A Behavioral Heterogeneous Agent New Keynesian Model

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Abstract

We develop a model which delivers realistic intertemporal marginal propensities to consume, monetary policy that is amplified through indirect general equilibrium effects, and fiscal multipliers that can be larger than one. Simultaneously, the model resolves the forward guidance puzzle, remains stable at the effective lower bound and determinate under an interest-rate peg. Even though the model incorporates household heterogeneity and bounded rationality, it remains analytically tractable and allows for a three-equation representation. The model nests a wide range of existing models as special cases, none of which can produce all the listed features within one model. We derive an equivalence result of models featuring bounded rationality and models featuring incomplete information and learning. This extended model generates hump-shaped responses of aggregate variables and a novel behavioral amplification channel that is absent in existing HANK models.

Keywords: Behavioral Macroeconomics, Heterogeneous Households, Monetary Policy, Forward Guidance, Fiscal Policy, New Keynesian Puzzles

JEL Codes: E21, E52, E62, E71

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1 Introduction

New Keynesian models with household heterogeneity have become popular for analyzing monetary policy, fiscal policy, and business cycles.[1] These Heterogeneous Agent New Keynesian (HANK) models can generate, among other features, intertemporal Marginal Propensities to Consume (iMPCs) that are in line with the data (Auclert et al. (2018), Kaplan and Violante (2020)), monetary policy that is amplified through indirect general equilibrium effects (Kaplan et al. (2018), Auclert (2019), and Auclert et al. (2020b)), and fiscal multipliers that are larger than one even under constant real rates (Auclert et al. (2018)).[2] The quantitative nature and complexity of these models has motivated a burgeoning literature to develop Tractable HANK (THANK) models for a clearer understanding of the HANK transmission mechanisms. Thereby, the THANK literature has uncovered a major challenge present in models featuring household heterogeneity: when generating the aforementioned "desirable" HANK features, HANK models tend to aggravate major NK puzzles such as the forward guidance puzzle, unreasonably large recessions at the Effective Lower Bound (ELB) and the Taylor principle fails to be sufficient for determinacy (see Werning (2015), Bilbiie (2021) and Acharya and Dogra (2020)).[3] This trade-off prevents an extensive analysis of monetary policy and fiscal policy within one single framework.

We propose such a framework by constructing a New Keynesian model which incorporates household heterogeneity and behavioral frictions in the form of cognitive discounting. The

[1] For monetary policy see, e.g., Kaplan et al. (2018), Auclert (2019), Auclert et al. (2020b), Luetticke (2021), McKay et al. (2016), Hagedorn et al. (2019a), Kyriazis (2022). For fiscal policy see, e.g., Auclert et al. (2018), Hagedorn et al. (2019b), Ferriere and Navarro (2018), Oh and Reis (2012), Wolf (2021), Bayer et al. (2020), Seidl and Seyrich (2021), McKay and Reis (2016). For business cycle analyses see, Guerrieri and Lorenzoni (2017), Bayer et al. (2019).

[2] Auclert et al. (2018) provide empirical estimates of iMPCs. The importance of indirect channels for monetary policy is empirically supported in Ampudia et al. (2018), Samarina and Nguyen (2019) and Holm et al. (2021). Nakamura and Steinsson (2014) and Chodorow-Reich (2019) provide recent evidence on fiscal multipliers above one. Ramey (2019) also shows that fiscal multipliers can be substantially above one under accomodative monetary policy.

[3] While these issues have been highlighted in tractable models mainly, an earlier version of Auclert et al. (2018) and the discussion of these issues in Acharya and Dogra (2020) show similar indeterminacy problems of quantitative HANK models. In addition and in line with the THANK literature, Hagedorn et al. (2019a) show that whether forward guidance is dampened *or* amplified in the standard one asset quantitative HANK model depends on the cyclicality of inequality.

resulting *behavioral HANK* model generates the desired HANK features and *simultaneously* offers a resolution to the NK puzzles, thereby providing a unifying framework for extensive monetary and fiscal policy analysis. In the behavioral HANK model, indirect general equilibrium effects account for large parts of the transmission of monetary policy to consumption and fiscal policy is amplified. In addition, the model matches estimated iMPCs in the data which is a crucial statistic to discipline HANK models (Auclert et al. (2018)). At the same time, the model resolves the forward guidance puzzle as the effectiveness of future monetary policy is weaker than contemporaneous monetary policy and the response of current output declines with the horizon of the announced interest-rate change. Additionally, we show that the behavioral HANK model restores the Taylor principle. In fact, it features determinacy even under an interest-rate peg for a large area of the parameter space. Relatedly, the behavioral HANK model remains stable during prolonged periods at the ELB.

We highlight how the behavioral friction interacts with household heterogeneity and show that both are necessary for our results. What is more, our framework nests a wide range of existing models such that we can cleanly compare these existing models to the behavioral HANK model and thus, highlight the advantage of our framework. The main take-away is that none of the competing models can generate the desired HANK features while simultaneously offering a resolution to the NK puzzles.

To arrive at our framework, we extend the textbook Representative Agent New Keynesian model (RANK) in two dimensions. First, we introduce household heterogeneity following the THANK literature, as summarized below. There are two groups of households, savers and hand-to-mouth households, and households face an exogenous probability to switch their type. This uninsurable idiosyncratic risk leads to precautionary-savings motives of households together with heterogeneity in income and MPCs. Second, we introduce bounded rationality by the means of cognitive discounting as in Gabaix (2020). Households anchor their expectations about future macroeconomic variables to the steady state but are myopic or inattentive to future deviations from it.[4]

Despite these two departures from the textbook RANK, we can describe the entire model dynamics around the steady state by three equations isomorphic to the textbook model: an IS curve, a Phillips curve, and a rule for monetary policy. Key to our analysis is the behavioral HANK IS equation which takes the following form:

$$\widehat{y}_t = \psi_f \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma} \left(\widehat{i}_t - \mathbb{E}_t \pi_{t+1} \right),$$

where $\widehat{y}_t$ denotes total output (in log-deviations from its steady state), $\mathbb{E}_t$ is the *rational* expectations operator, $\widehat{i}_t$ denotes the nominal interest rate, π_t is the inflation rate, and $\frac{1}{\gamma}$ is the intertemporal elasticity of substitution. Compared to RANK, two extra coefficients show up: ψ_c and ψ_f.

ψ_c governs the sensitivity of today's output with respect to the contemporaneous real interest rate. ψ_c is shaped by household heterogeneity and crucially depends on the cyclicality of income inequality: if income inequality is countercyclical, which seems to be the empirical consensus, $\psi_c > 1$ and contemporaneous monetary policy is amplified through general equilibrium forces.[5,6] In addition, $\psi_c > 1$ is also sufficient for fiscal multipliers to be larger than one conditional on the real interest rate being constant. The other coefficient, ψ_f, captures the sensitivity of today's output with respect to changes in expected future output. ψ_f is shaped by household heterogeneity *and* the behavioral friction as it depends on the cyclicality of income risk *and* the degree of bounded rationality of households. Given countercyclical income inequality, income risk is also countercyclical. Countercyclical risk induces

[4] Gabaix (2019) and Gabaix (2020) discuss the empirical evidence in favor of cognitive discounting and Angeletos and Lian (2017) show how other forms of bounded rationality or lack of common knowledge lead to observationally-equivalent outcomes.

[5] Patterson (2019) provides empirical evidence for the countercyclicality of inequality. Coibion et al. (2017), Ampudia et al. (2018) and Samarina and Nguyen (2019) provide evidence of countercyclical inequality conditional on monetary policy shocks. Almgren et al. (2019) show that output in countries with higher shares of hand-to-mouth households responds more strongly to monetary policy shocks which, through the lens of the model, implies countercyclical inequality.

[6] "Amplification" does not need to be interpreted literally as γ can always be adjusted to scale the impact effect. Hence, it should rather be understood as a high importance of general equilibrium (indirect) effects relative to direct effects.

compounding in the Euler equation and, thus, competes with cognitive discounting which induces discounting in the Euler equation. However, even for a small degree of bounded rationality—much smaller than the empirics suggest—the discounting through bounded rationality dominates the compounding through countercyclical income risk. Hence, in the behavioral HANK model it holds that $\psi_f < 1$ which makes the economy less sensitive to expectations and news about the future which is the key to resolve the NK puzzles.

Furthermore, we characterize the iMPCs in the behavioral HANK model analytically and analyze how household heterogeneity and bounded rationality affect these iMPCs. If income risk is more countercyclical, i.e., hand-to-mouth households are more exposed to the business cycle, the aggregate MPC in the year of the income windfall increases, especially when households are less behavioral. Boundedly-rational households tend to save more than rational households out of the windfall as they cognitively discount the decrease in their future marginal utility which lowers the current MPC. As time progresses, however, bounded rationality increases the aggregate MPC as the behavioral savers start to consume their previously-saved income. These dynamic effects are particularly pronounced when idiosyncratic risk is relatively high.

We demonstrate that the behavioral HANK model can have qualitatively different policy implications than its rational counterpart by an illustrative scenario. To this end, we consider the case of an *overheating* economy which the monetary authority wants to tame by hiking interest-rates by $x\%$. This rate hike can be implemented immediately or by raising the rate $\frac{x}{k}\%$ over k consecutive periods. A well-known feature of the RANK model is that monetary policy becomes more effective the more it is back-loaded. While this is also the case in THANK, the opposite is true in the behavioral HANK model: monetary policy is more effective when it is completely *front-loaded*, i.e., when $k = 1$. The increased effectiveness, however, comes at the cost of an increase in inequality which is more pronounced in the behavioral HANK model when monetary policy is front-loaded.

We close by assuming that behavioral agents anchor their beliefs to *past observations* of the respective variable instead of the respective steady state values. This enables us to formally derive an equivalence result between models with bounded rationality and incomplete information: the reduced form of the extended behavioral HANK model is equivalent to models featuring incomplete information and learning (see Angeletos and Huo (2021)).[7] Thus, we show how to bridge the gap between models of bounded rationality and state-of-the-art models featuring incomplete information and learning.

We calibrate the extended model to match recent findings from survey expectations data and show that the model endogenously generates hump-shaped responses of macro aggregates to monetary policy shocks. The backward-looking component in households' expectations induces endogenous persistence and thus, households respond *as if* contemporaneous (or future) shocks are persistent even when the shocks are actually completely transitory. This yields an endogenous *behavioral-amplification mechanism* that is absent in existing HANK models. A similar reasoning extends to future interest rate changes even though their effects become smaller as the interest cut is expected to take place at a later date. Thus, the extended behavioral HANK model also rules out the forward guidance puzzle. In addition, it again delivers determinacy under an interest rate peg.

Outline. The rest of the paper is structured as follows. In Section 2, we summarize the related literature. We present our behavioral HANK model in Section 3 and our main analytical results in Section 4. In Section 5, we extend the model by allowing agents to anchor their expectations to their prior observations and show how this enables the model to generate hump-shaped responses of aggregate variables. Section 6 concludes.

[7] Angeletos and Huo (2021) derive their result under incomplete information and learning to reconcile these features with behavioral myopia and frictions such as habit persistence and adjustment costs. We now complement their equivalence result with a model that solely relies on bounded rationality.

2 Related Literature

Tractable HANK models have been used to either deliver amplification of shocks and policies *or* to deliver dampening of the effects of forward guidance.[8] McKay et al. (2017) use a tractable HANK model with in-built procyclical risk to approximate their finding in McKay et al. (2016) in which, again, procyclical risk provides a solution to the forward guidance puzzle. Ravn and Sterk (2017) and Ravn and Sterk (2021) show that incorporating search-and-matching frictions into a tractable HANK model delivers countercyclical risk and amplification of business cycle shocks. Debortoli and Galí (2018) approximate the amplification of monetary policy of their HANK model by a Two Agent NK model (TANK)—which can be thought of as a special case of a THANK model.[9] Werning (2015) provides an incomplete-markets irrelevance benchmark which shows that contemporaneous monetary policy and forward guidance is as strong as in RANK if income risk is acyclical. Acharya and Dogra (2020) show similarly to Werning (2015) that the resolution to NK puzzles such as the forward guidance puzzle depends on the cyclicality of risk by constructing a THANK model in which the precautionary savings motive of households is the only difference to RANK. While procyclical risk as in McKay et al. (2016) and McKay et al. (2017) resolves the forward guidance puzzle and allows for sufficiency of the Taylor principle, countercyclical risk aggravates these puzzles. Bilbiie (2020) and Bilbiie (2021) go one step further and show that in THANK models, income risk co-moves with income inequality. Since contemporaneous monetary and fiscal policy is amplified with countercyclical inequality and dampened with procyclical inequality, Bilbiie (2021) shows that tractable HANK models can either solve the NK puzzles or generate policy amplification but not both at the same time—a *Catch-22*.

[8] Examples of tractable HANK models that do not focus on amplification or resolving puzzles include Challe and Ragot (2016), Acharya et al. (2020), Challe (2020), Bilbiie and Ragot (2021), Bilbiie et al. (2021), Bonciani and Oh (2021), Broer et al. (2020) and see, e.g., Caballero and Simsek (2019) or Caballero and Simsek (2020) for tractable models of *belief heterogeneity*.

[9] While abstracting from the cyclicality of income risk, TANK models which date back to Campbell and Mankiw (1989), Mankiw (2000), Galí et al. (2007), and Bilbiie (2008) can generate monetary and fiscal amplification. Cantore and Freund (2021) use a TANK model to match empirically-observed iMPCs and Maliar and Naubert (2019) provide a recent in-depth analysis of TANK models.

One of our contributions is to show how HANK models can overcome this Catch-22.[10]

A mostly-detached strand of the literature has suggested to relax the assumption of full-information rational expectations (FIRE) to weaken the effectiveness of future monetary policies, thereby resolving the forward guidance puzzle (Wiederholt (2015), Angeletos and Lian (2018), Andrade et al. (2019), Gabaix (2020), Pfäuti (2021) and Roth et al. (2021)). We complement these papers by introducing household heterogeneity in terms of iMPCs, asset-market participation status, and exposure to the business cycle. This way, our model cannot only resolve the forward guidance puzzle (and other NK puzzles) but also simultaneously deliver amplification of contemporaneous monetary and fiscal policy as well as match empirical estimates of iMPCs.

