

3. $y_{jt} \in [0,1]$ *are consistent with demand schedule* (9) *and final output* Y_t *given by* (8).

4. *Inflation* π_t *is consistent with Phillips curve* (10).

5. *Given prices* h_t, r_t, q_t, mc_t *and technology shock* Z_t *the intermediate goods producers choices* K_t, H_t, u_t *are consistent with optimality conditions* (12)-(14).

6. *Given price* q_t, *the intermediate goods producers choices* I_t *are consistent with optimality condition* (15).

7. *The labor packer's zero profit condition* $h_t = w_t$ *is fulfilled.*

8. *The wage level* w_t *is consistent with* (18).

9. *The Liquid Asset Funds' portfolio choice is consistent with* (23).

10. *The return of liquid assets is given by* (24).

11. *Given inflation* π_t *and output growth* Y_t/Y_{t-1}, *the monetary authority set* r^R_{t+1} *according to* (19).

12. *Taking the remaining values as given, the government sets taxes according to* (21) *and issues debt* B^g_{t+1} *so that* (20) *holds.*

13. *The market for liquid asset clears, i.e.,*
$$A^l_t = \int_0^1 a_{it} di \quad .$$

14. *The government bond market clears, i.e.,*
$$B^l_t = B^g_t \quad .$$

15. *The capital market clears, i.e.,*
$$K_t = \frac{A^l_t - B^l_t}{q_{t-1}} + \int_0^1 k_{it} di \quad .$$

16. *The market for investment good clears, i.e.,*
$$K_{t+1} = (1-\delta(u_t))K_t + \left[1 - \frac{\phi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t$$

17. *The market for labor services clears, i.e.,*
$$H_t = N_t \int_{m^\Xi}^1 s_{it} di.$$

18. *The market for intermediate goods clears, i.e.,*
$$\int_0^1 y_t(j) dj = F_t(u_t K_t, H_t)$$

19. The final good market clears, i.e.,

$$Y_t = C_t + G_t + I_t + \frac{\phi}{2}\left[\frac{I_t}{I_{t-1}} - 1\right]^2 + \bar{R}\int_0^1 \mathbb{1}(a_{it} \leq 0)a_{it}di$$
$$- \left[\phi + \frac{\Psi}{2}\left(1 - \frac{B_t^l}{A_t^l}\right)^2\right] A_t^l$$

where $\mathbb{1}(\cdot)$ denotes the indicator function.

20. The distributions of income and wealth evolve according to household's policy function and the exogenous transition probabilities $\pi^s(\cdot|\cdot)$, ζ and ι.

A.3 Details on numerical implementation

A.3.1 Details on Steady State Solution

The household problem needs to be solved on a discretization of the state space: I choose 90 grid points for both a and k, either of which are non-linearly spaced as household decision functions tend to be more non-linear for lower levels of assets. In particular, the grid points for both a for k are spaced according to the "double exponential" rule, i.e.

$$\mathcal{X} = x_{min} + \exp(\exp(\mathbf{u}(\log(1 + \log(1 + x_{max} - x_{min})), n_i)) - 1) - 1$$

where x_{min} is the minimum value on the grid for variable x, x_{max} the maximum value and $\mathbf{u}(0, x_{max})$ a vector of equidistant points on the interval $[0, x_{max}]$. Since household value- and policy functions will feature and additional kink around $a = 0$ when the borrowing penalty kicks in, I add 5 additional grid points in the immediate vicinity of that point. Given that individual labor productivity is discretized to 17 points, this means that the household problem is solved on a tensor grid of $90 \times 90 \times (17 + 1) = 145800$ points (the "entrepreneur" status adds an "income" state to the 17 "skill" states). The discretization of the individual labor productivity process follows an off-the-shelf method à la Tauchen (1986). Whenever interpolation is needed off the grid, I use linear interpolation
For the implementation of the multidimensional EGM algorithm, I follow the replication codes for Bayer et al. (2024) closely.[27] Given the random illiquid asset adjustment, the EGM scheme only needs to iterate over marginal value functions (i.e. the derivatives of V with respect to m and k) and does not compute V directly.
For finding the steady, I iterate over r_{ss}^l and r_{ss}^k: Given these values, the remaining steady variables can be backed out and the household-problem solved. I then use a heuristic updating procedure to search for r_{ss}^l and r_{ss}^k so that the asset markets clear.

A.3.2 Details on State Space Perturbation

As already indicated in the main text, the model's dynamic equilibrium is approximated using First-Order Perturbation around its non-stochastic steady state. For the State Space

[27] As of October 2024, these replication codes are available under `https://github.com/BASEforHANK/BASEtoolbox.jl`.

perturbation à la Bayer et al. (2024), note that when using the discretized representations of the marginal value functions as well as the joint income/asset distribution, the equilibrium can be represented as the solution to a non-linear difference equation of the form

$$\mathbb{E}_t F(\mathbf{y_t}, \mathbf{x_t}, \mathbf{y_{t+1}}, \mathbf{x_{t+1}}) = 0 \tag{29}$$

as e.g. used by Schmitt-Grohe and Uribe (2004). $\mathbf{y}$ denotes a vector of control variables, which includes the households' marginal value functions on the grid and $\mathbf{x}$ a vector of state variables, which includes the discretized distribution.

In theory, one could find the linearized equilibrium using the standard approach of computing the Jacobians of F as in (29) and then solve the resulting linear difference equation relying on methods such as Klein (2000). In practice, however, such an approach would involve very high computational costs for the 2-asset HANK model, given that the full $\mathbf{y}$ and $\mathbf{x}$ have a combined length exceeding $200,000$.

To overcome this problem, Bayer et al. (2024) propose a procedure which conducts dimension reduction in 2 steps, one before computing the Jacobians and one after. Specifically, it first uses a Discrete Cosine Transform (DCT) to dimension-reduce the marginal value functions: The values resulting from such a DCT are coefficients of a fitted multi-dimensional Chebychev polynomial, of which only a subset are selected to be perturbed: Bayer et al. (2024) propose to use the nodes that are most important for describing the derivatives of the steady state marginal value functions to changes in the set of prices that households directly take into account (e.g., interest rates and the wage). The other coefficients are kept at their steady state values.

For reducing the dimensionality of the joint distribution in the first step, the authors furthermore suggest splitting it into marginals and a copula, where the latter is in effect treated as an interpolator mapping the steady state marginal distributions into the joint distribution. That "interpolator" can also be dimension-reduced through a DCT or just kept fixed, so one only perturbs the marginals as well as selected coefficients of the copula, which have substantially lower dimension. Overall, in my application the procedure manages to shrink the effective dimensionality of the system to a manageable number of approx. 1400, for which an initial perturbation solution is obtained.
The second step further reduces the set of DCT coefficients by using the first step solution to check which ones vary only very little with the aggregate shocks and are thus not important for explaining model dynamics. It is useful if the model has to be repeatedly solved for different parameters, such as for checking model stability for different parameters as e.g., in Section 4. For a more detailed exposition, see Bayer et al. (2024).

