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Monetary Policy Along the Yield Curve: Why Can Central Banks Affect Long-Term Real Rates?
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ABSTRACT

Real interest rates are widely considered to be driven by real forces over time, with monetary policy having only short-lived effects. We present theory and evidence suggesting instead that monetary policy may (unintentionally) contribute to low-frequency dynamics in real rates. We first show how temporary demand shocks generate persistent movements in forward real rates and r* -estimates. We then demonstrate how such "real rate hysteresis" emerges if the central bank overestimates the sensitivity of aggregate demand to permanent real-rate changes when inferring r*. Such overestimation can arise if the central bank insufficiently incorporates life-cycle forces in its model of r*.

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1 Introduction

Movements in long-term real interest rates continue to receive considerable attention. Not only due to their relation with aggregate outcomes, but also because they affect the distribution of wealth through their impact on asset valuations. The typical explanations for movements in real rates are *real* and *slow-moving* in nature, such as productivity growth, demographics, income inequality, and/or changes in the demand and supply of safe assets. One factor that is generally downplayed in explaining real rates over the long term, is monetary policy, which is seen as a mere *follower* of real trends. This reflects the view that real outcomes ought to be invariant to monetary policy beyond horizons long enough to allow prices to be reset.

From this perspective, it is puzzling that long-term real rates – including their "forward" versions – seem rather volatile and sensitive to monetary policy shocks.[1] Building on this observation, we first shift focus towards examining how the Federal Reserve's *systematic response* to temporary demand shock affects real interest rates in the longer term. We find that, when the Fed acts to try and offset a temporary demand shock (identified from a sentiment index), long-term real rates move in the same direction; the same holds with respect to a popular estimate for the natural rate of interest, r^*. The observed movements are highly persistent, outlasting the shock's effects on activity and inflation by many years. In light of this evidence, the main part of this paper explores forces that may explain such "real rate hysteresis".

Our starting point is a standard New Keynesian setup from where we look for minimal departures which could produce such a pattern. Our analysis points to one key parameter: the elasticity of aggregate demand with respect to permanent changes in real interest rates. We first show that if the central bank (and households) overestimate this elasticity, this can cause real rates to stay away from r^* for long after the direct effects of a shock have dissipated – *without* large effects on activity and inflation. Such lack of feedback makes it hard to detect the error, giving the misperception the ability to last over time.

In a next step, we examine what could cause agents to have such a misperception. Here, we point to the fact that models used for monetary policy are often focused on short-run forces and therefore may not be sufficiently rich to properly gauge this key elasticity. In particular, we show how the addition of life-cycle forces to a New Keynesian setup can substantially reduce the potency of highly persistent deviations from r^*. If this

[1] We discuss the literature below but see, e.g., Cochrane and Piazzesi (2002) who also nicely voice the standard view (p.91): "Target changes seem to be accompanied by large changes in long-term interest rates (...) Can the Fed really raise the short rate 1 percent for five years or more, without leading to 1 percent lower inflation that would cancel any effect on longer yields?".

is not sufficiently recognized by agents in the model, including the central bank, it can create the type of real rate hysteresis we observe.

Since there are no generally agreed upon empirical estimates for the elasticity of excess demand to permanent changes in real rates, the perception of this elasticity is primarily shaped by models. There, the link between excess demand and real interest rates can typically be expressed as:

$$\hat{y}_t = -\mathbb{E}_t \sum_{j=0}^{\infty} \psi_j (r_{t+1+j} - r^*), \tag{1}$$

where $\hat{y}_t$ is the percent deviation in output from its natural level and $\mathbb{E}_t(r_{t+1+j} - r^*)$ captures expected deviations in real interest rates from the natural rate. Such a representation is consistent with – but more general than – a standard log-linearized New Keynesian model. Now suppose the real rate deviates from r^* in a persistent fashion via $(r_t - r^*) = \rho(r_{t-1} - r^*) + \epsilon_t$. Then, the impact effect "$\Psi(\rho)$" on excess demand of a unit interest rate shock equals the persistence-weighted sum of horizon j-specific effects ψ_j, i.e., $\Psi(\rho) = \sum_{j=0}^{\infty} \psi_j \rho^j$. While the literature offers many estimates of $\Psi(\rho)$ for low values of ρ, knowing how $\Psi(\rho)$ behaves as ρ approaches 1 is what is relevant for our purposes. If $\Psi(1)$ is large, persistent deviations from r^* create substantial excess demand and this should be easily noticed. But if $\Psi(1)$ is close to 0, keeping r persistently away from r^* would be difficult to detect as it would not substantially affect activity and inflation.

In most infinitely-lived agent models, the potency of interest rates rises with the shock's persistence ρ due to the compounded power of intertemporal substitution.[2] Hence, it is often believed that $\Psi(1)$ is large. But, when thinking about the impact of very persistent rate changes, forces other than intertemporal substitution are likely important. Persistent rate changes affect working households' desire to accumulate wealth, whilst also changing consumption possibilities of retirees. These life-cycle forces are generally absent from New Keynesian models because they are predominantly used for short-term analyses, where ρ is assumed low. But since $\Psi(1)$ determines what happens when real rates persistently deviate from r^*, it is important to incorporate these lower frequency forces if one wants to explore why and when real rate hysteresis might arise.

To understand the forces behind $\Psi(\rho)$ when ρ is close to 1, this paper develops a Finitely-Lived Agent New Keynesian (FLANK) model. Such a model yields a rich but concise description of the relation between the future rate path and activity. A key

[2]For the baseline New Keynesian model, $\Psi(1) = \infty$. This has raised issues like the Forward Guidance puzzle, initiating work on the discounted Euler equation (Del Negro et al., 2023; McKay et al., 2016, 2017; Gabaix, 2020). But even with a discounted Euler equation, the potency of monetary policy rises with persistence: $\Psi'(\rho) > 0$, meaning that $\Psi(1)$ is still quite large.

insight is that the impact of highly persistent deviations from r^* can be summarized by two effects. First, there is a valuation effect on assets with positive duration, working in the conventional direction (higher rates lowering demand). Second, there is an effect on the marginal propensity to consume (MPC) out of financial wealth. This tends to work in the *unconventional* direction – leaving a net total effect which implies that persistent rate changes might not affect excess demand much, or even with the unconventional sign.

To understand why $\Psi(1)$ may be small, consider a retired household, or one saving to retire in the future. It is not clear they should consume more in response to persistently lower rates, even if that has created capital gains (Auclert, 2019; Moll, 2020; Fagereng et al., 2021; Greenwald et al., 2023): the typical household starts out being "short duration" by having a prospective labor income stream that is of shorter duration than their prospective consumption stream, due to the presence of a retirement phase. As a result, when rates fall persistently, households may see the present discounted value of their liabilities go up by more than that of their assets – making them want to hold *more* assets, to compensate for each unit now yielding less. The existence of such an "interest income effect" implies that the aggregate MPC out of financial wealth might *decrease* when rates fall in a persistent way.[3] This works in the unconventional direction, with lower rates *dampening* demand. Since the asset valuation effect operates in the conventional direction, the competing forces could roughly offset each other.

The above discussion is illustrative. Our model enables us to analyze under what conditions $\Psi(1)$ may be small. This will be shown to depend on several factors, including the expected duration of working and retirement phases, and average asset duration. But a key parameter is the elasticity of intertemporal substitution (EIS). For $EIS \geq 1$, FLANK behaves much like standard infinitely-lived agent models, with the potency of interest rates rising with persistence and $\Psi(1)$ being quite large. Real rates then cannot depart from r^* for long without creating strong inflation or deflation. In contrast, for $EIS < 1$ (a case with strong empirical support; Yogo, 2004, Havránek, 2015; Best et al., 2020; Ring, 2025) the MPC out of wealth becomes *increasing* in the real rate, thus

[3] This aligns with Ring (2025), who empirically finds that wealth taxation – lowering the rate of return – *raises* savings; some studies report the opposite (Jakobsen et al., 2020) but, as argued in Brülhart et al. (2022), this may be due to tax evasion/avoidance. That income effects may dominate substitution also aligns with retirees not dissaving much (De Nardi et al., 2016; Fella et al., 2024; Auclert et al., 2024), mainly consuming the return on their savings (Daniel et al., 2021; Crawley, 2025). It is also consistent with empirical papers documenting how monetary policy appears less potent for retirees (Imam, 2015; Wong, 2015; Kopecky and Mangiante, 2026). Rajan (2013) already worried that persistently low rates post-GFC might not be expansionary because "savers put more money aside as rates fall in order to meet the savings they think they will need when they retire". Nabar (2011), Aizenman et al. (2019), Van den End et al. (2020), and Ahmed et al. (2024) find support for this in aggregate data.

countering valuation effects. Very persistent rate changes may then have only small effects on activity and inflation. These variables, which shape monetary policy by their presence in typical central bank mandates, then become very "forgiving" towards a central bank working with a wrong view of r^*. Instead, *the central bank's perception of* r^* can emerge as an important driver of real rates over time, allowing for real rate hysteresis to emerge.

Related literature. Our paper relates to work analyzing the impact of monetary policy shocks on long-term real rates. Cochrane and Piazzesi (2002) and Piazzesi (2005) document such sensitivity in U.S. data, with Skinner and Zettelmeyer (1995) reporting similar evidence for Germany, France, and the U.K. Hillenbrand (2025) notes that nearly all of the post-1980 decline in long-term U.S. rates occurred in a narrow window around FOMC meetings. Nakamura and Steinsson (2018), Hansen, McMahon and Tong (2019), and Hillenbrand (2025) explain these findings via a central bank information effect; Rungcharoenkitkul and Winkler (2023) allow for two-sided learning, with markets not just learning from the central bank, but the reverse occurring as well. Hanson and Stein (2015) allude to the impact of monetary policy on the term premium, Bianchi et al. (2022) and Pflueger and Rinaldi (2022) focus on the impact on the equity premium, while Beaudry et al. (2024) develop a model featuring r^*-multiplicity. We do not wish to deny that these factors might play a role, but propose a novel mechanism that has different implications. Our explanation aligns well with empirical results in Rigon (2022) and Hofmann et al. (2025), who find that Hillenbrand's (2025) finding mostly runs through changes in expected (real) short rates – not through information effects or term premiums.

We also build on papers that have enriched the New Keynesian model with asset-price driven transmission channels (Caballero and Simsek, 2024; Caballero et al., 2025) and agent heterogeneity, such as the "TANK/HANK" literature (Galí et al., 2007; Bilbiie, 2008; Oh and Reis, 2012; Gornemann et al., 2014; Werning, 2015; McKay et al., 2016; Guerrieri and Lorenzoni, 2017; Ravn and Sterk, 2017; Den Haan et al., 2018; Kaplan et al., 2018; Debortoli and Galí, 2024; Auclert et al., 2025).[4] We also build on Auclert (2019), who analyzes the impact of transitory rate changes and shows how unhedged interest rate exposure, distinguishing between net assets that pay "today" versus "in the future", is sufficient for the first-order response of consumption to shocks. For persistent rate changes the exact timing of cash flows matters. In light of this, Greenwald et al. (2023) develop

[4]Given this literature's focus on idiosyncratic income risk, consideration of retirement risk seems a natural complement as this can be seen as the (high) risk of becoming "long-term unemployed" late in life, potentially due to an adverse health shock. Borella et al. (2025) find that some 80% of U.S. wealth holdings are driven by retirement, health care, and bequest motives; wage risk accounts for about 10%.

a model to understand how the observed, persistent decline in real rates has affected wealth inequality, documenting how lower rates contract consumption possibilities for "the young" who do not yet hold many financial assets with positive duration.

Our work furthermore links to papers asking whether lower rates are always expansionary. Bilbiie (2008) features "inverted aggregate demand logic" due to limited asset market participation. In Mian et al. (2021) monetary stimulus promotes debt accumulation, giving a short-term boost at the expense of longer-run drag. In Abadi et al. (2023), Eggertsson et al. (2024), and Cavallino and Sandri (2023) rate cuts can be contractionary due to an adverse impact on the banking sector or capital flows.

Gertler's (1999) OLG setup, which we deploy, has also been used to analyze monetary policy by, among others, Sterk and Tenreyro (2018) and Galí (2021). Sterk and Tenreyro (2018) focus on a redistribution channel of monetary policy when prices are fully flexible; Galí (2021) studies monetary policy under bubble-driven fluctuations. Fujiwara and Teranishi (2008) examine the impact of demographics on r^* alongside the distributional impact of monetary policy on workers versus retirees (also see Den Haan et al. (2026) for a richer model featuring unemployment risk). Bielecki et al. (2022) offer a more general OLG model to analyze the heterogeneous impact monetary policy can have across generations; Eggertsson et al. (2019) and Rachel and Summers (2019) use OLG models to formalize thinking about "secular stagnation". Our paper, in contrast, focuses on the impact that a retirement savings motive has on the monetary transmission mechanism and the resulting powers of central banks over long-run outcomes and interest rates. Finally, Del Negro et al. (2023) bring finite lives to a New Keynesian setup, abstracting from retirement. To mitigate the Forward Guidance puzzle, they need high mortality risk – yielding an expected lifetime of about 4 to 8 years (but, as they point out, OLG models can be seen as proxying models of agents hitting liquidity constraints). Thanks to the presence of retirees, whose behavior is quite different to that of workers, our model can be calibrated to data on expected working/retired lives *and still* solve various puzzles.

Outline. After documenting the persistent imprint left by the systematic part of monetary policy on long-term real rates in Section 2, Section 3 discusses how this pattern could result from a central bank overestimating the potency of highly persistent deviations from r^*. Section 4 tractably extends the New Keynesian model with life-cycle forces and uses the model to examine the effects of having real rates deviate from r^* for long periods. Our main finding is that the key elasticity may be much lower than conventionally thought (possibly even close to 0). Section 5 combines elements of Sections 3 and 4 to show how they jointly can explain the apparent "long arm of monetary policy". Section 6 concludes.

2 The long arm of monetary policy

As noted in our Introduction, there is ample evidence that monetary policy *shocks* affect long-term real rates. One potential explanation is a central bank information effect, with markets updating their beliefs about the economy following monetary surprises (Nakamura and Steinsson, 2018; Hillenbrand, 2025). In this section, we present a related but different pattern; one which builds on the observation that, at least since the early 1990s, temporary demand shocks have had an extremely persistent effect on long-term real interest rates. While such a pattern could be due to different mechanisms, we will argue in Sections 3 and 4 why this pattern may plausibly reflect how monetary policy reacts to shocks – and especially how such reactions incorporate the central bank's evolving view regarding the long-run equilibrium real rate, r^*. In contrast to the information effect, this mechanism will point to monetary policy being a contributing factor to low frequency movements in real interest rates.

As it is commonly accepted that monetary policy reacts to demand shocks,[5] we construct demand-side "sentiment shocks" from the U.S. sentiment index of Shapiro et al. (2020) with the aim of identifying how the economy reacts to a temporary demand shock. We estimate a five-variable VAR for the U.S. featuring (i) real GDP growth (results are very similar when using the unemployment rate instead; see Appendix A), (ii) core PCE inflation, (iii) the Federal funds rate, (iv) the sentiment index, and (v) the 5-year/5-year (5y5y) forward real rate.[6] Data are monthly (for the sentiment index we take a monthly average of daily data) and the baseline sample spans 1993m1, when the monthly real GDP growth series starts, to 2019m12, to exclude Covid dynamics. Our baseline estimation has 12 lags. Applying a Cholesky decomposition to a VAR with this ordering orthogonalizes sentiment with respect to current and lagged values of growth, inflation, and the Federal funds rate, lagged values of sentiment itself and the 5y5y forward real rate, whilst allowing this forward rate to respond to a sentiment shock on impact. (Very similar results are obtained when ordering the sentiment index first, or last.)

Figure 1 shows the resulting Impulse Response Functions (IRFs) for the sentiment

[5]Central banks often "look through" supply shocks, which limits the possibility of real rate hysteresis arising. However, very big supply shocks – which do induce rate changes, like that associated with Covid – might lead to a similar form of hysteresis. We leave the exploration of this possibility for future work.

[6]We use the growth rate in S&P Global's monthly real GDP index (available at www.spglobal.com/market-intelligence/en/solutions/products/us-monthly-gdp-index) but results are robust to analysis at the quarterly frequency, where we can use standard BEA data. From FRED, we use PCEPILFE (to calculate core PCE inflation), DFF (the effective Federal funds rate), THREEFY5 (the 5-year Treasury yield), and THREEFY10 (the 10-year Treasury yield); from these latter two, one can calculate the 5y5y forward rate (where we use inflation expectations from the Cleveland Fed to calculate ex-ante real rates).

index, inflation, and real GDP growth to a 1 standard deviation, positive shock to sentiment. They look like responses expected to a temporary demand shock.[7] Inflation and growth first rise, but subsequently all variables return to trend at the 2-3 year horizon. Based on these IRFs, there is little reason to expect that such shocks would change the long-run equilibrium real interest rate r^*. In particular, most macroeconomic models imply that temporary shocks should not have any *causal* impact on the long end of the yield curve. It is furthermore worth noting that given the sentiment shock has no effect on long-run growth, this rules out a "Ramsey channel" by which a sustained desire to borrow against higher future income growth could cause persistent increases in long-term real rates.

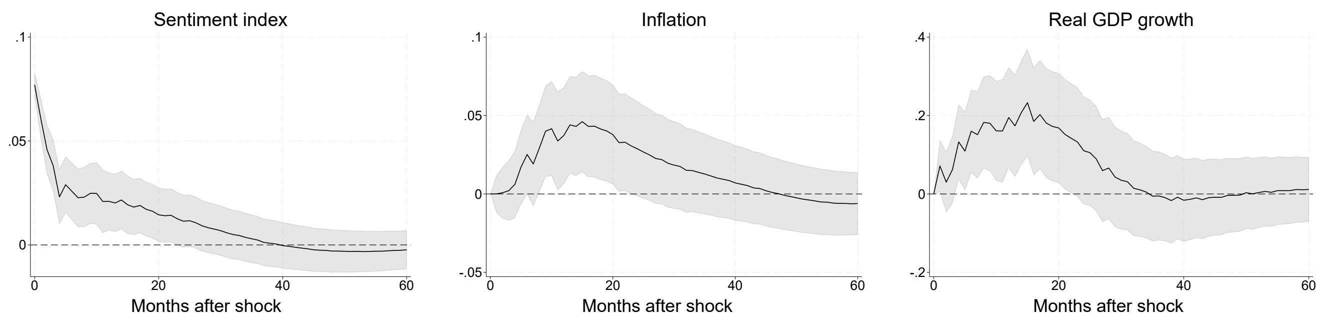

Figure 1: Baseline IRFs for sentiment, inflation, and growth to a 1 standard deviation sentiment shock. Shaded areas represent 95% confidence bands.

However, the responses of various interest rates paint a different picture. Figure 2 contains the associated IRFs for the Federal funds rate and the 5y5y forward real rate. Both respond with a degree of persistence that is greater than what was observed in Figure 1. Since the 5y5y forward real rate is the current expectation for the 5-year real Treasury yield in 5 years' time, standard theory suggests that it should be tightly linked to r^* and therefore insulated from the Fed's stabilization efforts. Accordingly, temporary shocks shouldn't affect it much. But this is not what Figure 2 shows. Instead, the 5y5y forward rate *does respond* – moving in the same direction as Fed policy and still standing at an elevated level after 5 years.[8] Quantitatively, it is interesting how the Federal funds rate and the 5y5y forward rate end up in a similar place, albeit with the former IRF surrounded by greater uncertainty. All in response to a sentiment shock, 5

[7] This shock could also be the reflection of a temporary boom in productivity. More generally, for our exercise we do not need the shock to be a pure shock to sentiment (or even demand): all that is required is that the shock – and its effect on growth and inflation – is temporary, triggers a monetary policy reaction, while having no direct, causal impact on long-term real rates.