We share the combination of household heterogeneity and some deviation from FIRE with Farhi and Werning (2019), Auclert et al. (2020b), Broer et al. (2021), Angeletos and Huo (2021), Laibson et al. (2021) and Gallegos (2021). In contrast to all these papers, we offer analytical insights into how the two frictions matter for policy analysis, and how bounded rationality can resolve several puzzles present in NK models while it at the same time allows the model to keep desirable HANK features, such as amplification of monetary policy and fiscal multipliers above one. Auclert et al. (2020b) derive iMPCs in a HANK model with sticky information. We complement their analysis by providing closed-form solutions. To the best of our knowledge, we are the first to provide analytical iMPCs in a HANK model with some departure from FIRE.

Angeletos and Huo (2021) derive an IS equation in a HANK model featuring incomplete information and show how this generates hump-shaped responses of macro aggregates to monetary policy shocks. We derive an equivalent IS equation by extending the behavioral

[10] Bilbiie (2021) provides two theoretical possibilities of how to sidestep the Catch-22. The first possibility is a pure risk channel which can, in theory, break the comovement of income risk and inequality. Yet to do so, it requires a calibration which seems highly at odd with the data. A second possibility is to drastically narrow down the policy space: in a world in which monetary policy is described by Wicksellian price level targeting or fiscal policy follows a nominal bond rule, there would be no Catch-22. Hagedorn et al. (2019a) use a similar description of fiscal policy to solve the forward guidance puzzle in a HANK model, in which contemporaneous monetary policy is amplified. In contrast, in our model, there is no Catch-22 *independently* of the exact specification of monetary and fiscal policy.

framework in Gabaix (2020). We thus bridge the gap between the literature that relaxes the *full-information* part of FIRE and the one that relaxes the *rational-expectations* part. We further highlight how bounded rationality can generate a behavioral amplification mechanism in addition to the HANK amplification mechanism.

3 A Behavioral HANK Model

In this section, we present our tractable NK model featuring household heterogeneity and bounded rationality (BR). Our framework is sufficiently general such that it nests a broad spectrum of existing models—such as the textbook RANK model (see, e.g., Woodford (2003) or Galí (2015)), TANK and THANK models (see Bilbiie (2021)) as well as the behavioral RANK model in Gabaix (2020).

3.1 Structure of the Model

Households. The economy is populated by a unit mass of households, indexed by $j \in [0, 1]$. Households obtain utility from (non-durable) consumption, C_t^j, and dis-utility from working N_t^j. Households discount future utility at rate $\beta \in [0, 1]$. Assuming a standard, separable, CRRA utility function, households' lifetime utility is given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(C_t^j)^{1-\gamma}}{1-\gamma} - \frac{(N_t^j)^{1+\varphi}}{1+\varphi} \right),$$

where φ denotes the inverse Frisch elasticity and γ denotes the relative risk aversion. For most of the paper, we focus on $\gamma = 1$, that is, log-utility $log(C_t^j)$.

Households can save or borrow in government bonds, paying nominal interest i_t, and acquire shares of intermediate monopolistic firms. We introduce household heterogeneity following Bilbiie (2021) and allow for the possibility that households participate in financial markets infrequently. When they do participate, they can freely buy or sell bonds and shares and receive all the profits, D_t, from the monopolistic firms. Otherwise, they simply receive the payoff from their previously acquired bonds. We denote households participating in financial markets by S as they will be Savers in equilibrium, and the non-participants by H as they will be $H$and-to-mouth. A saver remains a saver with probability s and becomes hand-to-mouth with probability $1-s$. Hand-to-mouth households remain hand-to-mouth with probability h and switch with probability $1-h$. In what follows, we focus on stationary equilibria where $\lambda \equiv \frac{1-s}{2-s-h}$ denotes the constant share of hand-to-mouths.

We use the same simplyfing assumptions as in Bilbiie (2021) which allow for a tractable solution. In particular, we assume that households belong to a family whose utilitarian intertemporal welfare is maximized by its family head. The head can only provide insurance within types but not across types, i.e., the head pools all the resources within types. When households switch from savers to the hand-to-mouth type, they only keep their government bonds. Thus, stocks cannot be used to self-insure. Using the in- and outflows between both groups and the stationary distribution, we get the following relationships between real, per-capita, beginning-of-period-t+1 bonds, B^j_{t+1} and end-of-period-t per-capita real values (before moving across types), Z^j_{t+1}:

$$\begin{aligned} B^S_{t+1} &= sZ^S_{t+1} + (1-s)Z^H_{t+1} \\ B^H_{t+1} &= (1-h)Z^S_{t+1} + hZ^H_{t+1}. \end{aligned} \tag{1}$$

We allow for the possibility that the family head is boundedly rational (BR) in the way we describe in detail in Section 3.3.[11] The program of the family head is

$$\begin{aligned} W\left(B^S_t, B^H_t, \psi_{ct}\right) = \max_{\{C^S_t, C^H_t, Z^S_{t+1}, Z^H_{t+1}, N^S_t, N^H_t, \iota_{t+1}\}} & \Big[(1-\lambda)U\left(C^S_t, N^S_t\right) + \lambda U\left(C^H_t, N^H_t\right)\Big] \\ & + \beta \mathbb{E}^{BR}_t W\left(B^S_{t+1}, B^H_{t+1}, \psi_{ct+1}\right) \end{aligned}$$

[11] Instead of assuming that the family head is boundedly rational we could assume that the individual households are boundedly rational and that the family head respects their beliefs and acts accordingly. Gabaix (2020) discusses these two possibilities in a representative-agent framework.

subject to the respective budget constraints

$$C_t^S + Z_{t+1}^S + v_t \iota_{t+1} = W_t N_t^S + \iota_t (v_t + D_t) + \frac{1+i_{t-1}}{1+\pi_t} B_t^S + T_t^S \tag{2}$$

$$C_t^H + Z_{t+1}^H = W_t N_t^H + T_t^H + \frac{1+i_{t-1}}{1+\pi_t} B_t^H, \tag{3}$$

$$Z_{t+1}^H, Z_{t+1}^S \geq 0$$

where W_t is the real wage, ι_t are the shares of stocks traded at price ν_t, B_t denotes the liquid asset holdings (government bonds), and T_t^j are transfers to type-j households. We assume that these transfers are financed by a proportional tax on profits, τ^D, such that they entail a redistribution from S households to H households.

We obtain the following optimality conditions: the savers' Euler equation

$$U'\big(C_t^S\big) \geq \beta R_t \mathbb{E}_t^{BR}\Big[sU'\big(C_{t+1}^S\big) + (1-s)U'\big(C_{t+1}^H\big)\Big] \tag{4}$$

$$\text{and } 0 = Z_{t+1}^S\Big[U'\big(C_t^S\big) - R_t \mathbb{E}_t^{BR}\Big[sU'\big(C_{t+1}^S\big) + (1-s)U'\big(C_{t+1}^H\big)\Big]\Big],$$

the Euler equation of the hand-to-mouth households

$$U'\big(C_t^H\big) \geq \beta R_t \mathbb{E}_t^{BR}\Big[(1-h)U'\big(C_{t+1}^S\big) + hU'\big(C_{t+1}^H\big)\Big] \tag{5}$$

$$\text{and } 0 = Z_{t+1}^H\Big[U'\big(C_t^H\big) - R_t \mathbb{E}_t^{BR}\Big[(1-h)U'\big(C_{t+1}^S\big) + hU'\big(C_{t+1}^H\big)\Big]\Big],$$

and the demand for shares

$$U'\big(C_t^S\big) \geq \beta \mathbb{E}_t\left[\frac{v_{t+1} + D_{t+1}}{v_t} U'\big(C_{t+1}^S\big)\right] \text{ and } \iota_{t+1} = \iota_t = (1-\lambda)^{-1}, \tag{6}$$

with $R_t = \mathbb{E}_t\left[\frac{1+i_t}{1+\pi_{t+1}}\right]$ being today's real interest rate. Note that here we assume that all agents have rational expectations about returns (including real rates). This assumption follows Gabaix (2020) and relaxing the assumption would only strengthen our results (see

Appendix C). The respective labor-leisure equations of both types are given by:

$$-U'\left(N_t^S\right) = W_t U'(C_t^S) \tag{7}$$

$$-U'\left(N_t^H\right) = W_t U'(C_t^H). \tag{8}$$

In what follows, we focus on equilibria in which the H households will always be off their Euler equation—e.g, because they do not have access to financial markets—such that equation (5) always holds with strict inequality. In addition, we follow the THANK tradition and assume a zero liquidity equilibrium.[12] As shares cannot be transferred to the H state, the Euler equation for the shares (equation (4)) simply prices the shares. Thus, the savers' bond Euler equation is the only Euler equation that is an equilibrium equation. Importantly, it features a self-insurance motive as savers demand bonds to self-insure their idiosyncratic risk of type-switching.

Firms. We assume a standard NK firm side as in Bilbiie (2020). All households consume the same aggregate basket of goods, $j \in [0,1]$, $C_t = (\int_0^1 C_t(j)^{(\epsilon-1)/\epsilon} dj)^{\epsilon/(\epsilon-1)}$ where $\epsilon > 1$ is the elasticity of substitution between the individual goods. Each firm faces demand $C_t(j) = (P_t(j)/P_t)^{-\epsilon} C_t$ where $P_t(j)/P_t$ denotes the individual price relative to the aggregate price index, $P_t^{1-\epsilon} = \int_0^1 P_t(j)^{1-\epsilon} dj$, and produces with the linear technology $Y_t(j) = N_t(j)$. The real marginal cost is given by W_t. We assume that the government pays the standard NK optimal subsidy financed by a lump-sum tax on firms. Hence, the profit function is: $D_t(j) = (1+\tau^S)[P_t(j)/P_t]Y_t(j) - W_t N_t(j) - T_t^F$. Total profits are then $D_t = Y_t - W_t N_t$ and zero in steady state. As dividends are the only source of difference in income in steady state, we have a full-insurance steady state such that $C^H = C^S = C$. In the log-linear dynamics around this steady state, profits vary inversely with the real wage $\widehat{d}_t = -\widehat{w}_t$.[13] We allow for steady state inequality in Appendix C and show that our results are not driven by this

[12]See Krusell et al. (2011), McKay et al. (2017), Ravn and Sterk (2017), and Bilbiie (2021).

[13]Note that throughout the paper variables with a hat on top denote log-deviations from steady state.

assumption and are in fact barely affected even by substantial inequality in the steady state.

Government. Fiscal policy induces the optimal steady state subsidy and taxes profits at rate τ^D and rebates these taxes as a transfer to H households, such that $T^H = \frac{\tau^D}{\lambda} D_t$. As will become clear later, the level of τ^D is key for the exposure of H households to the business cycle and thus for the cyclicality of inequality. Here, we abstract from government spending to keep it simple, but we introduce government spending in Section 4.

In most of the analysis, we assume that monetary policy follows a standard (log-linearized) Taylor rule

$$\widehat{i}_t = \phi \pi_t + \epsilon_t^{MP}, \tag{9}$$

with ϵ_t^{MP} being the monetary policy shock which will be specified in the sections below.

Market Clearing. Market clearing requires $Y_t = C_t = \lambda C_t^H + (1-\lambda) C_t^S$ and $N_t = \lambda N_t^H + (1-\lambda) N_t^S$.

3.2 Log-Linearized Model

We now focus on the log-linearized dynamics around the full-insurance, zero-liquidity steady state. The market clearing conditions yield $\widehat{y}_t = \widehat{c}_t = \lambda \widehat{c}_t^H + (1-\lambda)\widehat{c}_t^S$ and $\widehat{n}_t = \lambda \widehat{n}_t^H + (1-\lambda)\widehat{n}_t^S$. Importantly, we can write the consumption of the hand-to-mouth households as

$$\widehat{c}_t^H = \chi \widehat{y}_t, \tag{10}$$

with

$$\chi = 1 + \varphi \left(1 - \frac{\tau^D}{\lambda}\right) \tag{11}$$

measuring the cyclicality of the household H's consumption. As χ is the main coefficient from our household heterogeneity set-up, we will discuss several values for χ throughout the paper. Different levels of χ should then be thought of as different redistributive tax-transfer systems and, hence, from different levels of τ^D.

Combining equation (10) with the goods market clearing condition yields

$$\widehat{c}_t^S = \frac{1-\lambda\chi}{1-\lambda}\widehat{y}_t, \tag{12}$$

which implies that consumption inequality is given by:

$$\widehat{c}_t^S - \widehat{c}_t^H = \frac{1-\chi}{1-\lambda}\widehat{y}_t. \tag{13}$$

Equation (13) shows why we interpret $\chi > 1$ as countercyclical inequality: if $\chi > 1$, inequality increases in recessions and decreases in booms.

The bond Euler equation of S households is given by

$$\widehat{c}_t^S = s\mathbb{E}_t^{BR}\left[\widehat{c}_{t+1}^S\right] + (1-s)\mathbb{E}_t^{BR}\left[\widehat{c}_{t+1}^H\right] - \frac{1}{\gamma}\left(\widehat{i}_t - \mathbb{E}_t\pi_{t+1}\right), \tag{14}$$

where $\frac{1}{\gamma}$ denotes the intertemporal elasticity of substitution. For the case without type-switching, i.e., for $s = 1$, equation (14) boils down to a standard Euler equation. For $s \in [0, 1)$, however, the agent takes into account that she might switch type and self-insures against becoming hand-to-mouth next period.

Supply Side. We distinguish between two set-ups for the supply side: For the main part, we follow Bilbiie (2021) and assume that firms are not forward-looking and, thus, we can summarize the supply side of the economy by a static Phillips Curve

$$\pi_t = \kappa\widehat{y}_t, \tag{15}$$

where $\kappa \geq 0$ captures the slope of the Phillips Curve.[14] Yet, we also relax this assumption in Appendix C and show that a forward-looking (NK) Phillips Curve barely affects our results.

3.3 Bounded Rationality

To model bounded rationality, we follow Gabaix (2020) and introduce the behavioral parameter, $\bar{m} \in [0,1]$ which captures the degree of rationality, in the sense that a higher $\bar{m}$ denotes a smaller deviation from rational expectations.[15] Rational expectations are captured by $\bar{m} = 1$. The degree of rationality can potentially differ across agents or depend on the variable of interest. For simplicity, however, we focus on one common $\bar{m}$ for all agents and variables.