A.3.3 Details on Sequence Space Perturbation

As already mentioned in the main text, in addition to the State Space perturbation method described above, I also use a Sequence Space linearization method à la Auclert et al. (2021), as its allows to flexibly expose the economy to various news shocks. This proves useful particular for the analysis in Section 6.2: Firstly, the analysis in that Section requires the model to be able to handle a binding lower bound on the nominal interest rate. As already pointed out by McKay and Wieland (2021), this can be achieved (relatively) easily in a Sequence space setting using news shocks. The idea is that if an aggregate shock would cause the central bank (CB) to violate the ELB in a certain number of periods, one can solve for a sequence of pre-announced monetary policy (news) shocks that would keep the economy at the ELB instead. The CB then enforces the ELB by announcing exactly these shocks. Secondly, the same feature of a sequence space solution makes it easy to consider different interest rules. This is because in a linearized model, those can similarly be imposed by announcing a suitable set of news shocks to the policy rule in place (McKay and Wolf, 2023).

I obtain the Sequence Space Jacobians (SSJs) of the model's heterogeneous agent block as described in Auclert et al. (2021), although I rely on automatic differentiation instead of finite differences to ensure accuracy of the derivatives. For obtaining the general equilibrium SSJ's, I then build on the model representation proposed by Bhandari et al. (2023), which, for given Heterogeneous Agents SSJs, yields the GE SSJs as Auclert et al. (2021)'s Directed Acyclical Graph (DAG) approach.[28] I use a truncation horizon of $T = 500$ periods, as my 2-asset HANK model features relatively-long lived IRFs due to the presence of investment adjustment costs and shocks with quite high persistence.

A.3.4 Details on Filtering algorithm

To construct series of business cycle shocks making the model match given time series of observed variables, I adopt the filtering method developed by McKay and Wieland (2021). As these authors show, it can be interpreted as a restricted version of a Kalman filter. A brief description of the approach is provided below:

The method is applicable if we have a vector Y_t of n_y observed variables for a number of periods $t = 1, .., T_{obs}$ and want to obtain vectors of n_e shocks ϵ_t which make the linearized model generate the outcomes Y_t. This requires $n_e \geq n_y$, with my description below focussing on the case $n_e = n_y$ relevant for my application. Let $R(\tau, i)$ denote vectors containing $(\tau + 1)$th elements of the IRFs for the variables in Y in response to a unit change in the ith element of ϵ_t, which can be obtained using one of the solution methods described above. The matrix

$$R_\tau = [R(\tau, 1), R(\tau, 2), ..., R(\tau, n_e)]$$

concatenating these vectors horizontally thus describes how the shock vector ϵ_t affects the observables in period $t + \tau$.

It is assumed that the model is initially in steady state and that $Y_0 = Y_{ss} = 0$. Denote

[28] An example application for a simpler HANK model can be found under https://mhaense1.github.io/SSJ_Julia_Notebook/SSJ_notebook_2.html.

by Q_t cumulative effect of previous shocks on Y_t, i.e.

$$Q_t = \sum_{\tau=0}^{t-1} R(t-\tau)\epsilon_\tau \tag{30}$$

Naturally, $Q_1 = Y_0$. One can then obtain obtain $\{\epsilon_t\}_{t=1}^{T_{obs}}$ as follows: Starting from $t = 1$, get ϵ_t as

$$\epsilon_t = R(0)^{-1}(Y_t - Q_t) \tag{31}$$

and then compute Q_{t+1} as in (30). Afterwards, do the same for $t+1$ and so on.
A complication arises if the model features a potentially binding ELB on the policy rate r^R, as it indeed does in my application. While a SSJ solution allows simulating the model under an ELB by imposing it via news shocks to the monetary policy rule, a simultaneity problem arises for filtering: If the shocks as obtained in (31) would cause the model to eventually violate the ELB, adding additional news shocks will cause those ϵ_t to no longer produce the empirical Y_t. Hence, ϵ_t and the ELB news shocks need to solved for jointly, for which McKay and Wieland (2021) propose an iterative procedure that I adapt to my setting.

B Data Construction

B.1 Data for model exercise

This Appendix describes the construction of the data used for the model exercises in Section 6.2. The analysis uses the following aggregate variables, the data for which were again obtained from the Federal Reserve Economic Data (FRED) platform:

- **Nominal Rate**: The variable corresponds to the federal funds rate (FRED series FEDFUNDS).
- **Inflation**: (Gross) Inflation corresponds to the growth of the GDP deflator (GDPDEF) compared to the previous quarter.
- **Output**: (Real) Output corresponds to the sum of the following variables divided by the GDP deflator and current population (CNP16OV):
  - Personal Consumption Expenditures: Non-durable Goods (PCND)
  - Personal Consumption Expenditures: Durable Goods (PCDG)
  - Personal Consumption Expenditures: Services (PCESV)
  - Gross Private Domestic Investment (GPDI)
  - Government Consumption Expenditure and Gross Investment (GCE)
- **Investment**: Gross Private Domestic Investment (GPDI) divided by the GDP deflator and current population (CNP16OV).

- **Transfers**: (Real) Transfer payments consist of the sum of the following variables divided by the GDP deflator and current population (CNP16OV).
  - Federal government current transfer payments: Government social benefits to persons (B087RC1Q027SBEA)
  - Federal government current transfer payments: Grants-in-aid to state and local governments (FGSL)

  The definition of this variable follows Bianchi et al. (2023).
- **Hours worked:** Nonfarm Business Sector Hours Worked for All Workers (HOANBS) divided by either the level of the civilian labor force (CNP16OV) or the civilian labor force (CLF16oV).
- **Labor Compensation:** Compensation of Employees (W209RC1) divided by the GDP deflator (GDPDEF) and current population (CNP16OV).

The pre-covid trends for Output, Government Consumption, Investment and Transfers are taken to be linear time trends estimated for the respective variables over the period 2014Q1 to 2019Q4.

Finally, for the comparison between model-implied and actual public debt, I use an approximation of the market value of treasury debt held by the domestic debt public: To the best of my knowledge, there is no publicly available breakdown of the market value of US treasury debt into domestic and foreign holdings throughout the entire period 2020Q1-2024Q2. Instead, I calculate a "foreign share" s^f as Federal Debt Held by Foreign and International Investors (FDHBFIN) over Federal Debt held by the Public (FYGFDPUN) and then take the market value of domestically-held public debt to be $(1 - s^f)$ times the Market Value of Marketable Treasury Debt (MVMTD027MNFRBDAL) minus Federal government checkable deposits and currency as reported in Federal Reserve's Financial Accounts of the United States (FL313020005.Q): The latter would reduce the governments net liquid asset supply from the perspective of the model.

Implicitly, the approximation being correct requires the treasury debt portfolios held by domestic and foreign agents to not differ systematically in terms of maturity structure etc. The US Treasury (2024) reports foreign holdings to have weighted average maturity of 6.3 years, a bit but not overwhelmingly higher than the overall average.

C Aggregate response to fiscal shock: Robustness

This appendix aims to address potential concerns regarding the generality and robustness of the paper's main insights in Section 4. In particular, the respective model exercises were conducted only in the context of a particular fiscal policy scenario and the model features several parameters whose values are subject to empirical controversies.

C.1 Alternative Fiscal Shocks

Firstly, to what extent do the results in Section 4 depend on the used fiscal policy scenario? To answer this question, I firstly considered an alternative scenario with a government consumption shock instead of the transfer shock. In particular, Appendix Figure F.8 displays the macroeconomic response to a persistent increase in government consumption G, assumed to increase by 2.5% on impact and afterwards following an AR(1)-decay with persistence 0.9. While the aggregate responses naturally differ, considering different asset market structures has quantitatively comparable effects.