[8] The dip around the 20-month mark stems from the 10-year rate responding by less than the 5-year one at those horizons; this then reverses gradually over time, making the 5y5y forward rate rise back up.

years prior, which otherwise appears to trigger purely transitory effects and which would not be expected to have any direct causal impact on long rates. This points to a degree of hysteresis in long-term interest rates that is difficult to square with conventional models.

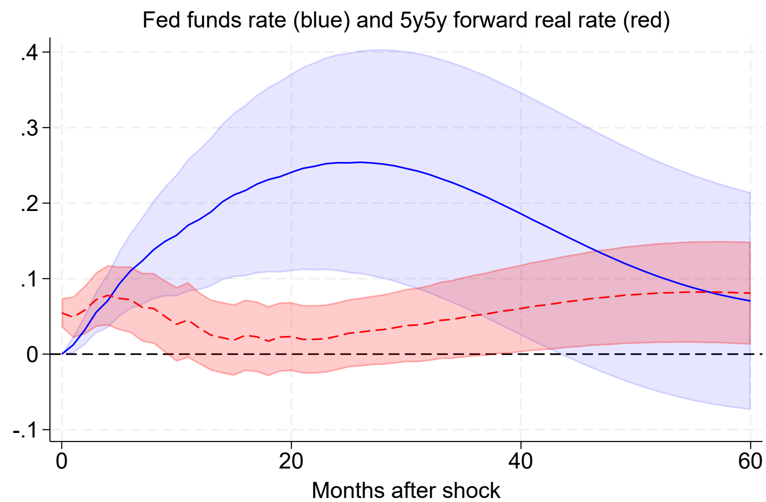

Figure 2: Baseline IRFs for the Federal funds rate (blue) and 5y5y forward real rate (red) to a 1 standard deviation sentiment shock. Shaded areas represent 95% confidence bands.

In Appendix A we document similar results when first regressing the sentiment index on other variables – in particular unemployment and the VIX (the latter included to ensure our sentiment shocks do not capture fluctuations in uncertainty, which are distinct). There, we take a two-step approach – first orthogonalizing the sentiment index with respect to the unemployment rate and VIX, followed by using the residuals as an internal instrument (Plagborg-Møller and Wolf, 2021) in a VAR containing the same variables as Figure 1. Near-identical results follow from using the residuals as an external instrument in a proxy-SVAR (Stock and Watson, 2012; Mertens and Ravn, 2013).

Figure 3 shows further robustness. Since responses of sentiment, the Federal funds rate, inflation, and growth are much like those in Figures 1 and 2, we focus on long-term rates. Panel (a) replicates our main result when doubling the VAR's lag length to 24 months; panel (b) documents robustness to estimation via Local Projections (LPs), using 12 months of lags. When using LPs we can also follow the spirit of Inoue et al. (2026) and test whether the IRF is different from 0 across a range of horizons – thus moving beyond hypothesis testing at each individual month. Specifically, we can test the joint null that all response coefficients in years 4 and 5 after the shock are equal to 0. With respect to long-term real rates *in the long run*, theory makes the strongest prediction that there should be no response to temporary factors in earlier years. Yet a joint test on these coefficients rejects the null hypothesis of there being no effect (p-value $= 0.032$).

Panel (c) confirms our headline result when using the 10-year real Treasury yield (FRED code: REAINTRATREARAT10Y); panel (d) shows robustness to using LPs, again with 12 months of lags. A joint test on the LP coefficients over years 4 and 5 is once more rejected (p-value $= 0.009$).

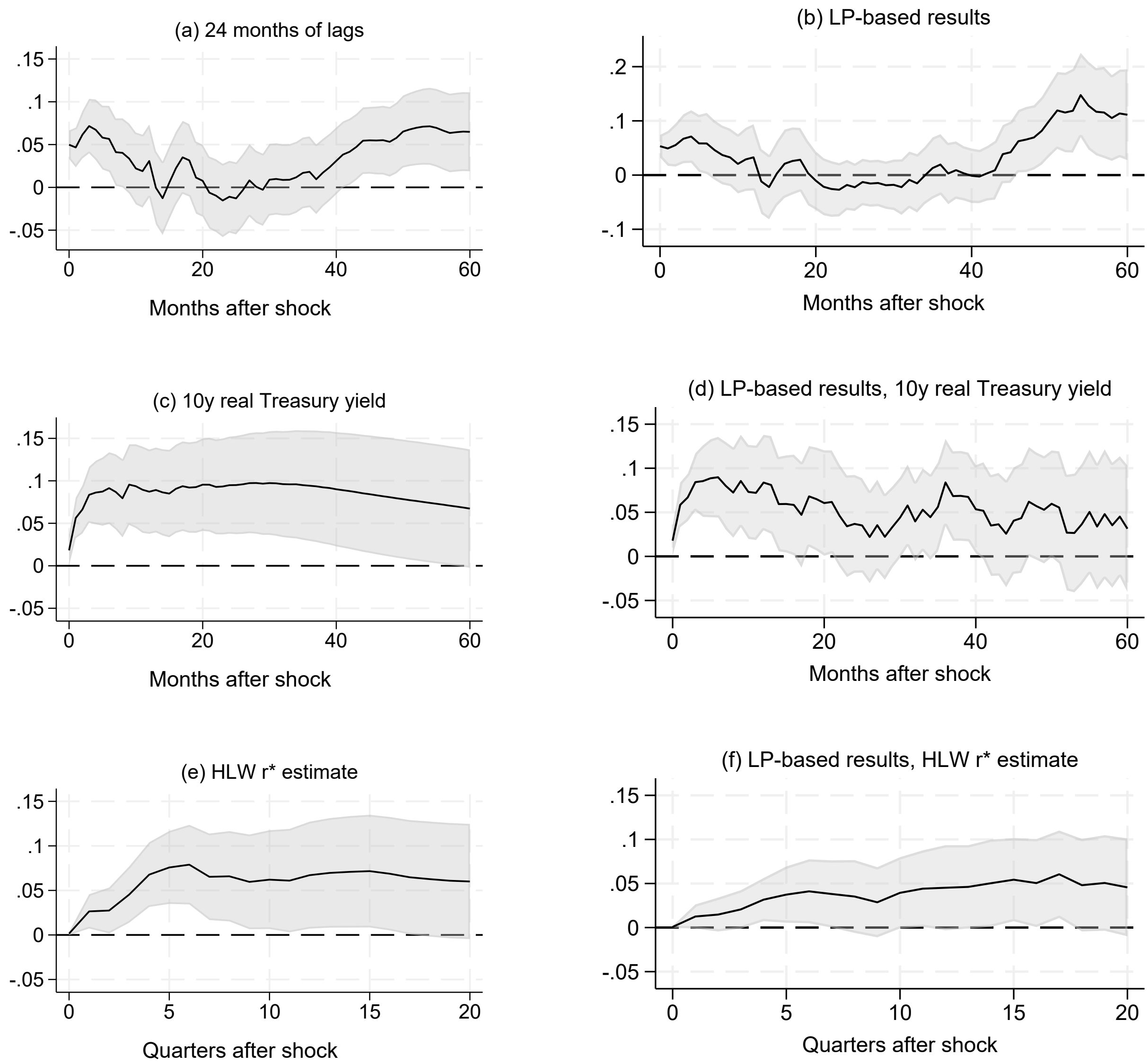

Figure 3: Robustness checks. VAR-implied responses of the 5y5y forward real rate, unless stated otherwise (and see the text for further descriptions). Shaded areas represent 95% confidence bands.

Panels (e) and (f) show that the r^*estimate of Holston, Laubach, and Williams (2017, "HLW") behaves similarly in response to the shock. This r^* estimate is available at the quarterly frequency since 1961, so we can exploit a longer sample (1980q1-2019q4, with the starting date determined by the availability of the sentiment index). Panel (e) displays the result for our baseline VAR; panel (f) uses LPs. In both cases, estimation is at the quarterly frequency and includes 8 lags, i.e., 2 years' worth of data. As before, a joint test that the LP coefficients over years 4 and 5 are equal to 0 is rejected (p-value $= 0.013$).

In the remainder of this paper we propose an explanation to the above patterns. In particular, we develop a model in which short-run stabilization efforts by the central bank can leave a long-lasting imprint on long-term real rates. This ultimately stems from a misperception by the central bank, which overlooks a relevant "persistence-potency trade-off" associated with monetary policy in our model, which arises when the central bank underestimates the role of life-cycle forces in consumption-saving decisions.

3 What can cause real rate hysteresis?

The previous section documented that temporary demand shocks appear to have rather persistent effects on interest rates – noticeable long after the shock's effects on growth and inflation have dissipated. While there may be several explanations, this section examines conditions under which this can result from a feedback between (i) how interest rates affect the economy and (ii) how the central bank views and sets rates.

A main challenge for central banks is disentangling rather temporary shocks, e.g. to demand, from shocks to the "natural", long-run equilibrium rate (r^*), which tend to be more persistent. This begs the question: is there a risk that a central bank misdiagnosing the situation – erroneously interpreting a temporary shock as partly a shock to r^* – ends up keeping rates away from their natural level for long?

To clarify when this may occur, consider a stylized setup featuring only temporary demand shocks (e.g., shocks to the household's discount factor), but the central bank thinks there may be shocks to both demand and to r^*. Demand shocks are observable and known to follow an autoregressive process: $\varepsilon_t^d = \rho_d \varepsilon_{t-1}^d + \epsilon_t^d$, with $0 < \rho_d < 1$. Shocks to r^* are viewed as unobservable, and the central bank believes r^* to follow a random walk. The output gap is determined via:

$$\hat{y}_t = -\mathbb{E}_t \sum_{j=0}^{\infty} \psi_j (r_{t+1+j} - r^*) + \mathbb{E}_t \sum_{j=0}^{\infty} \omega_j \varepsilon_{t+j}^d, \tag{2}$$

which is a rather general formulation, for example nesting the popular "discounted" Euler equation (Del Negro et al., 2023; McKay et al., 2017).[9] The coefficient sequences $\{\psi_j\}_{j=0}^{\infty}$

[9] Starting from $\hat{y}_t = \alpha \mathbb{E}_t \hat{y}_{t+1} - \frac{1}{\sigma}(r_{t+1} - r^*) + \frac{1}{\sigma}\varepsilon_t^d$, where $\alpha < 1$ captures some discounting and σ is the inverse elasticity of substitution, its forward solution yields (2) with particular values for ψ_j and ω_j.

and $\{\omega_j\}_{j=0}^{\infty}$ capture the sensitivity of the output gap to, respectively, the expected real rate gap and the expected value of the demand process. Define $\Psi(\rho_d) \equiv \sum_{j=0}^{\infty} \psi_j \rho_d^j$ and $\Omega(\rho_d) \equiv \sum_{j=0}^{\infty} \omega_j \rho_d^j$. Crucially, the central bank doesn't know the true values of these coefficients. Instead, it works with *perceived* sequences, $\{\psi_j^{CB}\}_{j=0}^{\infty}$ and $\{\omega_j^{CB}\}_{j=0}^{\infty}$ (superscripted "CB"), where at least some parameters ψ_j^{CB} and ω_j^{CB} are not equal to their true values ψ_j and ω_j. Hence, the central bank believes the output gap to follow:

$$\hat{y}_t^{CB} = -\mathbb{E}_t \sum_{j=0}^{\infty} \psi_j^{CB}(r_{t+1+j} - r_t^{*,CB}) + \mathbb{E}_t \sum_{j=0}^{\infty} \omega_j^{CB} \varepsilon_{t+j}^d, \tag{3}$$

where $r_t^{*,CB}$ is the central bank's time-t perception of r^*. When the central bank aims to close the output gap in the face of demand shocks, it will set its policy rate according to:

$$\mathbb{E}_t r_{t+1} = r_t^{*,CB} + \frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)} \varepsilon_t^d, \tag{4}$$

The ratio $\frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)}$ captures the perceived differential effect of demand versus interest rates on $\hat{y}_t$; in standard models (where a monetary policy shock is just a particular type of demand shock) this ratio equals unity.

Households are assumed to know the central bank's policy rule (4) and its view about r^* (e.g., because the central bank openly publishes its r^* estimates), so that household expectations are identical to those of the central bank. Accordingly, and in contrast to models featuring a central bank information effect, there is no asymmetry of information about the perceived r^*, or the future path of rates, between the central bank and the public.

If the true r^* were known ($r_t^{*,CB} = r^*$, $\forall t$), a central bank implementing (4) would succeed in keeping $\hat{y}_t = 0$. But since r^* is unobservable, and believed to be time-varying, the central bank will try to infer r^* from output gap realizations. Given the central bank's view about the functioning of the economy, optimal updating implies:

$$r_{t+1}^{*,CB} = r_t^{*,CB} + \frac{1}{\Psi^{CB}(1)} \hat{y}_t, \tag{5}$$

where $\Psi^{CB}(1) \equiv \sum_{j=0}^{\infty} \psi_j^{CB}$ plays a crucial role in what follows. It captures the *perceived* effect, on the output gap, of keeping interest rates permanently away from r^*; analogously, $\Psi(1) \equiv \sum_{j=0}^{\infty} \psi_j$ captures the *true* strength of this effect.[10]

[10]Equation (5) assumes that the central bank aims to close the output gap (by applying (4)) and updates its view of r^* based on subsequent output gap realizations. Assuming instead that the central

In this setup, output gap realizations feed into policy, which in turn affects the output gap. If the central bank's view of the economy is perfectly in line with how the economy actually functions, this feedback loop works well and the central bank learns the true value of r^* within one period. In this case, a demand shock would not have any effect on a central bank's perception of the natural rate, or its policy stance in the long run.

But this no longer applies when there is some misperception, i.e., when some perceived coefficients ψ_j^{CB} and ω_j^{CB} differ from their true values ψ_j and ω_j. Given the central bank's policy rule (4) and its updating equation (5), the central bank's perception of r^* will now start interacting with a richer determination of the output gap. In particular, the central bank will end up partly misattributing the effects of demand shocks to changes in r^*. This affects the output gap, which will influence anew the central bank's perception of the natural rate, in turn affecting the policy stance via (4). This feedback loop yields an autoregressive process for the central bank's perception error with respect to r^*:[11]

$$(r_{t+1}^{*,CB} - r^*) = \rho_1 (r_t^{*,CB} - r^*) + \rho_2 \varepsilon_t^d, \text{ with} \tag{6}$$
$$\rho_1 = 1 - \frac{\Psi(1)}{\Psi^{CB}(1)};\, \rho_2 = \frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(1)} \left[\frac{\Omega(\rho_d)}{\Omega^{CB}(\rho_d)} - \frac{\Psi(\rho_d)}{\Psi^{CB}(\rho_d)} \right].$$

From the expression for ρ_2 we see that the central bank's view of r^* is only insulated from demand shocks if the actual functioning of the economy is in line with the central bank's perceptions. But if the central bank misperceives the effect of demand shocks ($\Omega(\rho_d)/\Omega^{CB}(\rho_d) \neq 1$) and/or of real interest rates ($\Psi(\rho_d)/\Psi^{CB}(\rho_d) \neq 1$), $\rho_2 \neq 0$ and the central bank will start misattributing some of the effects of demand shocks to changes in r^*. For example: following an adverse demand shock, a central bank overestimating the potency of its policy stance ($\Psi(\rho_d) < \Psi^{CB}(\rho_d)$) might conclude that r^* has fallen, when noting that its stimulative response has not succeeded in closing the output gap.

The first term in (6) tells us that, when ρ_1 is equal or close to 0, such errors would only last while demand shocks are directly affecting activity. But with ρ_1 close to 1 (i.e., when $\frac{\Psi(1)}{\Psi^{CB}(1)}$ is close to 0), demand shocks continue affecting interest rates for long after the direct effects of the shock have essentially died out.

The key element therefore is how the true $\Psi(1)$ compares to the central bank's per-

bank targets inflation, and updates its views about r^* based on inflation outturns, has similar implications when inflation obeys a standard New Keynesian Phillips curve. More generally, the Divine Coincidence applies with respect to demand shocks in a New Keynesian setup, meaning that inflation stabilization and output gap stabilization are equivalent.

[11] This follows from first noting that, given (4), the output gap will obey $\hat{y}_t = -\Psi(1)(r_t^{*,CB} - r^*) + \left[\Omega(\rho_d) - \frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)}\Psi(\rho_d)\right] \varepsilon_{t+j}^d$. Combining this with (5) yields (6).

ception of this object, $\Psi^{CB}(1)$. When $\frac{\Psi(1)}{\Psi^{CB}(1)}$ is small, the central bank *overestimates* the potency of permanent rate changes and will update its beliefs towards the true r^* only very slowly. This type of slow learning happens for two reasons. First, when $\Psi(1)$ is small, being wrong about r^* will not be very apparent as the economy becomes very "forgiving" towards a central bank setting policy based on a mistaken view of r^*. This gives rise to a muted system in which learning is rather difficult. Second, when $\Psi^{CB}(1)$ is relatively big, an observed output gap only triggers minor updates to the central bank's perception of r^* (because a big $\Psi^{CB}(1)$ means that the central bank believes $\hat{y}_t$ to be very sensitive to mistaken views on r^*); see equation (5). Since $r_t^{*,CB}$ is the intercept to the central bank's policy rule (4), any associated misperceptions end up affecting the policy stance – potentially thus in a rather persistent way. As $\rho_1 \to 1$, the central bank's perception of r^* converges to $r_t^{*,CB} = \rho_2\varepsilon_0/(1-\rho_d)$ as $t \to \infty$, permanently shifting the the central bank's policy rule. This can give the central bank some lasting – yet unconscious – control over interest rate trends.

While the above model is highly simplified, the resulting intuition is likely more general.[12] In particular, if the central bank does not have an exact knowledge of the economy, it is reasonable to expect that demand shocks might be confused with shocks to r^*. But that by itself would not explain the observations presented in Section 2. The most important insight from this model is that inference errors regarding r^* can become long-lasting if the actual effect of the misperception, as governed by $\Psi(1)$, is small. Since $\Psi(1)$ represents how the economy reacts to permanent changes in interest rates, this points to the importance of understanding its driving forces. This is what we turn to next, when showing how life-cycle forces – which are neglected by the standard (discounted) Euler equation approach to demand – can lead to $\Psi(1)$ being rather small.

4 A New Keynesian model with workers and retirees

This section explores the determinants of the elasticity of aggregate demand with respect to a permanent change in the real rate of interest, denoted $\Psi(1)$. The goal of this section is to examine how this elasticity may be affected by the life-cycle forces associated with saving for retirement. As discussed, if the true elasticity is much smaller than perceived by the central bank (i.e., for low values of $\frac{\Psi(1)}{\Psi^{CB}(1)}$), it could lead to real rate hysteresis.

[12] To see the likely generality, note that equation (1) can be decomposed as $\hat{y}_t = -\sum_{j=0}^{\infty}\psi_j \mathbb{E}_t(r_{t+1+j} - r^{*,CB}) - \Psi(1)(r^{*,CB} - r^*)$. It then follows that if $\Psi(1) \approx 0$, the true value of r^* has no big effect on the output gap – giving rise to the "muted" system in which beliefs about r^* can become subject to quasi-self-fulfilling dynamics (as any misperceptions don't show up in the output gap or inflation).

Since it is unclear what exact value central banks use for $\Psi^{CB}(1)$ – other than it being positive and reasonably large[13] – this section will proceed in a conservative way by asking if the true elasticity can shrink towards (or go below) 0, automatically yielding a small ratio $\frac{\Psi(1)}{\Psi^{CB}(1)}$ regardless of the precise value for $\Psi^{CB}(1)$.