Let X_t denote some variable (or vector of variables) and let us define X_t^d as some default value the agent may have in mind, e.g., the steady state value of X, and $\tilde{X}_{t+1} \equiv X_{t+1} - X_t^d$ denote the deviation from this default value.[16]

Cognitive discounting, or bounded rationality, is modelled such that the behavioral agent's expectation about X_{t+1} is given by

$$\mathbb{E}_t^{BR}\left[X_{t+1}\right] = \mathbb{E}_t^{BR}\left[\tilde{X}_{t+1} + X_t^d\right] \equiv \bar{m}\mathbb{E}_t\left[\tilde{X}_{t+1}\right] + X_t^d, \tag{16}$$

where $\bar{m} \in [0,1]$ is the behavioral parameter introduced above and $\mathbb{E}_t[\cdot]$ is the rational expectations operator. We see from equation (16) how the behavioral agent anchors her

[14] To arrive at this static Phillips curve, we can either assume that firms are completely myopic or that they face a Rotemberg-style adjustment cost relative to yesterday's market average price index (see Bilbiie (2021)).

[15] While Gabaix (2020) embeds bounded rationality in a NK model, the basic idea of behavioral inattention (or sparsity) has been proposed by Gabaix earlier already (see Gabaix (2014, 2016)) and a handbook treatment of behavioral inattention is given in Gabaix (2019). These papers also show how to microfound and endogenize $\bar{m}$. Benchimol and Bounader (2019) study optimal monetary policy in a NK model with this kind of behavioral frictions.

[16] Gabaix (2020) focuses on the case in which X_t denotes the state of the economy. He shows (Lemma 1 in Gabaix (2020)) that this form of cognitive discounting also applies to all other variables. We, on the other hand, directly apply cognitive discounting to all variables. Given Lemma 1 in Gabaix (2020), our results would be unchanged, but our more direct method simplifies some of the derivations, especially in Section 5. Gabaix (2019) and Gabaix (2020) discuss the empirical evidence in favor of cognitive discounting.

expectations to the default value and cognitively discounts future deviations from this default value. This formulation of cognitive discounting coincides with the formulation in Gabaix (2020) in the case that X has mean zero and X_t^d denotes the steady state. Later on we will allow for more general default values.

The exact micro-foundation or underlying behavioral friction is not crucial for the rest of our analysis. For example, Angeletos and Lian (2017) show how other forms of bounded rationality or lack of common knowledge lead to observationally-equivalent outcomes for the case in which X_t^d denotes the steady state. In our extension in Section 5, we show how our general framework in equation (16) can reconcile bounded rationality with more complex models of incomplete information and learning as in Angeletos and Huo (2021).

Log-linearizing equation (16) around the steady state yields

$$\mathbb{E}_t^{BR}\left[\widehat{x}_{t+1}\right] = (1-\bar{m})\widehat{x}_t^d + \bar{m}\mathbb{E}_t\left[\widehat{x}_{t+1}\right] \tag{17}$$

and as X_t^d is the steady state value, we obtain $\mathbb{E}_t^{BR}\left[\widehat{x}_{t+1}\right] = \bar{m}\mathbb{E}_t\left[\widehat{x}_{t+1}\right]$.

To calibrate $\bar{m}$, we follow Gabaix (2020) who states that empirical estimates of $\bar{m}$ point towards values of about 0.65. Nevertheless, he chooses 0.85 as a conservative choice for his benchmark value which we also take as our benchmark calibration. One goal of our paper is to understand the role of $\bar{m}$ for policy analysis and the interplay of $\bar{m}$ and household heterogeneity. Thus, we will often deviate from our benchmark and vary $\bar{m}$ to get a clearer understanding of bounded rationality and its implications for HANK models.

4 Results

In this section, we first show how the behavioral HANK model can be summarized by three equations isomorphic to the textbook RANK model. We highlight how the behavioral HANK model nests a wide spectrum of existing models and show how it overcomes several challenges present in these existing models. What is more, we show how only the behavioral HANK model can overcome all of these challenges at the same time. Eventually, we analytically characterize the intertemporal marginal propensities to consume and show how they depend on bounded rationality, household heterogeneity, and the interaction of the two.

4.1 The Three-Equation Representation

The behavioral HANK model can be summarized by three equations: a Phillips curve, representing the aggregate supply side captured by equation (15), a Taylor rule for monetary policy (equation (9)), and the *behavioral HANK IS equation* which together determine aggregate demand.

We obtain the behavioral HANK IS equation by combining the hand-to-mouth households' consumption (10) with the savers' consumption (12) and their consumption Euler equation (14).

Proposition 1. *The behavioral HANK IS equation is given by*

$$\widehat{y}_t = \psi_f \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma}\left(\widehat{i}_t - \mathbb{E}_t \pi_{t+1}\right), \tag{18}$$

where

$$\psi_f \equiv \bar{m}\delta = \bar{m}\left[1 + (\chi - 1)\frac{1-s}{1-\lambda\chi}\right]$$

and

$$\psi_c \equiv \frac{1-\lambda}{1-\lambda\chi}.$$

Equation (18) nests a wide range of IS equations: the IS equation in the standard rational-expectations RANK (see, e.g., Woodford (2003) or Galí (2015) for a textbook treatment) by setting $\psi_f = \psi_c = 1$, the *behavioral* RANK of Gabaix (2020) by $\delta = \psi_c = 1$, the TANK model of Bilbiie (2008) by $\bar{m} = \psi_f = 1$, and the rational THANK by Bilbiie (2021) by

$\bar{m} = 1$.

4.2 Policy Amplification and Puzzles

We first show how our behavioral HANK model can generate the desirable HANK features such as fiscal multipliers larger than one and monetary policy that mainly works through indirect, general equilibrium, channels and how it simultaneously resolves NK puzzles.

Overcoming the Catch-22. The Catch-22 (Bilbiie (2021)) describes the issue that in the rational model amplification of contemporaneous monetary policy (ignoring fiscal spending for the moment) compared to the representative-agent model requires

$$\chi > 1, \tag{19}$$

whereas the solution of the forward guidance puzzle[17] requires

$$\chi < 1. \tag{20}$$

Note that *amplification* here can be understood as a more prominent role for indirect effects relative to direct effects.[18]

The Catch-22 illustrates how the rational model cannot generate amplification and resolve the forward guidance puzzle simultaneously. One of the main reasons for the popularity of

[17] We define the forward guidance puzzle as the model feature that announcements about future changes in the interest rate affects output today as strong (or even stronger) than contemporaneous changes in the interest rate. For detailed analyses of the forward guidance puzzle in RANK, see McKay et al. (2016) and Giannoni et al. (2015). Miescu (2022) provides empirical evidence that conventional monetary policy is more effective than forward guidance.

[18] The decomposition into direct and indirect effects in Bilbiie (2020) is still valid in our model as long as the shocks are i.i.d., which is what we focus on. If we allow for persistent shocks, bounded rationality dampens both direct and indirect effects simultaneously. The importance of indirect effects in HANK models has been extensively discussed in Kaplan et al. (2018) and is empirically supported in Ampudia et al. (2018), Samarina and Nguyen (2019) and Holm et al. (2021). Thus, we think the focus on the relative importance of indirect vs. direct effects is somewhat cleaner as the *magnitude* of the impact effect of the shock can always be scaled by the intertemporal elasticity of substitution $\frac{1}{\gamma}$.

models with heterogeneous households is their ability to deliver a steeper Keynesian cross (see Bilbiie (2020)) or a prominent role for general equilibrium channels of monetary policy, which is obtained with $\chi > 1$. We will thus take "amplification" as the desirable outcome, which here means that we assume $\chi > 1$.

Note that condition (20) is necessary but not sufficient for solving the forward guidance puzzle. The sufficient condition takes the inflation response into account and is given by

$$\delta + \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\kappa < 1. \tag{21}$$

The following proposition shows how our behavioral HANK model resolves the Catch-22.

Proposition 2. *In the behavioral HANK model, there is amplification of monetary policy relative to RANK if and only if*

$$\chi > 1, \tag{22}$$

and the forward guidance puzzle is ruled out if

$$\bar{m}\delta + \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\kappa < 1, \tag{23}$$

or in terms of $\bar{m}$*:*

$$\bar{m} < \frac{1 - \frac{1-\lambda}{\gamma(1-\lambda\chi)}\kappa}{\delta}. \tag{24}$$

Proposition 2 shows that for a sufficiently low $\bar{m}$, the behavioral HANK model can resolve the Catch-22. The reason is the following: The behavioral friction leaves the relative importance of direct vs. indirect effects—i.e., amplification of current monetary policy—unaltered, as amplification is solely determined by a contemporaneous redistribution towards the high MPC households (see Bilbiie (2020)) and, hence, unaffected by bounded rationality. In contrast, bounded rationality affects how households perceive their idiosyncratic risk. In particular, it opposes the compounding effects stemming from the expected countercyclical income risk. If the behavioral friction dominates, i.e., when condition (24) holds, the behavioral HANK model delivers a discounted Euler equation. Given our calibration, it follows, that $\bar{m} < 0.93$ is sufficient.[19] Gabaix (2020) states that empirical estimates of $\bar{m}$ point to a realistic value of 0.65 but focuses for the sake of a conservative calibration on $\bar{m} = 0.85$. Both of these values are sufficient to resolve the Catch-22 in our model. Thus, already a small deviation from rational expectations is enough to resolve the Catch-22.

We graphically illustrate the Catch-22 of the rational THANK model and the resolution of it in the behavioral HANK model in Figure 1. The figure shows the response of contemporaneous output relative to the initial response in the RANK model with rational expectations for anticipated i.i.d. monetary policy shocks occurring at different times k and a Taylor coefficient of 0 (as in Bilbiie (2021)).[20]

The orange-dotted line denotes the baseline calibration of the rational THANK model. We see that this model is able to generate contemporaneous amplification of monetary policy shocks, that is, an output response that is relatively stronger than in RANK. Put differently, the GE effects are relatively strong. Yet, at the same time, it exacerbates the forward guidance puzzle as shocks occurring in the future have much stronger effects on today's output than shocks today. The black-dashed-dotted line shows how the forward guidance puzzle can be resolved by allowing for $\chi < 1$. Yet, this comes at the cost that the model is unable to generate amplification of contemporaneous monetary policy shocks. Furthermore, even for the quite low χ, the decay happens relatively slowly.[21]

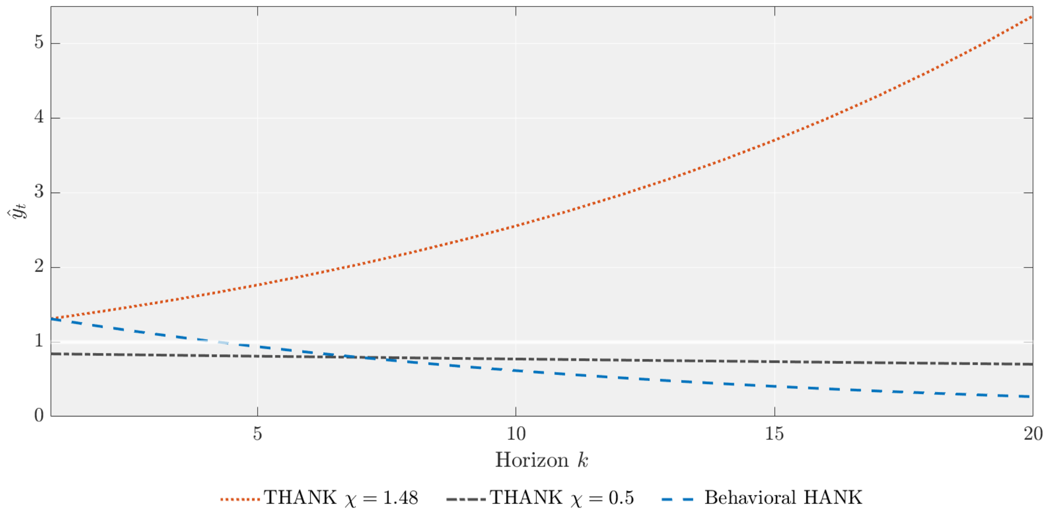
The blue-dashed line shows that the behavioral HANK model generates both: amplification of contemporaneous monetary policy and a resolution of the forward guidance puzzle.

[19] The calibration is as follows: $\chi = 1.48$, $\lambda = 0.33$, $s = 0.9457$ (this corresponds to a s of 0.8 in annual terms), $\gamma = 1$, $\kappa = 0.02$ and we set the Taylor coefficient to 0 for the forward guidance exercise. This calibration is close to the calibration in Bilbiie (2021) and Bilbiie (2020) and is set in order to replicate several findings on the New Keynesian cross coming from more quantitative HANK models. If we exactly take the calibration in Bilbiie (2021), the condition for $\bar{m}$ would be even weaker. Even when we vary certain parameters, we always focus on cases with $\lambda < \chi^{-1}$.

[20] Under fully-rigid prices (i.e., $\kappa = 0$), the RANK model would deliver a constant response for all k. The same is true for TANK, i.e., THANK without type switching. Whether the constant response would lie above or below its RANK counterpart depends on $\chi \lesseqgtr 1$ in the same way the initial response depends on $\chi \lesseqgtr 1$.

[21] Bilbiie (2020) calibrates $\chi = 0.3$ to approximate the forward guidance dampening results in McKay et al. (2016) and McKay et al. (2017).

Figure 1: Resolving the Catch-22



Note: This figure shows the response of total output in period 0 to anticipated i.i.d. monetary policy shocks occurring at different horizons k, relative to the initial response in the RANK model under rational expectations (equal to 1). The parameters are set to $\lambda = 0.33$, $s = 0.9457$, $\gamma = 1$, $\kappa = 0.02$.

Note that also rational TANK models (thus, turning off type switching) or the behavioral RANK model of Gabaix (2020) would not deliver amplification and resolve the forward guidance puzzle simultaneously. TANK models would face the same issues as the rational RANK model in the sense that they cannot solve the forward guidance puzzle while bounded rationality in a RANK model cannot deliver initial amplification.

Revisiting the Taylor Principle. According to the Taylor principle, monetary policy needs to sufficiently respond to changes in inflation in order to have a determinate equilibrium. In the rational RANK model the Taylor principle is given by $\phi > 1$. The following proposition shows that both household heterogeneity and bounded rationality affects this condition.[22]

Proposition 3. *The behavioral HANK model has a determinate, locally unique equilibrium if and only if:*

$$\phi > \phi^* = 1 + \frac{\bar{m}\delta - 1}{\frac{\kappa}{\gamma}\frac{1-\lambda}{1-\lambda\chi}}. \tag{25}$$

[22] We focus on bounded equilibria.