Secondly, I computed IRFs for the original transfer shock but assuming that the fiscal authority consolidates by reducing government consumption G instead of changing taxes. The respective results are provided in Appendix Figure F.9. For this alternative, the aggregate wealth effect due to less wasteful (in this model) government spending causes household consumption to increases slightly more and investment to decrease less. But as long public debt and hence its liquidity effect evolve similarly, there are no major changes compared to the baseline fiscal rule.

C.2 Alternative model parameterizations

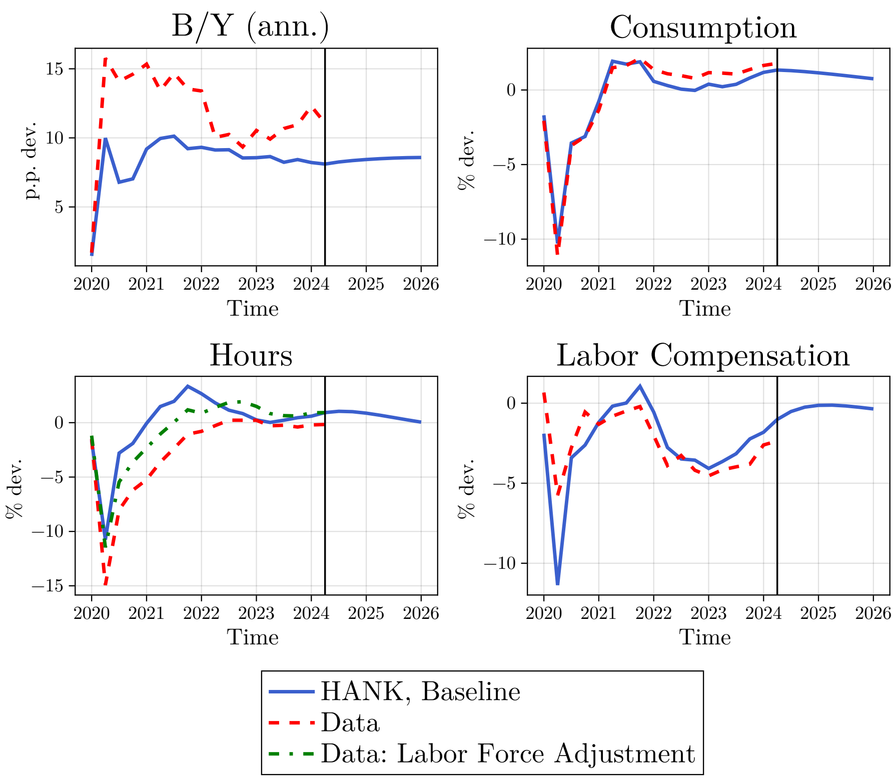
Like every New Keynesian model, the framework used for the above analysis contains several parameters subject to empirical controversies, in particularly the "slopes" of the New Keynesian Price- and Wage Phillips curves. Additionally, since investment demand was found to be important for the transmission of the debt-driven inflation, it is relevant to check to whether the above results are due to specific values for the model's capital utilization- and adjustment costs. To address this, I varied the parameters one-by-one to assert robustness with respect to the Baseline calibration's parameter choices. The resulting IRFs to the transfer shock are displayed in Appendix F and briefly summarized below.

Allowing for higher or lower price stickiness by varying the NKPC slope κ affects the absolute size of the inflation responses to the fiscal shock, but not so much the relative importance of the asset market structure. The same is the case for wage stickiness (c.f. Appendix Figures F.10 and F.11). Results are similarly robust to considering alternatives values for the investment adjustment- and utilization parameters, which affect the responses of inflation and real aggregates only moderately (Appendix Figures F.12 and F.13).

C.3 Sticky Expectations

It is well known that heterogeneous agent (HA) business cycle models struggle to match empirically estimated IRFs of aggregate consumption to some business cycle shocks: In the data, such responses are often found to be very smooth, while HA models generate initial jumps due to household's high MPCs and the absence of "habit formation" assumption. However, several authors argued that HA models extended with "sticky expectations", in

Figure D.1: Non-targeted variables: Model vs. Data



Note: B/Y represents the market value of public debt B^g over annualized GDP. The construction of the data series is specified in Appendix B.

that households only infrequently update their information about macroeconomic aggregates, can resolve the tension(see Carroll et al., 2020; Auclert et al., 2020).

Here, I address the potential concern that my baseline model's "debt inflation" dynamics may hinge on its (perhaps less desirable) full information rational expectation assumptions and introduce sticky expectations as in Auclert et al. (2020). I assume that households update their information with a quarterly probability of 10%, close to the estimation result in Auclert et al. (2020) and more sticky than in the calibration of Carroll et al. (2020). The corresponding results for the transfer shock are displayed in Appendix Figure F.14: The responses are quite similar to the baseline in Section 4 and the key insight on the relevance of the asset market structure is essentially unaffected.

D Auxiliary model analyses

D.1 Comparison for untargeted variables

In this Appendix, I gauge how well the model relates to some non-targeted moments so as to be able to judge what aspects of the economy it does or does not capture well. Again, the construction of the additional data used here is specified in Appendix B. The top-left panel of Figure D.1 compares the relative value of public debt in the model with an approximation of the market value of domestically held US federal debt in the data. As anticipated, the model generates a smaller expansion, implying that if anything, my exercise have under-estimate the amount of "debt inflation" for a given calibration.

While aggregate consumption was not directly targeted in the construction of the shocks, the resulting fits the data very well: This is not surprising as in the model (and reality), the by far most important components of GDP are private investment and consumption. Having targeted both output and investment, a good fit for consumption is essentially by construction.[29]

A relevant and more interesting set of non-targeted model variables relates to labor supply. Here, the success of my model partly depends on which data moment one would consider the most relevant real-world counter-part for the simple set-up in my HANK model: In the center panel of Figure D.1, we observe that if one follows the common convention of using Hours Worked divided by the aggregate population (red-dashed line), my model substantially over-estimates the labor supply recovery after the pandemic. In contrast, if adjusting by the size of the civilian labor force (green dot-dashed line), it does a better job.

Given that the conventional DSGE labor market set-up in my model is arguably too simplistic to capture details such as time-varying participation and composition-effects important during the pandemic recovery, a perhaps more reasonable demand is it matching well the overall amount of labor compensation paid ($h_t H_t$ in the model), which directly matters for the model households' aggregate consumption- and savings decisions. While my model overstates the initial drop at the beginning of the pandemic, it matches its subsequent dynamics well, exuding confidence that the HANK framework captures the relevant economic forces at work at least after 2020.[30]

Finally, one may be wondering whether the model's forecast of elevated inflation and a decreasing federal funds rate is at odds with the developments after 2024:Q2. On this issue, recall that the forward simulation does not account for subsequent shocks hitting the economy and any further disturbances could of course explain the difference. Indeed, from the perspective of 2024:Q2, inflation expectations in my model do not seem unreasonably out of touch with various measures of inflation expectations at the time: According to the Cleveland Fed's model of inflation expectations, 1- and 2-year expected inflation was approx. 2.7% and 2.6% in June 2024, respectively. The May 2024 Survey of Professional Forecasters suggests an expected inflation of 3.1% for 2024 and 2.5% for the period 2024 - 2028, while FOMC member's inflation expectations ranged between $2.5 - 3.0\%$ for 2024 and $2.2 - 2.5\%$ for 2025 at the time (c.f. Federal Open Market Committee, 2024). For comparison, my model's predicted inflation rate is approx. 2.7% for 2024 and 2.6% for

[29]The fact that the match is not perfect is due to the variables being de-trended separately and the dynamics of government consumption not being targeted.