The setup we consider is one where standard monopolistically competitive firms face price adjustment frictions and households solve life-cycle consumption-savings decisions.[14] We refer to this model as "FLANK", for Finitely-Lived Agent New Keynesian model. Our analysis is done within a closed economy (Cesa-Bianchi et al. (2023), Obstfeld (2023), and Auclert et al. (2024) offer open economy considerations) and is therefore best thought of as applying to a rather large economy, like the U.S.

Environment. There is a measure one of households, subject to a life cycle as in Gertler (1999, which builds on Yaari (1965) and Blanchard (1985)). Each household starts life in a working state and transits out with Poisson probability δ_1 – either due to being sent to retire, or because a health shock prevents further work. At this transition, the household enters retirement where it faces Poisson death probability δ_2. Deceased households are immediately replaced by new, working households, yielding a constant share of workers $\vartheta = \frac{\delta_2}{\delta_1+\delta_2}$.

Retired Households. A retired household derives income from its financial wealth, reflecting past savings and a possible lump-sum public pension payment. Retirees invest their wealth in a portfolio of short- and long-term bonds. Short-term bonds are one-period assets whose gross nominal return, i_t, is set by the central bank. Their real return is $r_{t+1} \equiv i_t/\pi_{t+1}$, where π denotes the gross inflation rate. We model long-term bonds as real perpetuities with coupons decaying geometrically at rate μ (Woodford, 2001). A bond issued in period t then pays $(1-\mu)^h$ units of consumption $h+1$ periods later; hence, the bond's duration decreases in μ ($\mu = 1$ reduces this bond to a one-period instrument). The gross return on the long-term bond is $r^b_{t+1} = \frac{1+(1-\mu)q_{t+1}}{q_t}$, where q_t is the long-term bond's price. The optimization problem faced by a retired household j with CRRA-preferences (where σ is the coefficient of relative risk aversion, making $1/\sigma$ the EIS) reads:

[13] In the canonical New Keynesian model, this elasticity is infinite; under a discounted Euler equation, a specification that gained popularity post-GFC, this elasticity is $\frac{1}{\sigma(1-\alpha)}$ where α is the discount parameter in the Euler equation, commonly set to a value around 0.97; see Del Negro et al. (2023) and McKay et al. (2017). Under log-utility ($\sigma = 1$), this yields $\Psi^{CB}(1) = 33.3$; for $\sigma = 5$, one gets $\Psi^{CB}(1) = 6.7$.

[14] The real side of the model shares certain features with the continuous time model in Beaudry et al. (2024) but differs by being stochastic, set in discrete time, allowing for long-term debt, and being embedded in a New Keynesian setup.

$$
\begin{aligned}
V_t^r\left(\tilde{a}_t^j\right) &= \max_{c_t^j,\alpha_t^j,\tilde{a}_{t+1}^j}\left\{\frac{\left(c_t^j\right)^{1-\sigma}}{1-\sigma}+\left(1-\delta_2\right)\beta_t\mathbb{E}_t\left[V_{t+1}^r\left(\tilde{a}_{t+1}^j\right)\right]\right\}, \\
s.t.\ \tilde{a}_{t+1}^j &= r_{t+1}^j\left(\tilde{a}_t^j-c_t^j\right), \qquad (7) \\
r_{t+1}^j &= r_{t+1}+\left(r_{t+1}^b-r_{t+1}\right)\alpha_t^j \qquad (8)
\end{aligned}
$$

where c_t^j is consumption, $\alpha_t^j \equiv \left(q_t b_t^j\right)/a_t^j$ is the share of wealth invested in long-term bonds "b", and $\tilde{a}_t^j \equiv r_t^j a_{t-1}^j$ is the beginning-of-period t stock of wealth held by household j, such that the real rate of return r_t^j works on whatever is left after period-$(t-1)$ consumption has been financed, i.e., on $a_{t-1}^j = \tilde{a}_{t-1}^j - c_{t-1}^j$. Finally, $\beta_t \equiv \beta e^{\varepsilon_t^\beta}$, where ε_t^β is a demand shifter. Optimal consumption satisfies:

$$
\left(c_t^j\right)^{-\sigma} = \left(1-\delta_2\right)\beta_t\mathbb{E}_t\left[\frac{dV^r\left(\tilde{a}_{t+1}^j\right)}{d\tilde{a}_{t+1}^j}r_{t+1}^j\right], \qquad (9)
$$

with the portfolio optimality condition:

$$
0 = \mathbb{E}_t\left[\frac{dV^r\left(\tilde{a}_{t+1}^j\right)}{d\tilde{a}_{t+1}^j}\left(r_{t+1}^b-r_{t+1}\right)\right]. \qquad (10)
$$

By the envelope theorem, $\frac{dV_t^r\left(\tilde{a}_t^j\right)}{d\tilde{a}_t^j} = \left(c_t^j\right)^{-\sigma}$, this boils down to $0 = \mathbb{E}_t\left[\left(c_{t+1}^j\right)^{-\sigma}\left(r_{t+1}^b-r_{t+1}\right)\right]$.

Guessing that $V_t^r\left(\tilde{a}_t^j\right) \equiv \frac{\left(\tilde{a}_t^j\right)^{1-\sigma}}{1-\sigma}\left(\Gamma_t^j\right)^{-\sigma}$, with Γ_t^j conjectured to be a function of the future path of r_t^j and independent of $\tilde{a}_t^j$, gives:

$$
\frac{dV_t^r\left(\tilde{a}_t^j\right)}{d\tilde{a}_t^j} = \left(\tilde{a}_t^j\Gamma_t^j\right)^{-\sigma}. \qquad (11)
$$

By using the envelope theorem in (11) we obtain:

$$
\left(c_t^j\right)^{-\sigma} = \left(\tilde{a}_t^j\Gamma_t^j\right)^{-\sigma} \Leftrightarrow c_t^j = \tilde{a}_t^j\Gamma_t^j, \qquad (12)
$$

which we can plug into (7) to yield:

$$
\tilde{a}_{t+1}^j = r_{t+1}^j\tilde{a}_t^j\left(1-\Gamma_t^j\right). \qquad (13)
$$

Finally, plugging (11)-(13) into (9) gives a non-linear difference equation for Γ_t:

$$\left[\left(\Gamma_t^j\right)^{-1} - 1\right]^{\sigma} = (1-\delta_2)\,\beta_t \mathbb{E}_t\left[r_{t+1}\left(\Gamma_{t+1}^j r_{t+1}^j\right)^{-\sigma}\right]. \tag{14}$$

This verifies our guess that Γ_t^j is independent of $\tilde{a}_t^j$ and only a function of expected future rates and demand shocks. Note from (12) that Γ_t^j equals the MPC out of (beginning of period) financial wealth for retirees, which plays an important role to the interpretation of our findings later on. We can thus write the utility of retirees as $V^r\left(\tilde{a}_t^j, \Gamma_t^j\right) = (1-\sigma)^{-1}\left(\tilde{a}_t^j\right)^{1-\sigma}\left(\Gamma_t^j\right)^{-\sigma}$, where V^r depends both on the stock of assets $(\tilde{a}_t^j)$ as well as on the entire future path of interest rates working over that stock (captured via Γ_t). Given a value of assets $\tilde{a}_t^j$, retirees are better off when rates are expected to be high, as this offers them a superior interest income stream.

Let $c_t^r \equiv \int_{\mathbf{R}_{r,t}} c_t^j dj/(1-\vartheta)$ be the consumption of the representative retiree and define $a_t^r \equiv \int_{\mathbf{R}_{r,t}} a_t^j dj/(1-\vartheta)$ as their (end of period) financial wealth, where $\mathbf{R}_{r,t}$ denotes the set of retired households at time t. Since all retired households choose the same asset portfolio, that is $\alpha_t^j = \alpha_t^r$ for all $j \in \mathbf{R}_{r,t}$, this implies $\Gamma_t^j = \Gamma_t$ for all $j \in \mathbf{R}_{r,t}$. Therefore:

$$c_t^r = a_t^r\left[\left(\Gamma_t^j\right)^{-1} - 1\right]^{-1},$$

where $\left[\left(\Gamma_t^j\right)^{-1} - 1\right]^{-1}$ reflects the MPC out of (end of period) financial wealth of the representative retiree, with a_t^r evolving as:

$$a_{t+1}^r = \left[(1-\delta_2)\,a_t^r r_{t+1}^r + \delta_2\left(a_t^w r_{t+1}^w + \tau_{t+1}^r\right)\right]\left(1-\Gamma_{t+1}^j\right).$$

where τ^r is the lump-sum transfer received by households upon retirement. It can be seen as a public pension transfer that is paid once to the household upon retiring, and thereafter managed by the household.

Working Households. Next, consider a working household. It receives a real wage w_t for any labor input ℓ_t it provides, plus transfers from good-producing firms and transfers from/to the government. Workers face a δ_1 probability of moving into retirement next period. Their problem reads:

$$V_t^w\left(\tilde{a}_t^j\right) = \max_{c_t^j, \ell_t^j, \alpha_t^j, \tilde{a}_{t+1}^j}\left\{\frac{\left(c_t^j\right)^{1-\sigma}}{1-\sigma} - \frac{\left(\ell_t^j\right)^{1+\varphi}}{1+\varphi} + \beta_t \mathbb{E}_t\left[(1-\delta_1)\,V_{t+1}^w\left(\tilde{a}_{t+1}^j\right) + \delta_1 V_{t+1}^r\left(\tilde{a}_{t+1}^j + \tau_{t+1}^r\right)\right]\right\},$$

$$s.t.\ \tilde{a}_{t+1}^j = r_{t+1}^j\left(\tilde{a}_t^j - c_t^j + \ell_t^j w_t + z_t^j + \tau_t^w + \tau_t^n\right),$$

$$r_{t+1}^j = r_{t+1} + \left(r_{t+1}^b - r_{t+1}\right)\alpha_t^j$$

where z_t^j represents dividends received from good-producing firms. τ_t^w and τ_t^n both represent tax/transfer schemes. τ_t^w is a government-imposed tax used to pay expenditures and interest on debt. τ_t^n is a tax/transfer scheme which ensures that the inheritance received by newly-born households makes them resemble existing working households – enabling us to consider a representative working household. Optimality yields the Euler equation:

$$\left(c_t^j\right)^{-\sigma} = \beta_t \left\{(1-\delta_1)\,\mathbb{E}_t\left[\left(c_{t+1}^j\right)^{-\sigma} r_{t+1}\right] + \delta_1 \mathbb{E}_t\left[\left(\tilde{a}_{t+1}^j + \tau_{t+1}^n\right)^{-\sigma} \Gamma_{t+1}^{-\sigma} r_{t+1}\right]\right\}, \tag{15}$$

supplemented by the labor supply schedule, $w_t = \left(c_t^j\right)^{\sigma}\left(\ell_t^j\right)^{\varphi}$, and the portfolio decision:

$$0 = \mathbb{E}_t\left[\left\{(1-\delta_1)\left(c_{t+1}^j\right)^{-\sigma} + \delta_1 \frac{dV_{t+1}^r\left(\tilde{a}_{t+1}^j\right)}{d\tilde{a}_{t+1}^j}\right\}\left(r_{t+1}^b - r_{t+1}\right)\right].$$

Note how the Euler equation for working households (15) features two terms on the RHS: the first term is familiar from models without retirement and implies that a lower interest rate, *ceteris paribus*, decreases the household's desire to save; this is standard intertemporal substitution. The second term stems from the prospect of retirement and shows how consumption is driven by wealth ($\tilde{a}_{t+1}^j$) adjusted for the expected path of interest rates (as captured by $\Gamma_{t+1}^{-\sigma} r_{t+1}$).

Let c_t^w denote the consumption of the representative worker and a_t^w its end-of-period financial wealth. Then, c_t^w solves:

$$\left(c_t^w\right)^{-\sigma} = \beta_t \left\{(1-\delta_1)\,\mathbb{E}_t\left[\left(c_{t+1}^w\right)^{-\sigma} r_{t+1}\right] + \delta_1 \mathbb{E}_t\left[\left(a_t^w r_{t+1}^w \Gamma_{t+1}\right)^{-\sigma} r_{t+1}\right]\right\},$$

where a_t^w evolves as:

$$a_{t+1}^w = (1-\delta_1)\,a_t^w r_{t+1}^w + \delta_1 a_t^r r_{t+1}^r - c_{t+1}^w + \ell_{t+1} w_{t+1} + z_{t+1} + \tau_{t+1}^w.$$

Good-producing firms. Each working household $j \in \mathbf{R}_{w,t}$ owns a firm that produces a differentiated good using the technology $y_t^j = A\ell_t^j$. Upon retiring, households liquidate their firms which are replaced by new ones owned by new working households. Firms are monopolistically competitive and set prices subject to a quadratic adjustment cost (Rotemberg, 1982). Let P_t^j be the price chosen by firm j at time t and $\pi_t^j \equiv P_t^j / P_{t-1}^j$ be its growth rate. Then, the firm pays adjustment cost $\Theta\left(\pi_t^j\right) = \frac{\theta}{2}\left(\pi_t^j - \bar{\pi}\right)^2 y_t^j$, where $\bar{\pi}$ is the inflation target and θ governs the cost of adjusting prices. The resulting Phillips curve takes the standard form (which, to a first-order approximation, has the same reduced form as under Calvo-pricing; Roberts (1995)):

$$\left(\pi_t - \bar{\pi}\right)\pi_t = \lambda\left(\frac{\epsilon}{\epsilon - 1}mc_t - 1\right) + \mathbb{E}_t\left[\Lambda^w_{t,t+1}\left(\pi_{t+1} - \bar{\pi}\right)\pi_{t+1}\frac{y_{t+1}}{y_t}\right],$$

where $\lambda \equiv (\epsilon - 1)/\theta$ represents the slope of the Phillips curve and ϵ is the elasticity of substitution between product varieties (with households consuming the CES aggregate); $y_t = \int_{\mathbf{R}_{w,t}} y_t^j dj$ denotes aggregate output, while $\Lambda^w_{t,t+1}$ is the working household's stochastic discount factor:

$$\Lambda^w_{t,t+1} = \beta_t \frac{(1-\delta_1)\left(c^w_{t+1}\right)^{-\sigma} + \delta_1\left(a^w_t r^w_{t+1}\Gamma_{t+1}\right)^{-\sigma}}{\left(c^w_t\right)^{-\sigma}}.$$

This captures that households place more weight on the future when their marginal utility is high, but it features the additional forces stemming from retirement: households now place more weight on the future when they hold fewer assets a^w_t or when the interest rate path is lower (as captured via Γ).

The real marginal cost of production is $mc_t = (1-\tau_t)\,w_t/A$, where τ_t is a wage subsidy financed through lump-sum taxes levied on firms. We use this subsidy to undo the steady-state markup and eliminate the impact of labor supply wealth effects on inflation, such that $mc_t = \frac{\epsilon-1}{\epsilon}\left(\frac{y_t}{\vartheta A}\right)^{1+\varphi}$. Since firms are identical, the real dividend generated by each firm is $z_t = \frac{y_t}{\vartheta}\left[1 - \frac{\theta}{2}\left(\pi_t - \bar{\pi}\right)^2\right] - \ell_t w_t$.

Government. The government's budget constraint reads:

$$s^g_t + q_t b^g_t = q_{t-1}b^g_{t-1}r^b_t + s^g_{t-1}r_t + \vartheta\tau^w_t + \vartheta\delta_1\tau^r_t,$$

where s^g_t and b^g_t are the supply of short- and long-term government bonds, respectively. Without loss of generality, we take the limit for $s^g_t \downarrow 0$ and assume $b^g_t = b^g$, for all $t \geq 0$. This implies that tax policy must satisfy $\vartheta\tau^w_t + \vartheta\delta_1\tau^r_t = -b^g\left(1 - \mu q_t\right).$

The central bank sets monetary policy according to the following rule:

$$i_t = r^*\bar{\pi}\left(\frac{\mathbb{E}_t\left[\pi_{t+1}\right]}{\bar{\pi}}\right)^{1+\phi} e^{\varepsilon^i_t}, \tag{16}$$

where $\phi > 0$ governs the central bank's response to expected inflation-deviations from target, r^* is the steady-state real interest rate, and ε^i_t is a monetary policy shock.

Market clearing . Market clearing requires:

$$\vartheta c_t^w + (1-\vartheta)\, c_t^r = y_t \left[1 - \frac{\theta}{2}(\pi_t - \bar{\pi})^2\right],$$
$$\vartheta a_t^w + (1-\vartheta)\, a_t^r = q_t b^g,$$
$$\vartheta b_t^w + (1-\vartheta)\, b_t^r = b^g,$$

where $b_t^r \equiv \int_{\mathbf{R}_{r,t}} b_t^j dj / (1-\vartheta)$ and $b_t^w \equiv \int_{\mathbf{R}_{w,t}} b_t^j dj / \vartheta$ are the long-term bond holdings of the representative retiree and the representative worker, respectively.

Exogenous Processes. We allow the model to be hit by two types of shocks: first, a standard monetary policy shock "ε_t^i" to the Taylor rule (16) and, second, a demand shock to β, ε_t^β. Both are assumed to follow AR(1) processes:

$$\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \sigma_i \epsilon_t^i, \tag{17}$$
$$\varepsilon_t^\beta = \rho_\beta \varepsilon_{t-1}^\beta + \sigma_\beta \epsilon_t^\beta, \tag{18}$$

with innovations ϵ following a standard-normal distribution, while σ's scale standard deviations. We furthermore assume a zero inflation target ($\bar{\pi} = 1$). The equilibrium and steady-state equations of our model can be found in Appendix B.

4.1 Analytical version of the model

To allow for the derivation of analytical results, let us assume that the transfer received by households upon retirement, τ^r, is designed to keep the distribution of financial wealth between workers and retirees constant at its steady-state level.[15] (Later, we shall show that this assumption is not driving the model's implications – neither qualitatively nor quantitatively.) We set the level of government debt, b^g, so that the steady-state real interest rate (r^*) equals $1/\beta$. This makes the log-linearized system nest the standard representative agent New Keynesian ("RANK") model for $\delta_1 = 0$ (when every household remains in its working state *ad infinitum*). Finally, for the main propositions, we will focus on the case where $\delta_2 < \mu$, which implies that the expected duration of retirement is greater than the average duration offered by bonds.[16] This means that, in equilibrium, households' saving efforts in the asset with positive duration cannot fully close their

[15] To simplify the algebra, the time-varying nature of the transfer is unexpected, so that workers do not anticipate receiving a transfer that varies with the state of the economy. This assumption is not necessary for our main results, but does make the presentation more transparent.