Appendix A shows how to derive Proposition 3. One implication of Proposition 3 is that the Taylor principle is not sufficient in the rational THANK model with $\chi > 1$ (this has been shown by Bilbiie (2021) and in a similar way by Acharya and Dogra (2020)). Bounded rationality, on the other hand, relaxes the condition. Given our calibration and $\bar{m} = 0.85$, it follows that $\phi^* = -3.07$. Thus, the Taylor principle is sufficient but not necessary as the economy features a stable unique equilibrium even under an interest rate peg. In this sense, the behavioral HANK model overcomes the famous result in Sargent and Wallace (1975) who have shown that an interest rate peg leads to equilibrium indeterminacy.[23]

The Lower Bound Problem. Related to the determinacy issues under a peg, the traditional New Keynesian model struggles to explain how the economy can remain stable when the effective lower bound (ELB) on nominal interest rates is binding for an extended period of time. If this is the case, RANK predicts unreasonably severe recessions and, in the limit case in which the ELB binds forever, there is even indeterminacy in RANK. The intuition is directly related to our discussion about determinacy under a peg: A forever binding ELB basically implies that the Taylor coefficient is equal to zero and, thus, the nominal rate is pegged at the lower bound thereby violating the Taylor principle.[24]

We now show that the behavioral HANK model resolves these issues. To this end, let us add a natural-rate shock r_t^n to the IS equation (18). We assume that in period t the natural rate decreases to a value $\widetilde{r}^n$ that is sufficiently negative such that the natural rate in levels is below the ELB. The natural rate stays at $\widetilde{r}^n$ for $k \geq 0$ periods and after k periods, the economy returns immediately back to steady state. Agents correctly anticipate the length of the binding ELB. For simplicity, we assume fully-rigid prices, i.e., $\kappa = 0$ and $\pi_t = 0$ for all t, but this is not crucial for what follows. Iterating the IS equation (18) forward, it follows

[23] Similar to our finding, Angeletos and Lian (2021) show (in a model without household heterogeneity) that small frictions in memory and intertemporal coordination lead to a unique equilibrium which is the same as the one selected by the Taylor principle but it does no longer depend on it.

[24] Note that this statement also extends to models featuring more elaborate monetary policy rules including the Wicksellian price-level targeting rule, as they all collapse to the same "rule" in a world of an ever-binding ELB.

that output in period t is given by

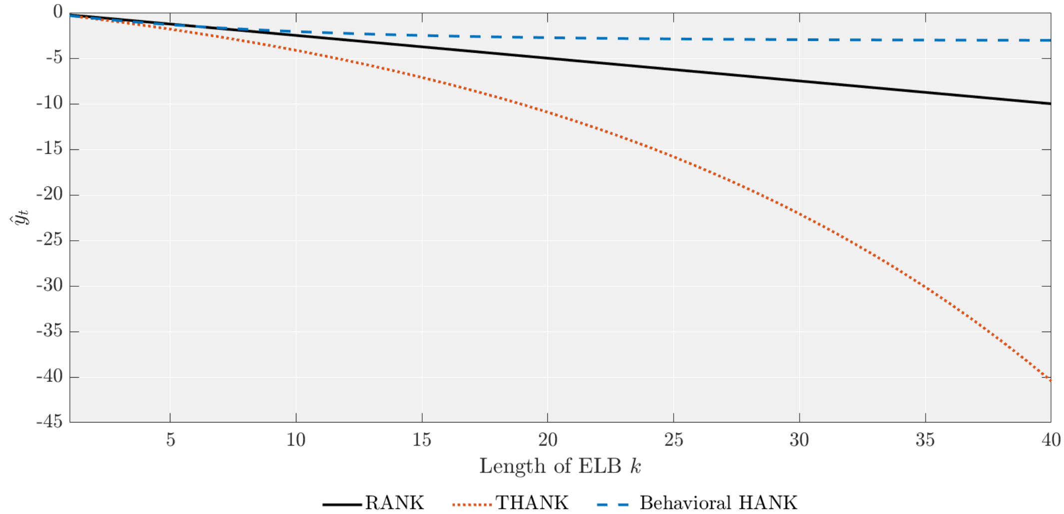
$$\widehat{y}_t = -\frac{1-\lambda}{\gamma(1-\lambda\chi)} \underbrace{\left(\widehat{i}_{ELB} - \widetilde{r}^n\right)}_{>0} \sum_{j=0}^{k} (\bar{m}\delta)^j \,, \tag{26}$$

where the term $\left(\widehat{i}_{ELB} - \widetilde{r}^n\right) > 0$ captures the shortfall of the policy response due to the binding ELB. Under rational expectations and the empirically realistic assumption of amplification, which requires $\chi > 1$ and, thus, $\delta > 1$, output implodes as $k \to \infty$. The same is true in the traditional RANK model which is captured by $\chi = 1$ and $\delta = 1$. In the behavioral HANK model, however, this is not the case. As long as $\bar{m}\delta < 1$, the output response in t is bounded even when $k \to \infty$. The condition $\bar{m}\delta < 1$ is the same as for determinacy under a peg in the economy with fully-rigid prices. It follows that $\bar{m} < 0.95$ is enough to rule out unboundedly-severe recessions at the ELB even if the ELB is expected to persist forever and the model delivers amplification to monetary shocks.

We illustrate the resolution of the lower bound problem graphically in Figure 2. The figure shows the output response in the three different economies to different lengths of a binding ELB. The shortcoming of monetary policy due to the ELB, i.e., the gap $\left(\widehat{i}_{ELB} - \widetilde{r}^n\right) > 0$, is set to a relatively small value of 0.25% (1% annually), and we set $\bar{m} = 0.85$. Figure 2 shows the implosion of output in the rational RANK and even more so in the rational THANK model: an ELB that binds for 40 quarters, and thus, 10 years, would decrease output in the rational THANK model by 40%. On the other hand, output in the behavioral HANK model would still be well-defined and drop by 3%.

Fiscal Multipliers. To characterize fiscal multipliers, we follow Bilbiie (2021) and assume government spending g_t to follow an AR(1) with persistence $\mu \geq 0$, and to be 0 in steady state. The government taxes all agents uniformly to finance g_t.

Figure 2: The Effective Lower Bound Problem



Note: This figure shows the contemporaneous output response for different lengths of a binding ELB k and compares the responses across different models.

In this case, we obtain the aggregate IS equation

$$\widehat{c}_t = \bar{m}\delta\mathbb{E}_t\widehat{c}_{t+1} - \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\left(\widehat{i}_t - \mathbb{E}_t\pi_{t+1}\right) + \zeta\left[\frac{\lambda(\chi-1)}{1-\lambda\chi}\left(g_t - \bar{m}\mathbb{E}_t g_{t+1}\right) + (\delta-1)\bar{m}\mathbb{E}_t g_{t+1}\right],$$

where $\zeta \equiv \frac{\varphi}{\gamma\left(1+\frac{\varphi}{\gamma}\right)}$. The static Phillips Curve in this setting is given by $\pi_t = \kappa c_t + \kappa\zeta g_t$.

The following Proposition characterizes the fiscal multiplier in the behavioral HANK model.

Proposition 4. *The fiscal multiplier in the behavioral HANK model is given by*

$$\frac{\partial\widehat{y}_t}{\partial g_t} = 1 + \frac{1}{1-\nu\mu}\frac{\zeta}{1+\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\phi\kappa}\left[\frac{\chi-1}{1-\lambda\chi}\left[\lambda + \bar{m}\mu(1-s-\lambda)\right] - \kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}(\phi-\mu)\right],$$

where

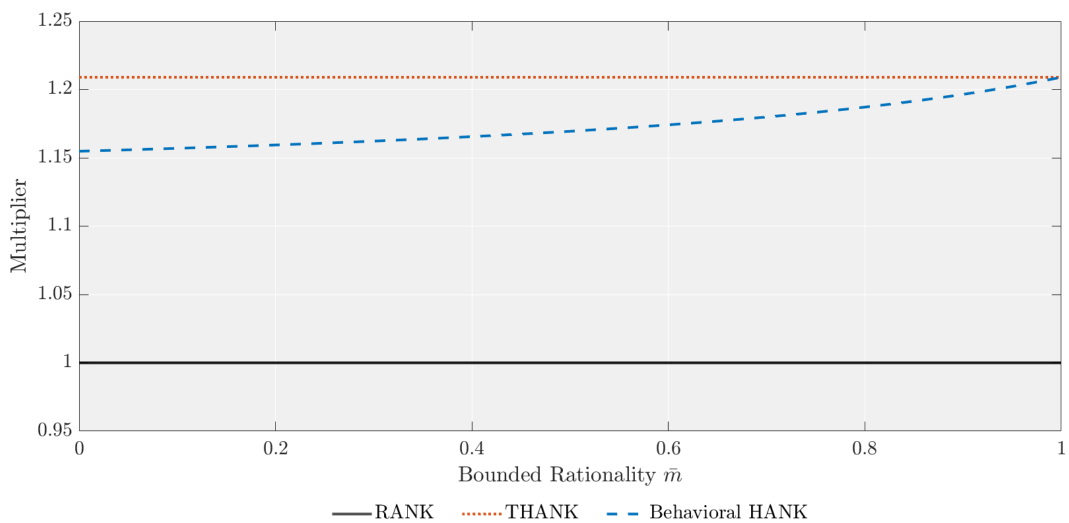
$$\nu \equiv \frac{\bar{m}\delta + \frac{1}{\gamma}\kappa\frac{1-\lambda}{1-\lambda\chi}}{1+\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\phi\kappa}. \tag{27}$$

A corollary of Propositon 4 is that in the case of persistent government spending, $\mu > 0$, and in the amplification case ($\chi > 1$), more bounded rationality, i.e., a lower $\bar{m}$, leads to a lower fiscal multiplier.[25] Bounded rationality weakens the fiscal multiplier as boundedly-rational agents discount the fact that an increase in government spending today has a positive effect on future spending as well. In the case of an i.i.d. spending shock, the fiscal multiplier is independent of $\bar{m}$.

We follow Bilbiie (2021) and set $\kappa = 0$ in which case the fiscal multiplier in the RANK model is 1, thus, the *consumption* response is 0 (see Bilbiie (2011) and Woodford (2011)).[26] In this constant real interest rate case, the fiscal multiplier is strictly above one in the behavioral HANK model despite being dampened by bounded rationality.

Figure 3 illustrates this by showing the fiscal multiplier in the behavioral HANK model for varying degrees of $\bar{m}$ (blue-solid line). For this exercise, we set the persistence to a medium value, $\mu = 0.6$. We see that the fiscal multiplier is substantially above one under bounded rationality but somewhat weaker than under rational expectations.

Figure 3: Fiscal Multipliers



Note: This figure shows the fiscal multipliers for different degrees of bounded rationality (blue-dashed line). The orange-dotted line plots the fiscal multiplier in the rational version of the model and the black-solid line shows the zero-multiplier in the RANK model.

[25] This also assumes that the risk of becoming hand-to-mouth is not excessively high, i.e., $1 - s > \lambda$, which is the case under any reasonable parameterization.

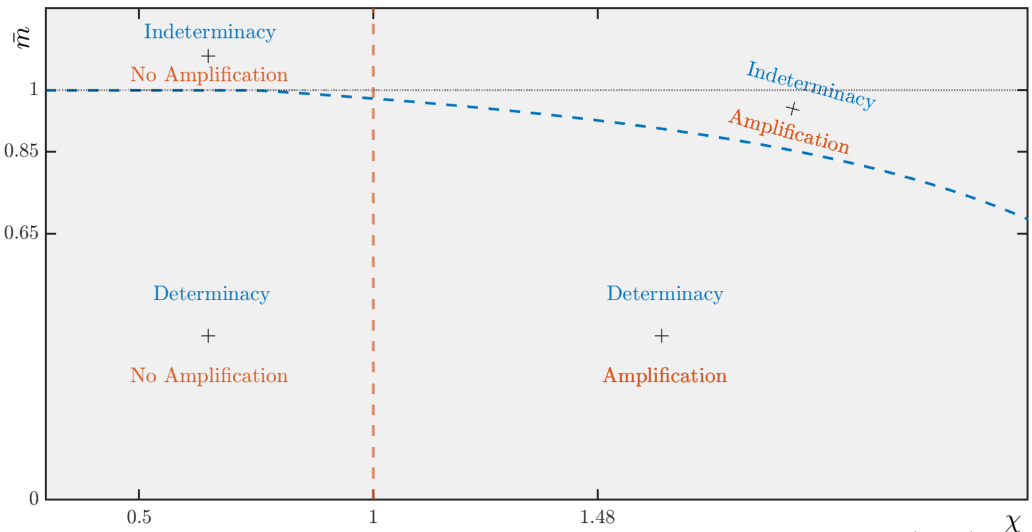
[26] Auclert et al. (2018) also use a constant real interest rate case to show that their HANK model can generate fiscal multipliers larger than one.

It is noteworthy that the behavioral HANK model does not rely on a specific financing type to achieve fiscal multipliers larger than one. This is in contrast to the behavioral RANK model in Gabaix (2020). In the behavioral RANK model, bounded rationality can also increase the multiplier but only if the government delays taxing the agents to finance the contemporaneous spending as boundedly-rational agents will then discount the future increases in taxes. In the rational THANK model, on the other hand, the fiscal multiplier can in principle be larger than one with $\chi < 1$ if the hand-to-mouth households pay relatively less than the savers (see Bilbiie (2020) or Ferriere and Navarro (2018)). Both of these channels would also push up the multiplier in the behavioral HANK model, yet it does not depend on any of these two to achieve fiscal multipliers larger than 1.

The Behavioral HANK as a Unifying Framework. Figure 4 shows how bounded rationality and household heterogeneity interact to generate the desirable HANK features and to simultaneously resolve the NK puzzles. The blue and orange dashed lines split the parameter space $(\chi, \bar{m})$ in the following sense: The blue line denotes the cut-off values below which the model is determinate under an interest-rate peg while above it the model is indeterminate (with the line itself belonging to the indeterminacy region). Determinacy under a peg is sufficient to rule out the forward guidance puzzle as well as the lower bound problem, and thus, is a sufficient statistic to resolve the discussed NK puzzles. The orange line denotes the cut-off values such that to the right of it, the model generates amplification while left from it—again including the line—the model does not generate amplification.