[30]The smaller initial drop in labor compensation despite the strong fall in hours at the beginning of the Covid-pandemic is due to composition effects, with much more low-income than high-income workers being laid off in early 2020.

2025. There is less publicly available data for expectations about the federal funds rate. The model-implied values, approx. 3.2% for the end of 2025 and 2.9% for the end of 2026, fall within the ranges of the June 2024 FOMC Summary of Economic Projections (SOEP), although only at the lower end for 2025 (again, see Federal Open Market Committee, 2024).

D.2 Evaluation of the Difference rule

As alluded to in the main text, another possibility to counteract the "debt inflation" might be the so-called Difference rule originally proposed Orphanides and Williams (2002) and suggested by Campos et al. (2024) to address public debt's interest rate effects. These authors formulate it as

$$\log(1 + r^R_{t+1}) = \log(1 + r^R_t) + \theta_\pi \left(\log(\pi_t) - \log(\pi_{SS})\right), \tag{32}$$

i.e., it resembles a Taylor rule with the previous nominal rate replacing the usual long-term r^*: This has the appealing property of not requiring any knowledge of a neutral rate whatsoever. It is worth noting, though, that despite the similar appearance, it implies a quite different conduct of monetary policy. In particular, the rule requires the central bank to never cut the nominal rate as long as inflation remains above target (but keep raising it instead). For the quantitative evaluation, I initially follow Campos et al. (2024) by parameterizing the Difference rule in the same way as the Taylor rule, i.e., $\theta_\pi = 1.5$.

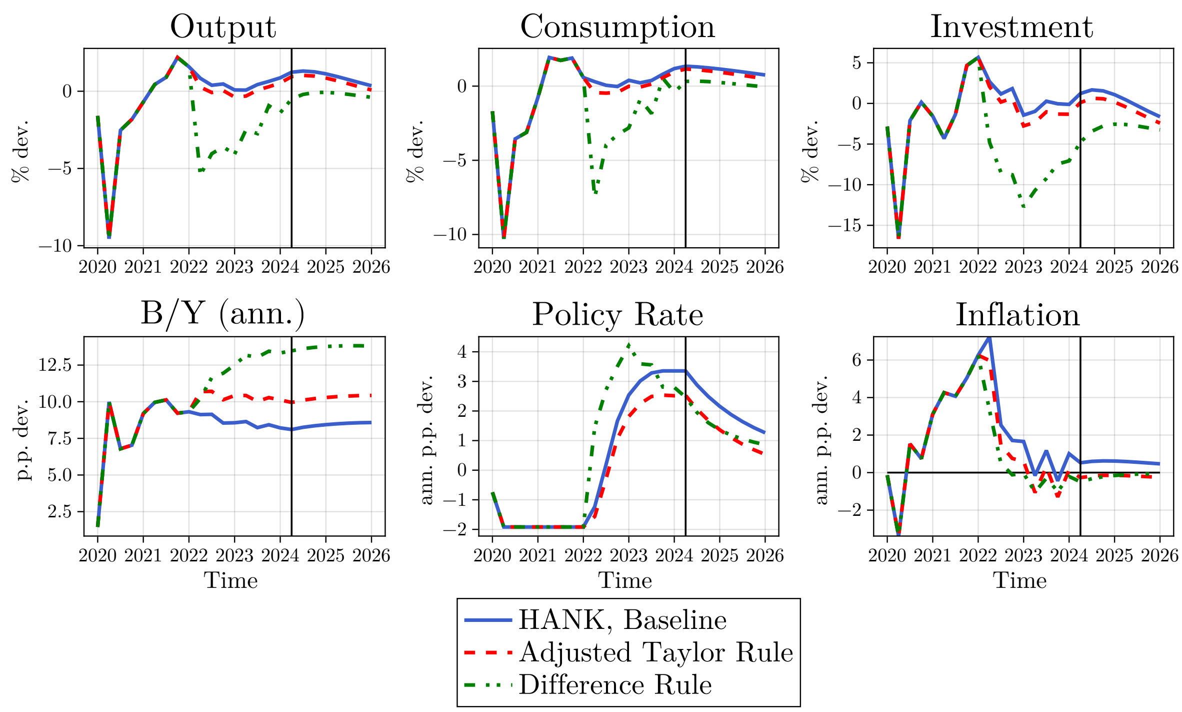
For the post-2022 scenario, this yields the dynamics displayed in Figure D.2. While the difference rule is able to eliminate inflation rapidly, it induces stark declines of consumption and investment amid a rapidly rising nominal rate. While I do not evaluate welfare and central banks are typically assumed to be willing to accept some costs in real activity to counteract rising price levels, it seems questionable that policymakers would have preferred this outcome to the Baseline. What explains these results? Actually, the difference rule is very "hawkish" if calibrated with the same θ_π as a Taylor rule: Reformulating it as

$$\log(1 + r^R_{t+1}) = \rho_R \log(1 + r^R_t) + (1 - \rho_R) \left(\log(1 + r^R_t) + \frac{\theta_\pi}{1 - \rho_R} \left(\log(\pi_t) - \log(\pi_{SS})\right) \right)$$

to resemble a Taylor rule with nominal rate persistence indicates that the latter's corresponding inflation reaction would be a very strict $\frac{\theta_\pi}{1-\rho_R} = 7.5$ under a standard $\theta_\pi = 1.5$ and $\rho_R = 0.8$ parameterization. Since the Difference rule does not require the familiar condition $\theta_\pi > 1$ to ensure determinacy, one can alternatively consider the parameterization $\theta_\pi = (1 - \rho_R) \times 1.5 = 0.3$. This yields mixed results: If subjected to the same monetary disturbances as the Baseline interest rule, it would induce very persistent but less severe output losses, but if not, result in an outcome somewhat similar to the debt-adjusted Taylor rule (see Appendix Figures D.3 and D.4, respectively). The former outcome likely reflects that a Difference rule reacting little to the current situation but necessarily depending strongly on the previous policy stance will have to "carry around" monetary policy shocks for a long time and thus exacerbate their effect.

Overall, it seems that while the Difference rule holds conceptual appeal and may induce desirable dynamics in various scenarios, it also seems to provide for downsides in richer

Figure D.2: Response to transfer shocks: Alternative rules incl. Difference rule



Note: B/Y represents the market value of public debt B^g over annualized GDP.

Rate gap	δ_0	β	ζ	λ	$\bar{R}$	G_{ss}
3.74% (Baseline model)	0.0175	0.9838	0.0005	0.0363	0.0355	0.5650
2.71%	0.02	0.9866	0.0004	0.067	0.0299	0.5832
1.70%	0.0225	0.9894	0.0003	0.1068	0.0222	0.5986
0.69%	0.025	0.9921	0.0003	0.1760	0.0131	0.6137

Table E.1: Alternative calibrations used in Section 5.3

settings featuring, e.g., inefficient "cost-push" shocks and/or monetary policy shocks. Ensuring that established operating procedures are sufficiently responsive to government debt supply and that this is widely understood may thus be a better option, although its welfare effects should be investigated further.