[16] Our propositions technically only require the weaker condition that $(1-\delta_2)^{1/\sigma} > 1 - \mu$ (which is easily satisfied when σ is large), but imposing the stronger condition $\delta_2 < \mu$ eases exposition.

negative duration gap, stemming from the need to finance consumption in retirement.[17]

With these simplifications, the log-linearized equilibrium reads:

$$\hat{y}_t = (1-\gamma)\,\hat{c}^w_t + \gamma \hat{c}^r_t \tag{19}$$

$$\hat{c}^r_t = \hat{q}_t + \left[\beta\,(1-\delta_2)^{\frac{1}{\sigma}}\right]^{-1} \hat{\Gamma}_t \tag{20}$$

$$\hat{c}^w_t = (1-\delta_1)\left(\mathbb{E}_t \hat{c}^w_{t+1} - \frac{1}{\sigma}\mathbb{E}_t \hat{r}_{t+1}\right) + \delta_1\left(\hat{q}_t + \left[\beta\,(1-\delta_2)^{\frac{1}{\sigma}}\right]^{-1}\hat{\Gamma}_t\right) - \frac{1-\delta_1}{\sigma}\varepsilon^\beta_t \tag{21}$$

$$\hat{\Gamma}_t = \beta\,(1-\delta_2)^{\frac{1}{\sigma}}\left[\mathbb{E}_t\hat{\Gamma}_{t+1} + \frac{\sigma-1}{\sigma}\mathbb{E}_t\hat{r}_{t+1} - \frac{1}{\sigma}\varepsilon^\beta_t\right] \tag{22}$$

$$\hat{q}_t = \beta\,(1-\mu)\,\mathbb{E}_t\hat{q}_{t+1} - \mathbb{E}_t\hat{r}_{t+1} \tag{23}$$

$$\hat{\pi}_t = \kappa \hat{y}_t + \beta \mathbb{E}_t \hat{\pi}_{t+1} \tag{24}$$

$$\mathbb{E}_t\hat{r}_{t+1} = \hat{i}_t - \mathbb{E}_t\hat{\pi}_{t+1} - \varrho \tag{25}$$

$$\hat{i}_t = \varrho + (1+\phi)\,\mathbb{E}_t\hat{\pi}_{t+1} + \varepsilon^i_t \tag{26}$$

where $\varrho \equiv \log r^*$, $\kappa \equiv \lambda(1+\varphi)$, and $\gamma \equiv \delta_1/[1+\delta_1-(1-\delta_2)^{\frac{1+\sigma}{\sigma}}]$ is the steady-state consumption share of retirees. Hats denote deviations from steady state (except for $\hat{i}_t$, which is $\log(i_t)$).

From (21) one can see how the workers' Euler equation features both standard intertemporal substitution, as captured by the first RHS term, and a second term which captures wealth-related factors associated with retirement. As the probability of retiring δ_1 goes up, the weight on wealth-related factors increases relative to intertemporal substitution. Greater retirement preoccupations thus imply that wealth-related factors will be more central to consumption decisions and the monetary transmission mechanism.

Note from (20) and (21) that wealth-related factors consist of two parts: an effect via the asset price, $\hat{q}_t$, and an effect stemming from the impact on retirees' MPC out of financial wealth, $\hat{\Gamma}_t$. Regarding the former, (23) shows that a higher expected rate path depresses the price q of the long-term bond. Via equations (20) and (21) this lowers consumption demand. We call this the "asset valuation channel". It works as a pure financial wealth effect and in the conventional direction, with rate hikes weighing on

[17] This is clear to pension funds (to whom many have outsourced their retirement savings): they often have negative duration gaps of about 10 years, which forced many to increase premiums over the zero-interest rate era, asking for greater saving efforts from their members. See, e.g., https://macrosynergy.com/research/low-for-long-rates-pressure-on-pensions-and-insurances/. As a concrete example, ABP (the largest Dutch pension fund) issued a statement back in 2019 (www.abp.nl/content/dam/abp/nl/documents/persbericht%20premie-indexatie%202020.pdf) saying "Pensions are becoming increasingly expensive [...] With the current pension ambition and the expectation that interest rates will remain low for a long time, higher premiums will be needed."

activity (see Caramp and Silva (2023) for a RANK model featuring this effect, also via long-term bonds).

When $\sigma > 1$, retirees' MPC out of financial wealth is positively related to the expected rate path, bringing a countervailing force. The reason is that, given the value of assets, a higher rate path implies that these assets will come with a superior income stream. This reduces the need to hold as many assets for retirement, lowering asset demand, stimulating demand for goods. We call this the "asset demand channel". Since working households care about the retirement state when $\delta_1 > 0$, $\hat{\Gamma}_t$ shows up in (21) too (just weighted by the retirement probability δ_1). This channel works in the unconventional direction when $\sigma > 1$, with higher rates *boosting* activity.

Before deriving explicit expressions for the impact of future rates on current activity, we need to ensure that the equilibrium of the system (19)-(23) is well defined, i.e. stable and unique. Recall that the monetary reaction is governed by $(1+\phi)$, which expresses the degree to which expected interest rates are raised in response to expected inflation. The conventional Taylor principle calls for $\phi > 0$. However, in our setup the model is determinate even for $\phi = 0$:

Proposition 1. *With $\theta > 0$ (sticky prices), a constant real rate policy ($\phi = 0$) is sufficient to deliver determinacy.*

All proofs are in Appendix C. In light of Proposition 1, the rest of the paper will set $\phi = 0$ to ensure determinacy while allowing us to discuss the effects of different real rate paths on activity. Once we solve (20) and (21) forward, the impact of future rates and demand shocks on current activity and inflation can be expressed as:

$$\hat{y}_t = -\sum_{j=0}^{\infty} \psi_j \mathbb{E}_t \hat{r}_{t+1+j} - \sum_{j=0}^{\infty} \omega_j \mathbb{E}_t \varepsilon^{\beta}_{t+j} \tag{27}$$

$$\hat{\pi}_t = -\sum_{j=0}^{\infty} \psi^{\pi}_j \mathbb{E}_t \hat{r}_{t+1+j} - \sum_{j=0}^{\infty} \omega^{\pi}_j \mathbb{E}_t \varepsilon^{\beta}_{t+j} \tag{28}$$

with $\psi_0 = \frac{1}{\sigma}$, $\psi^{\pi}_0 = \frac{\kappa}{\sigma}$,

$$\psi_j = (1-\delta_1)\psi_{j-1} - \xi^{\psi}_j,$$
$$\psi^{\pi}_j = \beta\psi^{\pi}_{j-1} + \kappa\psi_j,$$

$$\xi^{\psi}_j \equiv \frac{\sigma-1}{\sigma}\left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right]\beta^j(1-\delta_2)^{\frac{j}{\sigma}} - \left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\mu)}{\beta(1-\mu)}\right]\beta^j(1-\mu)^j,$$

and with $\omega_0 = \frac{1}{\sigma}$, $\omega_0^\pi = \frac{\kappa}{\sigma}$,

$$\begin{aligned}
\omega_j &= (1-\delta_1)\omega_{j-1} - \xi_j^\omega, \\
\omega_j^\pi &= \beta\omega_{j-1}^\pi + \kappa\omega_j, \\
\xi_j^\omega &\equiv -\frac{1}{\sigma}\left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right]\beta^j(1-\delta_2)^{\frac{j}{\sigma}}.
\end{aligned}$$

Here, each coefficient ψ_j represents the isolated impact that the real rate at horizon j has on output in the present, with ψ_j^π being the same object for inflation; the ω-coefficients are the equivalent objects with respect to discount rate shocks (with a positive shock to the discount rate implying a negative demand shock). It is always true that an increase in the short rate $\mathbb{E}_t\hat{r}_{t+1}$ depresses activity, as this is driven solely by intertemporal substitution ($\psi_0 = \frac{1}{\sigma}$). However, the effect of *future* interest rates becomes ambiguous as three forces are at play: intertemporal substitution, valuation effects, and effects on asset demand. Before exploring the ψ_j's in FLANK, it is worth recalling that our model collapses to RANK for $\delta_1 = 0$. There, $\psi_j = \frac{1}{\sigma}$ and $\psi_j^\pi = \kappa\frac{1-\beta^{j+1}}{1-\beta}\psi_j$ for all $j \geq 0$. This implies that near-term interest rate hikes always have the exact same output effect as rates further out into the term structure, with this effect always equal to $-\frac{1}{\sigma}$.

But when $\delta_1 > 0$ the sign of ψ_j becomes dependent on the $EIS = 1/\sigma$. If the EIS is sufficiently large, intertemporal substitution remains dominant and rates at all horizons will have conventionally-signed effects. But when the EIS is small enough, rates further out into the future will obtain the *unconventional* sign, since asset demand effects (driven by the interest income effect) will dominate:

Proposition 2. *For $\delta_1 > 0$ (i.e., when introducing retirement risk, giving rise to our "FLANK" model), we have that:*

(a) The ability of interest rates to affect activity and inflation in the conventional direction (i.e., with contractionary shocks lowering activity and inflation, and vice versa) is weakened relative to RANK: $\psi_j < \frac{1}{\sigma}$ and $\psi_j^\pi < \frac{\kappa}{\sigma}\frac{1-\beta^{j+1}}{1-\beta}$, for all $j \geq 1$;

(b) In the limit, taking the horizon j to infinity, $\mathbb{E}_t\hat{r}_{t+1+j}$ ceases to affect activity and inflation in the present: $\lim_{j\to\infty}\psi_j = 0$ and $\lim_{j\to\infty}\psi_j^\pi = 0$;

(c) At every horizon $j \geq 1$, ψ_j and ψ_j^π are decreasing in σ; they eventually become negative as σ is increased;

(d) The ability of interest rate policy to affect activity and inflation in the conventional

direction is increasing in retirees' death probability (δ_2) *and increasing in the duration of available assets (i.e., decreasing in* μ*) for all* $j \geq 1$.

The key takeaway from Proposition 2 is that life-cycle forces make the effect of interest rates on activity vary along the yield curve – both quantitatively and qualitatively. In our setup, higher near-term rates have the conventional, i.e., contractionary effect ($\psi_j > 0$ for $j < \widetilde{j}$), whereas higher rates further out into the term structure can simultaneously be expansionary ($\psi_j < 0$ for $j > \widetilde{j}$). Figure 4 visualizes this by plotting how ψ_j evolves with the horizon j. As the dashed lines show, $\psi_j = 1/\sigma\ \forall j$ in RANK, whereas the solid lines convey the more involved forces present in FLANK.

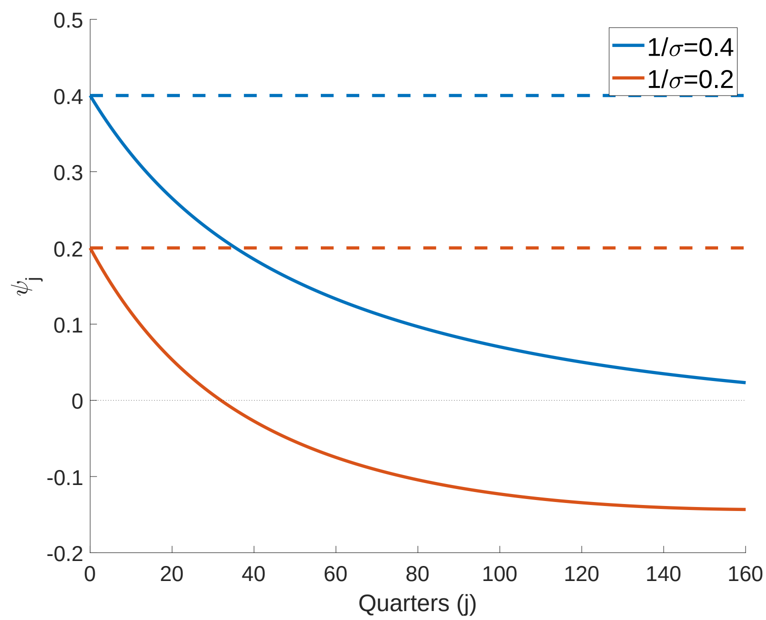

Figure 4: Evolution of ψ_j-coefficients along the yield curve in FLANK (solid) and RANK (dashed).

Parts (a) and (b) of Proposition 2 are shared by models with a discounted Euler equation (McKay et al., 2017). Parts (c) and (d) are specific to FLANK. Part (c) implies that, in FLANK, interest rates further out in the yield curve may have *opposite* effects to that of near-term rates, with higher long-term rates *boosting* activity. This is something that can neither arise in RANK, nor under a discounted Euler equation.

Part (d) of Proposition 2 provides additional insight on the ψ_j's. It shows that interest rate policy loses potency in the conventional direction as households' expected time spent in retirement rises (lower δ_2). This increases the duration of household liabilities – with them having to finance a longer consumption stream in retirement, where households rely on asset income. This means that low future rates, which are normally expansionary, incite more savings by workers and slower asset depletion by retirees.

It is important to emphasize that Part (c) of Proposition 2 is central to our key results regarding $\Psi(1) \equiv \sum_{j=0}^{\infty} \psi_j$, as it implies that persistent rate changes may produce weaker – or even unconventional – effects compared to more temporary ones.

4.2 Effect of interest rate persistence on potency and direction

We can now discuss how the potency of monetary policy shocks changes with their persistence. Consider an AR(1) shock ε_t^i to the interest rate rule. The time path for the expected real rate is then given by $\mathbb{E}_t \hat{r}_{t+1+j} = \mathbb{E}_t \varepsilon_{t+j}^i = (\rho_i)^j \epsilon_t^i$. The impact responses to such a monetary policy shock are:

$$\hat{y}_t = -\Psi(\rho_i)\epsilon_t^i, \tag{29}$$

$$\hat{\pi}_t = -\frac{\kappa}{1-\rho_i\beta}\Psi(\rho_i)\epsilon_t^i, \tag{30}$$

where

$$\begin{aligned}\Psi(\rho_i) &\equiv \sum_{j=0}^{\infty} \psi_j \rho_i^j \qquad (31)\\ &= \frac{1}{\sigma}\frac{(1-\gamma)(1-\delta_1)}{1-\rho_i(1-\delta_1)} - \left[\gamma + \frac{\delta_1(1-\gamma)}{1-\rho_i(1-\delta_1)}\right]\left[\frac{\frac{\sigma-1}{\sigma}}{1-\rho_i\beta(1-\delta_2)^{\frac{1}{\sigma}}} - \frac{1}{1-\rho_i\beta(1-\mu)}\right]\end{aligned}$$

captures the effect of a monetary policy shock ϵ_t^i with persistence ρ_i on current output. Since our model features no state variables, $\hat{y}_t = \rho_i^t \hat{y}_0$ and $\hat{\pi}_t = \rho_i^t \hat{\pi}_0$ – implying that results continue to apply at all horizons $t > 0$.

Equations (29) and (30) have interesting implications for how a shock's persistence affects its potency. If either $\delta_1 = 0$ (no retirement preoccupations) or $\sigma \leq 1$, then more persistent monetary policy shocks always have greater potency than temporary ones. In particular, when persistence ρ_i goes to 1, the potency of monetary shocks becomes very large, and goes to infinity for $\delta_1 = 0$ (i.e., in RANK). This is why monetary policy is generally thought to be unable to keep real rates away from neutral (r^*) for long periods without having major effects on inflation. However, in the presence of a retirement savings motive ($\delta_1 > 0$) and if $\sigma > 1$ ($EIS < 1$), the link between shock persistence and potency becomes more involved. The model then generally hosts a "persistence-potency trade-off", meaning that – beyond some threshold level – a more persistent monetary policy shock will be *less* potent than a more temporary one. This arises because the effects of monetary shocks on consumption are not just driven by intertemporal substitution in FLANK. Instead, they are also shaped by how the rate change affects the desire to accumulate, and hold on to, assets (to enable consumption in retirement). The latter depends on whether the lower (higher) rates are incentivizing households to hold more (less) wealth and whether valuation effects are sufficiently large to offset any changes in their desire to save. As σ increases, intertemporal substitution becomes less relevant and the impact on asset demand will eventually dominate the valuation effect. This then causes more persistent shocks to have less of an effect on activity than more temporary changes.[18] Interestingly, such a pattern has been observed by various empirical studies, including Uribe (2022), McKay and Wolf (2023, their Appendix C.2), Miescu (2023), Swanson (2024), and Braun et al. (2025); our Appendix D provides further evidence.

In fact, the operation of monetary policy can even flip sign. To visualize this, Figure 5 plots $\Psi(\rho_i)$ as ρ_i varies between 0.6 and 1.[19] The figure shows that, for rather transitory rate changes, life-cycle forces do not affect the monetary transmission mechanism much, i.e., FLANK behaves much like RANK for low ρ_i. But as ρ_i increases, the two models diverge: whereas RANK implies that very persistent shocks are incredibly potent in the conventional direction (with potency going to infinity in the limit), FLANK suggests the opposite may arise – with $\Psi(1)$ close to 0 (or slightly negative) being a plausible outcome. The version of RANK featuring a *discounted* Euler equation ("D-RANK", with discount parameter α set to 0.97, which can be seen as an approximation to HANK; McKay et al., 2017) behaves much like RANK, except for not shooting off to infinity (recall footnote 13). Importantly, D-RANK does not display a persistence-potency trade-off, which is unique to our FLANK model.

4.3 The effect of (near-)permanent monetary policy shocks

As set out in Section 3, $\Psi(1)$ – the sensitivity of aggregate demand to permanent real-rate deviations – is key to understanding the (unconscious) control central banks might have over dynamics in real interest rates. Here, we therefore explore this object. While our log-linearized model is not formally equipped to analyze truly permanent real-rate deviations, it is insightful to consider the expression for Ψ that results in the limit where

[18] This result is reminiscent of Lucas and Rapping (1969), who show that the response of labor supply may vary with the persistence of the wage impulse. When the latter is rather transitory, the substitution effect is likely dominant – making labor supply increase with the wage rate. But when the wage changes in a rather persistent manner, the income effect gains importance – potentially causing labor supply to fall with wages.

[19] This figure was generated with the following quarterly calibration: $\sigma = 4$, $\beta = 0.995$, $\delta_1 = 1/180$ (an expected working life of 45 years), $\delta_2 = 1/80$ (an expected retired life of 20 years), and $\mu = 0.0369$ (average bond duration of 6 years).

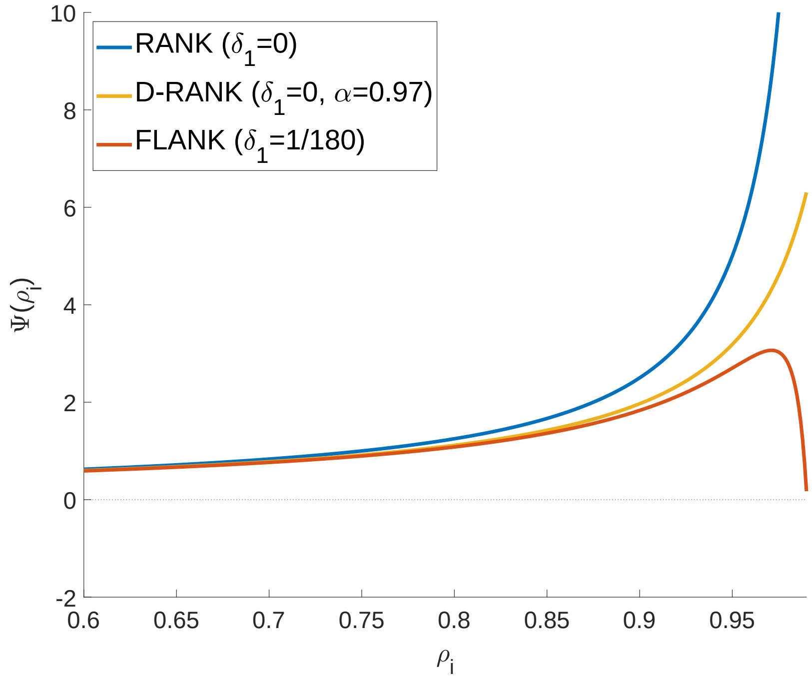

Figure 5: $\Psi(\rho_i)$ in RANK and FLANK. Other parameters calibrated as in footnote 19.