This split of the parameter space into four areas allows us to distinguish the models discussed so far and to show how the behavioral HANK can overcome the limitations inherent in existing model. The RANK model is located in the "indeterminacy + no amplification" region as $\bar{m} = 1$ and $\chi = 1$. The behavioral RANK can either be in "indeterminacy + no amplification" or in "determinacy + no amplification" depending on the degree of rationality. Rational THANK models can either be in "indeterminacy + no amplification", "determinacy

Figure 4: The Behavioral HANK as a Unifying Framework



Note: The figure characterizes four possible regions depending on whether the considered $(\chi, \bar{m})$-pair delivers determinacy under an interest-rate peg or not and whether the model generates amplification of contemporaneous monetary and fiscal policy or not (we only extend the y-axis above 1 for the sake of readability).

+ no amplification" or in "indeterminacy + amplification" while rational TANK models can only be in "indeterminacy + no amplification" or in "indeterminacy + amplification". Importantly, both cannot be in "determinacy + amplification". Only the behavioral HANK model can deliver "determinacy + amplification". Furthermore, the behavioral HANK model can in principle cover the whole parameter space as it nests all the aforementioned models as special cases.

Having discussed the aggregate implications of the model, we now zoom in closer into the model and derive the iMPCs and show how they depend on bounded rationality, household heterogeneity, and the interaction of the two.

4.3 Intertemporal MPCs

The HANK literature shows that the iMPCs are a key statistic for conducting policy analysis (see, e.g., Auclert et al. (2018), Auclert et al. (2020a), and Kaplan and Violante (2020)). We follow the THANK/TANK literature and define the aggregate iMPCs in the behavioral HANK model as the partial derivative of aggregate consumption at time k, $\widehat{c}_k$, with respect to aggregate disposable income, $\tilde{y}_0$, keeping everything else fixed (see Bilbiie (2021), Cantore and Freund (2021), and Auclert et al. (2018)). In addition, we calibrate the model annually as the empirical evidence on the iMPCs is annual (see Fagereng et al. (2021)). In particular, we set $s = 0.8$, $\chi = 1.48$, $\lambda = 0.33$, $\gamma = 1$ and $\beta = 0.95$. These values lie within the standard range of values used in the THANK literature (see Bilbiie (2020) or Bilbiie (2021)). We set the cognitive discounting parameter $\bar{m}$ to 0.85 as our baseline case, but we often vary it to show how the results change with $\bar{m}$.

The following Proposition characterizes the iMPCs in the behavioral HANK model.[27]

Proposition 5. *The intertemporal MPCs in the behavioral HANK model, i.e., the aggregate consumption response in period k to a one-time change in aggregate disposable income in period 0, are given by*

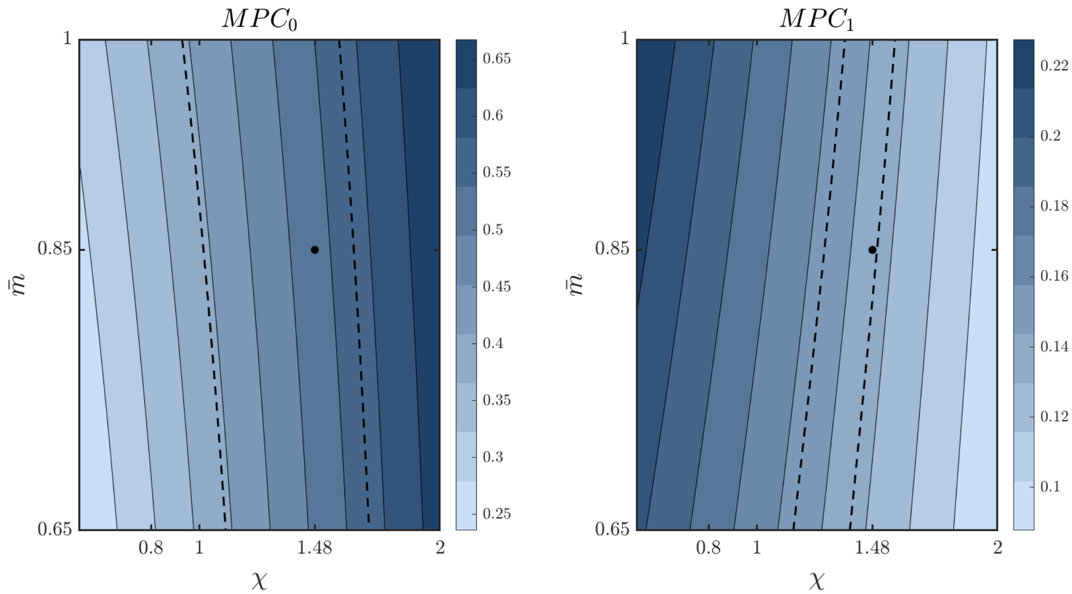
$$\frac{d\widehat{c}_0}{d\widetilde{y}_0} = 1 - \frac{1-\lambda\chi}{s\bar{m}}\mu_2^{-1}$$
$$\frac{d\widehat{c}_k}{d\widetilde{y}_0} = \frac{1-\lambda\chi}{s\bar{m}}\mu_2^{-1}\left(\beta^{-1} - \mu_1\right)\mu_1^{k-1}, \qquad \textit{for } k > 0,$$

where the parameters μ_1 and μ_2 depend on the underlying parameters, including $\bar{m}$ and χ and are detailed in Appendix D.

Figure 5 graphically depicts how the interplay of bounded rationality $\bar{m}$ and household heterogeneity χ determines the size of the aggregate iMPCs. The left panel depicts the aggregate MPCs to spend within the first year (in period 0) and the right panel shows aggregate MPCs to spend within the second year (in period 1) after the temporary increase in income in time 0. Darker colors represent larger MPCs. First, note that with our baseline calibration—$\chi = 1.48$ and $\bar{m} = 0.85$ as shown by the black dots—the behavioral HANK model generates iMPCs within the first year of 0.55 and within the second year of 0.15. This lies exactly in the estimated corridor for the iMPCs in the data which are between $0.42 - 0.6$ within the first and $0.14 - 0.16$ within the second year (see dashed lines). Away from our

[27] See Appendix D for the derivation.

Figure 5: Intertemporal MPCs, Bounded Rationality and Household Heterogeneity



Note: This figure shows the aggregate intertemporal MPCs, i.e., the aggregate consumption response in year 0 (left) and year 1 (right) to a change in aggregate disposable income in year 0 for different χ (x-axis) and $\bar{m}$ (y-axis). The dashed lines show the range of empirically-estimated iMPCs and the black dot shows the model estimate given our baseline calibration. Darker colors represent larger MPCs.

baseline calibration, an increase in χ increases the MPCs in the first year but decreases them in the second year.[28] In contrast, an increase in $\bar{m}$ increases the aggregate MPC in the first year and in the second year.

Let us first turn to the role of χ for the iMPCs: Recall, the higher χ, the more sensitive is the income of the H households to a change in aggregate income. Thus, with higher χ, H households gain weight in relative terms for the aggregate iMPCs while the savers loose weight in relative terms. This pushes up the aggregate MPC within the first year, but pushes down the aggregate MPC within the second year as households that were hand-to-mouth in the period of the income windfall will have a MPC of 0 in the second year.

Bounded rationality, captured by $\bar{m}$, affects only the MPCs of the savers as only savers—whether behavioral or rational—intertemporarily optimize. The savers' Euler equation dic-

[28]Note that when considering micro moments like the iMPCs, $\chi = 1$ is not sufficient anymore for the model to collapse to RANK but rather to THANK which behaves in the aggregate exactly like RANK (see the incomplete-markets irrelevance result in Werning (2015)). Hence, the RANK iMPCs are not pictured in Figure 5. Yet, Proposition 5 still nests RANK for $\chi = 1$ and $\lambda = 0$.

tates that the decrease in today's marginal utility of consumption—following the increase in consumption—is equalized by a decrease in tomorrow's expected marginal utility. For the behavioral saver, however, the decrease in tomorrow's marginal utility needs to be more substantial as she cognitively discounts the expectations about the future decrease. Hence, the behavioral saver saves relatively more out of the income windfall. This pushes down the aggregate MPCs in $t = 0$. The same is true for the aggregate MPC in $t = 1$, in which there are two opposing forces at work: on the one hand, the saver again cognitively discounts the expectations about the future decrease in the marginal utility which depresses their consumption. On the other hand, savers have accumulated more wealth from period $t = 0$. Given our calibration, in $t = 1$ the former dominates. Figure 11 in Appendix D shows that, beginning in $k = 3$, the latter effect starts to dominate. If we increase the idiosyncratic risk of becoming hand-to-mouth, i.e., increase the transition probability $1-s$, the aggregate MPC is already in $t = 1$ higher for lower $\bar{m}$. The reason is that a smaller fraction of initial savers remains savers which pushes upwards consumption in $k = 1$ (see Figure 10 in Appendix D).

The effects of a change in $\bar{m}$ are more pronounced at lower levels of χ. Combining our discussion about the role of χ and $\bar{m}$, this is intuitive: the lower χ, the higher is the relative importance of the savers for the aggregate iMPCs and, in turn, the stronger is the effect of $\bar{m}$ on the aggregate iMPCs. These interaction effects are quite substantial: at $\chi = 1.48$, a decrease of $\bar{m}$ from 1 to 0.65 decreases the MPC_0 by 7% and the MPC_1 by more than 11%.

4.4 Policy Implications: The Timing of Monetary Policy

We close this section by briefly discussing the policy implications of the behavioral HANK model. In particular, we illustrate that the behavioral HANK can generate different policy implications than its rational counterpart. To this end, we analyze how the timing of monetary policy affects its effectiveness and its distributional consequences.

Consider that the central bank wants to increase the nominal interest rate by x%, for example, to fight an overheating economy. The central bank decides whether to implement this policy within one quarter or to gradually raise the interest rate by $\frac{x}{k}\%$ for k consecutive quarters.

Lemma 1. *The effect of a $\frac{x}{k}\%$ interest rate hike over k consecutive periods decreases current output by*

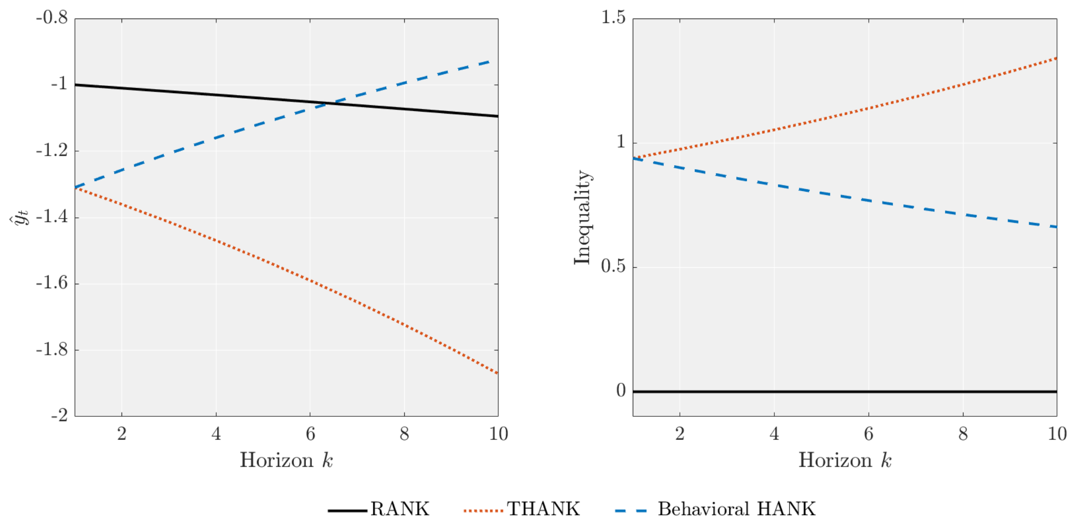
$$\widehat{y}_t = \frac{\psi_c}{\gamma}\left[\sum_{j=0}^{k-1}\left(\psi_f + \frac{\psi_c}{\gamma}\kappa\right)^j\right]\frac{x}{k}.$$

The left panel of Figure 6 depicts the result in Lemma 1 for the behavioral HANK model and compares it to its rational counterpart and the rational RANK model. The solid-black line shows the well-known feature of RANK that the effects of monetary policy on current output become stronger when monetary policy is back-loaded: the further the interest hike is stretched out, the higher is the response on current output. The orange-dotted line shows that this feature is even more pronounced in the rational THANK model as the line is steeper than in the RANK model.

In contrast, the blue-dashed line of the behavioral HANK model is increasing and not decreasing in k. Thus, back-loading monetary policy decreases its effect on current output. To put it differently, monetary policy is most effective on current output if it is completely front-loaded. Hence, if the central bank wants to fight an overheating of the economy as effectively as possible, the behavioral HANK model implies front-loading the interest rate hike, while its rational counterpart suggests to rather back-load the hike.

The right panel of Figure 6 depicts the effects of the different timing of the monetary policy hikes on consumption inequality, as defined in equation (13). It shows that if monetary policy front-loads the interest rake hike, it increases inequality the most whereas a more gradual increase in the interest rates would have weaker effects on inequality. This illustrates a trade-off for the central banker: the more effectively monetary policy combats the overheating, the more it increases inequality.

Figure 6: Monetary Policy Timing: Effectiveness and Distributional Consequences



Note: This figure shows the response of current output (left panel) of a cumulative interest-rate hike by $x\%$ implemented over k consecutive periods. The right panel shows the corresponding response of inequality, defined as $\widehat{c}_t^S - \widehat{c}_t^H$.

5 Bounded Rationality and Incomplete Information: An Equivalence Result

In this section, we derive an equivalence result between bounded rationality and incomplete information. In particular, we show how a change in the default value in the behavioral setup leads to the same IS equation as in models with incomplete information and learning (see Angeletos and Huo (2021)).

To this end, we now assume that behavioral agents anchor their expectation to their *last observation* instead of to the steady state values. A possible interpretation is that agents anchor their beliefs to what they read or hear in the news. Models featuring some form of backward-looking behavior indeed tend to match the expectations data coming from household surveys quite well (see, for example, Adam et al. (2017), Adam et al. (2020), Angeletos and Huo (2021), and Angeletos et al. (2021)). The backward-looking components in these models usually arise from an incomplete or noisy information setting as well as some form of (Bayesian) learning. We now show how our bounded rationality setup generates expectations that resemble these aforementioned expectations models.