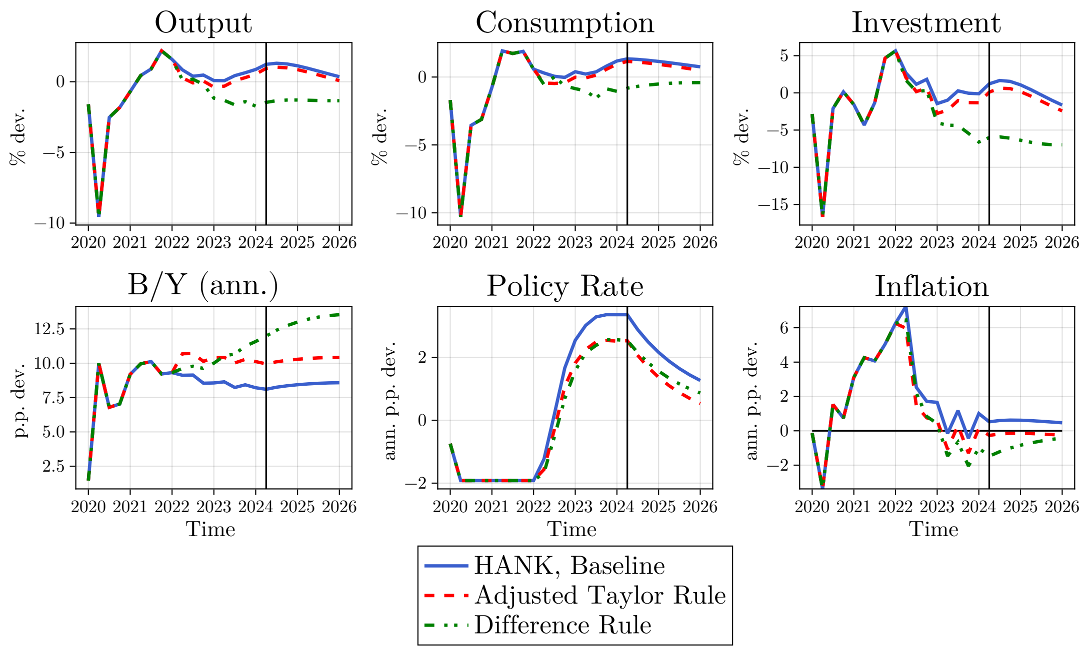
E Additional Tables

This Appendix contains auxiliary Tables referred to in the main text.

F Additional Figures

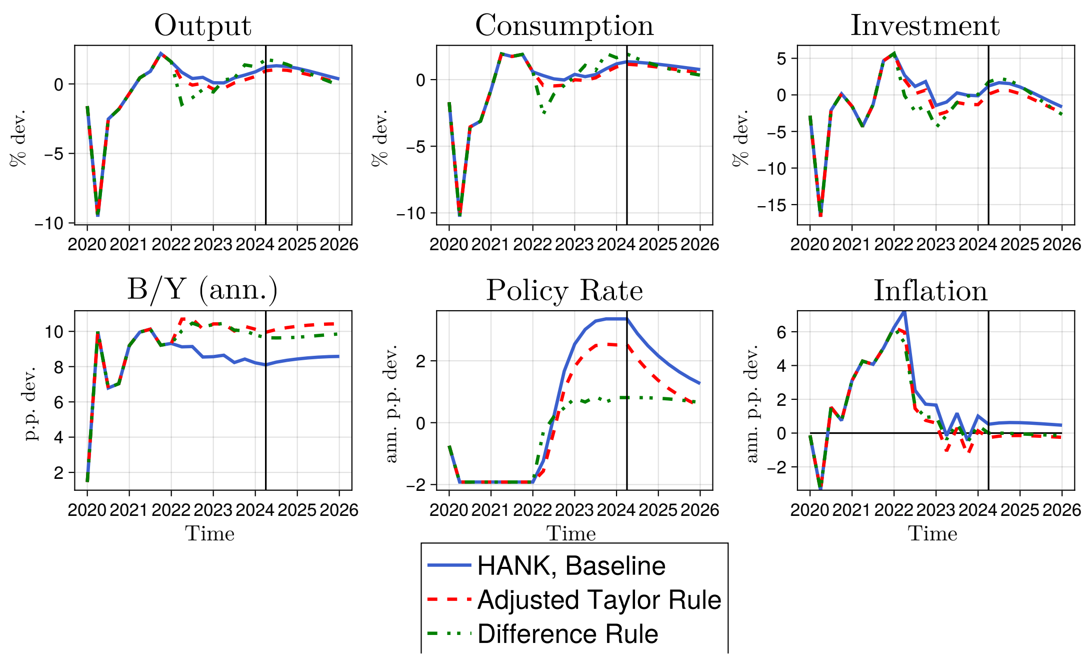
This Appendix contains auxiliary Figures referred to in the main text.

Figure D.3: Alternative rules: Difference rule with $\theta_\pi = 0.3$



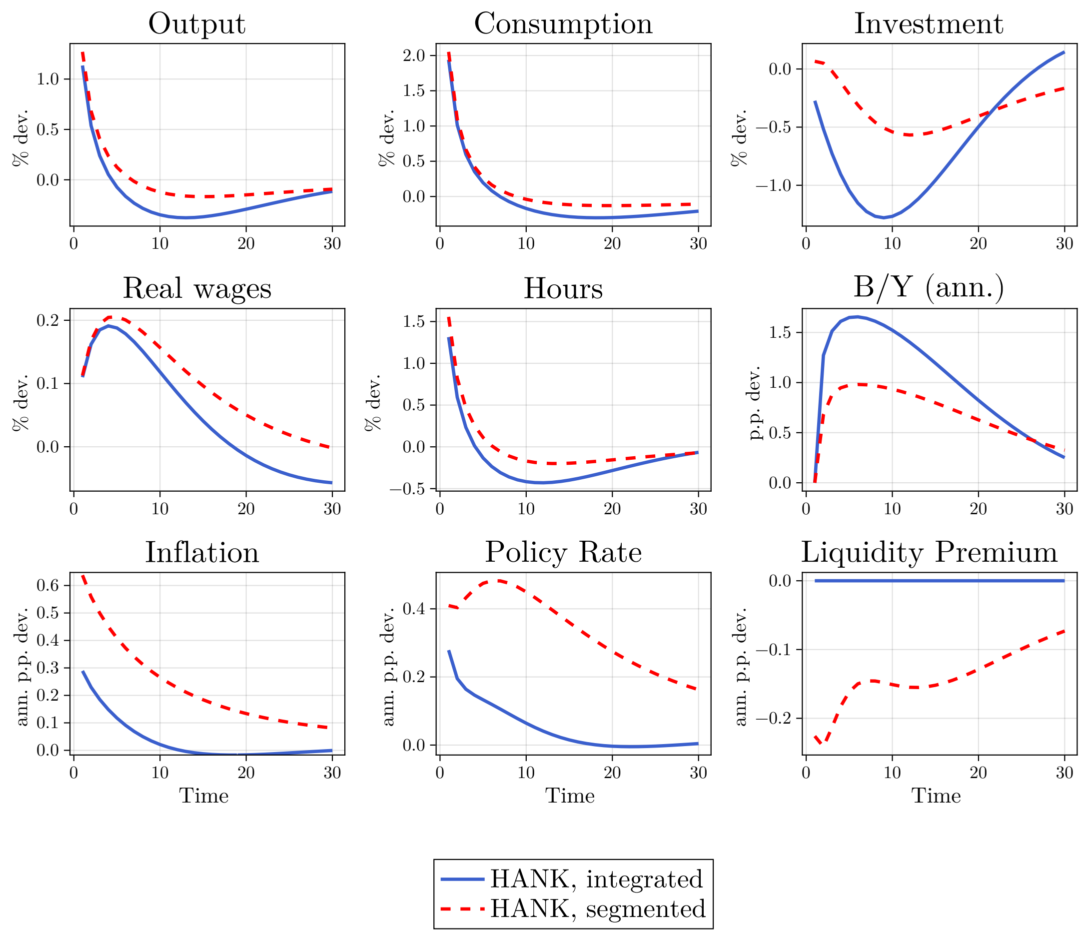
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure D.4: Alternative rules: Difference rule with $\theta_\pi = 0.3$ and no monetary shocks