$\rho_i \to 1$ in equation (31):

$$\Psi(1) = \sum_{j=0}^{\infty} \psi_j = \underbrace{\frac{1}{\sigma} \frac{(1-\gamma)(1-\delta_1)}{\delta_1}}_{\textit{intertemporal substitution}} - \underbrace{\frac{\sigma - 1}{\sigma} \frac{1}{1 - \beta(1-\delta_2)^{\frac{1}{\sigma}}}}_{\textit{asset demand}} + \underbrace{\frac{1}{1-\beta(1-\mu)}}_{\textit{asset valuation}}. \tag{32}$$

The first term captures intertemporal substitution among working households. It is always positive and goes to 0 as $EIS = \frac{1}{\sigma} \to 0$. The second term, which combines workers and retirees, is the asset demand effect. It is primarily driven by the duration of household liabilities (as governed by the death probability δ_2, which determines the expected length of retirement where households still want to consume, but only enjoy interest income).[20] When $\sigma > 1$ this term works in the *unconventional* direction. The third term captures the asset valuation effect, driven by asset duration as governed by μ. Whenever the sum of the last two terms is negative, meaning that the duration in the household's asset portfolio is not enough to compensate for its negative duration gap stemming from the need to finance consumption in retirement, the total effect $\Psi(1)$ could be close to 0 (as the first term in (32) is positive). In the special case where $\frac{1}{\sigma} \to 0$ and $\mu \to 0$, we have

[20] The asset demand effect is maximized for $1/\sigma \to 0$. There, the household is infinitely risk averse, meaning that it only consumes its interest income – never daring to touch the principal (including capital gains) for fear of outliving assets. This actually seems a reasonable approximation to the observed behavior of retirees, who do not dissave much in retirement; recall footnote 3.

$\Psi(1)$ *exactly* equal to 0: consumption then equals the flow value of wealth, $(r-1)a$, while the value of wealth is proportional to $\frac{1}{r-1}$.

Equation (32) also allows for a reinterpretation, featuring just two forces. Combining the effects relating to intertemporal substitution and asset demand, one obtains a term that captures the effect of a permanent rate increase on the economy's average MPC out of financial wealth ($MPCoW$):[21]

$$\Psi(1) = -\underbrace{\left(\frac{\sigma-1}{\sigma}\frac{1}{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}} - \frac{1}{\sigma}\frac{(1-\gamma)(1-\delta_1)}{\delta_1}\right)}_{average\ MPC\ out\ of\ financial\ wealth\ (MPCoW)} + \underbrace{\frac{1}{1-\beta(1-\mu)}}_{asset\ valuation}. \tag{33}$$

Since the asset valuation effect always works in the conventional direction (higher rates depress demand), equation (33) implies that $\Psi(1) \approx 0$ is possible if the $MPCoW$ rises sufficiently in response to a permanent rate increase. In FLANK, this can easily happen because agents have less need to hold assets, to maintain a given retirement consumption stream, when assets generate a higher return.

Ultimately, the above discussion concerns a quantitative question. For the calibration used in Figure 5, $\Psi(1)$ is indeed close to 0. But since there is uncertainty over parameters, Figure 6 presents a heatmap.[22] It varies the $EIS(=\frac{1}{\sigma})$ and average bond maturity ($\frac{1}{\mu}$), conveying the different values taken on by $\bar{\Psi}(1) = \frac{1}{4}\Psi(1)$ (the division by 4 is done so that the figures capture the policy rate deviating permanently from r^* by 1 percentage point *on an annualized basis*; in the equations, r is the *quarterly* interest rate). For the other parameters, of which there are only three, we fix $\delta_1 = 1/180$ (an expected working life of 45 years), $\delta_2 = 1/80$ (an expected retirement span of 20 years), and $\beta = 0.995$.

To identify the plausible range for the EIS, we draw from Best et al. (2020) which uses a frontier empirical strategy. Their preferred EIS estimate lies close to 0 (at around 0.1). At the other end, they report values up to 0.3 (see their Table 3B, pooled estimate), so we go up to 0.35 to be inclusive of higher values. With respect to bonds, we focus on average maturities greater than 4 years to capture a set of interpretations for assets held. Lower durations (higher μ) are appropriate when solely thinking of government bonds (which, for the U.S., currently have an average maturity of just over 5 years); higher

[21] Averaging is over workers and retirees. The effect on the $MPCoW$ for retirees is given by $\frac{\sigma-1}{\sigma}\frac{1}{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}$, while that on working households equals $\frac{\sigma-1}{\sigma}\frac{1}{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}} - \frac{1}{\sigma}\frac{1-\delta_1}{\delta_1}$. Since $\frac{1}{\sigma}\frac{1-\delta_1}{\delta_1} > 0$, the effect of r on the $MPCoW$ of working households is less positive (or more negative) than that on retirees – the reason being that interest income is less important to the former group.

[22] Since our model is log-linearized, it is not formally equipped to handle fully permanent shocks, which is why Figure 6 is generated with $\rho_i = 0.99$.

durations (lower μ) are reasonable when thinking of a combination of bonds, equity, and real estate.[23] We aim to be quite inclusive in the range of parameters explored, to give a sense of possible outcomes.

In Figure 6, blue areas represent positive values for $\bar{\Psi}(1)$ (the "conventional" region); red areas represent *negative* values, where permanently lower rates *depress* activity. White areas indicate $\bar{\Psi}(1)$ close to 0, with black lines marking iso-$\bar{\Psi}(1)$ curves. An iso-$\bar{\Psi}(1)$ curve of $\pm 1\%$ implies that a permanent real rate increase by 1 percentage point, would cause an output gap of 1%. With a standard Euler equation, including the discounted version, the whole area would be dark blue. In fact, for RANK the entire surface would be valued at $+\infty$. In contrast, Figure 6's left panel shows that negative values for $\bar{\Psi}(1)$ are about as likely as positive ones. FLANK thus gives little reason to believe that persistently low (high) interest rates are more likely to stimulate (depress) the economy, than to depress (stimulate) it. This, by itself, is an important take-away: while much of our discussion focuses on the idea that $\bar{\Psi}(1)$ may be close to 0, the possibility of $\bar{\Psi}(1)$ being negative (instead of positive) suggests that low-for-long policies may have contributed to depressing the economy, instead of stimulating it.

The area where $\bar{\Psi}(1)$ is *exactly* equal to 0 is of measure 0 – making it not very relevant. Nonetheless, the figure shows that there is a considerable area where $\bar{\Psi}(1)$ may be considered quite small. Recall that from 1990 to 2019, the U.S. output gap varied by several percentage points without inflation moving much. This suggests that, when inflation expectations are well anchored, an output gap of a few percentage points might not affect inflation by a lot (more generally, this may be due to the Phillips curve being rather flat, as for example argued by Hazell et al. (2022)). Accordingly, Figure 6 hosts a considerable region where a permanent departure of real rates from r^* could be consistent with inflation remaining close to target.

At this stage, one may recall that the above results were derived under the assumption that the relative wealth share of retired versus working households was held constant via a tax-transfer scheme. Does this affect the properties of $\bar{\Psi}(1)$? Figure 6's middle panel, which shows the same heatmap *without* the simplifying assumption, points to robustness: both the qualitative and quantitative features of $\bar{\Psi}(1)$ are virtually unchanged.

Another dimension along which to explore robustness, concerns our omission of productive capital K. While one might think that the associated "investment channel" of

[23] Weber (2018) puts the duration of the S&P 500 at around 20 years. The duration of housing is estimated to be around 8 years (Burgert et al., 2024). In the Fed's FRB/US model, a highly persistent unit monetary policy shock changes household aggregate wealth holdings by approximately 10% (putting duration at around 10 years).

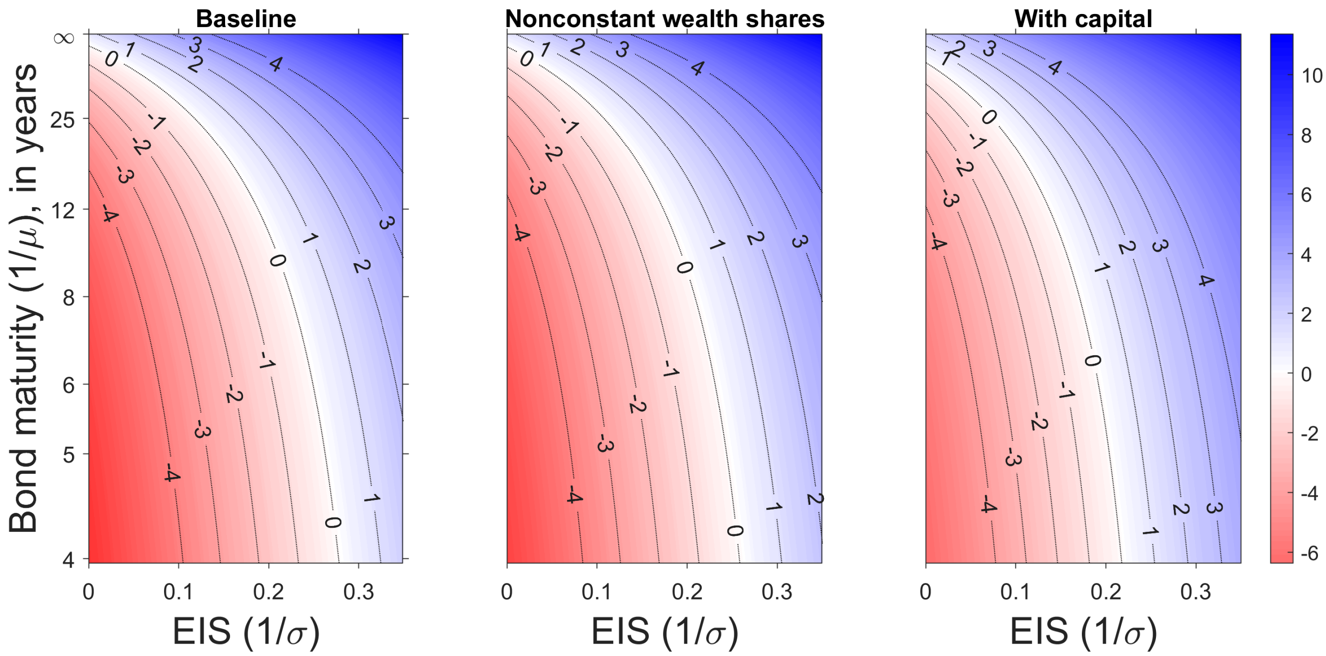

Figure 6: $\bar{\Psi}(1)$ as a function of σ and μ in FLANK. The left panel refers to the baseline model (featuring a transfer scheme to keep the wealth shares constant at steady state); the middle panel does not impose this simplifying assumption; the right panel refers to the model with capital. Other parameters are calibrated as in footnote 19 (and footnote 24).

monetary policy could overturn our findings, this is not the case. This is illustrated by the right panel in Figure 6, which plots the heatmap after extending our model with capital and quadratic investment adjustment costs (details are in Appendix E).[24] It looks similar to the heatmaps generated without capital, suggesting that such an abstraction is a decent approximation for the question central to this paper. To understand why, it helps to think of r^* as the interest rate which sets long-run excess demand ("XD") to 0. Its natural logarithm can be defined as $\ln XD = \ln(C+I) - \ln F(K,L) = \ln(C+\nu K) - \ln F(K,L)$, where "$\nu$" is capital's depreciation rate. Differentiating with respect to $\ln r$, whilst holding consumption and labor supply constant, gives $\frac{\partial \ln XD}{\partial \ln r}\big|_{C,L} = \left(\frac{I}{Y} - \frac{K\cdot\partial F/\partial K}{F(K,L)}\right)\frac{\partial \ln K}{\partial \ln r}$. Since the investment share $\frac{I}{Y}$ tends to be smaller than the capital share $\frac{K\cdot\partial F/\partial K}{F(K,L)}$ (in the U.S., the former is about 20% versus 30% for the latter), one can see that the partial effect of higher interest rates is to create excess *demand* (not excess supply) in the natural case where $\frac{\partial \ln K}{\partial \ln r} < 0$. The reason lies in the fact that investment does not just come with a

[24]This introduces three new parameters, calibrated as follows. We set the output elasticity for labor $\eta = 2/3$ (to get a two-thirds labor share) and capital's depreciation rate $\nu = 0.035$. This is slightly above the traditional value of 0.025 to reflect that, nowadays, much capital is intangible (e.g., software) and depreciates faster (Corrado et al., 2009). We finally set the quadratic investment adjustment cost $\iota = 25$, to match the 2.5x volatility of investment relative to output observed in post-1982 U.S. data.

demand aspect to it, but also affects (increases) future supply. Hence, what is required for excess demand to be strongly negatively related to r, is that *consumption* is strongly negatively related to r. This explains our focus on the latter.

5 Real rate hysteresis: a quantification

Armed with a model in which $\Psi(1)$ can easily be quite small, one may be left wondering: what does this imply for the central bank's perception of r^*, and its (overlooked) ability to persistently affect long-term real rates along the way? To answer that question, which links back to the empirical evidence of Section 2, this section combines Section 3's general "learning about r^*" model with the quantitative insights stemming from Section 4.

In particular, we consider a central bank working with a perceived value $\Psi^{CB}(1) = 6.3$, meaning it believes that the potency of the permanent component of monetary policy is broadly in line with predictions from a discounted Euler equation (or HANK; recall footnote 13). This, however, is an overestimation: the true data generating process – assumed to be our FLANK model – is such that $\Psi(1) = 0.2$ as implied by the calibration described in footnote 19, which sits somewhere in the middle of the heatmaps presented in Figure 6 (but still falls in the "conventional" region).

Let us furthermore assume that the central bank views a monetary policy shock to be a particular incarnation of a demand shock, meaning it works with $\Psi^{CB}(\rho_d) = \Omega^{CB}(\rho_d)$; again, the truth is such that these objects are generated by our FLANK model. There, it holds that $\Omega(\rho_d) > \Psi(\rho_d)$ – the reason being that a standard demand shock does *not* come with an offsetting interest income effect, meaning it works more strongly in the conventional direction; see Appendix F for a discussion of this feature of our model.

Relative to the simple model of Section 3, we add some realism by having the central bank apply interest rate smoothing, governed by ρ_r so that we can match the gradual, hump-shaped response of the Federal funds rate visible in Figure 2. The central bank thus sets the interest rate according to a generalized version of equation (4):

$$\mathbb{E}_t r_{t+1} = \rho_r r_t + (1 - \rho_r) \left(r_t^{*,CB} + \frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)} \varepsilon_t^d \right). \tag{34}$$

Allowing for interest rate smoothing adds a state variable, affecting the learning problem; see Appendix G, where we derive and present the generalized form of equation (6) which underpins Figure 7 (but (6) continues to be relevant for the intuition).

The experiment starts with a positive demand shock hitting, as in Figure 7(a). In implementing this exercise, we pick a standard quarterly value for interest rate smoothing ($\rho_r = 0.8$) and consider quite a transient demand shock ($\rho_d = 0.75$).

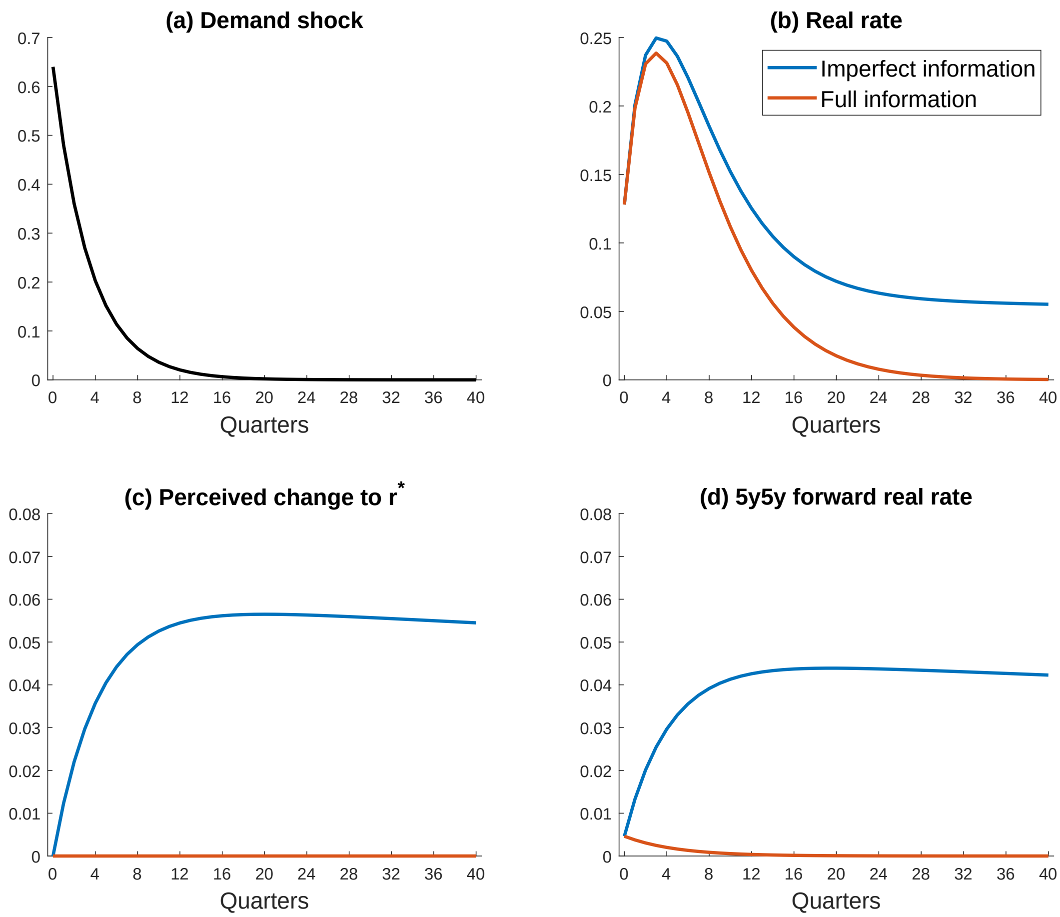

Figure 7: Real rate hysteresis. See text for calibration details.

As panel (b) shows, when the central bank is imperfectly informed about the true r^*, a demand shock causes the central bank to move its policy rate with much greater persistence (with this rate also settling at a level that is higher by around one-fifth of the peak effect, scaled to be 25 basis points). The enhanced persistence aligns with Campbell and Shiller's (1991: 513) observation that changes in policy rates turn out to be more persistent ex post, than originally envisioned ex ante. The reason lies in the central bank erroneously attributing part of the positive demand shock to r^* having risen; see panel (c). And because $\frac{\Psi(1)}{\Psi^{CB}(1)}$ is quite small (at $\frac{0.2}{6.3} \approx 0.03$), meaning that the system is very "forgiving" to a central bank working with a wrong r^*, this perception error is slow to correct – recall the discussion around equation (6). As a result, this misperception (which our model quantifies to around 5 basis points for a shock that moves the policy rate by 25 basis points at its peak – a degree of pass-through that is similar to that documented in

Section 2) lives on for an extended period of time, shaping short- and longer-term rates along the way. The latter point is shown in panel (d), which plots the response of the 5y5y forward real rate.[25] Under full information, where the central bank knows the true r^*, the forward rate moves only marginally on impact and mostly reflects the persistence of the underlying shock, ρ_d (the persistence would be exactly equal without interest rate smoothing; for $\rho_r > 0$, the persistence in the forward rate is slightly higher than ρ_d). But when combined with the informational imperfection, and the resulting learning dynamic set out in Section 3, this variable starts responding in a way much like the hysteresis-like pattern observed in Section 2. In that case, the systematic response of monetary policy, aimed at stabilizing output and inflation in the face of shocks, ends up shaping short- and longer-term interest rates in a highly persistent fashion – and associated asset prices alike.

6 Discussion: assumptions and extensions

6.1 Assumptions

Our conclusions are robust to the relaxation of various assumptions – including some that might seem restrictive at first. In particular, Appendix H discusses how many assumptions can be relaxed quite easily, without changing our key insights. This for example applies to the addition of hand-to-mouth agents, a bequest motive, and allowing for "equity" or "housing" as investment options.