Proposition 6. *Set the boundedly-rational agents' default value to the variable's past value*

$$X_t^d = X_{t-1}. \tag{28}$$

In this case, the boundedly-rational agent's expectations of X_{t+1} becomes

$$\mathbb{E}_t^{BR}\left[X_{t+1}\right] = (1-\bar{m})X_{t-1} + \bar{m}\mathbb{E}_t\left[X_{t+1}\right]. \tag{29}$$

It is noteworthy that Proposition 6 also holds if we instead assume that a fraction $1-\bar{m}$ of savers is purely backward looking while a fraction $\bar{m}$ is completely forward looking and rational. In either case, these backward-looking expectations introduce a backward-looking component into the behavioral IS equation as summarized in the following Proposition.[29]

Proposition 7. *For the case that the behavioral agents' default value is the past value of the respective variable, i.e., $X_t^d = X_{t-1}$, the behavioral HANK IS equation is given by*

$$\widehat{y}_t = \psi_f \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma}\left(\widehat{i}_t - \mathbb{E}_t \pi_{t+1}\right) + (1-\bar{m})\delta \widehat{y}_{t-1}. \tag{30}$$

Proposition 7 shows that the change in the agents' default value does not change the existing behavioral and heterogeneity coefficients ψ_f and ψ_c, respectively, in Proposition 1. Yet, anchoring to past realizations introduces an additional backward-looking term in the IS equation, similar to models relying on habit persistence. Angeletos and Huo (2021) derive an IS equation with the same reduced form which, however, is based on an incomplete-information setting and learning. We complement their findings by showing that we can generate the equivalent outcome based on a *behavioral* relaxation of FIRE. Proposition 7 thus offers a way to reconcile models that relax the *full-information* part of FIRE with models that relax the *rational-expectations* part of it.

[29] In Appendix A we prove Proposition 7 for both interpretations.

Angeletos and Huo (2021) calibrate the coefficients in front of $\mathbb{E}_t\widehat{y}_{t+1}$ and $\widehat{y}_{t-1}$ to match evidence from survey expectations data. By following their calibration, we can back out the implied $\bar{m}$ and χ. We leave the other parameters as in Section 4. This implies $\bar{m} = 0.59$ and $\chi = 0.72$, thus, relatively low values compared to the calibration above. We complement the backward-looking behavioral HANK IS equation with the static Phillips Curve (15).

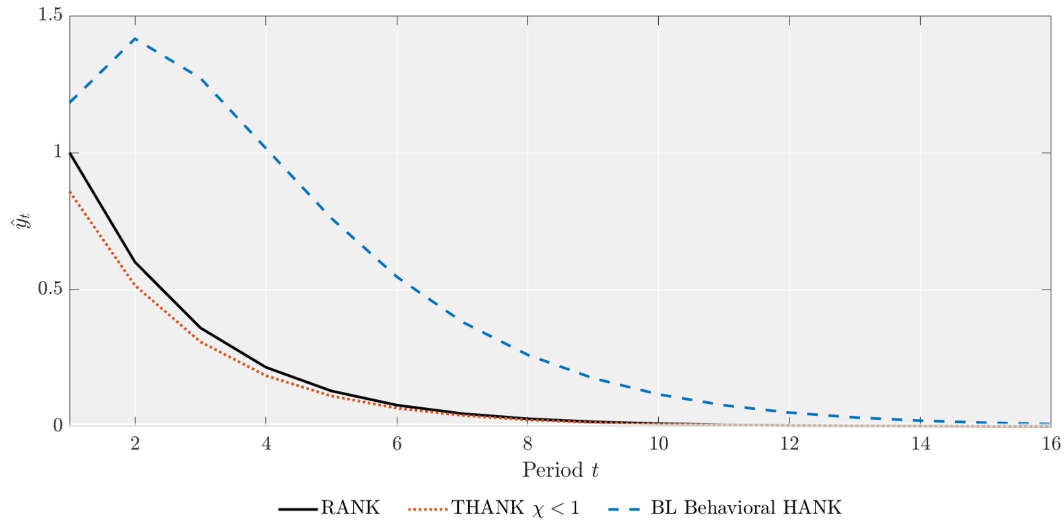
Determinacy. We numerically verify that the backward-looking behavioral HANK model restores the Taylor principle. In fact, the equilibrium is determinate even under an interest-rate peg. Thus, also the backward-looking behavioral HANK model overturns the Sargent and Wallace (1975) result with this calibration.

Impulse-Response Functions. We now show how the backward-looking behavioral HANK model generates hump-shaped impulse responses and a novel behavioral amplification channel. To this end, we examine how output in the backward-looking behavioral HANK model responds to an expansionary monetary policy shock and compare the response to its rational counterpart and the RANK version of the model. We set the Taylor coefficient to 1.5, thus, guaranteeing determinacy also in the rational models and the persistence of the shock to an intermediate value, $\rho^{MP} = 0.6$.

Figure 7 shows the corresponding impulse-response functions. The blue-dashed line shows the results for our behavioral HANK, the orange-dotted line for its rational counterpart (THANK) while the black-solid line shows RANK.

Two things stand out. First, the behavioral HANK model delivers amplification compared to RANK—even in the first period—and second, the backward-looking anchor generates hump-shaped responses. The latter has been highlighted in Angeletos and Huo (2021). Turning to amplification, we see that the behavioral HANK model gives rise to a *behavioral amplification channel*: the initial output response is amplified although the model features procyclical inequality ($\chi < 1$) and, thus, the heterogeneity frictions themselves would generate dampening.

Figure 7: Output Response to a Monetary Policy Shock



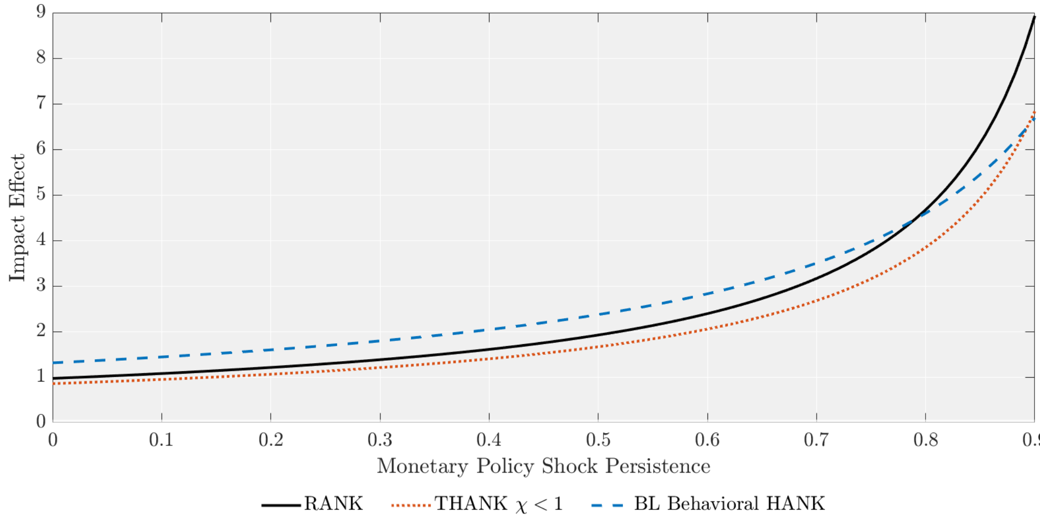
Note: This figure shows the output response to a monetary policy shock for different models.

Where does the behavioral amplification come from? Given the backward-looking component in households' expectations, the increase in today's output is expected to persist as it becomes tomorrow's default value for the household's expectations. This, in turn, further increases today's output response. Yet, there is an opposing channel at work: a persistent shock not only decreases interest rates today but also expected future interest rates. Households discount these future changes and, thus, perceive the shock as less expansionary compared to a rational agent dampening the initial response. Given our calibration, the first channel dominates, thereby generating amplification as depicted in Figure 7.

Given the two opposing forces at work, the degree of initial amplification depends on the persistence of the shock. Figure 8 shows the initial response of all three models for different degrees of persistence of the shock. It shows that as the persistence declines, the difference in the initial responses increases in relative terms. Thus, the relative amplification is largest for an i.i.d. shock.

In addition, comparing the backward-looking behavioral HANK model to its rational counterpart shows that for $\rho^{MP} < 0.9$, there is behavioral amplification while for more

Figure 8: Initial Output Response for Varying Degrees of the Persistence



Note: This figure shows the initial output response to monetary policy shocks with different degrees of persistence.

persistent shocks, there is behavioral dampening. The comparison with RANK shows that for $\rho^{MP} < 0.80$, the behavioral amplification dominates the heterogeneity dampening due to $\chi < 1$.

Behavioral Amplification and Forward Guidance. We now analyze analytically the behavioral-amplification mechanism and its implication for the forward guidance. In the backward-looking behavioral HANK model, the output response to an interest rate change depends on the (expected) infinite future even when the shock is completely transitory. To see this, consider the following. The monetary authority decreases the nominal interest rate in period t to $\widetilde{i}_t < 0$ but will keep it at steady state thereafter (the argument extends to changes of the interest rate in the future). Output and inflation would be expected to go back to zero in $t+1$ under rational expectations. This is, however, not true for the backward-looking behavioral HANK model.

To understand this, combine the static Phillips Curve (a static Phillips curve is again not crucial for the argument but facilitates the derivations) with the behavioral HANK IS equation to arrive at

$$\widehat{y}_t = (1-\bar{m})\delta\widehat{y}_{t-1} - \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\widetilde{i}_t + \left[\delta\bar{m} + \kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]\mathbb{E}_t\widehat{y}_{t+1}.$$

If households expect future output to be back to steady state, a one time, completely transitory decrease in the nominal interest rate changes contemporaneous output by

$$\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi} > 0, \tag{31}$$

which would be the case in the rational model or the behavioral model in which the households' default value equals the steady state. As output in t increases, however, expectations in $t+1$ of output in $t+2$ will be above steady state. This feeds back into output already in t.

To see this, note that we can write the IS equation as

$$\begin{aligned}
&\widehat{y}_t\left[1-(1-\bar{m})\delta\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]\right] = \\
&(1-\bar{m})\delta\widehat{y}_{t-1} - \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\left[\widetilde{i}_t + \left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]\mathbb{E}_t\left[\widetilde{i}_{t+1}\right]\right] \\
&+\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]^2\mathbb{E}_t\widehat{y}_{t+2}.
\end{aligned}$$

Thus, if households would assume that $\widehat{y}_{t+2}$ will be zero but not $\widehat{y}_{t+1}$, the discussed interest-rate change in t increases output in t by

$$\frac{\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}}{1-(1-\bar{m})\delta\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]},$$

which is larger than the effect for models without a backward-looking anchor as can be seen in (31). Put differently, the initial output response is amplified through a behavioral channel.

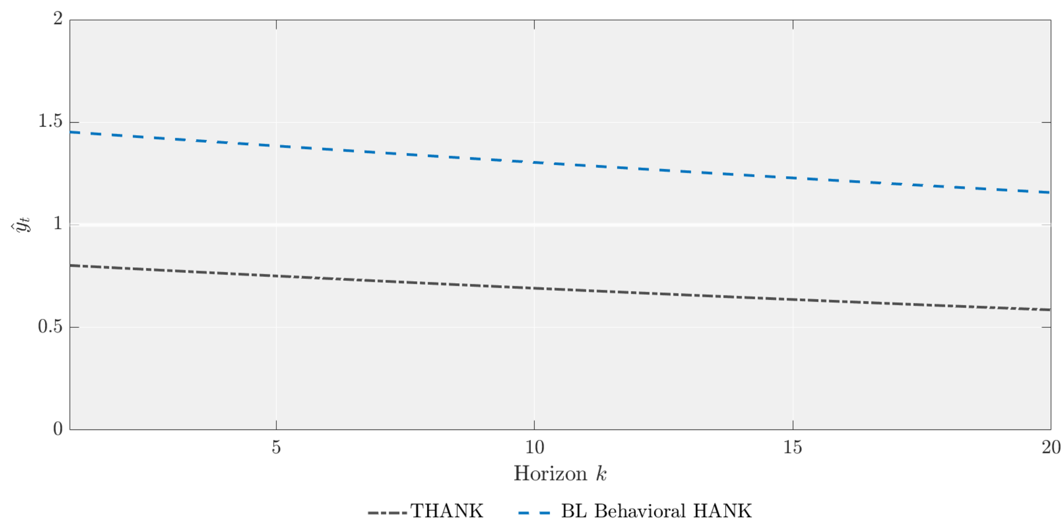
Turning to forward guidance, an expected change in the nominal interest rate in period

$t+1$, affects output in t by

$$-\frac{\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]}{1-(1-\bar{m})\delta\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]},$$

if we assume output in $t+2$ to be back to zero. Given our calibration, the term $\left[\delta\bar{m}+\kappa\frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\right]$ is smaller than 1. Thus, an interest rate change tomorrow has a smaller effect on output today than a contemporaneous interest rate change such that there is no forward guidance puzzle in the backward-looking behavioral HANK model. We can continue in this fashion to show that the effects increase with the iteration but decrease with the period of the shock.

Figure 9: Forward Guidance with Backward-Looking Anchor



Note: This figure shows the period-t output response to an anticipated i.i.d. monetary policy shock in period $t+k$ for three different economies.

Figure 9 shows these patterns graphically. First, the behavioral amplification channel discussed above is reflected in the contemporaneous effect ($k=0$) which is stronger than without the backward-looking expectations —reflected in the black-dashed-dotted line. Second, increasing the horizon k shows that there is no forward guidance puzzle in the backward-looking behavioral HANK model. To sum it up, also the backward-looking behavioral HANK model amplifies contemporaneous monetary policy while it simultaneously dampens the effects of forward guidance.

6 Conclusion

We propose a framework that generates both desirable HANK features and resolves NK puzzles: in our behavioral HANK model, monetary policy mainly works through indirect effects, fiscal multipliers are larger than one, and the model generates empirically realistic intertemporal marginal propensities to consume. At the same time, there is no forward guidance puzzle, output remains stable even for (infinitely) long spells at the ELB and the model is determinate under a peg. By incorporating all these features, the behavioral HANK model provides a suitable framework for extensive policy analysis. This is in stark contrast to existing models that are nested within our framework but cannot incorporate all these features simultaneously. What is more, we show that the behavioral HANK model can have different policy implications than its rational counterpart, e.g., when it comes to the timing of monetary policy.

We further show that by a small change in the agents' default value to which they anchor their expectations, the resulting backward-looking behavioral HANK model endogenously generates hump-shaped responses of macroeconomic aggregates to monetary policy shocks. In addition, it gives rise to a behavioral amplification channel which allows the model to deliver amplification compared to RANK under conditions in which the rational model would imply dampening. Importantly, the behavioral HANK model achieves all these features while remaining analytically tractable. Thus it offers a simple framework to study a broad array of questions in future research.