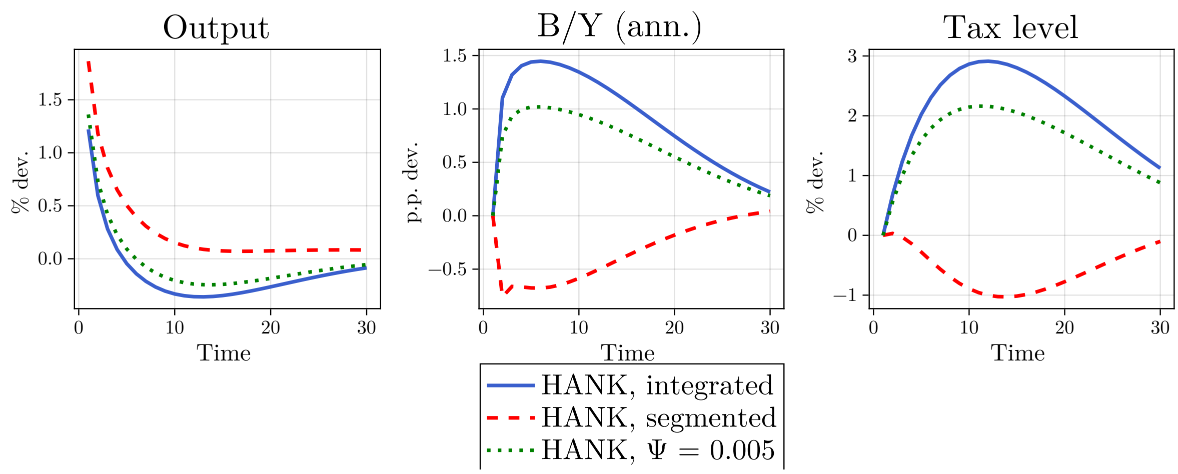
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure F.5: Model IRFs to fiscal shock



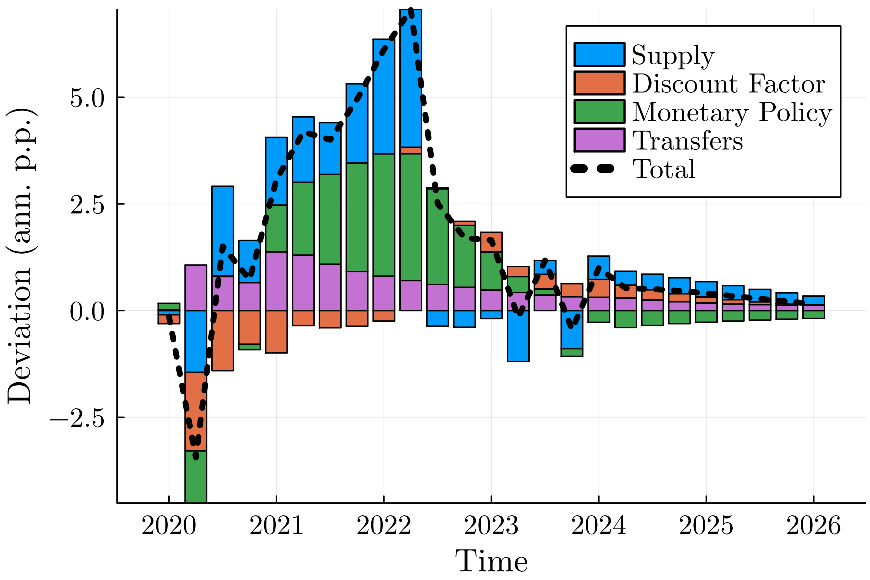
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP. The liquidity premium is defined as $\mathbb{E}_t\left(\frac{q_{t+1}+r^k_{t+1}}{q_t}-\frac{R^r_t}{\pi_{t+1}}\right)$.

Figure F.6: Model IRFs: Self-financing



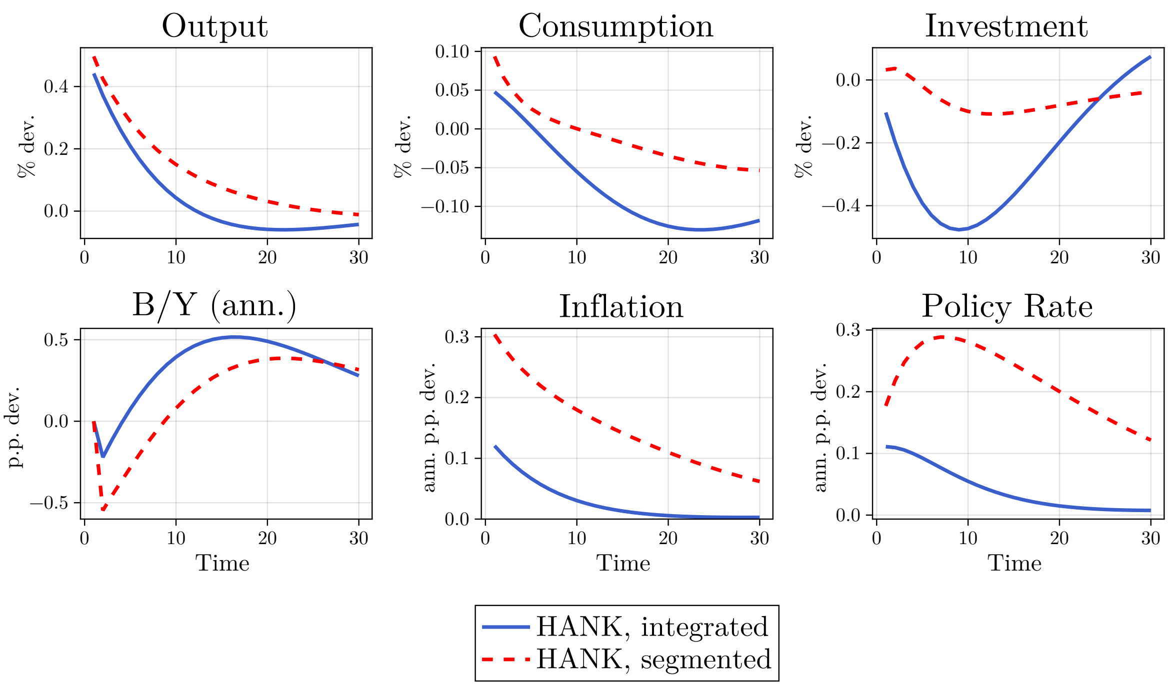
Note: The figure displays IRFs to a one-time transfer shock under $\theta_\pi = 1.05$ and $\theta_y = 0$. B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State.