It should be noted that this paper only offers a *local* analysis. There, rates can deviate from r^* "for long" without doing much to activity or inflation. However, if the deviation became very large, many of the local properties could change. As shown in Beaudry et al. (2024), the underlying asset demand function is C-shaped. This means that, at very high real rates, asset demand will eventually become increasing in returns (even for $EIS \ll 1$). This implies that large deviations in interest rates away from r^* would not be possible without creating a large economic boom or contraction. Hence, from a global perspective, the true r^* should be viewed as remaining relevant, thus placing implicit bounds on how far interest rates could deviate from the true r^*. Yet, locally, central banks may have some leeway to deviate from the true r^*.

[25] This rate is calculated as $\sum_{h=5}^{9} \mathbb{E}_t[r_{t+1+h}]/5$, to represent the average policy rate that is expected to apply between years 6 and 10, conditional on the time-t information set (which includes the central bank's time-t perception of the natural rate, $r_t^{*,CB}$, consistent with the notion that central banks – like the Fed – are communicating their r^* estimates quite transparently).

6.2 Extensions for future work

By offering a highly tractable framework combining life-cycle forces and monetary policy, our work opens several avenues for future work. Our finding that conventional monetary policy may be less potent when retirement preoccupations are more prevalent (or when household assets are of shorter duration) suggests that central banks may need to move the interest rate *by more* to achieve a given effect on output and prices in an aging society (or a "post-QE world" where central banks hold large long-term bond portfolios, leaving less duration in household portfolios). This may have adverse consequences for financial stability. We do not model these interactions here, but such an extension could be warranted.

Second, while FLANK is already heterogeneous-agent in nature, hosting workers and retirees, other forms of heterogeneity are interesting to consider. Heterogeneity in the MPC out of wealth seems a natural candidate. Empirical studies find that this object varies across the wealth distribution, with richer households having lower MPCs (Di Maggio et al., 2020; Chodorow-Reich et al., 2021). Our model's logic then suggests that greater inequality can weaken the monetary policy transmission – as the asset valuation effect is normally an important force working in the conventional direction. But when consumption demand of asset holders is not very sensitive to valuation effects, this channel loses potency. The model of Bardoczy and Velasquez-Giraldo (2024), which combines MPC-heterogeneity with life-cycle dynamics, seems to hold great potential in this regard.

When it comes to adding realism, countries typically do not solely rely on funded pension plans – also providing retirees with a basic retirement income via pay-as-you-go (PAYG) systems, financed by taxing workers. The generosity of such schemes however tends to be limited,[26] leaving an important role for the saving dynamics central to our paper – a role that would only gain importance if one were to explicitly model bequest motives (a PAYG pension cannot be bequeathed to one's offspring). Our model also clarifies that the importance of retirement forces to the monetary transmission mechanism is greater when PAYG pensions are less generous. As rising old-age dependency ratios are putting PAYG systems under pressure (OECD, 2021), our analysis suggests that the importance of retirement forces to monetary policy may rise over time.

It would also be interesting to characterize optimal policy in FLANK. Since the model suggests that very persistent rate changes might not affect demand by much, this implies

[26] For example: 2023 U.S. Social Security payments were about $1,782 per month (see https://www.cbpp.org/sites/default/files/atoms/files/8-8-16socsec.pdf). Most young, working Americans are moreover pessimistic about their future Social Security benefits (Turner and Rajnes, 2021), increasing the importance of their own saving efforts.

that interest rate policy may be ill-equipped to offset persistent demand shocks. The latter may be better left to fiscal policy, with monetary policy instead focusing on stabilization in response to disturbances that are deemed more transient in nature.

Finally, to us, the region of the model's parameter space where $\Psi(1) \approx 0$ carries considerable appeal: not only can it explain why central banks appear to have significant control over longer-term real rates, but also why central banks have been quite successful in fulfilling their mandate despite being very imperfectly informed about the location of r^*. In this light, it is interesting to explore what can widen the range where $\Psi(1)$ is small. Our initial efforts suggest that a bequest motive can do so (recall the discussion in Appendix H) but there may be other avenues such as Epstein-Zin (1989) preferences, which allow the EIS and coefficient of relative risk aversion to be calibrated separately, rather than imposing they are each other's inverse. More generally, there may be other forces – distinct from life-cycle considerations – that can undermine the potency of the highly persistent component of monetary policy, leading to $\Psi(1) \approx 0$. One possible channel runs via the impact on the banking sector (Abadi et al. (2023); Eggertsson et al. (2024)). But it may also be that the practice of interest rate smoothing induces agents to postpone their investment decisions when observing a first rate cut, on the expectation that further cuts are on their way (Caplin and Leahy, 1996). Alternatively, papers like Gopinath et al. (2017) and Asriyan et al. (2025) have argued that low-for-long policies might not be very potent as they promote capital misallocation.

7 Conclusion

Long-term real interest rates are usually seen as being driven by real forces, with monetary policy playing a transitory role – otherwise just *following* secular trends. This paper has argued that this view may be incomplete, with there actually existing a causal – though non-deliberate – link between the stance of monetary policy and long-term real rates (plus associated asset prices).

We began by documenting that temporary demand shocks, to which the Federal Reserve responds systematically, appear to leave a highly persistent imprint on forward real rates and estimates of r^* – suggesting that monetary policy may have a longer reach over real rates than standard models imply.

We then proposed a mechanism through which such "real rate hysteresis" can arise. The key object is the sensitivity of aggregate demand to very persistent deviations of real interest rates from the natural rate, denoted $\Psi(1)$. In standard New Keynesian models, this sensitivity is large: keeping real rates away from r^* for long should generate substantial excess demand, pushing inflation away from target, and forcing the central bank to reverse course. In contrast, we showed that once life-cycle forces are introduced, $\Psi(1)$ can be much smaller – potentially even close to 0. The reason is that persistent changes in real rates affect not only intertemporal substitution and asset valuations, but also households' desired asset holdings for retirement. When the elasticity of intertemporal substitution is low, the asset demand effect can broadly offset the valuation channel.

While we do not claim to know with certainty that the net effects are in fact approximately 0 – even though it is consistent with various empirical observations and calibrations offered in this paper – we do argue that such a possibility opens the door to a fundamentally different view regarding the powers of central banks. Especially, it offers an interpretation on the observed link between policy rates and long-term real rates that does not rely on central banks having private information. Instead, there may well exist a "persistence-potency trade-off", making the persistent component of monetary policy much less potent than commonly thought. Our model implies that if a central bank chooses to keep real rates low for a prolonged period, as many central banks did post-GFC, this may not boost the economy much – or even cause a slight contraction. If the central bank processes this disappointing outcome through the lens of a standard model, it is likely to conclude that r^* has fallen, which perpetuates the loose stance of monetary policy. The main effect of such a low-for-long policy would then be to lower long-term real rates and inflate asset prices (with significant distributional implications; Greenwald et al., 2023).

As a result, if central banks set policy based on a misperceived estimate of r^*, they would receive very few signals from output and inflation suggesting they are mistaken. In this sense, the economy is rather forgiving to such misperceptions. Accordingly, actions by a central bank may end up driving real rates over long periods of time, without them realizing this. It can lead to cases where a rate cut, initially intended to be purely temporary, acquires additional persistence as it subsequently induces the central bank to erroneously lower its estimate of r^* (and vice versa for a rate hike). It then becomes rational for markets to view central bank decisions and statements as relevant for long-term rates, even if they do not think central banks have private information about r^*. In sum, there may be a "long arm of monetary policy". Not because central banks deliberately choose long-run real interest rates, but because the economy provides too little feedback to prevent their beliefs about the associated natural rates from becoming self-sustaining.

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Appendix

A Additional robustness checks for Figures 1 and 2

Here, we present additional robustness checks for Figures 1 and 2. First, Figure A1 documents robustness when using the unemployment rate (instead of real GDP growth) as activity indicator in the VAR.

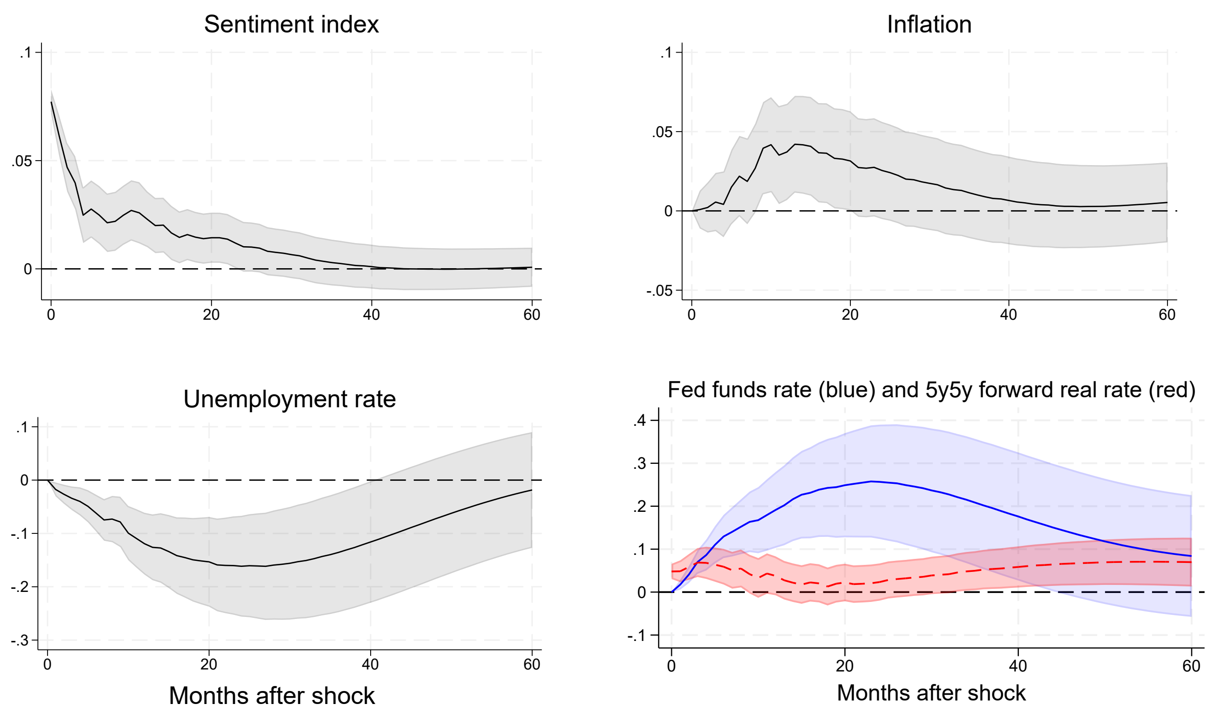

Figure A1: IRFs to a 1 standard deviation sentiment shock when using the unemployment rate as activity indicator. Shaded areas represent 95% confidence bands.

Next, we take a two-step approach. First, we orthogonalize the sentiment index with respect to the unemployment rate and the (logged) VIX index. Next, we use the residuals as an internal instrument in a VAR featuring our baseline variables. As shown in Figure A2, this produces very similar results to our baseline approach.

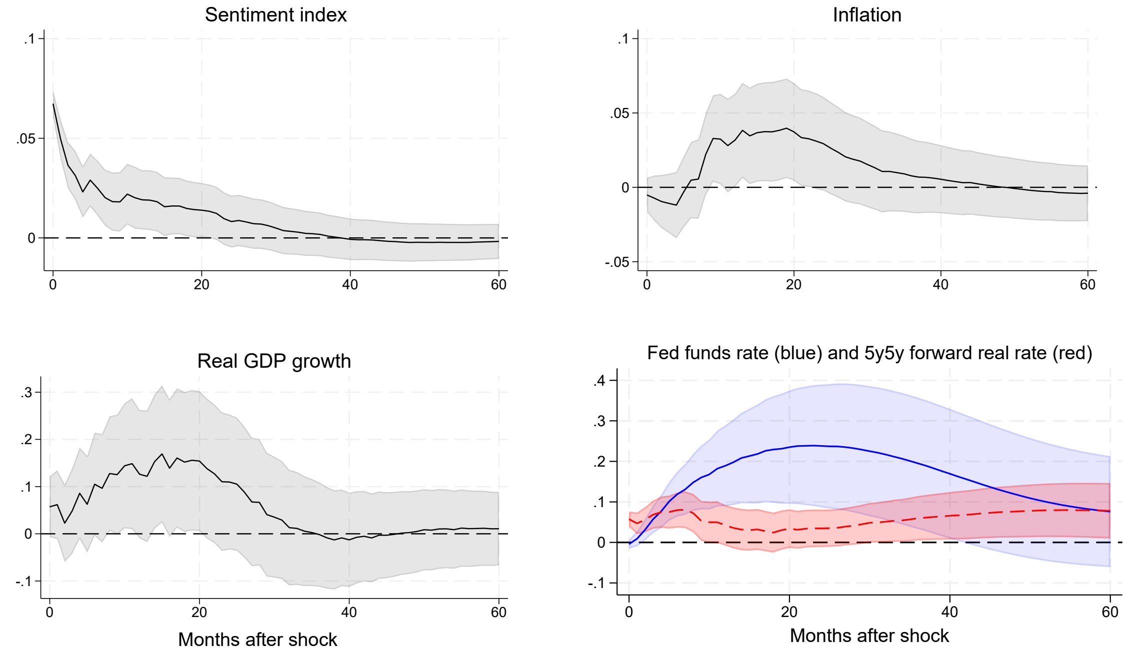

Figure A2: IRFs to a 1 standard deviation sentiment shock when first orthogonalizing the sentiment index with respect to the unemployment rate and VIX. Shaded areas represent 95% confidence bands.

B Equilibrium and steady state

The equilibrium of the model is described by the following equations:

$$y_t = \frac{\vartheta c_t^w + (1-\vartheta) c_t^r}{1 - \frac{\theta}{2}(\pi_t - \bar{\pi})^2}$$

$$c_t^r = a_t^r \left[(\Gamma_t)^{-1} - 1\right]^{-1}$$

$$(c_t^w)^{-\sigma} = \beta_t \left\{(1-\delta_1)\mathbb{E}_t\left[\left(c_{t+1}^w\right)^{-\sigma} r_{t+1}\right] + \delta_1 \mathbb{E}_t\left[\left(a_t^w r_{t+1}^w + \tau_{t+1}^r\right)^{-\sigma}(\Gamma_{t+1})^{-\sigma} r_{t+1}\right]\right\}$$

$$\left[(\Gamma_t)^{-1} - 1\right]^{\sigma} = (1-\delta_2)\beta_t \mathbb{E}_t\left[r_{t+1}\left(r_{t+1}^r \Gamma_{t+1}\right)^{-\sigma}\right]$$

$$(\pi_t - \bar{\pi})\pi_t = \lambda\left[\left(\frac{y_t}{\vartheta A}\right)^{1+\varphi} - 1\right] + \mathbb{E}_t\left[\Lambda_{t,t+1}^w (\pi_{t+1} - \bar{\pi})\pi_{t+1}\frac{y_{t+1}}{y_t}\right]$$

$$\Lambda_{t,t+1}^w = \beta_t \frac{(1-\delta_1)\left(c_{t+1}^w\right)^{-\sigma} + \delta_1\left(a_t^w r_{t+1}^w + \tau_{t+1}^r\right)^{-\sigma}(\Gamma_{t+1})^{-\sigma}}{(c_t^w)^{-\sigma}}$$

$$\Lambda_{t,t+1}^r = (1-\delta_2)\beta\frac{\left(r_{t+1}^r \Gamma_{t+1}\right)^{-\sigma}}{\left(\Gamma_t^{-1} - 1\right)^{\sigma}}$$

$$q_t b^g = \vartheta a_t^w + (1-\vartheta) a_t^r$$

$$0 = \vartheta(1-\alpha_t^w) a_t^w + (1-\vartheta)(1-\alpha_t^r) a_t^r$$

$$
\begin{aligned}
r^r_{t+1} &= r_{t+1} + \left[\frac{1+(1-\mu)\,q_{t+1}}{q_t} - r_{t+1}\right]\alpha^r_t \\
r^w_{t+1} &= r_{t+1} + \left[\frac{1+(1-\mu)\,q_{t+1}}{q_t} - r_{t+1}\right]\alpha^w_t \\
1 &= \mathbb{E}_t\left[\Lambda^r_{t,t+1}\frac{1+(1-\mu)\,q_{t+1}}{q_t}\right] \\
1 &= \mathbb{E}_t\left[\Lambda^w_{t,t+1}\frac{1+(1-\mu)\,q_{t+1}}{q_t}\right] \\
a^r_t &= \left[(1-\delta_2)\,a^r_{t-1}r^r_t + \delta_2\left(a^w_{t-1}r^w_t + \tau^r_t\right)\right](1-\Gamma_t) \\
i_t &= r\bar{\pi}\left(\frac{\mathbb{E}_t\left[\pi_{t+1}\right]}{\bar{\pi}}\right)^{1+\phi} e^{\varepsilon^i_t} \\
r_{t+1} &= \frac{i_t}{\pi_{t+1}}
\end{aligned}
$$

For a 0 inflation target ($\bar{\pi}=1$) and $\tau^r=0$, the steady-state real rate r solves:

$$
\frac{y}{r-\left[(1-\delta_2)\,\beta r\right]^{\frac{1}{\sigma}}}\,\frac{1+\delta_1\frac{\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}{1-(1-\delta_2)\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}}{\left[\frac{1-(1-\delta_1)\beta r}{\delta_1\beta r}\right]^{\frac{1}{\sigma}}+\frac{\delta_1}{1-(1-\delta_2)\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}} = \frac{b^g}{r-1+\mu}
$$

The left-hand side of this equation represents the steady-state demand for savings, while the right-hand side captures the steady-state value of the assets supplied to the economy. Let $\gamma \equiv (1-\vartheta)\,c^r/y$ denote the share of steady-state output consumed by retirees, and $\varsigma \equiv a^r/a^w$ denote the steady-state financial wealth of retirees relative to workers. Their equations are

$$
\begin{aligned}
\varsigma &= \frac{\delta_2\left[(1-\delta_2)\,\beta r\right]^{\frac{1}{\sigma}}}{1-(1-\delta_2)\left[(1-\delta_2)\,\beta r\right]^{\frac{1}{\sigma}}} \\
\gamma &= \frac{\delta_1}{\left[\frac{1-(1-\delta_1)\beta r}{\delta_1\beta r}\right]^{\frac{1}{\sigma}}\left\{1-(1-\delta_2)\left[(1-\delta_2)\,\beta r\right]^{\frac{1}{\sigma}}\right\}+\delta_1}
\end{aligned}
$$

Now assume that $a^r_t = \varsigma a^w_t$, $r=\beta^{-1}$ and τ^r_{t+1} is unexpected. The log-linearized equilibrium equations are then given by:

$$
\begin{aligned}
\hat{y}_t &= (1-\gamma)\,\hat{c}^w_t + \gamma\hat{c}^r_t \\
\hat{c}^r_t &= \hat{q}_t + \left[\beta\,(1-\delta_2)^{\frac{1}{\sigma}}\right]^{-1}\hat{\Gamma}_t \\
\hat{c}^w_t &= (1-\delta_1)\left(\mathbb{E}_t\hat{c}^w_{t+1} - \frac{1}{\sigma}\mathbb{E}_t\hat{r}_{t+1}\right) + \delta_1\left(\hat{q}_t + \left[\beta\,(1-\delta_2)^{\frac{1}{\sigma}}\right]^{-1}\hat{\Gamma}_t\right) - \frac{1-\delta_1}{\sigma}\varepsilon^\beta_t
\end{aligned}
$$

$$
\begin{aligned}
\hat{\Gamma}_t &= \beta\left(1-\delta_2\right)^{\frac{1}{\sigma}}\left[\mathbb{E}_t\hat{\Gamma}_{t+1}+\frac{\sigma-1}{\sigma}\mathbb{E}_t\hat{r}_{t+1}-\frac{1}{\sigma}\varepsilon_t^{\beta}\right]\\
\hat{\pi}_t &= \lambda\left(1+\varphi\right)\hat{y}_t+\beta\mathbb{E}_t\hat{\pi}_{t+1}\\
\hat{q}_t &= \beta\left(1-\mu\right)\mathbb{E}_t\hat{q}_{t+1}-\mathbb{E}_t\hat{r}_{t+1}\\
\hat{r}_{t+1} &= \hat{i}_t-\mathbb{E}_t\hat{\pi}_{t+1}-\varrho\\
\hat{i}_t &= \varrho+\left(1+\phi\right)\mathbb{E}_t\hat{\pi}_{t+1}+\varepsilon_t^{i}
\end{aligned}
$$

with $a_t^w = a_t^r = q_t$, $r_{t+1}^r = r_{t+1}^w = r_{t+1}$, and $\varrho \equiv \log r$.