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A Model Details and Derivations

A.1 Derivation of Proposition 1.

Combining equations (10) and (12) with the bounded-rationality setup in equation (17) for $\widehat{x}_t^d = 0$ as x_t^d is given by the steady state, we have

$$\begin{aligned}
\mathbb{E}_t^{BR}\left[\widehat{c}_{t+1}^H\right] &= \bar{m}\mathbb{E}_t\left[\widehat{c}_{t+1}^H\right] = \bar{m}\chi\mathbb{E}_t\left[\widehat{y}_{t+1}\right] \\
\mathbb{E}_t^{BR}\left[\widehat{c}_{t+1}^S\right] &= \bar{m}\mathbb{E}_t\left[\widehat{c}_{t+1}^S\right] = \bar{m}\frac{1-\lambda\chi}{1-\lambda}\mathbb{E}_t\left[\widehat{y}_{t+1}\right].
\end{aligned}$$

Plugging these two equations as well as equation (12) into the savers' Euler equation (14) yields

$$\frac{1-\lambda\chi}{1-\lambda}\widehat{y}_t = s\bar{m}\frac{1-\lambda\chi}{1-\lambda}\mathbb{E}_t\left[\widehat{y}_{t+1}\right] + (1-s)\bar{m}\chi\mathbb{E}_t\left[\widehat{y}_{t+1}\right] - \frac{1}{\gamma}\left(\widehat{i}_t - \mathbb{E}_t\pi_{t+1}\right).$$

Combining the $\mathbb{E}_t\left[\widehat{y}_{t+1}\right]$ terms and dividing by $\frac{1-\lambda\chi}{1-\lambda}$ yields the following coefficient in front of $\mathbb{E}_t\left[\widehat{y}_{t+1}\right]$:

$$\begin{aligned}
\psi_f &\equiv \bar{m}\left[s + (1-s)\chi\frac{1-\lambda}{1-\lambda\chi}\right] \\
&= \bar{m}\left[1 - 1 + s + (1-s)\chi\frac{1-\lambda}{1-\lambda\chi}\right] \\
&= \bar{m}\left[1 - \frac{1-\lambda\chi}{1-\lambda\chi} + s + (1-s)\chi\frac{1-\lambda}{1-\lambda\chi}\right] \\
&= \bar{m}\left[1 - \frac{1-\lambda\chi}{1-\lambda\chi} + \frac{(1-\lambda\chi)s}{1-\lambda\chi} + (1-s)\chi\frac{1-\lambda}{1-\lambda\chi}\right] \\
&= \bar{m}\left[1 + (\chi - 1)\frac{1-s}{1-\lambda\chi}\right].
\end{aligned}$$

Defining $\psi_c \equiv \frac{1-\lambda}{1-\lambda\chi}$ yields the behavioral HANK IS equation in Proposition 1:

$$\widehat{y}_t = \psi_f\mathbb{E}_t\widehat{y}_{t+1} - \psi_c\frac{1}{\gamma}\left(\widehat{i}_t - \mathbb{E}_t\pi_{t+1}\right).$$

A.2 Derivation of Proposition 2.

The first part comes from the fact that amplification is defined as

$$\frac{1-\lambda}{1-\lambda\chi} > 1,$$

which requires $\chi > 1$.

For the second part, recall how we model forward guidance (following Bilbiie (2021)). We assume a Taylor coefficient of 0, i.e., $\phi = 0$, such that the nominal interest rate is given by $\widehat{i}_t = \varepsilon_t^{MP}$. Replacing inflation using the Phillips curve (15), i.e., $\pi_t = \kappa\widehat{y}_t$, we can re-write the behavioral HANK IS equation from Proposition 1 as

$$\begin{aligned}\widehat{y}_t &= \psi_f \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma}\left(\varepsilon_t^{MP} - \kappa \mathbb{E}_t \widehat{y}_{t+1}\right) \\ &= \left(\psi_f + \psi_c \frac{1}{\gamma}\kappa\right) \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma} \varepsilon_t^{MP}\end{aligned}$$

The forward guidance puzzle is ruled out if and only if

$$\left(\psi_f + \psi_c \frac{1}{\gamma}\kappa\right) < 1,$$

which is the same as the condition stated in Proposition 2:

$$\bar{m}\delta + \frac{1}{\gamma}\frac{1-\lambda}{1-\lambda\chi}\kappa < 1.$$

Solving this for $\bar{m}$ yields

$$\bar{m} < \frac{1 - \frac{1-\lambda}{\gamma(1-\lambda\chi)}\kappa}{\delta},$$

which completes Proposition 1.

A.3 Derivation of Proposition 3.

Replacing $\widehat{i}_t$ by $\phi\pi_t = \phi\kappa\widehat{y}_t$ and $\mathbb{E}_t\pi_{t+1} = \kappa\mathbb{E}_t\widehat{y}_{t+1}$ in the IS equation (18), we get

$$\widehat{y}_t = \psi_f\mathbb{E}_t\widehat{y}_{t+1} - \psi_c\frac{1}{\gamma}\left(\phi\kappa\widehat{y}_t - \kappa\mathbb{E}_t\widehat{y}_{t+1}\right),$$

which can be re-written as

$$\widehat{y}_t\left(1 + \psi_c\frac{1}{\gamma}\phi\kappa\right) = \mathbb{E}_t\widehat{y}_{t+1}\left(\psi_f + \psi_c\frac{1}{\gamma}\kappa\right).$$

Dividing by $\left(1 + \psi_c\frac{1}{\gamma}\phi\kappa\right)$ and plugging in for ψ_f and ψ_c yields

$$\widehat{y}_t = \frac{\bar{m}\delta + \frac{(1-\lambda)\kappa}{\gamma(1-\lambda\chi)}}{1 + \kappa\phi\frac{1}{\gamma}\frac{(1-\lambda)}{1-\lambda\chi}}\mathbb{E}_t\widehat{y}_{t+1}.$$

To obtain determinacy, the term in front of $\mathbb{E}_t\widehat{y}_{t+1}$ has to be smaller than 1. Solving this for ϕ yields

$$\phi > \phi^* = 1 + \frac{\bar{m}\delta - 1}{\frac{\kappa}{\gamma}\frac{1-\lambda}{1-\lambda\chi}}, \tag{32}$$

which is the condition in Proposition 3. This illustrates how bounded rationality raises the likelihood that the Taylor principle ($\phi^* = 1$) is sufficient for determinacy, as the Taylor principle can only hold if

$$\bar{m}\delta < 1.$$

In the rational model, this boils down to $\delta < 1$. Thus, the Taylor principle can be sufficient under bounded rationality, i.e., $\bar{m} < 1$, even when $\delta > 1$, thus, even when allowing for amplification. Note that we could express condition (32) as

$$\phi > \phi^* = 1 + \frac{\psi_f - 1}{\frac{\kappa}{\gamma}\psi_c}.$$

A.4 Derivation of Proposition 7

To prove Proposition 7, we start from the Euler equation (14). For simplicity, we denote $\widehat{r}_t \equiv \widehat{i}_t - \mathbb{E}_t\pi_{t+1}$ as the real rate. Plugging in for $\widehat{c}_t^S$, $\widehat{c}_{t+1}^S$ and $\widehat{c}_{t+1}^H$ from equations (10) and (12), we get

$$\widehat{y}_t = s\mathbb{E}_t^{BR}\left[\widehat{y}_{t+1}\right] + (1-s)\frac{1-\lambda}{1-\lambda\chi}\mathbb{E}_t^{BR}\left[\widehat{y}_{t+1}\right] - \psi_c\widehat{r}_t,$$

which can be re-written as

$$\widehat{y}_t = \delta\mathbb{E}_t^{BR}\left[\widehat{y}_{t+1}\right] - \psi_c\widehat{r}_t.$$

Now, using the expectations setup from Proposition 6, we get $\delta\mathbb{E}_t^{BR}\left[\widehat{y}_{t+1}\right] = (1-\bar{m})\delta\widehat{y}_{t-1} + \bar{m}\delta\mathbb{E}_t\left[\widehat{y}_{t+1}\right]$ which proves Proposition 7.

In the main text, we mentioned how an alternative interpretation delivers the same IS equation. Assume a fraction $\bar{m}$ of savers are completely rational and forward looking and a fraction $1-\bar{m}$ is purely backward looking, i.e., their expectations are such that $\tilde{\mathbb{E}}_t^{BR}\left[\widehat{x}_{t+1}\right] = \widehat{x}_{t-1}$. Otherwise they are exactly the same and again, the family head pools resources such that their consumption is the same. The forward-looking households' Euler can then be written as

$$\widehat{c}_t^S = s\mathbb{E}_t\left[\widehat{c}_{t+1}^S\right] + (1-s)\mathbb{E}_t\left[\widehat{c}_{t+1}^H\right] - \frac{1}{\gamma}\widehat{r}_t$$

and the backward-looking households' Euler reads

$$\widehat{c}_t^S = s\widehat{c}_{t-1}^S + (1-s)\widehat{c}_{t-1}^H - \frac{1}{\gamma}\widehat{r}_t.$$

Weighting the first equation with $\bar{m}$ and the second with $1-\bar{m}$ and summing the two up yields the IS equation in Proposition 7 after substituting for $\widehat{c}_t^S$, $\widehat{c}_{t+1}^S$ and $\widehat{c}_{t+1}^H$ from equations (10) and (12).

B Calibration

Parameter	Value	Source/Target
	THANK Parameters	
γ	1	Bilbiie (2020)
κ	0.02	Bilbiie (2020)
χ	1.48	Bilbiie (2020)
λ	0.33	Bilbiie (2020)
s	$0.8^{1/4}$	Bilbiie (2020)
	Behavioral Parameter	
$\bar{m}$	0.85	Gabaix (2020)

Table 1: Baseline calibration.

Our baseline calibration is summarized in Table 1. For figure 5, i.e., to compute the iMPCs we choose a yearly calibration with $s = 0.8$ and $\beta = 0.95$ (this calibration is close to the iMPC exercise in Bilbiie (2021) but while he fixes χ to match the empirically-observed iMPCs, we vary χ together with $\bar{m}$ to examine their joint effects on iMPCs).

C Extensions

C.1 Allowing for Steady State Inequality.

So far, we have assumed that there is no steady state inequality, i.e., $C^H = C^S$. In the following, we relax this assumption and denote steady state inequality by $\Gamma \equiv \frac{C^S}{C^H}$. Recall the savers' Euler equation

$$\left(C_t^S\right)^{-\gamma} = \beta R_t \mathbb{E}_t^{BR}\left[s\left(C_t^S\right)^{-\gamma} + (1-s)\left(C_t^H\right)^{-\gamma}\right],$$

from which we can derive the steady state real rate

$$R = \frac{1}{\beta(s + (1-s)\Gamma^\gamma)}.$$

Log-linearizing the Euler equation yields

$$\widehat{c}_t^S = \beta R \bar{m} \left[s \mathbb{E}_t \widehat{c}_{t+1}^S + (1-s) \Gamma^\gamma \mathbb{E}_t \widehat{c}_{t+1}^H \right] - \frac{1}{\gamma} \left(\widehat{i}_t - \mathbb{E}_t \pi_{t+1} \right).$$

Combining this with the consumption functions and the steady state real rate yields the IS equation

$$\widehat{y}_t = \bar{m} \tilde{\delta} \mathbb{E}_t \widehat{y}_{t+1} - \frac{1}{\gamma} \frac{1-\lambda}{1-\lambda\chi} \left(\widehat{i}_t - \mathbb{E}_t \pi_{t+1} \right), \tag{33}$$

with

$$\tilde{\delta} \equiv 1 + (\chi - 1) \frac{(1-s)\Gamma^\gamma}{s + (1-s)\Gamma^\gamma} \frac{1}{1-\lambda\chi}.$$

From a qualitative perspective, the whole analysis in the paper could be carried out with $\tilde{\delta}$ instead of δ. Quantitatively the differences are small as well. Assume we set $\Gamma = 1.5$, we get $\tilde{\delta} = 1.074$ instead of $\delta = 1.051$. Thus, we need $\bar{m} < 0.91$ instead of $\bar{m} < 0.93$ for determinacy under a peg. Hence, the difference is quantitatively small even though $\Gamma = 1.5$ is quite large and would even imply negative steady state real rates.

C.2 Forward-Looking NKPC and Real Interest Rates

In the main part of the paper, we made the assumption that agents are rational with respect to real interest rates (as in Gabaix (2020)) and assumed a static Phillips Curve (as in Bilbiie (2021)). We now show that the results are barely affected by instead considering a forward-looking New Keynesian Phillips Curve (NKPC) and that agents are also boundedly rational with respect to real rates. Gabaix (2020) derives the NKPC under bounded rationality and shows that it takes the following form:

$$\pi_t = \beta M^f \mathbb{E}_t \pi_{t+1} + \kappa \widehat{y}_t,$$

with

$$M^f \equiv \bar{m}\left(\theta + \frac{1-\beta\theta}{1-\beta\theta\bar{m}}(1-\theta)\right),$$

where $1-\theta$ captures the Calvo probability of price adjustment.

Taking everything together (including the bounded rationality with respect to real interest rates), the model can be summarized by the following three equations:

$$\begin{aligned}
\widehat{y}_t &= \psi_f \mathbb{E}_t \widehat{y}_{t+1} - \psi_c \frac{1}{\gamma}\left(\widehat{i}_t - \bar{m}\mathbb{E}_t \pi_{t+1}\right) \\
\pi_t &= \beta M^f \mathbb{E}_t \pi_{t+1} + \kappa \widehat{y}_t \\
\widehat{i}_t &= \phi \pi_t.
\end{aligned}$$

Plugging the Taylor rule into the IS equation, we can write everything in matrix form:

$$\begin{pmatrix} \mathbb{E}_t \pi_{t+1} \\ \mathbb{E}_t \widehat{y}_{t+1} \end{pmatrix} = \underbrace{\begin{pmatrix} \frac{1}{\beta M^f} & -\frac{\kappa}{\beta M^f} \\ \frac{\psi_c}{\gamma \psi_f}\left(\phi - \frac{\bar{m}}{\beta M^f}\right) & \frac{1}{\psi_f}\left(1 + \frac{\psi_c \bar{m} \kappa}{\gamma \beta M^f}\right) \end{pmatrix}}_{\equiv A} \begin{pmatrix} \pi_t \\ \widehat{y}_t \end{pmatrix}. \tag{34}$$

For determinacy, we need

$$det(A) > 1; \quad det(A) - tr(A) > -1; \quad det(A) + tr(A) > -1.$$

The last condition is always satisfied. The first two conditions are satisfied if and only if

$$\phi > \max\left\{ \frac{\beta\delta M^f \bar{m} - 1}{\frac{\kappa}{\gamma}\frac{1-\lambda}{1-\lambda\chi}}, \bar{m} + \frac{(\delta\bar{m}-1)(1-\beta M^f)}{\frac{\kappa}{\gamma}\frac{1-\lambda}{1-\lambda\chi}} \right\}.$$

In the case of a static Phillips curve but bounded rationality with respect to the real rate, the second condition is the crucial one. To capture the static Phillips curve, we can simply set $M^f = 0$. In this case, it follows that we have a uniquely-determined (bounded) equilibrium for $\phi > -3.22$. Thus, the condition is even weaker as in the main part of the paper.