Figure F.7: Inflation decomposition: $\Psi = 0$ case



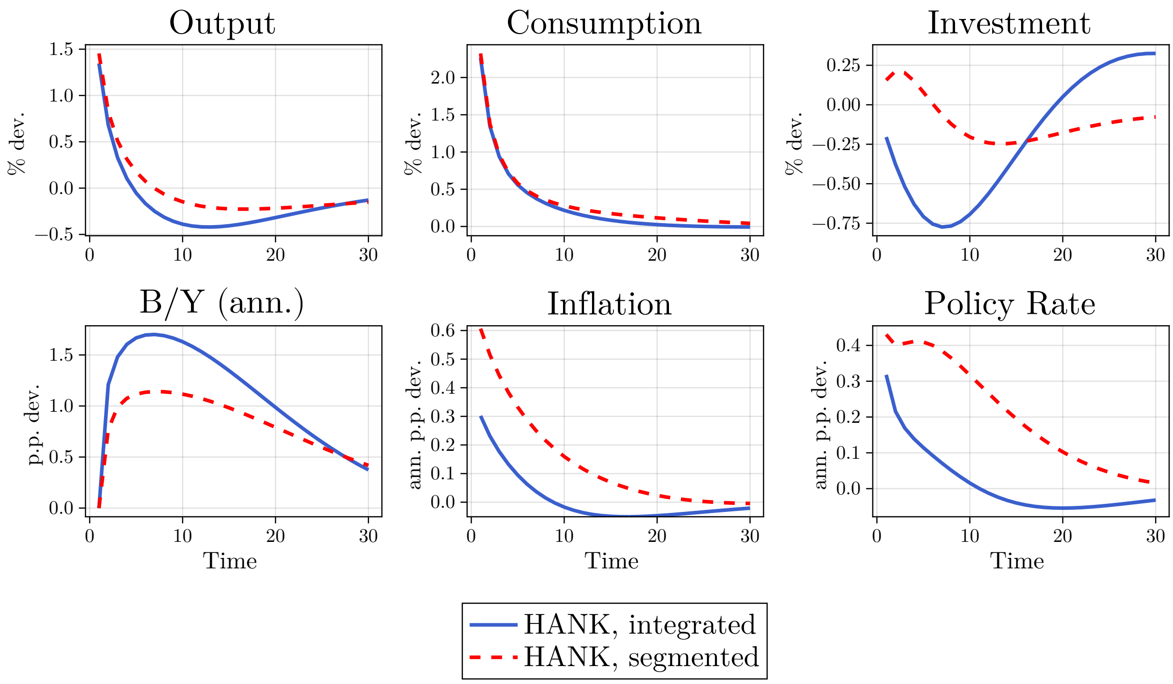
Note: "Supply" collects the impact of both the "cost-push"- and the investment technology shock.

Figure F.8: Model IRFs to Government spending shock



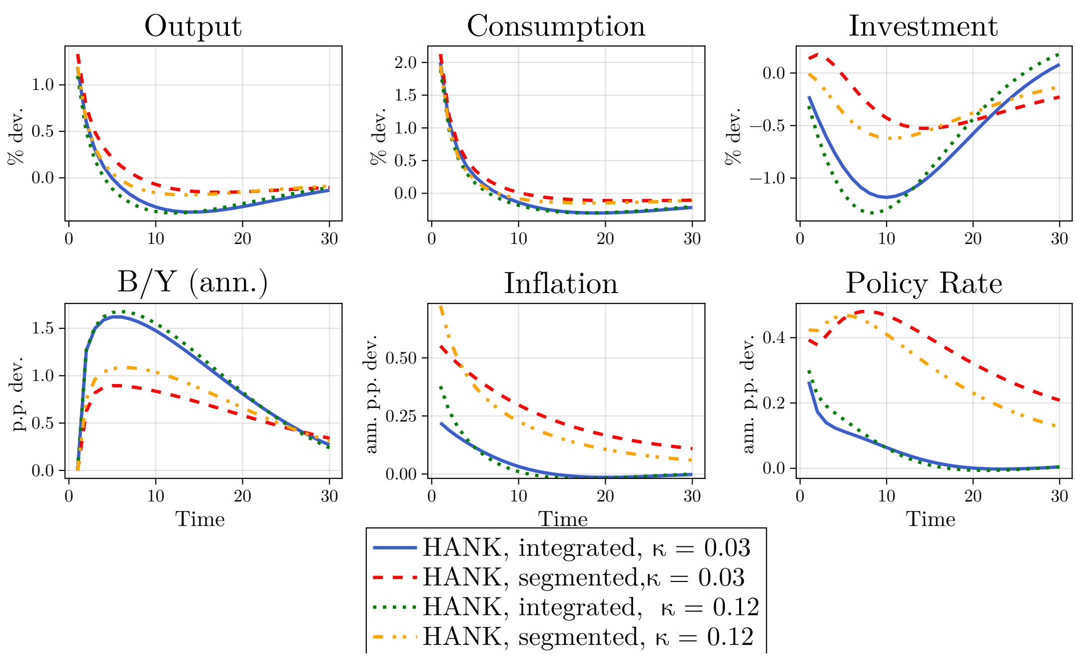
Note: B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State.

Figure F.9: Model IRFs to Transfer shocks: G adjusts



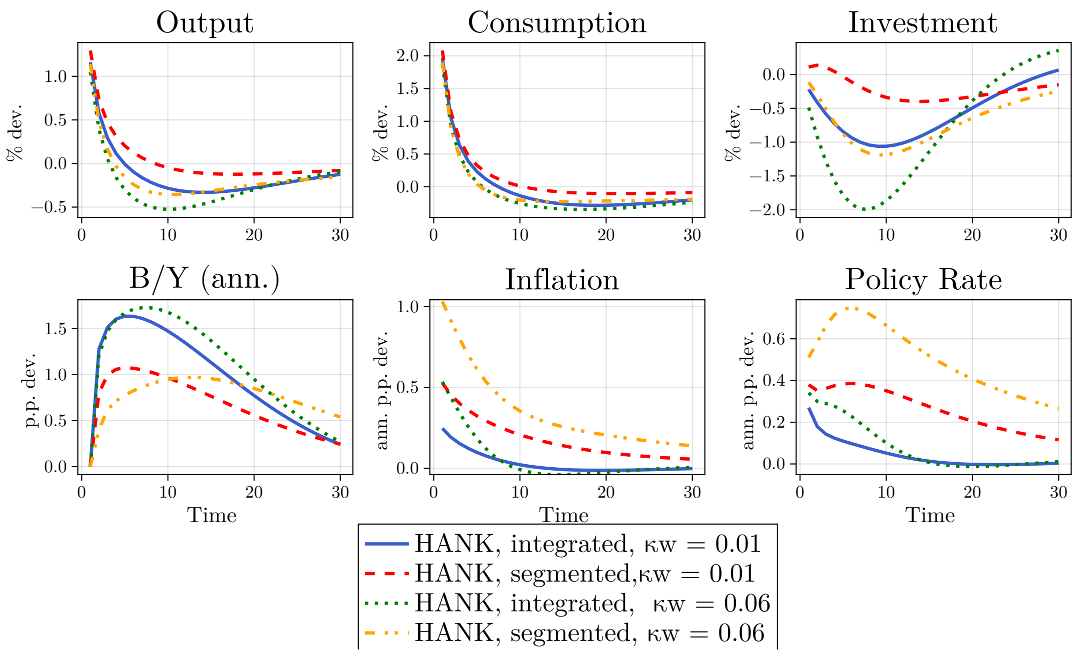
Note: B/Y represents the real market value of public debt B^g over annualized GDP. Figures display relative (in %) or percentage point (p.p.) deviations from Steady State. Instead of adjusting taxes, the government is assumed to consolidate its finance by following the rule $\log G_t = \rho_G \log G_{t-1} + (1-\rho_G)(\log G_{SS} - 0.85 * (\log B_t^g - \log B_{SS}))$ with $\rho_G = 0.9$.