C Proofs of Propositions

C.1 Proof of Proposition 1

When $\phi = 0$, the equilibrium dynamics are captured by:

$$
\begin{bmatrix} \hat{c}_t^w \\ \hat{\Gamma}_t \\ \hat{\pi}_t \\ \hat{q}_t \end{bmatrix} = \begin{bmatrix} 1-\delta_1 & \delta_1 & 0 & \beta\delta_1\left(1-\mu\right) \\ 0 & \beta\left(1-\delta_2\right)^{\frac{1}{\sigma}} & 0 & 0 \\ \kappa\left(1-\gamma\right)\left(1-\delta_1\right) & \kappa\left(1-\gamma\right)\delta_1+\kappa\gamma & \beta & \kappa\beta\left(1-\mu\right)\left[\left(1-\gamma\right)\delta_1+\gamma\right] \\ 0 & 0 & 0 & \beta\left(1-\mu\right) \end{bmatrix} \begin{bmatrix} \mathbb{E}_t\hat{c}_{t+1}^w \\ \mathbb{E}_t\hat{\Gamma}_{t+1} \\ \mathbb{E}_t\hat{\pi}_{t+1} \\ \mathbb{E}_t\hat{q}_{t+1} \end{bmatrix}
$$

The four eigenvalues of this system are $\left\{\beta, \beta\left(1-\mu\right), 1-\delta_1, \beta\left(1-\delta_2\right)^{1/\sigma}\right\}$. Since $\beta, \mu, \delta_1, \delta_2 \in (0,1)$ and $\sigma > 0$ then all four eigenvalues are less than 1 in modulus and the system has a unique stable solution.

C.2 Proof of Proposition 2

We start by deriving the "yield curve representation" of $\hat{y}_t$ and $\hat{\pi}_t$, equations (27) and (28). Assume $\phi = 0$, such that $\hat{r}_{t+1} = \varepsilon_t^i$. Solving q and Γ forward yields

$$
\begin{aligned}
\hat{q}_t &= -\mathbb{E}_t\hat{r}_{t+1}-\sum_{j=1}^{\infty}\beta^j\left(1-\mu\right)^j\mathbb{E}_t\hat{r}_{t+1+j}\\
\hat{\Gamma}_t &= \frac{\sigma-1}{\sigma}\sum_{j=0}^{\infty}\left[\beta\left(1-\delta_2\right)^{\frac{1}{\sigma}}\right]^{j+1}\mathbb{E}_t\hat{r}_{t+1+j}-\frac{1}{\sigma}\sum_{j=0}^{\infty}\left[\beta\left(1-\delta_2\right)^{\frac{1}{\sigma}}\right]^{j+1}\varepsilon_{t+j}^{\beta}
\end{aligned}
$$

Plug these into the workers' Euler equation to obtain

$$\hat{c}_t^w = (1-\delta_1)\,\mathbb{E}_t\hat{c}_{t+1}^w - \frac{1}{\sigma}\mathbb{E}_t r_{t+1} + \delta_1 \sum_{j=1}^{\infty}\beta^j\left[\frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{j}{\sigma}} - (1-\mu)^j\right]\mathbb{E}_t r_{t+1+j}$$
$$-\frac{1}{\sigma}\left[\delta_1\sum_{j=1}^{\infty}\beta^j(1-\delta_2)^{\frac{j}{\sigma}}\,\mathbb{E}_t\varepsilon_{t+j}^{\beta} + \varepsilon_t^{\beta}\right]$$

Through repeated substitution, we can express $\hat{c}_t^w$ as a function of future real interest rates and demand shocks only, as follows:

$$\hat{c}_t^w = -\sum_{j=0}^{\infty}\tilde{\psi}_j\mathbb{E}_t\hat{r}_{t+1+j} - \sum_{j=0}^{\infty}\tilde{\omega}_j\mathbb{E}_t\varepsilon_{t+j}^{\beta}$$

where $\tilde{\psi}_0 = \tilde{\omega}_0 = \frac{1}{\sigma}$ and

$$\begin{aligned}\tilde{\psi}_j &= \tilde{\psi}_{j-1}(1-\delta_1) - \delta_1\beta^j\left[\frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{j}{\sigma}} - (1-\mu)^j\right]\\ &= (1-\delta_1)^j\,\tilde{\psi}_0 - \delta_1\sum_{i=1}^{j}(1-\delta_1)^{j-i}\beta^i\left[\frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{i}{\sigma}} - (1-\mu)^i\right]\end{aligned}$$

$$\begin{aligned}\tilde{\omega}_j &= \tilde{\omega}_{j-1}(1-\delta_1) + \frac{\delta_1}{\sigma}\beta^j(1-\delta_2)^{\frac{j}{\sigma}}\\ &= (1-\delta_1)^j\,\tilde{\omega}_0 + \frac{\delta_1}{\sigma}\sum_{i=1}^{j}(1-\delta_1)^{j-i}\beta^i(1-\delta_2)^{\frac{i}{\sigma}}\end{aligned}$$

Now, plug the equations derived above for q and Γ into the retirees' consumption function to obtain a similar representation for $\hat{c}_t^r$:

$$\hat{c}_t^r = -\sum_{j=0}^{\infty}\bar{\psi}_j\mathbb{E}_t\hat{r}_{t+1+j} - \sum_{j=0}^{\infty}\bar{\omega}_j\mathbb{E}_t\varepsilon_{t+j}^{\beta}$$

where $\bar{\psi}_0 = \bar{\omega}_0 = \frac{1}{\sigma}$ and

$$\begin{aligned}\bar{\psi}_j &= \beta^j\left[(1-\mu)^j - \frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{j}{\sigma}}\right]\\ \bar{\omega}_j &= \frac{1}{\sigma}\beta^j(1-\delta_2)^{\frac{j}{\sigma}}\end{aligned}$$

Finally, we can use these representations for $\hat{c}_t^w$ and $\hat{c}_t^r$ to rewrite $\hat{y}_t$ as

$$\hat{y}_t = -\sum_{j=0}^{\infty} \psi_j \mathbb{E}_t \hat{r}_{t+1+j} - \sum_{j=0}^{\infty} \omega_j \mathbb{E}_t \varepsilon_{t+j}^{\beta}$$

where $\psi_j \equiv (1-\gamma)\tilde{\psi}_j - \gamma\bar{\psi}_j$ and $\omega_j \equiv (1-\gamma)\tilde{\omega}_j - \gamma\bar{\omega}_j$, which imply $\psi_0^y = \omega_0^y = \frac{1}{\sigma}$ and

$$\begin{aligned}
\psi_j &= \frac{1}{\sigma}(1-\gamma)(1-\delta_1)^j - (1-\gamma)\delta_1 \sum_{i=1}^{j} (1-\delta_1)^{j-i} \beta^i \left[\frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{i}{\sigma}} - (1-\mu)^i\right] \\
&\quad - \gamma\beta^j \left[\frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{j}{\sigma}} - (1-\mu)^j\right] \\
&= (1-\delta_1)\psi_{j-1} - \frac{\sigma-1}{\sigma}\left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right]\beta^j (1-\delta_2)^{\frac{j}{\sigma}} \\
&\quad + \left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\mu)}{\beta(1-\mu)}\right]\beta^j(1-\mu)^j \\
\omega_j &= \frac{1}{\sigma}(1-\gamma)(1-\delta_1)^j - \frac{1}{\sigma}(1-\gamma)\delta_1 \sum_{i=1}^{j}(1-\delta_1)^{j-i}\beta^i(1-\delta_2)^{\frac{i}{\sigma}} + \gamma\frac{1}{\sigma}\beta^j(1-\delta_2)^{\frac{j}{\sigma}} \\
&= (1-\delta_1)\omega_{j-1} + \frac{1}{\sigma}\left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right]\beta^j(1-\delta_2)^{\frac{j}{\sigma}}
\end{aligned}$$

Finally, solve $\hat{\pi}_t$ forward to obtain $\hat{\pi}_t = \kappa\sum_{j=0}^{\infty}\beta^j\mathbb{E}_t\hat{y}_{t+j}$. Then use the representation derived above to express $\hat{\pi}_t$as follows:

$$\hat{\pi}_t = -\sum_{j=0}^{\infty} \psi_j^{\pi} \mathbb{E}_t \hat{r}_{t+1+j} - \sum_{j=0}^{\infty} \omega_j^{\pi} \mathbb{E}_t \varepsilon_{t+j}^{\beta}$$

where $\psi_0^{\pi} = \kappa\psi_0$, $\omega_0^{\pi} = \kappa\omega_0$, and

$$\begin{aligned}
\psi_j^{\pi} &= \beta\psi_{j-1}^{\pi} + \kappa\psi_j \\
\omega_j^{\pi} &= \beta\omega_{j-1}^{\pi} + \kappa\omega_j
\end{aligned}$$

Proof of 2.a If $\delta_1 = 0$, then $\psi_j^y = \frac{1}{\sigma}$ and $\psi_j^{\pi} = \frac{\kappa}{\sigma}\frac{1-\beta^{j+1}}{1-\beta}$, for all $j \geq 0$. If $\delta_1 > 0$, then

$$\begin{aligned}
\psi_1^y &= \frac{1}{\sigma} - \frac{1}{\sigma}[\delta_1 + \gamma(1-\delta_1)]\left[1-\beta(1-\delta_2)^{\frac{1}{\sigma}}\right] - [\delta_1+\gamma(1-\delta_1)]\left[\beta(1-\delta_2)^{\frac{1}{\sigma}} - \beta(1-\mu)\right] \\
\psi_2^y &= \frac{1}{\sigma} - \frac{1}{\sigma}\left\{\left[1-\delta_1+\beta(1-\delta_2)^{\frac{1}{\sigma}}\right][\delta_1+\gamma(1-\delta_1)] + \delta_1\right\}\left[1-\beta(1-\delta_2)^{\frac{1}{\sigma}}\right] \\
&\quad - \left\{[\delta_1+\gamma(1-\delta_1)]\left[\beta(1-\delta_2)^{\frac{1}{\sigma}} + \beta(1-\mu)\right] + \delta_1(1-\gamma)(1-\delta_1)\right\}\left[\beta(1-\delta_2)^{\frac{1}{\sigma}} - \beta(1-\mu)\right] \\
\psi_3^y &= ...
\end{aligned}$$

If $\delta_2 < \mu$, then they are all strictly smaller than $\frac{1}{\sigma}$. Since $\psi_j < \frac{1}{\sigma}$ for all $j \geq 1$ and $\psi_j^\pi = \kappa \sum_{i=0}^{j} \beta^{j-i} \psi_i$, then also $\psi_j^\pi < \frac{\kappa}{\sigma} \frac{1-\beta^{j+1}}{1-\beta}$ for all $j \geq 1$.

Proof of 2.b Solve ψ_j backward to obtain:

$$\psi_j = (1-\delta_1)^j \psi_0 - \sum_{i=1}^{j} (1-\delta_1)^{j-i} \xi_i^\psi$$

where $\xi_i^\psi \equiv \frac{\sigma-1}{\sigma} \left[\delta_1 - \frac{\gamma}{(1-\delta_1)^{-1}} \frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right] \beta^j (1-\delta_2)^{\frac{i}{\sigma}} - \left[\delta_1 - \frac{\gamma}{(1-\delta_1)^{-1}} \frac{1-\beta(1-\mu)}{\beta(1-\mu)}\right] \beta^i (1-\mu)^i$. Now, since $\lim_{i\to\infty} \xi_i^\psi = 0$ then also $\lim_{j\to\infty} \psi_j = 0$, provided that $\delta_1 > 0$. Since $\psi_j^\pi = \kappa \sum_{i=0}^{j} \beta^{j-i} \psi_i$, then also $\lim_{j\to\infty} \psi_j^\pi = 0$.

Proof of 2.c The derivative of ψ_j with respect to σ is

$$\begin{aligned}\frac{\partial \psi_j}{\partial \sigma} = & -\frac{1}{\sigma^2}(1-\gamma)(1-\delta_1)^j - \gamma\beta^j \left[\frac{1}{\sigma^2}(1-\delta_2)^{\frac{j}{\sigma}} + \frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{j}{\sigma}} \left[-\ln(1-\delta_2)\right] \frac{j}{\sigma^2}\right] \\ & -(1-\gamma)\delta_1 \sum_{i=1}^{j} (1-\delta_1)^{j-i} \beta^i \left[\frac{1}{\sigma^2}(1-\delta_2)^{\frac{i}{\sigma}} + \frac{\sigma-1}{\sigma}(1-\delta_2)^{\frac{i}{\sigma}} \left[-\ln(1-\delta_2)\right] \frac{i}{\sigma^2}\right]\end{aligned}$$

Since all of the terms are negative (recall that $\delta_2 \in [0,1]$, therefore $-\ln(1-\delta_2) > 0$), then $\partial\psi_j/\partial\sigma < 0$. The derivative of ψ_j^π with respect to σ is $\partial\psi_j^\pi/\partial\sigma = \kappa \sum_{i=0}^{j} \beta^{j-i} \partial\psi_i/\partial\sigma$, which is therefore also negative. Finally, note that

$$\lim_{\sigma\to+\infty} \psi_j = -(1-\gamma)\delta_1 \sum_{i=1}^{j} (1-\delta_1)^{j-i} \beta^i \left[1-(1-\mu)^i\right] - \gamma\beta^j \left[1-(1-\mu)^j\right] < 0$$

which is strictly negative, as $\mu \in (0,1]$. Since ψ_j is continuous in σ and its limit for $\sigma \to +\infty$ is negative, then $\exists\sigma < +\infty$ such that $\psi_j < 0$. Similarly, since $\psi_j^\pi = \kappa \sum_{i=0}^{j} \beta^{j-i} \psi_i$ is continuous in σ and $\lim_{\sigma\to+\infty} \psi_j^\pi = \kappa \sum_{i=0}^{j} \beta^{j-i} \lim_{\sigma\to+\infty} \psi_i < 0$, then $\exists\sigma < +\infty$ such that $\psi_j^\pi < 0$.

Proof of 2.d The derivatives of ψ_j with respect to δ_2 and μ are

$$\begin{aligned}\frac{\partial \psi_j}{\partial \delta_2} &= \frac{1}{\sigma}\frac{\sigma-1}{\sigma}\frac{(1-\gamma)\delta_1 \sum_{i=1}^{j}(1-\delta_1)^{j-i}\beta^i i (1-\delta_2)^{\frac{i}{\sigma}} + \gamma\beta^j j (1-\delta_2)^{\frac{j}{\sigma}}}{1-\delta_2} > 0, \\ \frac{\partial \psi_j}{\partial \mu} &= -\frac{(1-\gamma)\delta_1 \sum_{i=1}^{j}(1-\delta_1)^{j-i}\beta^i i (1-\mu)^i + \gamma\beta^j j (1-\mu)^j}{1-\mu} < 0.\end{aligned}$$

Since $\psi_j^\pi = \kappa \sum_{i=0}^{j} \beta^{j-i}\psi_i$, the derivatives of ψ_j^π with respect to δ_2 and μ are

$$\frac{\partial \psi_j^\pi}{\partial \delta_2} = \kappa \sum_{i=0}^{j} \beta^{j-i} \frac{\partial \psi_i}{\partial \delta_2} > 0,$$
$$\frac{\partial \psi_j^\pi}{\partial \mu} = \kappa \sum_{i=0}^{j} \beta^{j-i} \frac{\partial \psi_i}{\partial \mu} < 0.$$

D Do the effects of monetary policy shocks vary with persistence?

An important feature of FLANK – distinguishing it from the standard New Keynesian model – is that rather transient monetary policy shocks do more to affect real activity in the conventional direction, than more persistent shocks (such as those associated with forward guidance). These contrasting predictions open the door to an empirical test, which is what we do here.

For the U.S., it has been observed (by, e.g., McKay and Wolf (2023)) that the monetary policy shock series by Romer and Romer (2004, "RR") rapidly leads to a short-lived peak in the Federal funds rate, while the shock of Gertler and Karadi (2015, "GK") captures a different dimension of monetary policy, more inclusive of "forward guidance", with the shock inducing a more delayed and persistent response in the policy rate.

To see whether these different shocks also yield different responses in activity, we generate IRFs by following Plagborg-Møller and Wolf (2021) in ordering the shock first in a recursive VAR (estimated at the monthly frequency) that also contains the Federal funds rate, the natural log of the CPI, the natural log of the commodity price index, and the natural log of Industrial Production (our measure of real activity[27]). All data are taken from Ramey (2016), who – in turn – used the updated RR series of Wieland and Yang (2020).

As Figure D3 shows, the RR shock – which induces a more transient increase in the Federal funds rate compared to the GK shock – leads to a stronger contraction in real activity; using a different specification, McKay and Wolf (2023, Appendix C.2) obtain a similar finding, pointing towards some robustness of the bottomline conclusion.[28] While this is strongly at odds with the standard New Keynesian model (where the potency of monetary policy shocks is *increasing* in persistence – even under a discounted Euler equation), the apparent emergence of a "persistence-potency trade-off" is more in line with our FLANK model.

[27]Looking at the response of the unemployment rate leads to the same conclusion.

[28]While McKay and Wolf (2023) find more evidence of the GK shock lowering activity, it is striking how – also in their specification – the RR shock is more potent on output, despite that impulse giving rise to a much smaller area under curve of the interest rate response. In the standard New Keynesian model, the strength of the activity response should be *increasing* in the area under the curve of the interest rate response.

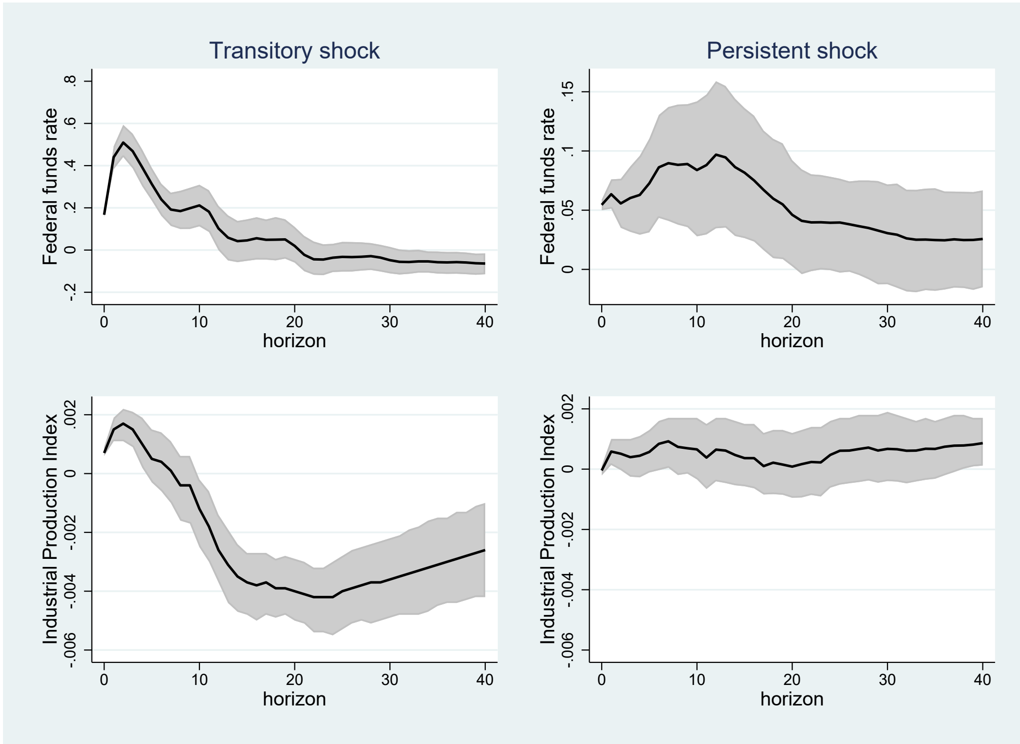

Figure D3: Response of Federal funds rate and industrial production index to monetary policy shocks of different persistence (transitory shock = RR; persistent shock = GK). VAR estimated at monthly frequency. Shaded areas represent 16th and 84th percentile confidence bands, obtained via bootstrapping.