If we allow for a forward-looking Phillips curve and using the same calibration as in the main text and relying on Gabaix (2020) for the two newly-introduced parameters, $\theta = 0.875$ and $\beta = 0.99$, it follows that we have determinacy even under an interest rate peg for $\bar{m} = 0.85$.

D Details on Intertemporal MPCs

In this section, we derive the iMPCs discussed in Section 4.3. Defining Y_t^j as type j's disposable income, we can write the households' budget constraints as

$$C_t^H = Y_t^H + \frac{1-s}{\lambda} R_t B_t$$
$$C_t^S + \frac{1}{1-\lambda} B_{t+1} = Y_t^S + \frac{s}{1-\lambda} R_t B_t,$$

where R_t denotes the real interest rate and B_t real bonds. Log-linearizing the two budget constraints around the zero-liquidity steady state and $R = \beta^{-1}$ yields

$$\widehat{c}_t^H = \widehat{y}_t^H + \frac{1-s}{\lambda} \beta^{-1} b_t \tag{35}$$
$$\widehat{c}_t^S + \frac{1}{1-\lambda} b_{t+1} = \widehat{y}_t^S + \frac{s}{1-\lambda} \beta^{-1} b_t, \tag{36}$$

where b_t denotes real bonds in shares of steady state output. Aggregating (35) and (36) delivers

$$\widehat{c}_t = \tilde{y}_t + \beta^{-1} b_t - b_{t+1}, \tag{37}$$

where $\tilde{y}_t$ denotes aggregate disposable income.

By plugging equations (35) and (36) into the savers' Euler equation (14), we can derive the dynamics of liquid assets b_t (ignoring changes in the real rate as this is a partial equilibrium exercise):

$$\begin{aligned} &\mathbb{E}_t b_{t+2} - b_{t+1} \left[\frac{1}{s\bar{m}} + \beta^{-1} s + \frac{(1-s)^2 \beta^{-1} (1-\lambda)}{s\lambda} \right] + \frac{\beta^{-1}}{\bar{m}} b_t = \\ &(1-\lambda) \mathbb{E}_t \widehat{y}_{t+1}^S + \frac{1-s}{s} (1-\lambda) \mathbb{E}_t \widehat{y}_{t+1}^H - \frac{1-\lambda}{s\bar{m}} \widehat{y}_t^S. \end{aligned} \tag{38}$$

Note that a change in total disposable income by one changes the hand-to-mouth households' disposable income by χ and the savers' disposable income by $\frac{1-\lambda\chi}{1-\lambda}$.

Let us denote the right-hand side of equation (38) by $-\mathbb{E}_t\widehat{z}_t$. Factorizing the left-hand side and letting F denote the forward-operator, it follows that

$$(F-\mu_1)(F-\mu_2)\mathbb{E}_t b_t = -\mathbb{E}_t\widehat{z}_t, \tag{39}$$

where μ_1 and μ_2 denote the roots of the characteristic equation

$$\mathbb{E}_t b_{t+2} - \phi_1 b_{t+1} - \phi_2 b_t = 0, \tag{40}$$

where

$$\phi_1 \equiv \left[\frac{1}{s\bar{m}} + \beta^{-1}s + \frac{(1-s)^2\beta^{-1}(1-\lambda)}{s\lambda}\right] \tag{41}$$

and

$$\phi_2 \equiv -\frac{\beta^{-1}}{\bar{m}}. \tag{42}$$

Thus, the roots are given by

$$\mu_{1,2} = \frac{\phi_1 \pm \sqrt{\phi_1^2 + 4\phi_2}}{2}. \tag{43}$$

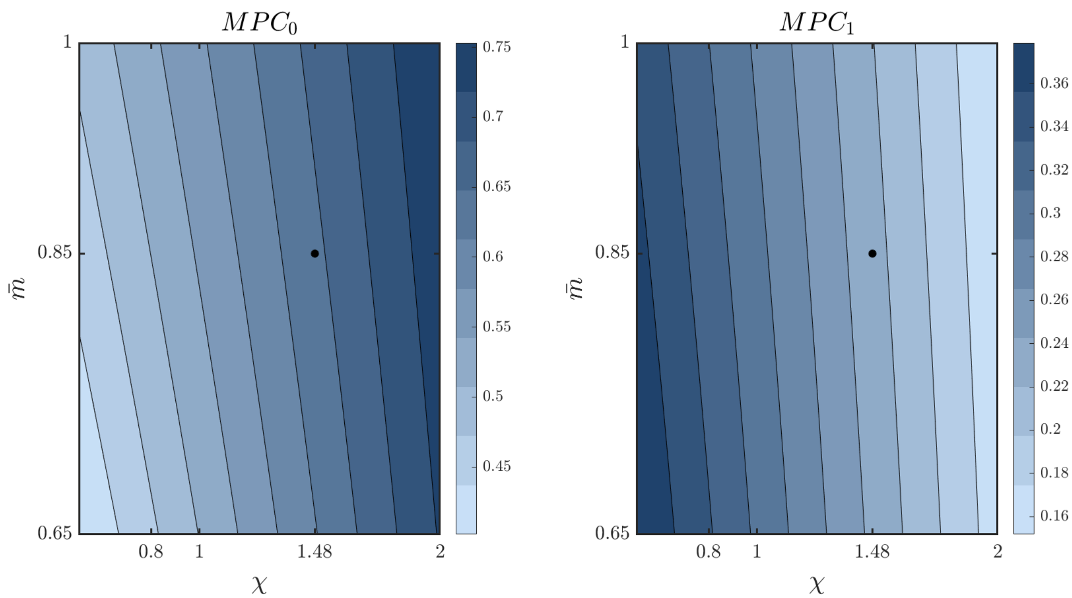
It follows that

$$\begin{aligned} b_{t+1} &= \mu_1 b_t - (F-\mu_2)^{-1}\mathbb{E}_t\widehat{z}_t \\ &= \mu_1 b_t + \frac{\mu_2^{-1}}{1-F\mu_2^{-1}}\mathbb{E}_t\widehat{z}_t. \end{aligned}$$

Note that $\mathbb{E}_t\widehat{z}_t$ can be written as $\frac{1-\lambda\chi}{s}\left(\delta\mathbb{E}_t\widehat{y}_{t+1} - \frac{1}{\bar{m}}\widehat{y}_t\right)$. Without loss of generality, we let $\mu_2 > \mu_1$ and we have $\mu_2 > 1$. Thus, we have $(1-F\mu_2^{-1})^{-1} = \sum_{l=0}^{\infty}\mu_2^{-l}F^l$. Thus, we end up with

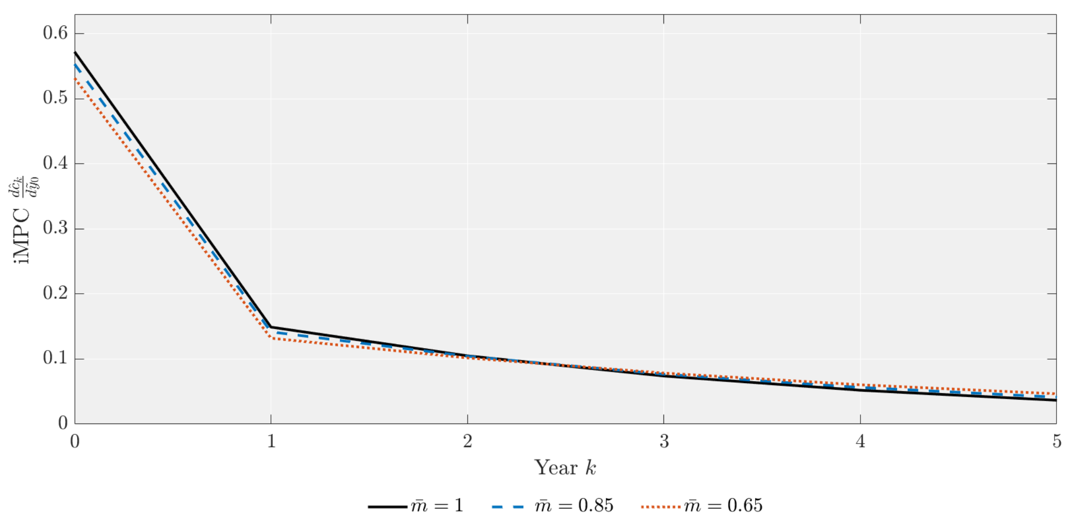
$$b_{t+1} = \mu_1 b_t + \frac{1-\lambda\chi}{s}\sum_{l=0}^{\infty}\mu_2^{-(l+1)}\mathbb{E}_t\left(\frac{1}{\bar{m}}\widehat{y}_{t+l} - \delta\widehat{y}_{t+1+l}\right). \tag{44}$$

Figure 10: Intertemporal MPCs, Bounded Rationality and Household Heterogeneity



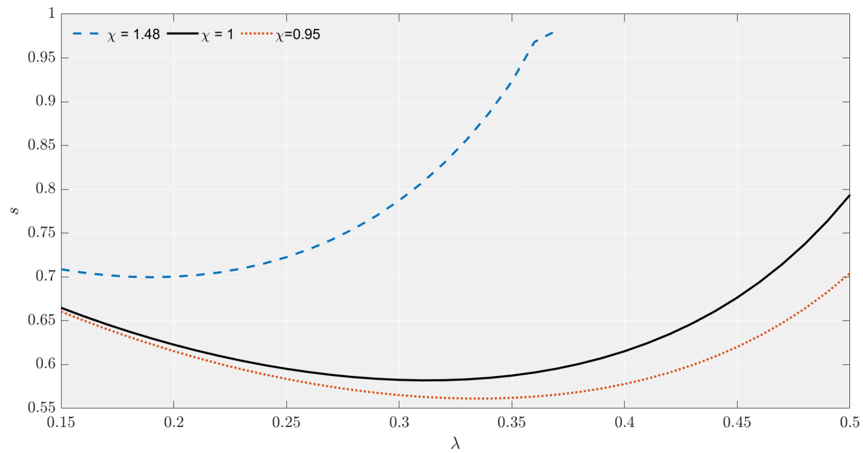
Note: This figure shows the aggregate intertemporal MPCs, i.e., the aggregate consumption response in year 0 (left) and year 1 (right) to a change in aggregate disposable income in year 0 for a transition probability $1 - s = 0.5$.

Figure 11: Intertemporal MPCs

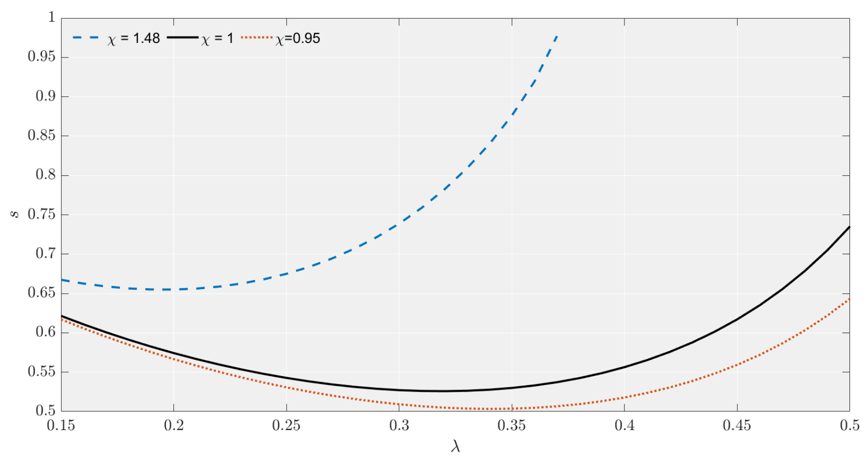


Note: This figure shows the aggregate intertemporal MPCs, i.e., the aggregate consumption response in year k to a change in aggregate disposable income in year 0 for different $\bar{m}$.

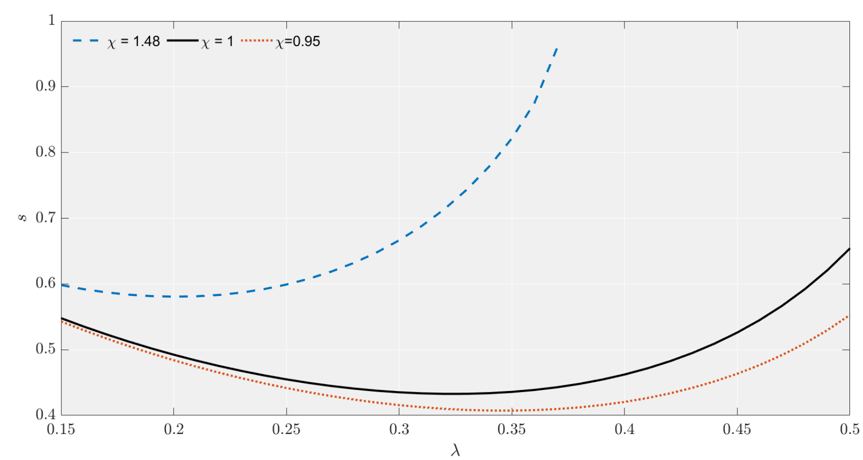
Figure 12: Intertemporal MPCs, Bounded Rationality and Household Heterogeneity



(a) $\bar{m} = 1$



(b) $\bar{m} = 0.85$



(c) $\bar{m} = 0.65$

Note: This figure depicts the (λ,s)-combinations such that the aggregate MPCs in the first year is 0.55.