Figure F.10: IRFs to transfer shock: Varying κ



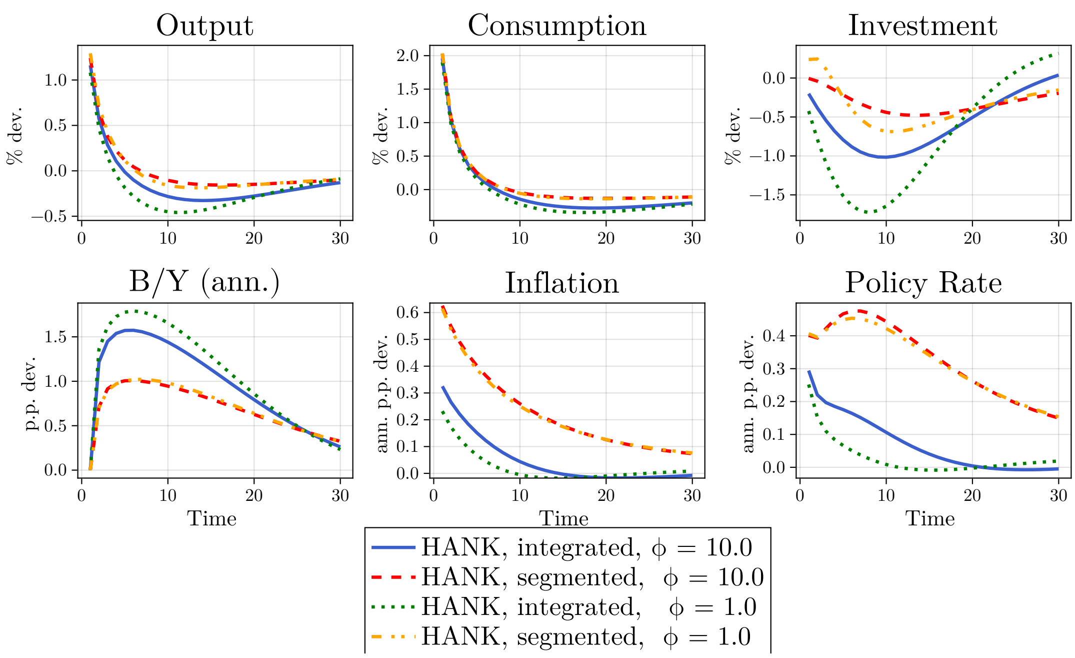
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure F.11: IRFs to transfer shock: Varying κ_w



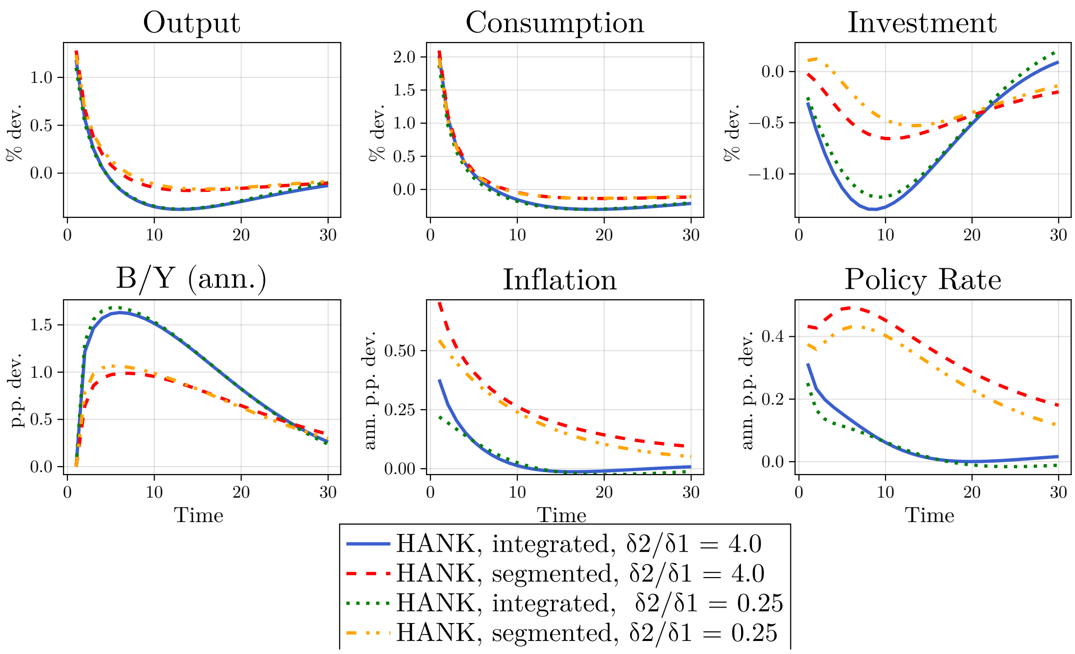
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure F.12: IRFs to transfer shock: Varying ϕ



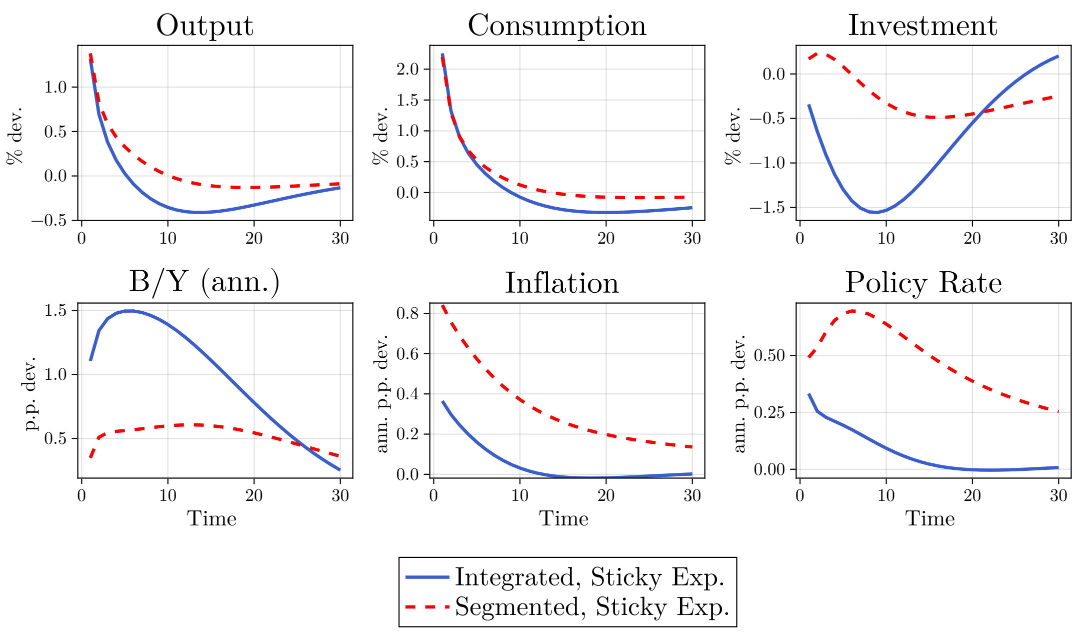
Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure F.13: IRFs to transfer shock: Varying δ_2/δ_1



Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.

Figure F.14: IRFs to transfer shock: Sticky Expectations



Note: B/Y represents the real market value of public debt B^g over 4 times (=annualized) GDP.