An alternative interpretation is to question the validity of, especially, the more persistent shock (which we simply took from Gertler and Karadi (2015)). It is however interesting to observe that other studies (using different shock series) have also found evidence to suggest that the potency of monetary policy shocks on activity decreases with persistence. Examples include Miescu (2023, for the U.S.), Swanson (2024, for the U.S.), and Braun et al. (2025, for the U.K.). A similar result is reported in Uribe (2022, for the U.S.), who takes a rather different approach to shock identification (not relying on high-frequency methods, but exploiting cointegrating relationships). FLANK is furthermore consistent with the observation that yield curve inversions tend to be followed by economic slowdowns (Harvey, 1988).[29] Our model suggests that such inversions might be more than "just" a recession signal, pointing to a potential causal link stemming from the notion that the combination of high short-term rates with lower long-term rates is contractionary on both ends of the curve.

Regardless of this, further empirical work aimed at identifying the causal impact of highly persistent monetary policy shocks would be desirable – also since it can help in the construction

[29] Also see Ang et al. (2006), who find that short-term rates have most predictive power when it comes to forecasting future GDP. This is again in line with our FLANK model, which implies that the short-term rate bears the least ambiguous relation to activity.

of policy counterfactuals (McKay and Wolf, 2023; Caravello et al., 2024).

E Extension with productive capital

In the extension with productive capital, good-producing firms operate the production function:

$$y_t = A\left(\ell_t\right)^{\eta}\left(k_{t-1}\right)^{1-\eta},$$

where $\eta \in (0,1)$. All capital is owned by households who rent it to good-producing firms and invest to produce new capital. Investment is subject to a quadratic adjustment cost, such that producing inv_t new units of capital costs $inv_t + \frac{\iota}{2}\left(\frac{inv_t}{k_{t-1}} - \nu\right)^2 k_{t-1}$ units of output, with $\iota > 0$. Existing capital depreciates at rate $\nu \in [0,1]$. Hence, its law of motion is $k_t = inv_t + (1-\nu)\,k_{t-1}$.

The optimal investment policy is:

$$inv_t = \left(\nu + \frac{q_t^k - 1}{\iota}\right) k_{t-1},$$

where q_t^k denotes the price of capital which is determined by the households' first order conditions:

$$1 = \mathbb{E}_t\left[\Lambda_{t,t+1}^r \frac{u_t + (1-\nu)\,q_{t+1}^k}{q_t^k}\right],$$

$$1 = \mathbb{E}_t\left[\Lambda_{t,t+1}^w \frac{u_t + (1-\nu)\,q_{t+1}^k}{q_t^k}\right],$$

where $u_t = \frac{1-\eta}{\eta}\frac{\epsilon-1}{\epsilon}\chi\left(\frac{y_t}{\vartheta A}\right)^{1+\frac{1+\varphi}{\eta}}\left(\frac{1}{k_{t-1}}\right)^{1+(1-\eta)\frac{1+\varphi}{\eta}}$ is the rental rate of capital. The returns on the portfolios of assets held by retirees and workers are:

$$r_{t+1}^r = r_{t+1} + \left[\frac{1+(1-\mu)\,q_{t+1}}{q_t} - r_{t+1}\right]\alpha_t^r + \left[\frac{1+(1-\nu)\,q_{t+1}^k}{q_t^k} - r_{t+1}\right]\check{\alpha}_t^r,$$

$$r_{t+1}^w = r_{t+1} + \left[\frac{1+(1-\mu)\,q_{t+1}}{q_t} - r_{t+1}\right]\alpha_t^w + \left[\frac{1+(1-\nu)\,q_{t+1}^k}{q_t^k} - r_{t+1}\right]\check{\alpha}_t^w,$$

where α_t^j denotes the share of household-j wealth invested in long-term bonds and $\check{\alpha}_t^j$ the share invested in capital. Market clearing in the asset markets requires:

$$q_t b^g = \vartheta \alpha_t^w a_t^w + (1-\vartheta)\,\alpha_t^r a_t^r,$$

$$q_t^k k_t = \vartheta \check{\alpha}_t^w a_t^w + (1-\vartheta)\,\check{\alpha}_t^r a_t^r,$$

$$0 = \vartheta\left(1 - \alpha_t^w - \check{\alpha}_t^w\right) a_t^w + (1-\vartheta)\left(1 - \alpha_t^r - \check{\alpha}_t^r\right) a_t^r,$$

while goods market clearing implies:

$$y_t = \frac{\vartheta c_t^w + (1-\vartheta)\, c_t^r + inv_t + \frac{\iota}{2}\left(\frac{inv_t}{k_{t-1}} - \nu\right)^2 k_{t-1}}{1 - \frac{\theta}{2}\left(\pi_t - \bar{\pi}\right)^2}.$$

Finally, the real marginal cost of production is $\frac{\chi}{\eta}\left(\frac{y_t}{\vartheta A}\right)^{\frac{1+\varphi}{\eta}}\left(\frac{1}{k_{t-1}}\right)^{(1-\eta)\frac{1+\varphi}{\eta}}$. Hence, the Phillips curve becomes:

$$\left(\pi_t - \bar{\pi}\right)\pi_t = \lambda\left[\frac{\chi}{\eta}\left(\frac{y_t}{\vartheta A}\right)^{\frac{1+\varphi}{\eta}}\left(\frac{1}{k_{t-1}}\right)^{(1-\eta)\frac{1+\varphi}{\eta}} - 1\right] + \mathbb{E}_t\left[\Lambda_{t,t+1}^w\left(\pi_{t+1} - \bar{\pi}\right)\pi_{t+1}\frac{y_{t+1}}{y_t}\right].$$

All other equations remain unchanged.

For a 0 inflation target ($\bar{\pi} = 1$) and $\tau^r = 0$, the steady-state real rate r solves:

$$\frac{y - \nu k}{r - \left[(1-\delta_2)\,\beta r\right]^{\frac{1}{\sigma}}}\frac{1 + \frac{\delta_1\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}{1-(1-\delta_2)\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}}{\left[\frac{1-\beta(1-\delta_1)r}{\beta\delta_1 r}\right]^{\frac{1}{\sigma}} + \frac{\delta_1}{1-(1-\delta_2)\left[(1-\delta_2)\beta r\right]^{\frac{1}{\sigma}}}} = \frac{b^g}{r - 1 + \mu} + k,$$

where:

$$k = (\eta)^{\frac{1}{1+\varphi}}\left(\frac{\epsilon - 1}{\epsilon}\frac{1-\eta}{r - 1 + \nu}\right)^{\frac{1}{\eta}},$$

$$y = \vartheta A\,(\eta)^{\frac{1}{1+\varphi}}\left(\frac{\epsilon - 1}{\epsilon}\frac{1-\eta}{r - 1 + \nu}\right)^{\frac{1-\eta}{\eta}}.$$

F Monetary versus demand shocks in FLANK

Another interesting feature of FLANK is that it breaks the equivalence (for example present in RANK) between monetary shocks and other types of demand shocks. Here, we illustrate this point by considering shocks to the discount rate (recall equation (18)), but the point is more general. Recall that the effects of discount rate shocks "ε_t^β" on output are given by:

$$\hat{y}_t = -\sum_{j=0}^{\infty}\omega_j \mathbb{E}_t \varepsilon_{t+j}^\beta$$

with $\omega_0^y = \frac{1}{\sigma}$,

$$\omega_j = (1-\delta_1)\omega_{j-1} - \xi_j^\omega,$$

$$\xi_j^\omega \equiv -\frac{1}{\sigma}\left[\delta_1 - \gamma(1-\delta_1)\frac{1-\beta(1-\delta_2)^{\frac{1}{\sigma}}}{\beta(1-\delta_2)^{\frac{1}{\sigma}}}\right]\beta^j(1-\delta_2)^{\frac{j}{\sigma}}.$$

Crucially, with $\delta_1 > 0$, the ω_j coefficients on the discount rate shock at each horizon $j > 0$ are *not* proportional to those for the monetary policy shock. For RANK ($\delta_1 = 0$) the coefficients *are* proportional. In that case, a monetary policy shock induces the exact same dynamics as a discount rate shock – meaning that the former is extremely well-suited to offset the latter. However, in FLANK that is no longer true: while discount rate shocks continue to operate via intertemporal substitution, policy-induced shocks to the interest rate are "special" as they come with an offsetting effect (changes in interest income affecting asset demand) that give rise to a persistence-potency trade-off. Note that the time-t impact of a persistent AR(1) discount rate shock is given by:

$$\begin{aligned}\Omega(\rho_\beta) &\equiv \sum_{j=0}^{\infty}\omega_j^y\rho_\beta^j \\ &= \frac{1}{\sigma}\frac{(1-\gamma)(1-\delta_1)}{1-\rho_\beta(1-\delta_1)} + \frac{1}{\sigma}\frac{\gamma + \frac{\delta_1(1-\gamma)}{1-\rho_\beta(1-\delta_1)}}{1-\rho_\beta\beta(1-\delta_2)^{\frac{1}{\sigma}}}\end{aligned}$$

Comparing this to equation (31) shows that $\Omega(\rho) > \Psi(\rho)$ in the case we consider (where $\sigma > 1$ and $\delta_2 < \mu$).

G Generalized learning rule

The addition of interest rate smoothing, and the state variable (a lag of the policy rate) that comes with it, affect the learning problem set up in Section 3. In particular, the central bank can now be shown *to expect* that the output gap will follow:

$$\hat{y}_t^{CB} = -\Psi^{CB}(\rho_r)\mathbb{E}_t r_{t+1} - (1-\rho_r)\left[\Lambda^{CB}(1)r_t^{*,CB} + \Lambda^{CB}(\rho_d)\frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)}\varepsilon_t^d\right] + \Psi^{CB}(1)r_t^{*,CB} + \Omega^{CB}(\rho_d)\varepsilon_t^d,$$

where ρ_r captures the degree of interest rate smoothing (per equation (34)) and:

$$\Lambda^{CB}(x) \equiv \sum_{j=0}^{\infty}\psi_j^{CB}x\frac{x^j-\rho_r^j}{x-\rho_r} = x\frac{\Psi^{CB}(x)-\Psi^{CB}(\rho_r)}{x-\rho_r}.$$

Output in reality, however, follows:

$$\hat{y}_t = -\Psi(\rho_r)\mathbb{E}_t r_{t+1} - (1-\rho_r)\left[\Lambda(1)r_t^{*,CB} + \Lambda(\rho_d)\frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)}\varepsilon_t^d\right] + \Psi(1)r^* + \Omega(\rho_d)\varepsilon_t^d,$$

where:

$$\Lambda(x) \equiv \sum_{j=0}^{\infty} \psi_j x \frac{x^j - \rho_r^j}{x - \rho_r} = x \frac{\Psi(x) - \Psi(\rho_r)}{x - \rho_r}.$$

In this case, the central bank's updating rule reads:

$$\begin{aligned} r_{t+1}^{*,CB} - r^* = \hat{\Psi}(\rho_r)\left(\mathbb{E}_t r_{t+1} - r^*\right) + \left[\hat{\Psi}(1) - \hat{\Psi}(\rho_r)\right]\left(r_t^{*,CB} - r^*\right) \\ + \left[(1-\rho_r)\rho_d \frac{\hat{\Psi}(\rho_d) - \hat{\Psi}(\rho_r)}{\rho_d - \rho_r} \frac{\Omega^{CB}(\rho_d)}{\Psi^{CB}(\rho_d)} - \hat{\Omega}(\rho_d)\right] \varepsilon_t^d, \end{aligned}$$

with

$$\hat{\Psi}(x) = \frac{\Psi^{CB}(x) - \Psi(x)}{\Psi^{CB}(1)} \text{ and } \hat{\Omega}(x) = \frac{\Omega^{CB}(x) - \Omega(x)}{\Psi^{CB}(1)},$$

which is the generalization of equation (6) in the presence of interest rate smoothing (setting $\rho_r = 0$ brings us back to (6)).

H Further extensions

Here, we discuss various assumptions underlying our model and how they generally can be relaxed quite easily, without changing our key insights.

Hand-to-mouth agents. Our model treats all households as intertemporal optimizers. This may seem inappropriate given the evidence supporting the presence of hand-to-mouth (HtM) consumers (Kaplan et al., 2014). Accordingly, the mechanisms in our model may appear relevant only for the financially well-off. We concur with this, but do not view it as a drawback for two reasons. First, the well-off account for much of total consumption demand – making them a natural focal point (in U.S. data, the wealthiest 20% account for nearly half of total consumption; Abbott and Brace, 2020). Second, one of the main insights from the HtM literature is that the dynamics of aggregate activity will primarily be driven by the behavior of optimizing households – even if the latter are only a fraction of the total population (Werning, 2015). With HtM households, the decisions of optimizers are transmitted to the wider economy via the non-optimizing households – potentially yielding amplification (Bilbiie, 2020; 2024), though recent micro-data from Norway fails to provide evidence for such amplification (Bilbiie et al., 2025). Either way, as long as the fraction of income going to HtM households is relatively stable, treating the economy as if solely driven by optimizers is a decent approximation. This is the interpretation we favor, recognizing that the modelled behavior may only reflect a subset of the population. While our model's structure is flexible enough to add HtM households, we choose not to – as this would complicate the setup without adding anything new.

Bequests. While our FLANK model does not include a bequest motive, its insights appear to be strengthened with such an extension: a bequest motive would likely accentuate the asset demand force present in FLANK. If parents not only care about the value of assets they pass on, but also about the expected rate of return, a simple modelling approach is to think of bequests as consumption past death. A bequest motive can then be proxied by lowering δ_2. To gauge the impact of this on $\bar{\Psi}(1)$ the right panel of Figure H4 regenerates our heatmap after reducing δ_2 from $\frac{1}{80}$ to $\frac{1}{120}$. As the figure shows, the range of parameter values where $\bar{\Psi}(1)$ is close to 0 (or positive) *expands* relative to our baseline (reproduced in the left panel).

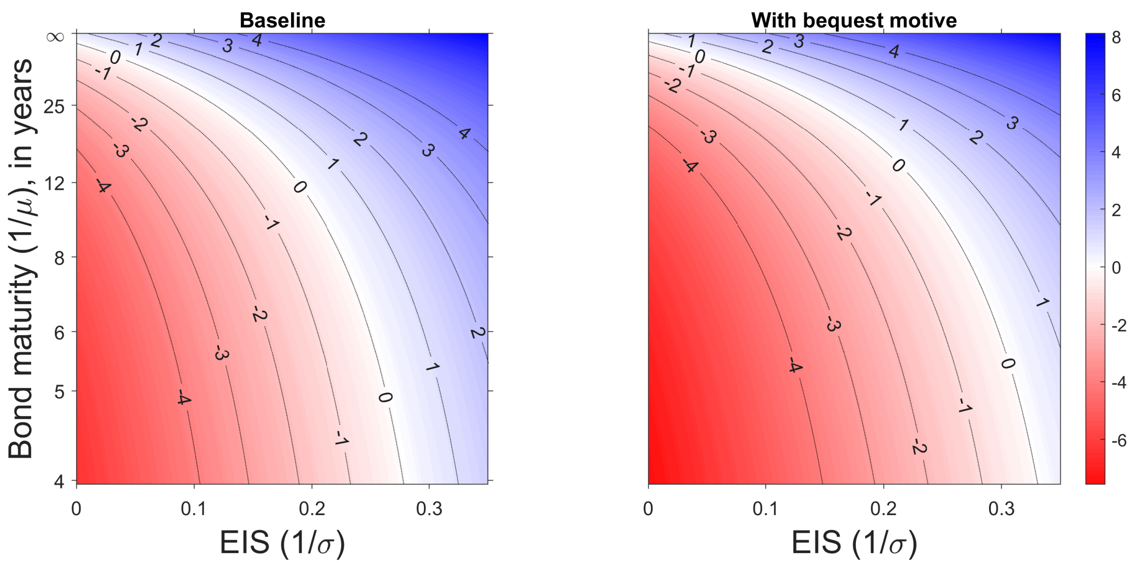

Figure H4: $\bar{\Psi}(1)$ as a function of σ and μ in FLANK. The left panel reproduces our baseline from Figure 6; the right panel proxies adding a bequest motive by setting $\delta_2 = 1/120$. Other parameters are calibrated as in footnote 19.

Equity. Agents only hold government bonds in our model, which may seem restrictive. Adding an equity market is straightforward. In our baseline setup, working households own all firms. Alternatively, firm equity could be traded in a market featuring workers and retirees, with the equity price responding to interest rates as implied by standard arbitrage. We have explored this modification and have not found it to affect our main results – motivating our choice for the simpler setup. The reason for this robustness lies in the fact that interest rates affect equity and long-term bond prices in the same direction. So, while the introduction of equity would make the model's asset valuation channel more involved, it would not change its nature. There are nonetheless two aspects that would change with equity. The first concerns the strength of the valuation channel. With only long-term bonds, the strength of this channel is governed by bond duration. But with equity, the strength would also be governed by the equity risk premium.[30] This does not change the main mechanism, but influences how to calibrate the model (as discussed in footnote 23). The second aspect that would change with equity is that it would open the door to exploring changes in risk premiums (Caramp and Silva (2021) offer an analysis along these lines), which is also related to the literature on safe asset demand (Caballero et al., 2016; 2017). At the moment, the route via which the central bank in our model can affect longer-term rates runs entirely through the expectations hypothesis. But a "low for long" policy might also trigger a search for yield, making investors move more into equity. We suspect that such a shift would compress the equity premium, making the risky rate of return fall by more than the safe rate – *adding* to the retirement savings challenge – but leave a formal analysis for future work.[31]

Housing. Along similar lines, the logic of the model would continue to hold if households were allowed to save in a housing asset. So, while our model contains a long-term bond as the asset through which saving takes place, the exact nature of the asset is of secondary importance. The more important issue is that this asset has positive duration, i.e., that its price "q" is inversely related to the interest rate.

[30]The steady-state value of equity would equal $\frac{d}{r+rp}$, where d is the dividend payment, r is the real rate, and rp is an equity risk premium. Recall that the steady-state bond price in the model is given by $\frac{1}{r+\mu}$, where $1/\mu$ governs bond duration. This illustrates that a lower equity premium implies that asset prices are more sensitive to real rate changes, which parallels the role played by bond duration.

[31]In reality, the risk premium appears to have *risen* since the 1980s (for reasons outside of our model), implying that the risky rate of return has fallen by less than the safe rate (Reis, 2022). This is no panacea for retirement savings though, as investing in riskier options implies that one ends up with a different (riskier) pension, to which one might again respond by wishing to hold more assets.